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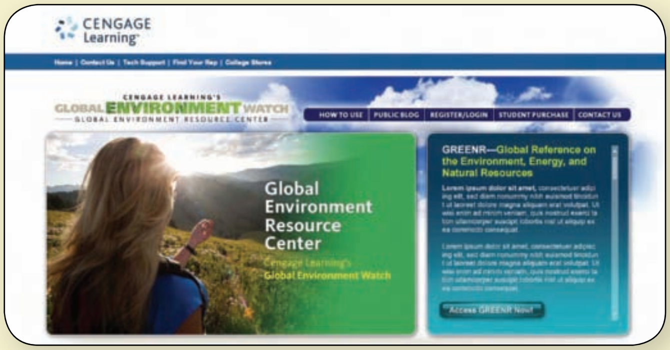

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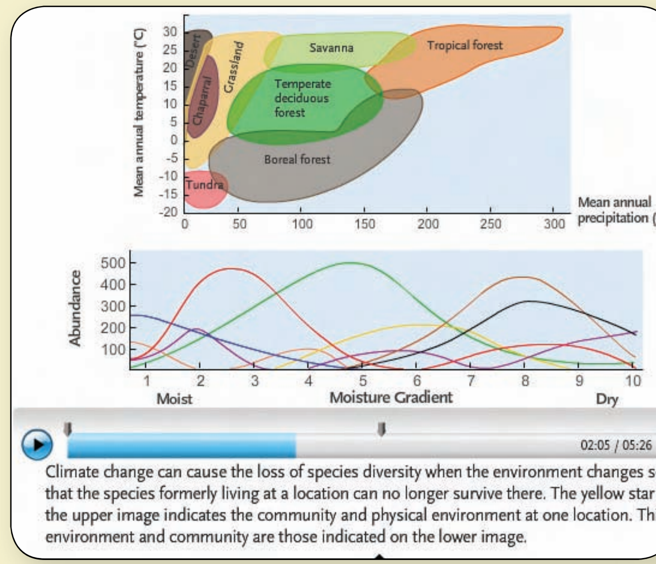

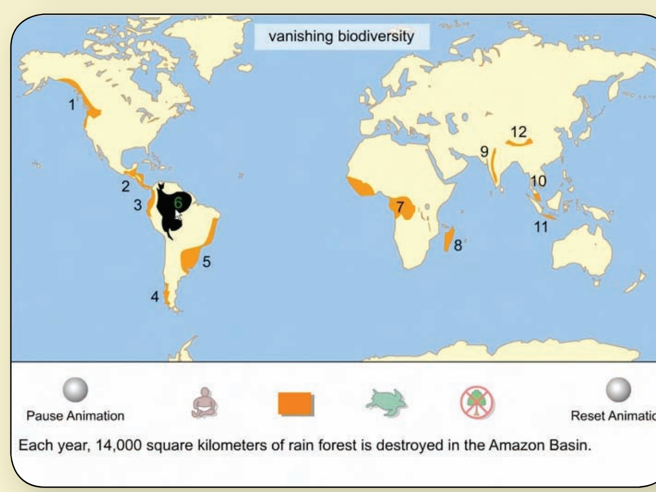

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Living in the Environment

SEVENTEENTH EDITION

G. Tyler Miller, Jr.

Scott E. Spoolman

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Living in the Environment, 17e
G. Tyler Miller, Jr. and Scott E. Spoolman

Publisher: Yolanda Cossio
Development Editor: Christopher Delgado
Assistant Editor: Alexis Glubka
Editorial Assistant: Joshua Taylor
Media Editor: Alexandria Brady
Marketing Manager: Tom Ziolkowski
Marketing Assistant: Elizabeth Wong
Marketing Communications Manager: Linda Yip
Content Project Manager: Hal Humphrey
Art Director: John Walker
Print Buyer: Linda Hsu
Rights Acquisitions Account Manager, Text: Roberta Broyer
Rights Acquisitions Account Manager, Image: Dean Dauphinais
Production Service/Compositor: Thompson Steele, Inc.
Text Designer: Carolyn Deacy
Photo Researcher: Abby Reip
Copy Editor: Deborah Thompson
Illustrator: Patrick Lane, ScEYEence Studios; Rachel Ciemma
Cover Designer: Jeanne Calabrese
Cover Image: Endangered Florida panther © John Pontier/Animals Animals—Earth Sciences. For more information about this photo, see p. iv.
Title Page Image: Green sea turtle © Reinhard Dirscherl/Alamy

Library of Congress Control Number: 2010934031

Hardbound Student Edition:

ISBN-13: 978-0-538-73534-6

ISBN-10: 0-538-73534-1

Looseleaf Advantage Student Edition:

ISBN-13: 978-0-538-49414-4

ISBN-10: 0-538-49414-X

Brooks/Cole
20 Davis Drive
Belmont, CA 94002-3098
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THIS BOOK PRINTED ON ACID-FREE RECYCLED PAPER

Printed in Canada
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About the Cover Photo

The Florida panther—the only subspecies of cougar found east of the Mississippi River—is the most endangered mammal in the United States and one of the world's most endangered animals. Thousands of these panthers once roamed the southeastern United States. But because of the growth and expansion of the human population, they are now found only in parts of Southern Florida including the Everglades and the Big Cypress Swamp in one of the state's most rapidly developing regions.

These animals come together only to breed, and they need large blocks of undisturbed land with sufficient populations of prey animals to feed upon. Their home territory can be as large as 500 square kilometers (200 square miles) for a male and 200 square kilometers (80 square miles) for a female. These solitary hunters stalk and ambush their prey mostly at dawn or dusk. Their favorite prey are large animals such as white-tailed deer and wild hogs, but they also eat raccoons, armadillos, rabbits, and even small alligators. There have been no documented panther attacks on humans in Florida.

Despite being placed on the U.S. endangered species list in 1967, only 80 to 100 Florida panthers are left in the wild. The greatest threat to their survival is loss and fragmentation of habitat. Another threat is an increasing number of deadly battles among male panthers over territory and access to females, as their habitat continues to shrink. Their small population is also threatened by collisions with automobiles, genetic defects from interbreeding, cat and dog diseases, and exposure to high levels of toxic mercury (from the fallout of coal-fired power plants) in their prey.

In 2008, a coalition of conservation organizations and landowners joined efforts to protect the panther's remaining habitat and to create a fund for acquiring additional habitat. Another goal is to build more underpasses along highways to help reduce panther road kills. Despite such efforts, the Florida panther could very well become extinct in the wild during your lifetime, as humans crowd them out.

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Paul W. Johnson/Biological Photo Service

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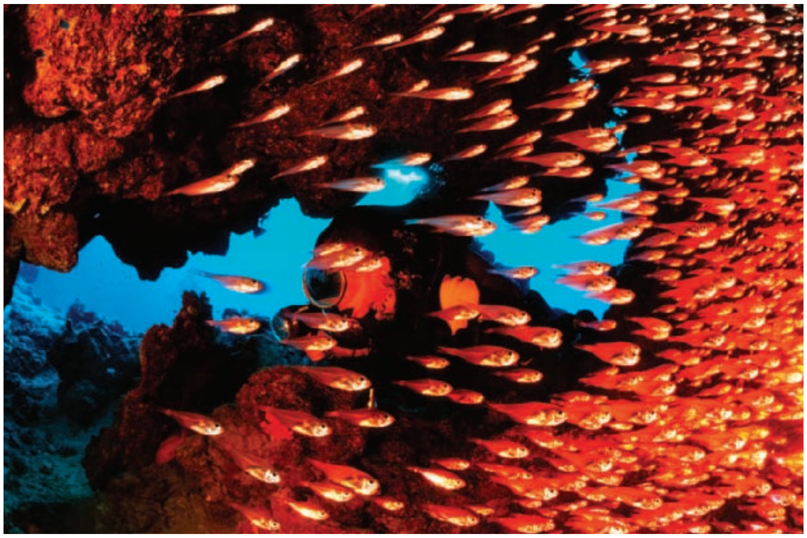

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PREFACE

For Instructors

We wrote this book to help instructors achieve three important goals: *first*, to explain to their students the basics of environmental science, including how life on the earth has survived for billions of years; *second*, to help their students to use this scientific foundation in order to understand the multiple environmental problems that we face and to evaluate possible solutions to them; and *third*, to inspire their students to make a difference in how we treat the earth on which our lives and economies depend, and thus in how we treat ourselves and our descendants.

To help achieve these goals, we view environmental problems and possible solutions to them through the lens of *sustainability*—the integrating theme of this book. We believe that most people can live comfortable and fulfilling lives, and that societies will be more prosperous and peaceful when sustainability becomes the chief measure by which personal choices and public policies are made.

The news media tend to be full of bad news about the environment. But environmental science is a field that is rife with good news and promise for a better future. We base this vision of a better world on realistic hopes. To emphasize this positive approach, we have added a new feature to this edition. We use *Good News* logos GOOD NEWS to mark areas in this text that present positive developments in humanity's efforts to deal with environmental problems.

What's New in This Edition?

Our texts have been widely praised for keeping users up-to-date in the rapidly changing field of environmental science. We continue to maintain this proven strength, and in this edition, we have added a major new feature and enhanced two of our tried-and-true learning tools:

- Each chapter contains new *Connections* boxes, which briefly describe connections between human activities and environmental consequences, environmental and social issues, and environmental issues and solutions.
- Over half of the book's 25 chapters have new *Core Case Studies* that are threaded throughout each chapter.
- We are making this highly visual book even more visually compelling by adding 178 new photos and 59 new figures, improving or updating 124 figures, and using an improved design that reinforces and enhances learning.

Concept-Centered Approach

To help students focus on the main ideas, we built each major chapter section around a *key question* and one or two *key concepts*, which state the section's most important take-away messages. In each chapter, all key questions and concepts are listed at the front of the chapter, and each chapter section begins with its key question and concepts (see pp. 55 and 191). Also, the concept applications are highlighted and referenced throughout each chapter.

In another new feature of this edition, we list *three big ideas* at the end of each chapter. This is one more way to reinforce key concepts and connections in order to enhance learning.

Sustainability Is the Integrating Theme of This Book

Sustainability, a watchword of the 21st century for those concerned about the environment, is the overarching theme of this textbook. You can see the sustainability emphasis by looking at the Brief Contents (p. iii).

Three **principles of sustainability** play a major role in carrying out this book's sustainability theme. These principles are introduced in Chapter 1, depicted in Figure 1-3 (p. 8 and on the back cover of the student edition), and used throughout the book, with each reference marked in the margin by SUSTAINABILITY. (See Chapter 12, pp. 281, 283, and 296.)

Core Case Studies and the Sustainability Theme

Each chapter opens with a *Core Case Study* (p. 31), which is applied throughout the chapter. These connections to the Core Case Study are indicated in the book's margin by CORE CASE STUDY. (See pp. 32, 34, 36, 40, 41, 49, 50, and 51.) *Thinking About* exercises strategically placed throughout each chapter challenge students to make these and other connections for themselves. Each chapter ends with a *Revisiting* box (pp. 28 and 165), which connects the Core Case Study and other material in the chapter to the three principles of sustainability.

Five Subthemes Guide the Way toward Sustainability

We use the following five major subthemes to integrate material throughout this book (see diagram on back cover of the student edition).

- ***Natural capital.*** Sustainability depends on the natural resources and natural services that support all life and economies. Examples of diagrams that illustrate this subtheme are Figures 1-4, p. 9; 8-5, p. 172; and 10-4, p. 220.
- ***Natural capital degradation.*** We describe how human activities can degrade natural capital. Examples of diagrams that illustrate this subtheme are Figures 1-9, p. 13; 7-18, p. 165; and 8-13, p. 179.
- ***Solutions.*** We pay a great deal of attention to the search for *solutions* to natural capital degradation and other environmental problems. We present proposed solutions in a balanced manner and challenge students to use critical thinking to evaluate them. Some figures and many chapter sections and subsections present proven and possible solutions to various environmental problems. Examples are Figures 12-34, p. 310; 13-12, p. 327; and 18-23, p. 487. We also present a number of technologies and social trends that could soon break out and change the world much more rapidly than we might think (Figure 25-12, p. 672).
- ***Trade-Offs.*** The search for solutions involves *trade-offs*, because any solution requires weighing advantages against disadvantages. Some 32 Trade-Offs diagrams present the advantages and disadvantages of various environmental technologies and solutions to environmental problems. Examples are Figures 12-22, p. 299; 16-25, p. 418; and 22-15, p. 601.
- ***Individuals Matter.*** Throughout the book, *Individuals Matter* boxes and some of the Core Case Studies describe what various scientists and concerned citizens have done to help us achieve sustainability (see pp. 359, 441, 626, and 637). Also, a number of *What Can You Do?* diagrams describe how readers can deal with the problems we face. Examples are Figures 10-28, p. 247; 16-38, p. 432; and 21-8, p. 563. Eight especially important things individuals can do—the *sustainability eight*—are summarized in Figure 25-10 (p. 670).

Science-Based Global Coverage

Chapters 2–8 discuss how scientists work and introduce scientific principles (see Brief Contents, p. iii) needed for a basic understanding of how the earth works and for evaluating proposed solutions to environmental problems. Important environmental science topics are explored in depth in *Science Focus* boxes distributed among the chapters (see pp. 35, 156, and 404). Science is also integrated throughout the book in various *Case Studies* (see pp. 184, 204, and 581) and in numerous figures. In addition, *Research Frontier* boxes list key areas of cutting-edge research, with links to such research provided on the website for this book (see pp. 99, 164, and 203). **GREEN CAREER** notations in the text point to various green careers on which further information can be found on the website for this book (see **www.cengage.com/login**).

This book also provides a *global perspective* on two levels. *First,* ecological principles help to reveal how all the world's life is connected and sustained within the biosphere (Chapter 3), and these principles are applied throughout the book. *Second,* the book integrates information and images from around the world into its presentation of environmental problems and their possible solutions. This includes 24 global maps and 27 U.S. maps in the basic text and in Supplement 8.

A range of premium online resources is available with this text, to best suit varying course needs. These online offerings include the animations related to the active figures (see Figures 3-11, p. 62 and 3-19, p. 70) as well as many other resources to help students learn and study. For a complete listing of what is available, see pp. xvii–xix of this preface.

Case Studies

In addition to the 25 Core Case Studies that are integrated through their respective chapters, 74 additional *Case Studies* (see pp. 241, 332, and 543) appear throughout the book (see items in **BOLD** type in the Detailed Contents, pp. v–xiii). The total of 99 case studies provides an in-depth look at specific environmental problems and their possible solutions.

Critical Thinking

The introduction on *Learning Skills* describes critical thinking skills for students (pp. 2–4). Specific critical thinking exercises are used throughout the book in several ways:

- As 102 *Thinking About* exercises. This interactive approach to learning reinforces textual and graphic information and concepts by asking students to analyze material immediately after it is presented rather than waiting until the end of chapter (see pp. 100, 288, and 356).
- In all Science Focus boxes.
- As 75 *Connections* boxes that stimulate critical thinking by exploring often surprising connections related to environmental problems (a new feature in this edition, see pp. 222, 530, and 573).

- In the captions of most of the book's figures (see Figures 12-A, p. 284; 15-24, p. 390; and 18-14, p. 477).
- As 118 *How Would You Vote?* exercises (see pp. 335 and 457).
- In end-of-chapter questions (see pp. 248 and 433).

Visual Learning

This is a highly visual book. Its 434 diagrams—183 of them new or improved to this edition—are designed to present complex ideas in understandable ways relating to the real world (see Figures 1-3, p. 8; 13-A, p. 321; and 19-D, p. 512). There are also 340 photographs—170 of them new to this edition (see Figures 3-3, p. 56; 4-3, p. 82; 8-3, p. 170; and 13-22, p. 338).

Finally, to enhance visual learning, over 200 animations, many referenced in the text and diagrams, are available online, as well as integrated into an e-book. This and other features make our online learning tools a great addition to the text. To find the premium online resource that's right for your students, talk to your Brooks/Cole sales representative.

Three Levels of Flexibility

There are hundreds of ways to organize the content of this course to fit the needs of different instructors with a wide variety of professional backgrounds as well as course lengths and goals. To meet these diverse needs, we have designed a highly flexible book that allows instructors to vary the order of chapters and sections within chapters without exposing students to terms and concepts that could confuse them.

We recommend that instructors start with Chapter 1 because it defines basic terms and gives an overview of sustainability, population, pollution, resources, and economic development issues that are discussed throughout the book. This provides a springboard for instructors to use other chapters in almost any order.

One often-used strategy is to follow Chapter 1 with Chapters 2–8, which introduce basic science and ecological concepts. Instructors can then use the remaining chapters in any order desired. Some instructors follow Chapter 1 with any or all of Chapters 23, 24, and 25 on environmental economics, politics, and worldviews, respectively, before proceeding to the chapters on basic science and ecological concepts.

We provide a *second level of flexibility* in nine Supplements (see p. xiii in the Detailed Contents and p. S1), which instructors can assign as desired to meet the needs of their specific courses. Examples include environmental history of the United States (Supplement 3), basic chemistry (Supplement 4), weather basics (Supplement 7), maps (Supplement 8), and basic environmental data and data analysis (Supplement 9).

There is also a *third level of flexibilty*. Instructors who want to emphasize a mastery of basic environmetal concepts and information can rely primarily on the detailed review questions at the end of each chapter and leave out any or all of the book's numerous critical thinking questions in Thinking About boxes, in many figure captions, and at the end of each chapter.

Major Changes in This Edition: A Closer Look

- 75 *Connections* boxes, which briefly describe connections between human activities and environmental consequences, environmental and social issues, and environmental issues and solutions (see pp. 22, 206, and 324).
- 14 new chapter-opening **Core Case Studies** (see pp. 5, 190, 217, 277, 317, and 697) and 24 new Case Studies within chapters (see pp. 282, 384, 418, and 606).
- 178 carefully selected new photographs (see Figures 2-16, p. 48; 4-1, p. 80; and 20-18, p. 547).
- 59 new figures (see Figures 3-16, p. 67; 7-3, p. 149; and 25-12, p. 672) and 124 improved figures.
- 135 *Good News* items, each identified by a GOOD NEWS to highlight the many positive achievements in dealing with environmental problems.
- Three *Big Ideas* for each chapter (see pp. 27, 214, 247, and 314). They are listed just before the review questions at the end of each chapter and reinforce three of the major take-away messages from each chapter.
- 14 new **Science Focus** boxes that provide greater depth on scientific concepts and on the work of environmental scientists (see pp. 76, 253, and 321).
- More than 4,000 updates based on information and data published in 2007–2010 with about 500 of these sources cited by year in the text.
- *Explore More* notations scattered throughout the text refer to Case Studies, Science Focus boxes, and stories of individuals who have carried out environmental research and of others who have acted to help make the world a better and more sustainable place to live. These supplementary items are available on our website at **www.cengagebrain.com/shop/ISBN/0538735341**.
- Connections to *The Habitable Planet*, a set of 13 videos produced by Annenberg Media. Each half-hour video describes research that two different scientists are doing on a particular environmental problem.
- Integration of material throughout much of the book on the growing ecological and economic impacts of China (see pp. 18, 125, 474, and index citations for China).
- More than 100 new or expanded topics including "A Vision of a More Sustainable World in 2060" (p. 5); IPAT equation of environmental impacts

(p. 17); tipping points (pp. 18–19); satellites, Google Earth, and the environment (p. 76); Individuals Matter: Edward O. Wilson (p. 85); projecting population change (p. 128); climate change and environmental refugees (p. 134); sea-grass beds (p. 174); saving eagles, overfishing, and losing rare great cormorants (p. 204); pesticides, honeybees, and food prices (p. 204); a scientist who confronted poachers (p. 206); good and bad bamboo (p. 233); the Malpai borderlands (p. 234); national parks and climate change (p. 239); ocean research robots (p. 253); lionfish as an invader species (p. 254); harmful effects of increasing ocean acidity (p. 257); clashing scientific views on fishing population estimates (p. 258); threat to the Great Lakes of an Asian carp invasion (p. 271); growing crops without soil (hydroponics, p. 282); detecting genetically modified fruit (p. 286); corn, ethanol, and ocean dead zones (p. 295); pesticides and organic foods (p. 301); corn, ethanol, and soil conservation (p. 307); raising salmon in an artificial ecosystem (p. 309); water footprints and virtual water (p. 321); China and water conservation (p. 336); deforestation and flooding in China (p. 341); 2010 earthquake in Haiti (Figure 14-7, p. 351); coral reefs, mangrove forests, and tsunami damage (p. 353); mercury poisoning and tropical gold mining (p. 359); Maria Gunno and mountaintop removal coal mining (p. 359); Bakken oil formation in the United States (p. 376); oil consumption, terrorism, and national security (p. 377); toxic coal ash (p. 384); smart electrical grid (p. 401); LED bulbs (pp. 400–401); electric car production in China and India (p. 403); compact fluorescent bulbs and mercury pollution (p. 408); bird deaths and wind turbines (p. 418); wind turbines and U.S. jobs (p. 419); Middlebury College and sustainable biomass burning (p. 419); biofuels and climate change (p. 420); corn, ethanol, and tortilla riots in Mexico (p. 422); producing gasoline and diesel fuel from algae and bacteria (p. 423); drinking water, latrines, and infectious diseases (p. 446); climate change and mercury pollution (p. 448); South Asian "brown-cloud" air pollution, food production, and solar power (p. 471); low-sulfur coal, atmospheric warming, and toxic mercury (p. 480); update on melting ice at the earth' poles (p. 492); validity of IPCC conclusions (p. 497); James Hansen (Individuals Matter, p. 502); bathtub CO_2 model (p. 512); carbon dioxide as an air pollutant (p. 517); greenhouse gas emissions in China (p. 518); atmospheric warming and the ozone layer (p. 523); the massive 2010 oil well blowout in the Gulf of Mexico (p. 547); environmental impact of magazines (p. 567); cell phones and endangered African gorillas (p. 573); recycling e-waste (p. 573); urban living and biodiversity protection (p. 593); Zipcars (p. 600); wind farms and high-speed trains (p. 602); high-speed trains in China (p. 602); new urban village of Vauban, Germany (p. 606); living building in the United States (p. 609); Muhammad Yunnus and microloans for the poor (p. 613); Denis Hayes, an environmental visionary (p. 637); the sustainability eight (Figure 25-10, p. 670); and emerging technologies and ideas that can change the world rapidly (Figure 25-12, p. 672).

In-Text Study Aids

Each chapter begins with a list of *Key Questions and Concepts* showing how the chapter is organized and what students will be learning (see p. 6). When a new term is introduced and defined, it is printed in boldface type and all such terms are summarized in the glossary at the end of the book and highlighted in review questions at the end of each chapter.

Thinking About exercises (102 in all) reinforce learning by asking students to think critically about the implications of various environmental issues and solutions immediately after they are discussed in the text. The captions of many figures contain questions that involve students in thinking about and evaluating their content.

Each chapter ends with a *Review* section containing a detailed set of review questions that include all the chapter's key terms in **bold** type (p. 28), followed by a set of *Critical Thinking* questions (p. 29) that encourage students to think critically and apply what they have learned to their lives. Following these questions in each chapter is a *Data Analysis* or *Ecological Footprint Analysis* problem built around ecological footprint data or some other environmental data set.

Supplements for Students

A multitude of electronic supplements available to students take the learning experience beyond the textbook:

- *CengageNOW* is an online learning tool that helps students access their unique study needs. Students take a pre-test that creates a personalized study plan and provides them with specific resources for review. A post-test then identifies content that might require further study. *How Do I Prepare* tutorials, another feature of *CengageNOW*, walk students through basic math, chemistry, and study skills to help them brush up quickly and be ready to succeed in their course.
- *WebTutor* on WebCT or Blackboard provides qualified adopters of this textbook with access to a full array of study tools, including flashcards, practice quizzes, animations, exercises, and Weblinks.
- *CourseMate* brings course concepts to life with interactive learning, study, and exam preparation tools that support the printed textbook. Watch student comprehension soar as your class works with the printed textbook and the textbook-specific website.

CourseMate goes beyond the book to deliver what you need!

- *Global Environment Watch.* Updated several times a day, the Global Environment Watch is a focused portal into GREENR—the Global Reference on the Environment, Energy, and Natural Resources—an ideal one-stop site for classroom discussion and research projects. This resource center keeps courses up-to-date with the most current news on the environment. Students can access information from trusted academic journals, news outlets, and magazines, as well as statistics, an interactive world map, videos, primary sources, case studies, podcasts, and much more.
- *Audio Study Tools*. Students can download these useful study aids, which contain valuable information such as reviews of important concepts, key terms, questions, clarifications of common misconceptions, and study tips.
- Access to *InfoTrac® College Edition* for teachers and students using *CengageNOW* and *WebTutor* on WebCT or Blackboard. This fully searchable online library gives users access to complete environmental articles from several hundred current periodicals and others dating back over 20 years.

The following materials for this textbook are available on the companion website at

www.cengage.com/login

- *Chapter Summaries* help guide student reading and study of each chapter.
- *Flash Cards* and the *Glossary* allow students to test their mastery of each chapter's Key Terms.
- *Chapter Tests* provide multiple-choice practice quizzes.
- *Information* on a variety of *Green Careers.*
- *Readings* list articles, books, and websites that provide additional information.
- *What Can You Do?* offers students resources for how they can effect individual change on key environmental issues.
- *Weblinks* and *Research Frontier Links* offer an extensive list of websites with news and research related to each chapter.

Other student learning tools include:

- *Essential Study Skills for Science Students* by Daniel D. Chiras. This book includes chapters on developing good study habits, sharpening memory, getting the most out of lectures, labs, and reading assignments, improving test-taking abilities, and becoming a critical thinker. Available for students upon instructor request.
- *Lab Manual.* New to this edition, this lab manual includes both hands-on and data analysis labs to help your students develop a range of skills. Create a custom version of this Lab Manual by adding labs you have written or ones from our collection with Cengage Custom Publishing. An Instructor's Manual for the labs will be available to adopters.
- *What Can You Do?* This guide presents students with a variety of ways through which they can affect the environment, and shows them how to track the effect their actions have on their carbon footprint. Available for students upon instructor request.

Supplements for Instructors

- *PowerLecture.* This DVD, available to adopters, allows you to create custom lectures in Microsoft® PowerPoint using lecture outlines, all of the figures and photos from the text, and bonus photos and animations. PowerPoint's editing tools allow use of slides from other lectures, modification or removal of figure labels and leaders, insertion of your own slides, saving slides as JPEG images, and preparation of lectures for use on the web.
- *Instructor's Manual*. Available to adopters, the Instructor's Manual has been thoughtfully revised and updated to make creating your lectures even easier. Some of the features new to this edition include updated answers to the end-of-chapter questions, including suggested answers for the review questions and the quantitative exercises, and a revised video reference list with web resources. Also available on PowerLecture.
- *Test Bank.* Available to adopters, the Test Bank contains thousands of questions and answers in a variety of formats, including multiple choice, true/false, fill-in-the-blank, critical thinking, and essay questions. Also available on PowerLecture.
- *Transparencies.* Featuring all the illustrations from the chapters, this set contains 250 printed transparencies of key figures, and 250 electronic masters. These electronic masters will allow you to print, in color, only those additional figures you need.
- *CourseMate.* How do you assess your students' engagement in your course? How do you know your students have read the material or viewed the resources you've assigned? How can you tell if your students are struggling with a concept? With CourseMate, you can use the included Engagement Tracker to assess student preparation and engagement. Use the tracking tools to see progress for the class as a whole or for individual students. Identify students at risk early in the course. Uncover which concepts are most difficult for your class, monitor time on task, and keep your students engaged.
- *ABC Videos for Environmental Science*. The 45 short and informative video clips cover current news stories on environmental issues from around the world. These clips are a great way to start a lecture or spark a discussion. Available on DVD with a workbook, on the PowerLecture DVD, and in *CengageNOW* with additional Internet activities.

- *ExamView.* This full-feature program helps you create and deliver customized tests (both print and online) in minutes, using its complete word processing capabilities. Also available on the PowerLecture DVD.

Other Textbook Options

Instructors who want a book with a different length and emphasis can use one of our three other books that we have written for various types of environmental science courses: *Environmental Science*, 13th edition (452 pages, Brooks/Cole 2010), *Sustaining the Earth: An Integrated Approach*, 10th edition (339 pages, Brooks/Cole, 2012), and *Essentials of Ecology*, 6th edition (276 pages, Brooks/Cole, 2012).

Additionally, Cengage Learning offers custom solutions for your course—whether it is making a small modification to *Living in the Environment* to match your syllabus or combining multiple sources to create a truly unique course. You can pick and choose chapters, and add additional cases, readings, articles, or labs to create a text that fits the way you teach. Contact your Cengage Learning representative to explore custom solutions for your course.

Help Us Improve This Book or Its Supplements

Let us know how you think we can improve this book. If you find any errors, bias, or confusing explanations, please e-mail us about your concerns at:

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We can correct most errors in subsequent printings of this edition, as well as in future editions.

Acknowledgments

We wish to thank the many students and teachers who have responded so favorably to the 16 previous editions of *Living in the Environment,* the 13 editions of *Environmental Science*, the nine editions of *Sustaining the Earth,* and the five editions of *Essentials of Ecology,* and who have corrected errors and offered many helpful suggestions for improvement. We are also deeply indebted to the more than 295 reviewers, who pointed out errors and suggested many important improvements in the various editions of these three books.

It takes a village to produce a textbook, and the members of the talented production team, listed on the copyright page, have made vital contributions. Our special thanks go to development editor Christopher Delgado, who patiently and expertly keeps us on track, production editors Hal Humphrey and Nicole Barone, copy editor Deborah Thompson, layout expert Judy Maenle, photo researcher Abigail Reip, artist Patrick Lane, media editor Alexandria Brady, assistant editor Alexis Glubka, editorial assistants Brandusa Radoias and Joshua Taylor, and Brooks/Cole's hard-working sales staff. Finally, we are fortunate and delighted to be working with Yolanda Cossio, the Biology Publisher at Brooks/Cole. We thank her for her inspiring leadership and for her many insights and questions that have helped us to improve this book.

We also thank Ed Wells and the team who developed the *Laboratory Manual* to accompany this book, and the people who have translated it into eight languages for use throughout much of the world.

G. Tyler Miller, Jr.
Scott E. Spoolman

Guest Essayists

Guest essays by the following authors are available on *CengageNOW*: **M. Kat Anderson**, ethnoecologist with the National Plant Center of the USDA's Natural Resource Conservation Center; **Lester R. Brown**, president, Earth Policy Institute; **Alberto Ruz Buenfil**, environmental activist, writer, and performer; **Robert D. Bullard**, professor of sociology and director of the Environmental Justice Resource Center at Clark Atlanta University; **Michael Cain**, ecologist and adjunct professor at Bowdoin College; **Herman E. Daly**, senior research scholar at the School of Public Affairs, University of Maryland; **Lois Marie Gibbs**, director, Center for Health, Environment, and Justice; **Garrett Hardin**, professor emeritus (now deceased) of human ecology, University of California, Santa Barbara; **John Harte**, professor of energy and resources, University of California, Berkeley; **Paul G. Hawken**, environmental author and business leader; **Jane Heinze-Fry**, environmental educator; **Paul F. Kamitsuja**, infectious disease expert and physician; **Amory B. Lovins**, energy policy consultant and director of research, Rocky Mountain Institute; **Bobbi S. Low**, professor of resource ecology, University of Michigan; **John J. Magnuson**, Director Emeritus of the Center for Limnology, University of Wisconsin, Madison; **Lester W. Milbrath**, director of the research program in environment and society, State University of New York, Buffalo; **Peter Montague**, director, Environmental Research Foundation; **Norman Myers**, tropical ecologist and consultant in environment and development; **David W. Orr**, professor of environmental studies, Oberlin College; **Noel Perrin**, adjunct professor of environmental studies, Dartmouth College; **David Pimentel**, professor of insect ecology and agricultural sciences, Cornell University; **John Pichtel**, Ball State University; **Andrew C. Revkin**, environmental author and environmental reporter for the *New York Times*; **Vandana Shiva**, physicist, educator, environmental consultant; **Nancy Wicks**, ecopioneer and director of Round Mountain Organics; and **Donald Worster**, environmental historian and professor of American history, University of Kansas.

Quantitative Exercise Contributors

Dr. Dean Goodwin and his colleagues, Berry Cobb, Deborah Stevens, Jeannette Adkins, Jim Lehner, Judy Treharne, Lonnie Miller, and Tom Mowbray, provided excellent contributions to the Data Analysis and Ecological Footprint Analysis exercises.

Cumulative Reviewers

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About the Authors

G. Tyler Miller, Jr.

G. Tyler Miller, Jr., has written 59 textbooks for introductory courses in environmental science, basic ecology, energy, and environmental chemistry. Since 1975, Miller's books have been the most widely used textbooks for environmental science in the United States and throughout the world. They have been used by almost 3 million students and have been translated into eight languages.

Miller has a professional background in chemistry, physics, and ecology. He has Ph.D. from the University of Virginia and has received two honorary doctoral degrees for his contributions to environmental education. He taught college for 20 years, developed one of the nation's first environmental studies programs, and developed an innovative interdisciplinary undergraduate science program before deciding to write environmental science textbooks full time in 1975. Currently, he is the president of Earth Education and Research, devoted to improving environmental education.

He describes his hopes for the future as follows:

If I had to pick a time to be alive, it would be the next 75 years. Why? First, there is overwhelming scientific evidence that we are in the process of seriously degrading our own life-support system. In other words, we are living unsustainably. Second, within your lifetime we have the opportunity to learn how to live more sustainably by working with the rest of nature, as described in this book.

I am fortunate to have three smart, talented, and wonderful sons—Greg, David, and Bill. I am especially privileged to have Kathleen as my wife, best friend, and research associate. It is inspiring to have a brilliant, beautiful (inside and out), and strong woman who cares deeply about nature as a lifemate. She is my hero. I dedicate this book to her and to the earth.

Scott Spoolman

Scott Spoolman is a writer and textbook editor with over 25 years of experience in educational publishing. He has worked with Tyler Miller since 2003 as a contributing editor on earlier editions of *Living in the Environment*, *Environmental Science,* and *Sustaining the Earth*.

Spoolman holds a master's degree in science journalism from the University of Minnesota. He has authored numerous articles in the fields of science, environmental engineering, politics, and business. He worked as an acquisitions editor on a series of college forestry textbooks. He has also worked as a consulting editor in the development of over 70 college and high school textbooks in fields of the natural and social sciences.

In his free time, he enjoys exploring the forests and waters of his native Wisconsin along with his family—his wife, environmental educator Gail Martinelli, and his children, Will and Katie.

Spoolman has the following to say about his collaboration with Tyler Miller:

I am honored to be working with Tyler Miller as a coauthor to continue the Miller tradition of thorough, clear, and engaging writing about the vast and complex field of environmental science. I share Tyler Miller's passion for insuring that these textbooks and their multimedia supplements will be valuable tools for students and instructors. To that end, we strive to introduce this interdisciplinary field in ways that will be informative and sobering, but also tantalizing and motivational.

If the flip side of any problem is indeed an opportunity, then this truly is one of the most exciting times in history for students to start an environmental career. Environmental problems are numerous, serious, and daunting, but their possible solutions generate exciting new career opportunities. We place high priorities on inspiring students with these possibilities, challenging them to maintain a scientific focus, pointing them toward rewarding and fulfilling careers, and in doing so, working to help sustain life on the earth.

My Environmental Journey

G. Tyler Miller, Jr.

My environmental journey began in 1966 when I heard a lecture on population and pollution problems by Dean Cowie, a biophysicist with the U.S. Geological Survey. It changed my life. I told him that if even half of what he said was valid, I would feel ethically obligated to spend the rest of my career teaching and writing to help students learn about the basics of environmental science. After spending six months studying the environmental literature, I concluded that he had greatly underestimated the seriousness of these problems.

I developed an undergraduate environmental studies program and in 1971 published my first introductory environmental science book, an interdisciplinary study of the connections between energy laws (thermodynamics), chemistry, and ecology. In 1975, I published the first edition of *Living in the Environment*. Since then, I have completed multiple editions of this textbook, and of three others derived from it, along with other books.

Beginning in 1985, I spent ten years in the deep woods living in an adapted school bus that I used as an environmental science laboratory and writing environmental science textbooks. I evaluated the use of passive solar energy design to heat the structure; buried earth tubes to bring in air cooled by the earth (geothermal cooling) at a cost of about $1 per summer; set up active and passive systems to provide hot water; installed an energy-efficient instant hot water heater powered by LPG; installed energy-efficient windows and appliances and a composting (waterless) toilet; employed biological pest control; composted food wastes; used natural planting (no grass or lawnmowers); gardened organically; and experimented with a host of other potential solutions to major environmental problems that we face.

I also used this time to learn and think about how nature works by studying the plants and animals around me. My experience from living in nature is reflected in much of the material in this book. It also helped me to develop the three simple principles of sustainability that serve as the integrating theme for this textbook and to apply these principles to living my life more sustainably.

I came out of the woods in 1995 to learn about how to live more sustainably in an urban setting where most people live. Since then, I have lived in two urban villages, one in a small town and one within a large metropolitan area.

Since 1970, my goal has been to use a car as little as possible. Since I work at home, I have a "low-pollute commute" from my bedroom to a chair and a laptop computer. I usually take one airplane trip a year to visit my sister and my publisher.

As you will learn in this book, life involves a series of environmental trade-offs. Like most people, I still have a large environmental impact, but I continue to struggle to reduce it. I hope you will join me in striving to live more sustainably and sharing what you learn with others. It is not always easy, but it sure is fun.

CENGAGE LEARNING'S COMMITMENT TO SUSTAINABLE PRACTICES

We the authors of this textbook and Cengage Learning, the publisher, are committed to making the publishing process as sustainable as possible. This involves four basic strategies:

- *Using sustainably produced paper.* The book publishing industry is committed to increasing the use of recycled fibers, and Cengage Learning is always looking for ways to increase this content. Cengage Learning works with paper suppliers to maximize the use of paper that contains only wood fibers that are certified as sustainably produced, from the growing and cutting of trees all the way through paper production. (See page 230 in this book for more information on *certification of forest products* such as paper.)
- *Reducing resources used per book.* The publisher has an ongoing program to reduce the amount of wood pulp, virgin fibers, and other materials that go into each sheet of paper used. New, specially designed printing presses also reduce the amount of scrap paper produced per book.
- *Recycling.* Printers recycle the scrap paper that is produced as part of the printing process. Cengage Learning also recycles waste cardboard from shipping cartons, along with other materials used in the publishing process.
- *Process improvements.* In years past, publishing has involved using a great deal of paper and ink for writing and editing of manuscripts, copyediting, reviewing page proofs, and creating illustrations. Almost all of these materials are now saved through use of electronic files. Except for our review of page proofs, very little paper and ink were used in the preparation of this textbook.

Learning Skills

Students who can begin early in their lives to think of things as connected, even if they revise their views every year, have begun the life of learning.

MARK VAN DOREN

Why Is It Important to Study Environmental Science?

Welcome to **environmental science**—an *interdisciplinary* study of how the earth works, how we interact with the earth, and how we can deal with the environmental problems we face. Because environmental issues affect every part of your life, the concepts, information, and issues discussed in this book and the course you are taking will be useful to you now and throughout your life.

Understandably, we are biased, but *we strongly believe that environmental science is the single most important course in your education*. What could be more important than learning how the earth works, how we affect its life-support system, and how we can reduce our environmental impact?

We live in an incredibly challenging era. We are becoming increasingly aware that during this century, we need to make a new cultural transition in which we learn how to live more sustainably by sharply reducing our degradation of our life-support system. We hope this book will inspire you to become involved in this change in the way we view and treat the earth, which sustains us, our economies, and all other living things.

You Can Improve Your Study and Learning Skills

Maximizing your ability to learn should be one of your most important lifetime educational goals. It involves continually trying to *improve your study and learning skills*. Here are some suggestions for doing so:

Develop a passion for learning. As the famous physicist and philosopher Albert Einstein put it, "I have no special talent. I am only passionately curious."

Get organized. Becoming more efficient at studying gives you more time for other interests.

Make daily to-do lists in writing. Put items in order of importance, focus on the most important tasks, and assign a time to work on these items. Because life is full of uncertainties, you might be lucky to accomplish half of the items on your daily list. Shift your schedule as needed to accomplish the most important items.

Set up a study routine in a distraction-free environment. Develop a written daily study schedule and stick to it. Study in a quiet, well-lighted space. Work while sitting at a desk or table—not lying down on a couch or bed. Take breaks every hour or so. During each break, take several deep breaths and move around; this will help you to stay more alert and focused.

Avoid procrastination. Avoid putting work off until another time. Do not fall behind on your reading and other assignments. Set aside a particular time for studying each day and make it a part of your daily routine.

Do not eat dessert first. Otherwise, you may never get to the main meal (studying). When you have accomplished your study goals, reward yourself with dessert (play or leisure).

Make hills out of mountains. It is psychologically difficult to climb a mountain, which is what reading an entire book, reading a chapter in a book, writing a paper, or cramming to study for a test can feel like. Instead, break these large tasks (mountains) down into a series of small tasks (hills). Each day, read a few pages of a book or chapter, write a few paragraphs of a paper, and review what you have studied and learned. As American automobile designer and builder Henry Ford put it, "Nothing is particularly hard if you divide it into small jobs."

Look at the big picture first. Get an overview of an assigned reading in this book by looking at the *Key Questions and Concepts* box at the beginning of each chapter. It lists both the key questions explored in the chapter sections and their corresponding key concepts, which are the critical lessons to learn in the chapter. Use this list as a chapter roadmap. When you finish a chapter you can also use the list to review.

Ask and answer questions as you read. For example, "What is the main point of a particular subsection or paragraph?" Relate your own questions to the key questions and key concepts addressed in each major chapter section. In this way, you can flesh out a chapter outline to help you understand the chapter material. You may even want to do such an outline in writing.

Focus on key terms. Use the glossary in your textbook to look up the meaning of terms or words you do not understand. This book shows all key terms in **boldface** type and lesser, but still important, terms in *italicized* type. The review questions at the end of each chapter also include the chapter's key terms in boldface. Flash cards for testing your mastery of key terms for each chapter are available on the website for this book, or you can make your own by putting a term on one side of an index card or piece of paper and its meaning on the other side.

Interact with what you read. We suggest that you mark key sentences and paragraphs with a highlighter or pen. Consider putting an asterisk in the margin next to material you think is important and double asterisks next to material you think is especially important. Write comments in the margins such as *beautiful*, *confusing*, *misleading*, or *wrong*. You might fold down the top corners of pages on which you highlighted passages and the top and bottom corners of especially important pages. This way, you can flip through a chapter or book and quickly review the key ideas.

Review to reinforce learning. Before each class session, review the material you learned in the previous session and read the assigned material.

Become a good note taker. Do not try to take down everything your instructor says. Instead, write down main points and key facts using your own shorthand system. Review, fill in, and organize your notes as soon as possible after each class.

Write out answers to questions to focus and reinforce learning. Answer the critical thinking questions found in *Thinking About* boxes throughout the chapters, in many figure captions, and at the end of each chapter. These questions are designed to inspire you to think critically about key ideas and connect them to other ideas and your own life. Also answer the review questions found at the end of each chapter. The website for each chapter has an additional detailed list of review questions for that chapter. Writing out your answers to the critical thinking and review questions can reinforce your learning. Save your answers for review and test preparation.

Use the buddy system. Study with a friend or become a member of a study group to compare notes, review material, and prepare for tests. Explaining something to someone else is a great way to focus your thoughts and reinforce your learning. Attend any review sessions offered by instructors or teaching assistants.

Learn your instructor's test style. Does your instructor emphasize multiple-choice, fill-in-the-blank, true-or-false, factual, or essay questions? How much of the test will come from the textbook and how much from lecture material? Adapt your learning and studying methods to this style. You may disagree with this style and feel that it does not adequately reflect what you know. But the reality is that your instructor is in charge.

Become a good test taker. Avoid cramming. Eat well and get plenty of sleep before a test. Arrive on time or early. Calm yourself and increase your oxygen intake by taking several deep breaths. (Do this also about every 10–15 minutes while taking the test.) Look over the test and answer the questions you know well first. Then work on the harder ones. Use the process of elimination to narrow down the choices for multiple-choice questions. Paring them down to two choices gives you a 50% chance of guessing the right answer. For essay questions, organize your thoughts before you start writing. If you have no idea what a question means, make an educated guess. You might earn some partial credit and avoid getting a zero. Another strategy for getting some credit is to show your knowledge and reasoning by writing something like this: "If this question means so and so, then my answer is ________."

Develop an optimistic but realistic outlook. Try to be a "glass is half-full" rather than a "glass is half-empty" person. Pessimism, fear, anxiety, and excessive worrying (especially over things you cannot control) are destructive and lead to inaction. Try to keep your energizing feelings of realistic optimism slightly ahead of any immobilizing feelings of pessimism. Then you will always be moving forward.

Take time to enjoy life. Every day, take time to laugh and enjoy nature, beauty, and friendship.

You Can Improve Your Critical Thinking Skills: Become Good at Detecting Baloney

Critical thinking involves developing the skills to analyze information and ideas, judge their validity, and make decisions. Critical thinking helps you to distinguish between facts and opinions, evaluate evidence and arguments, take and defend informed positions on issues, integrate information and see relationships, and apply your knowledge to dealing with new and different problems, and to your own lifestyle choices. Here are some basic skills for learning how to think more critically.

Question everything and everybody. Be skeptical, as any good scientist is. Do not believe everything you hear and read, including the content of this textbook, without evaluating the information you receive. Seek other sources and opinions.

Identify and evaluate your personal biases and beliefs. Each of us has biases and beliefs taught to us by our parents, teachers, friends, role models, and our own experience. What are your basic beliefs, values, and biases? Where did they come from? What assumptions are they based on? How sure are you that your beliefs, values, and assumptions are right and why? According to the American psychologist and philosopher William James, "A great many people think they are thinking when they are merely rearranging their prejudices."

Be open-minded and flexible. Be open to considering different points of view. Suspend judgment until you gather more evidence, and be willing to change your mind. Recognize that there may be a number of useful and acceptable solutions to a problem, and that very few issues are black or white. There are trade-offs involved in dealing with any environmental issue, as you will learn in this book. One way to evaluate divergent views is to try to take the viewpoints of other people. How do they see the world? What are their basic assumptions and beliefs? Are their positions logically consistent with their assumptions and beliefs?

Be humble about what you know. Some people are so confident in what they know that they stop thinking and questioning. To paraphrase American writer Mark Twain, "It's what we know is true, but just ain't so, that hurts us."

Evaluate how the information related to an issue was obtained. Are the statements you heard or read based on firsthand knowledge and research or on hearsay? Are unnamed sources used? Is the information based on reproducible and widely accepted scientific studies or on preliminary scientific results that may be valid but need further testing? Is the information based on a few isolated stories or experiences or on carefully controlled studies whose results were reviewed by experts in the field involved (*peer review*)? Is it based on unsubstantiated and dubious scientific information or beliefs?

Question the evidence and conclusions presented. What are the conclusions or claims? What evidence is presented to support them? Does the evidence support them? Is there a need to gather more evidence to test the conclusions? Are there other, more reasonable conclusions?

Try to uncover differences in basic beliefs and assumptions. On the surface, most arguments or disagreements involve differences in opinions about the validity or meaning of certain facts or conclusions. Scratch a little deeper and you will find that most disagreements are usually based on different (and often hidden) basic assumptions concerning how we look at and interpret the world around us. Uncovering these basic differences can allow the parties involved to understand where each is coming from and to agree to disagree about their basic assumptions, beliefs, or principles.

Try to identify and assess any motives on the part of those presenting evidence and drawing conclusions. What is their expertise in this area? Do they have any unstated assumptions, beliefs, biases, or values? Do they have a personal agenda? Can they benefit financially or politically from acceptance of their evidence and conclusions? Would investigators with different basic assumptions or beliefs take the same data and come to different conclusions?

Expect and tolerate uncertainty. Recognize that scientists cannot establish absolute proof or certainty about anything. However, the results of reliable science have a high degree of certainty.

Do the arguments used involve logical fallacies or debating tricks? Here are six of many examples of such tricks. *First*, attack the presenter of an argument rather than the argument itself. *Second*, appeal to emotion rather than facts and logic. *Third*, claim that if one piece of evidence or one conclusion is false, then all other related pieces of evidence and conclusions are false. *Fourth*, say that a conclusion is false because it has not been scientifically proven (scientists never prove anything absolutely). *Fifth*, inject irrelevant or misleading information to divert attention from important points. *Sixth*, present only either/or alternatives when there may be a number of options.

Do not believe everything you read on the Internet. The Internet is a wonderful and easily accessible source of information, including alternative explanations and opinions on almost any subject or issue—much of it not available in the mainstream media and scholarly articles. Web logs, or blogs, have become a major source of information, and are even more important than standard news media for some people. However, because the Internet is so open, anyone can post anything they want to some blogs and other websites with no editorial control or review by experts. As a result, evaluating information on the Internet is one of the best ways to put into practice the principles of critical thinking discussed here. Use and enjoy the Internet, but think critically and proceed with caution.

Develop principles or rules for evaluating evidence. Develop a written list of principles to serve as guidelines for evaluating evidence and claims (such as the list we are presenting here). Continually evaluate and modify this list on the basis of your experience.

Become a seeker of wisdom, not a vessel of information. Many people believe that the main goal of education is to learn as much as you can by gathering more and more information. We believe that the primary goal is to learn how to sift through mountains of facts and ideas to find the few *nuggets of wisdom* that are the most useful for understanding the world and for making decisions. This book is full of facts and numbers, but they are useful only to the extent that they lead to an understanding of key ideas, scientific laws, theories, concepts, and connections. The major goals of the study of environmental science are to find out how nature works and sustains itself (*environmental wisdom*) and to use *principles of environmental wisdom* to help make human societies and economies more sustainable, more just, and more beneficial and enjoyable for all. As writer Sandra Carey observed, "Never mistake knowledge for wisdom. One helps you make a living; the other helps you make a life." Or as American writer Walker Percy suggested, "Some individuals with a high intelligence but lacking wisdom can get all A's and flunk life."

To help you practice critical thinking, we have supplied questions throughout this book, found within each chapter in brief boxes labeled *Thinking About*, in the captions of many figures, and at the end of each chapter. There are no right or wrong answers to many of these questions. A good way to improve your critical thinking skills is to compare your answers with those of your classmates and to discuss how you arrived at your answers.

Know Your Own Learning Style

People have different ways of learning, and it can be helpful to know your own learning style. *Visual learners* learn best by reading and viewing illustrations and diagrams. They can benefit from using flash cards (available on the website for this book) to memorize key terms and ideas. This is a highly visual book with many carefully selected photographs and diagrams designed to illustrate important ideas, concepts, and processes.

Auditory learners learn best by listening and discussing. They might benefit from reading aloud while studying and using a tape recorder in lectures for study and review. *Logical learners* learn best by using concepts and logic to uncover and understand a subject rather than relying mostly on memory.

Part of what determines your learning style is how your brain works. According to the *split-brain hypothesis*, the left hemisphere of your brain is good at logic, analysis, and evaluation, and the right half of your brain is good at visualizing, synthesizing, and creating. One of our goals is to provide material that stimulates both sides of your brain.

The study and critical thinking skills encouraged in this book and in most courses largely involve the left brain. However, you can improve these skills by giving your left brain a break and letting your creative side loose. You can do this by brainstorming ideas with classmates with the rule that no left-brain criticism is allowed until the session is over.

When you are trying to solve a problem, try to rest, meditate, take a walk, exercise, or do something to shut down your controlling left-brain activity. This will allow the right side of your brain to work on the problem in a less controlled and more creative manner.

This Book Presents a Positive and Realistic Environmental Vision of the Future

There are always *trade-offs* involved in making and implementing environmental decisions. Our challenge is to give a balanced presentation of different viewpoints, the advantages and disadvantages of various technologies and proposed solutions to environmental problems, and the good and bad news about environmental problems, and to do this without injecting personal bias.

Studying a subject as important as environmental science and ending up with no conclusions, opinions, and beliefs means that both teacher and student have failed. However, any conclusions one does reach must be based on using critical thinking to evaluate different ideas and to understand the trade-offs involved. Our goal is to present a positive vision of our environmental future based on realistic optimism.

Help Us Improve This Book

Researching and writing a book that covers and connects ideas in such a wide variety of disciplines is a challenging and exciting task. Almost every day, we learn about some new connection in nature.

In a book this complex, there are bound to be some errors—some typographical mistakes that slip through and some statements that you might question, based on your knowledge and research. We invite you to contact us to point out any bias, to correct any errors you find, and to suggest ways to improve this book. Please e-mail your suggestions to Tyler Miller at **mtg@hotmail.com** or Scott Spoolman at **spoolman@tds.net**.

Now start your journey into this fascinating and important study of how the earth works and how we can leave the planet in a condition at least as good as what we found. Have fun.

Study nature, love nature, stay close to nature. It will never fail you.

FRANK LLOYD WRIGHT

Environmental Problems, Their Causes, and Sustainability

1

A Vision of a More Sustainable World in 2060

CORE CASE STUDY

Emily Briggs and Michael Rodriguez graduated from college in 2014. Michael earned a masters degree in environmental education, became a middle-school teacher, and loved teaching environmental science. Emily, meanwhile, went to law school and later established a thriving practice as an environmental lawyer.

In 2022, Michael and Emily met when they were doing volunteer work for an environmental organization. They later got married, had a child, and taught her about some of the world's environmental problems (Figure 1-1, left) and about the joys of nature that they had experienced as children (Figure 1-1, right). As a result, their daughter also became heavily involved in working to promote a more sustainable world and eventually passed this on to her child.

When Michael and Emily ware growing up, there had been increasing signs of stress on the earth's life support system—its land, air, water, and wildlife—due to the harmful environmental impacts of more people consuming more resources. But a major transition in environmental awareness began around 2010 when a growing number of people began transforming their lifestyles and economies to be more in tune with the ways in which nature had sustained itself for billions of years before humans walked the earth. Over several decades, this combination of environmental awareness and action paid off.

In January of 2060, Emily and Michael celebrated the birth of their grandchild. He was born into a world that was still rich with a great diversity of plants, animals, and ecosystems. The loss of this biological diversity, which had been a looming threat when Michael and Emily were young adults, had slowed to a trickle. And the atmosphere, oceans, lakes, and rivers were gradually cleansing themselves.

Energy waste had been cut in half. Energy from the sun, wind, flowing water, underground heat, and fuels produced from farm-raised grasses and algae had largely replaced energy from highly polluting oil and coal and from nuclear power with its dangerous, long-lived radioactive wastes. By 2050, significant atmospheric warming and the resulting climate change had occurred as many climate scientists had projected in the 1990s. But the threat of further climate change had begun to decrease, as the use of cleaner energy resources became the norm.

By 2060, farmers producing most of the world's food had shifted to farming practices that helped to conserve water and renew depleted soils. And the human population had peaked at 8 billion in 2040, instead of at the projected 9.5 billion, and then had begun a slow decline.

In 2060, Emily and Michael felt a great sense of pride, knowing that they and their child and countless others had helped to bring about these improvements so that future generations could live more sustainably on this marvelous planet that is our only home.

Sustainability is the capacity of the earth's natural systems and human cultural systems to survive, flourish, and adapt to changing environmental conditions into the very long-term future. It is about people caring enough to pass on a better world to all the generations to come. And it is the overarching theme of this textbook. Here, we describe the environmental problems we face, and we explore possible solutions. Our goal is to present to you a realistic and hopeful vision of what could be.

Mostovyl Sergii Igorevich/Shutterstock

Colin Hawkins/Getty Images

Figure 1-1 These parents—like Emily and Michael in our fictional vision of a possible world in 2060—are teaching their children about some of the world's environmental problems (left) and helping them to enjoy the wonders of nature (right). Their goal is to teach their children to care for the earth in hopes of passing on a better world to future generations.

Key Questions and Concepts*

1-1 What are three principles of sustainability?

CONCEPT 1-1A Nature has sustained itself for billions of years by relying on solar energy, biodiversity, and nutrient cycling.

CONCEPT 1-1B Our lives and economies depend on energy from the sun and on natural resources and natural services (*natural capital*) provided by the earth.

1-2 How are our ecological footprints affecting the earth?

CONCEPT 1-2 As our ecological footprints grow, we are depleting and degrading more of the earth's natural capital.

1-3 Why do we have environmental problems?

CONCEPT 1-3 Major causes of environmental problems are population growth, wasteful and unsustainable resource use, poverty, and the exclusion of environmental costs of resource use from the market prices of goods and services.

1-4 What is an environmentally sustainable society?

CONCEPT 1-4 Living sustainably means living off the earth's natural income without depleting or degrading the natural capital that supplies it.

Note: Supplements 2 (p. S3), 4 (p. S11), 5 (p. S18), and 8 (p. S30) can be used with this chapter.

*This is a *concept-centered* book, with the major sections of each chapter built around one or two key concepts derived from the natural or social sciences. Key questions and concepts are summarized at the beginning of each chapter. You can use this summary as a preview and as a review of the key ideas in each chapter.

Alone in space, alone in its life-supporting systems, powered by inconceivable energies, mediating them to us through the most delicate adjustments, wayward, unlikely, unpredictable, but nourishing, enlivening, and enriching in the largest degree—is this not a precious home for all of us? Is it not worth our love?

BARBARA WARD AND RENÉ DUBOS

1-1 What Are Three Principles of Sustainability?

▶ **CONCEPT 1-1A Nature has sustained itself for billions of years by relying on solar energy, biodiversity, and nutrient cycling.**

▶ **CONCEPT 1-1B Our lives and economies depend on energy from the sun and on natural resources and natural services (*natural capital*) provided by the earth.**

Environmental Science Is a Study of Connections in Nature

The **environment** is everything around us, or as the famous physicist Albert Einstein put it, "The environment is everything that isn't me." It includes the living and the nonliving things (air, water, and energy) with which we interact in a complex web of relationships that connect us to one another and to the world we live in.

Despite our many scientific and technological advances, we are utterly dependent on the environment for clean air and water, food, shelter, energy, and everything else we need to stay alive and healthy. As a result, we are part of, and not apart from, the rest of nature.

This textbook is an introduction to **environmental science**, an *interdisciplinary* study of how humans interact with the living and nonliving parts of their environment. It integrates information and ideas from the *natural sciences* such as biology, chemistry, and geology; the *social sciences* such as geography, economics, and political science; and the *humanities* such as philosophy and ethics. The three goals of environmental science are *to learn how nature works, to understand how we interact with the environment*, and *to find ways to deal with environmental problems and to live more sustainably*.

A key component of environmental science is **ecology**, the biological science that studies how **organisms**, or living things, interact with one another and

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. GOOD NEWS refers to good news about the environmental challenges we face.

with their environment. Every organism is a member of a certain **species**, a group of organisms that have a unique set of characteristics that distinguish them from all other organisms and, for organisms that reproduce sexually, can mate and produce fertile offspring. For example, all humans are members of a species that biologists have named *Homo sapiens sapiens.* (See Supplement 5, p. S18).

A major focus of ecology is the study of ecosystems. An **ecosystem** is a set of organisms within a defined area or volume that interact with one another and with and their environment of nonliving matter and energy. For example, a forest ecosystem consists of plants (especially trees), animals, and tiny microorganisms that decompose organic materials and recycle their chemicals, all interacting with one another and with solar energy and the chemicals in the ecosystem's air, water, and soil.

We should not confuse environmental science and ecology with *environmentalism*, a social movement dedicated to protecting the earth's life-support systems for all forms of life. Environmentalism is practiced more in the political and ethical arenas than in the realm of science.

Nature's Survival Strategies Follow Three Principles of Sustainability

Nature has been dealing with significant changes in environmental conditions that affect the planet for at least 3.5 billion years. This is why many environmental experts say that when we face an environmental change that becomes a problem for us or other species, we should learn how nature has dealt with such changes and then mimic nature's solutions.

In our study of environmental science, the most important question we can ask is, how did the incredible variety of life on the earth sustain itself for at least 3.5 billion years in the face of catastrophic changes in environmental conditions? Such changes had various causes, including gigantic meteorites impacting the earth, ice ages lasting for hundreds of millions of years, and long warming periods during which melting ice raised sea levels by hundreds of feet.

Considering the billions of years that life has existed on the earth, our species has been around for less than the blink of an eye (Figure 1-2). We named ourselves *Homo sapiens sapiens* (Latin for "wise man"). With our large and complex brains and language ability, we are a very smart species, but it remains to be seen whether we are as wise as we claim to be. Within only a few hundred years, we have taken over most of the earth to support our basic needs and rapidly growing wants. But in the process, we have degraded much of the earth. Many argue that a species in the process of degrading its own life-support system could not be considered wise.

To learn how to live more sustainably and thus more wisely, we need to find out how life on the earth has sustained itself. Our research leads us to believe that in the face of drastic environmental changes, there are three overarching themes relating to the long-term sustainability of life on this planet: *solar energy, biodiversity*, and *chemical cycling* (**Concept 1-1A**), as summarized in Figure 1-3 (p. 8). In other words, rely on the sun, promote multiple options for life, and reduce waste. These

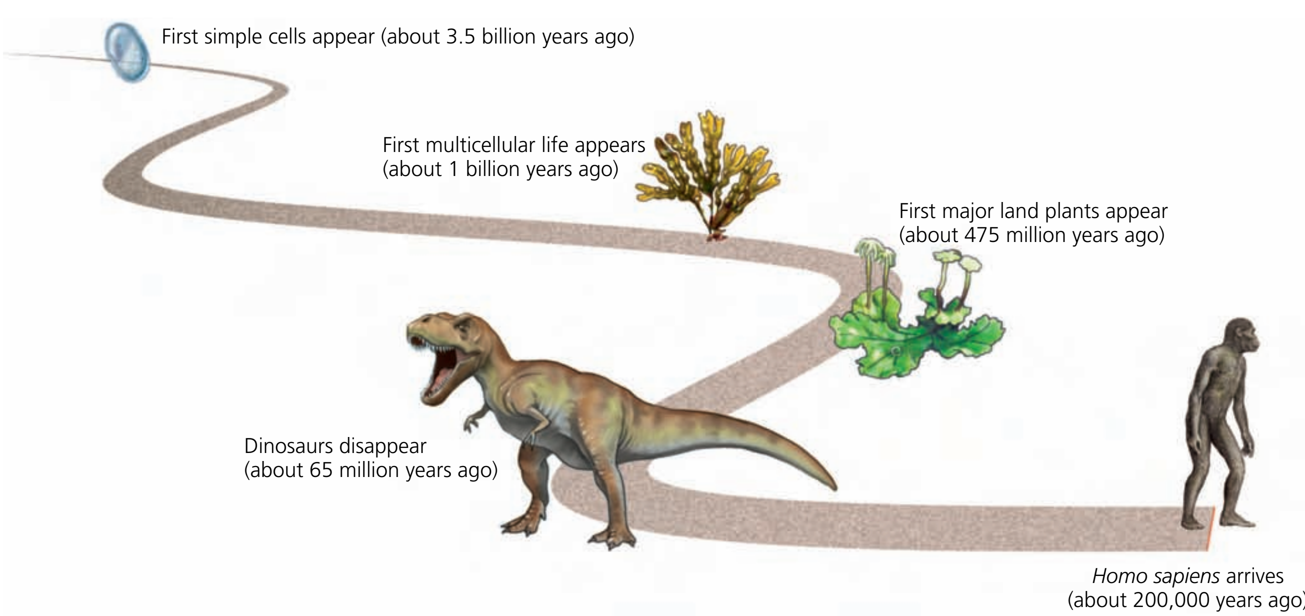

Figure 1-2 Here, the span of *Homo sapiens sapiens'* time on earth is compared with that of all life beginning about 3.5 billion years ago. If the length of this time line were 1 kilometer (0.6 miles), humanity's time on earth would occupy roughly the last 3 one-hundredths of a millimeter. That is less than the diameter of a hair on your head—compared with 1 kilometer of time.

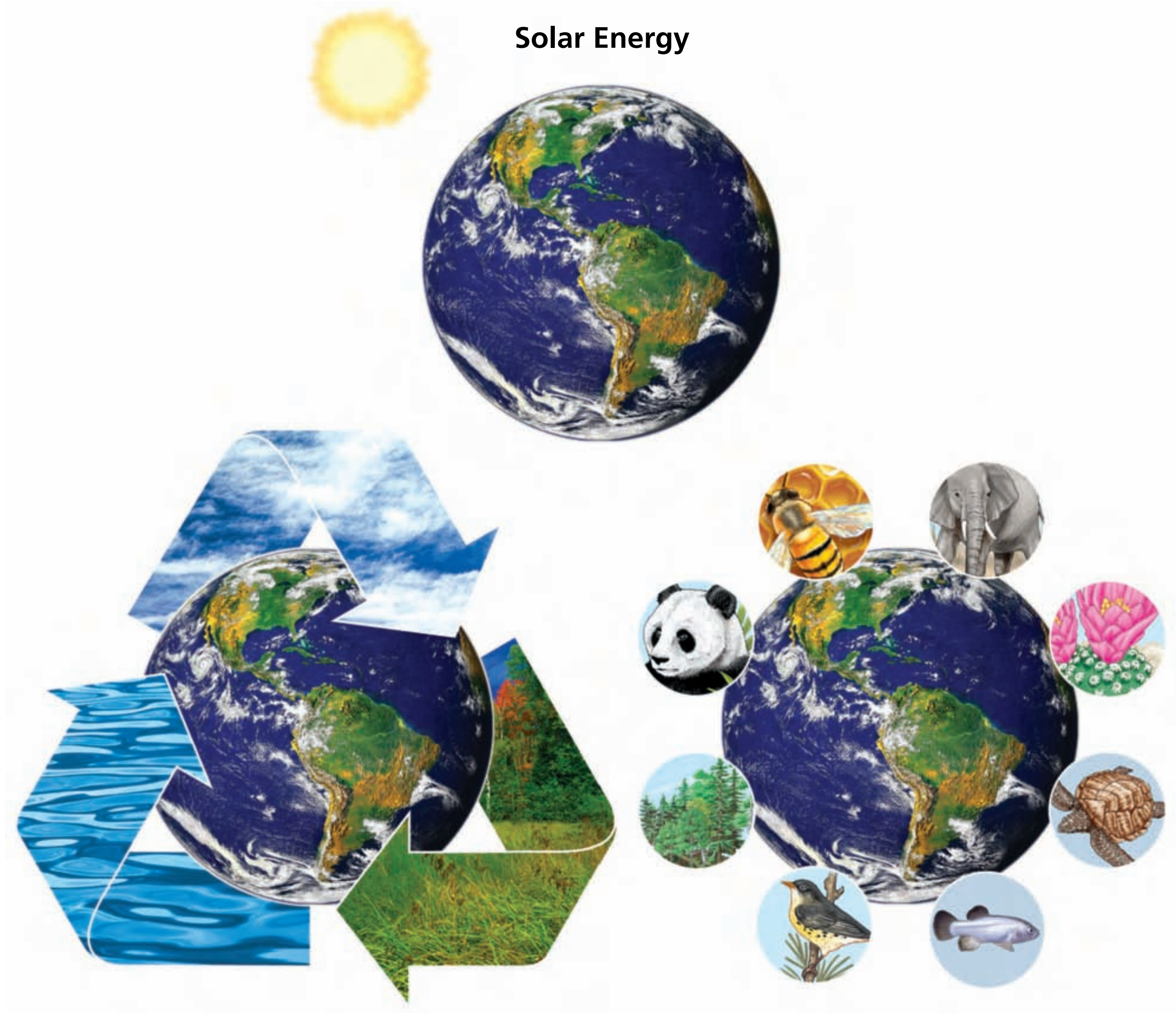

Figure 1-3 **Three principles of sustainability:** We derive these three interconnected principles of sustainability from learning how nature has sustained a huge variety of life on the earth for at least 3.5 billion years, despite drastic changes in environmental conditions (**Concept 1-1A**).

powerful and simple ideas make up three **principles of sustainability** or *lessons from nature* that we use throughout this book to guide us in living more sustainably.

- **Reliance on solar energy:** The sun warms the planet and supports *photosynthesis*—a complex chemical process used by plants to provide the *nutrients,* or chemicals that most organisms need in order to stay alive and reproduce. Without the sun, there would be no plants, no animals, and no food. The sun also powers indirect forms of solar energy such as wind and flowing water, which we can use to produce electricity.
- **Biodiversity** (short for *biological diversity*): This refers to the astounding variety of organisms, the natural systems in which they exist and interact (such as deserts, grasslands, forests, and oceans), and the natural services that these organisms and living systems provide free of charge (such as renewal of topsoil, pest control, and air and water purification). Biodiversity also provides countless ways for life to adapt to changing environmental conditions. Without it, most life would have been wiped out long ago.
- **Chemical cycling:** Also referred to as **nutrient cycling**, this circulation of chemicals from the environment (mostly from soil and water) through organisms and back to the environment is necessary for life. Natural processes keep this cycle going, and the earth receives no new supplies of these chemicals. Thus, for life to sustain itself, these nutrients must be cycled in this way, indefinitely. Without chemical cycling, there would be no air, no water, no soil, no food, and no life.

Sustainability Has Certain Key Components

Sustainability, the central integrating theme of this book, has several critical components that we use as subthemes. One such component is **natural capital**—the natural resources and natural services that keep us and other forms of life alive and support our human economies (Figure 1-4).

Natural resources are materials and energy in nature that are essential or useful to humans. They are often classified as *renewable resources* (such as air, water, soil, plants, and wind) or *nonrenewable resources* (such as copper, oil, and coal). **Natural services** are processes in nature, such as purification of air and water and renewal of topsoil, which support life and human economies.

In economic terms, *capital* refers to money and other forms of wealth that can support a person, a population, or an economy. It can provide a sustainable income if we use it properly—that is, if we do not spend it too quickly. If we protect capital by careful investment and spending, it can last indefinitely. Similarly, natural capital can support the earth's diversity of species as long as we use its natural resources and services in a sustainable fashion.

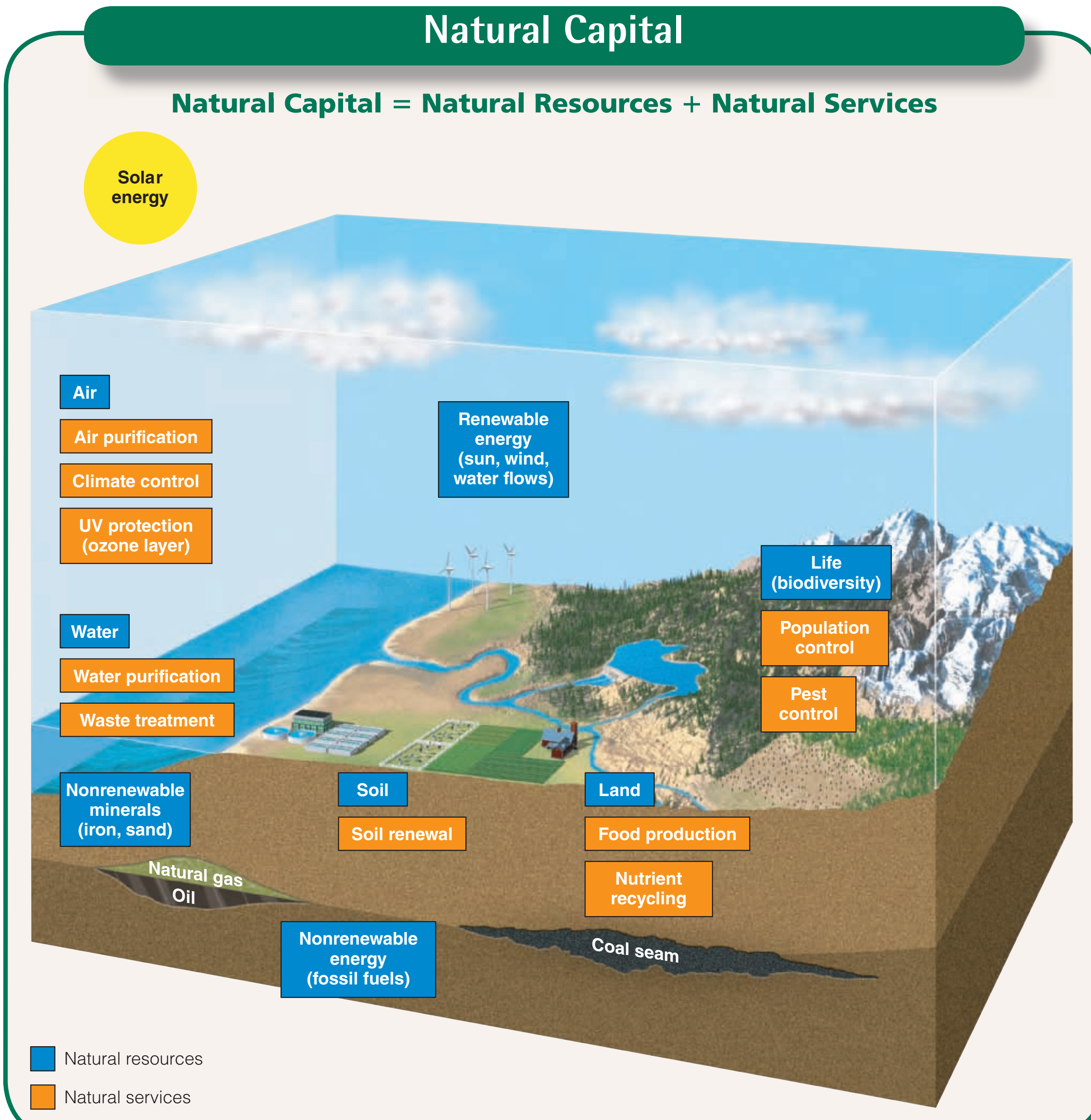

Figure 1-4 These key *natural resources* (blue) and *natural services* (orange) support and sustain the earth's life and human economies (**Concept 1-1A**).

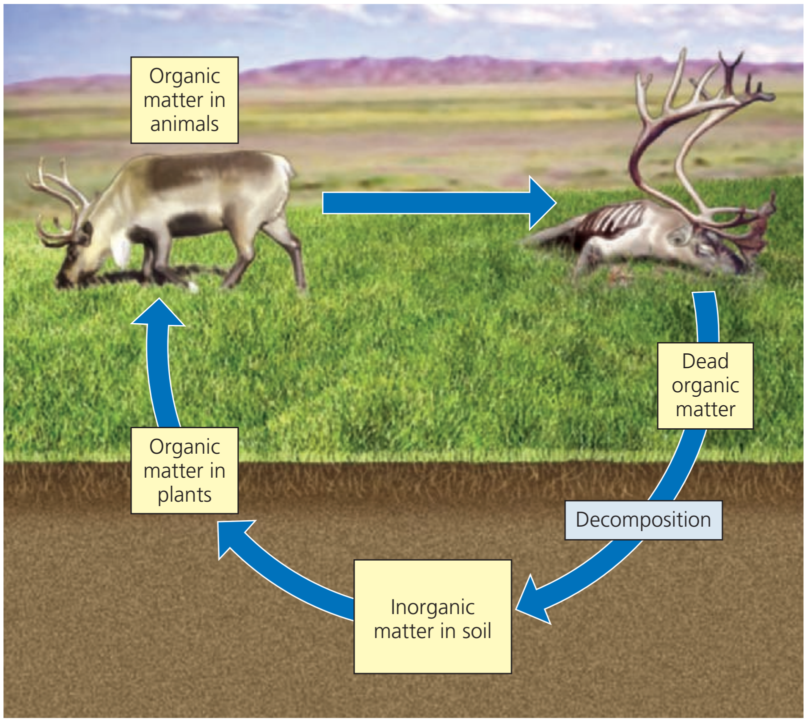

Figure 1-5 *Nutrient cycling:* This important natural service recycles chemicals needed by organisms from the environment (mostly from soil and water) through those organisms and back to the environment.

One vital natural service is nutrient cycling (Figure 1-5), an important component of which is *topsoil*, the upper layer of any soil in which plants can grow. It provides the nutrients that support plants, animals, and microorganisms living on land. Without nutrient cycling in topsoil, life as we know it could not exist. Hence, it is the basis for one of the three **principles of sustainability**.

Natural capital is supported by energy from the sun—another of the **principles of sustainability** (Figure 1-3). Without solar energy, natural capital and the life it supports would collapse. Thus, our lives and economies depend on energy from the sun, and on natural resources and natural services (*natural capital*) provided by the earth (**Concept 1-1B**).

A second component of sustainability—and another subtheme of this text—is to recognize that many human activities can *degrade natural capital* by using normally renewable resources faster than nature can restore them, and by overloading natural systems with pollution and wastes. For example, in some parts of the world, we are clearing mature forests much faster than they can grow back (Figure 1-6), eroding topsoil faster than nature can renew it, and withdrawing groundwater that was stored for thousands of years faster than nature can replenish it. We are also loading some rivers, lakes, and oceans with chemical and animal wastes faster than these bodies of water can cleanse themselves.

This leads us to a third component of sustainability: *solutions*. While environmental scientists search for solutions to problems such as the unsustainable use of forests and other forms of natural capital, their work is limited to finding the *scientific* solutions. The political solutions are left to political processes. For example, a scientific solution to the problem of depletion of forests might be to stop burning and cutting down biologically diverse, mature forests and to allow nature to replenish them. A scientific solution to the problem of pollution of rivers might be to prevent the dumping of chemicals and wastes into streams and allow them to recover naturally. But to implement such solutions, governments would probably have to enact and enforce environmental laws and regulations.

Frontpage/Shutterstock

Figure 1-6 **Natural capital degradation:** This was once a large area of diverse tropical rain forest in Brazil, but it has now been cleared to grow soybeans. According to ecologist Harold Mooney of Stanford University, conservative estimates suggest that between 1992 and 2008, an area of tropical rain forest larger than the U.S. state of California was destroyed in order to graze cattle and plant crops for food and biofuels.

The search for solutions often involves conflicts. For example, when a scientist argues for protecting a natural forest to help preserve its important diversity of plants and animals, the timber company that had planned to harvest the trees in that forest might protest. Dealing with such conflicts often involves making *trade-offs*, or compromises—another component of sustainability. For example, the timber company might be persuaded to plant a *tree farm*, a piece of land systematically planted with a rapidly growing tree species, in an area that had already been cleared or degraded, instead of clearing the trees in a diverse natural forest. In return, the company might receive the land at little or no cost and could harvest the trees for income in a fairly short time.

A shift toward environmental sustainability (**Core Case Study**)* should be based on scientific concepts and results that are widely accepted by experts in a particular field, as discussed in more detail in Chapter 2. But in making such a shift, what each of us does every day is important. In other words, *individuals matter*. This is another subtheme of this book. Some people are good at thinking of new scientific ideas and innovative solutions. Others are good at putting political pressure on government and business leaders to implement those solutions. In any case, a society's shift toward sustainability ultimately depends on the actions of individuals, beginning with the daily choices we all make. Thus, *sustainability begins at personal and local levels*.

CORE CASE STUDY

Some Resources Are Renewable and Some Are Not

From a human standpoint, a **resource** is anything that we can obtain from the environment to meet our needs and wants. Some resources such as solar energy, fertile topsoil, and edible wild plants are directly available for use. Other resources such as petroleum, iron, underground water, and cultivated crops become useful to us only with some effort and technological ingenuity. For example, petroleum was just a mysterious, oily fluid until we learned how to find and extract it and convert it into gasoline, heating oil, and other products.

Resources vary in terms of how quickly we can use them up and how well nature can replenish them after we use them. Solar energy is called a **perpetual resource** because its supply is continuous and is expected to last at least 6 billion years, while the sun completes its life cycle. A resource that takes anywhere from several days to several hundred years to be replenished through natural processes is a **renewable resource**, as long as we do not use it up faster than nature can renew it. Examples include forests, grasslands, fish populations, freshwater, fresh air, and fertile topsoil. The highest rate at which we can use a renewable resource indefinitely without reducing its available supply is called its **sustainable yield**.

Nonrenewable resources are resources that exist in a fixed quantity, or *stock*, in the earth's crust. On a time scale of millions to billions of years, geologic processes can renew such resources. But on the much shorter human time scale of hundreds to thousands of years, we can deplete these resources much faster than nature can form them. Such exhaustible stocks include *energy resources* (such as coal and oil), *metallic mineral resources* (such as copper and aluminum), and *nonmetallic mineral resources* (such as salt and sand).

As we deplete such resources, human ingenuity can often find substitutes. For example, during this century, a mix of renewable energy resources such as wind, the sun, flowing water, and the heat in the earth's interior could reduce our dependence on nonrenewable fuel resources such as oil and coal. Also, various types of plastics (some made from plants) and composite materials can replace certain metals. But sometimes there is no acceptable or affordable substitute.

We can recycle or reuse some nonrenewable resources, such as copper and aluminum, to extend their supplies. **Reuse** involves using a resource over and over in the same form. For example, we can collect, wash, and refill glass bottles many times (Figure 1-7). **Recycling** involves collecting waste materials (Figure 1-8, p. 12) and processing them into new materials. For example, we can crush and melt discarded aluminum to make new aluminum cans or other aluminum products. But we cannot recycle energy resources such as oil and coal. Once burned, their concentrated energy is no longer available to us. Reuse and recycling are two

Mark Edwards/Peter Arnold, Inc.

Figure 1-7 *Reuse:* This child and his family in Katmandu, Nepal, collect beer bottles and sell them for cash to a brewery that will reuse them.

*We use the opening Core Case Study as a theme to connect and integrate much of the material in each chapter. The arrow logo indicates these connections.


SuperStock RF/SuperStock

Figure 1-8 *Recycling:* This family is carrying out items for recycling. Scientists estimate that we could recycle and reuse 80–90% of the resources that we now use and thus come closer to mimicking the way nature recycles essentially everything. Recycling is important but it involves dealing with wastes we have produced. Ideally, we should focus more on using less, reusing items, and reducing our unnecessary waste of resources.

ways to live more sustainably (**Core Case Study**) by following one of nature's three principles of sustainability (Figure 1-3). CORE CASE STUDY

Recycling nonrenewable metallic resources uses much less energy, water, and other resources and produces much less pollution and environmental degradation than exploiting virgin metallic resources. Reusing such resources (Figure 1-7) requires even less energy, water, and other resources and produces less pollution and environmental degradation than recycling does.

Countries Differ in Levels of Unsustainability

Very few people consciously want to degrade their environment. In the past, most have done so probably without realizing it. But as the human population grows, more and more people seek to satisfy their needs and wants by using more resources. Governmental and societal leaders are charged with making this possible by maintaining and expanding their national economies, which can lead to growing environmental problems.

Economic growth is an increase in a nation's output of goods and services. It is usually measured by the percentage of change in a country's **gross domestic product (GDP)**, the annual market value of all goods and services produced by all businesses, foreign and domestic, operating within a country. Changes in a country's economic growth per person are measured by **per capita GDP**, the GDP divided by the total population at midyear.

While economic growth provides people with more goods and services, **economic development** is an effort to use economic growth to improve living standards. The United Nations (UN) classifies the world's countries as economically more developed or less developed, based primarily on their average income per person. The **more-developed countries** are those with high average income and they include the United States, Canada, Japan, Australia, New Zealand, and most European countries. According to UN and World Bank data, the more-developed countries, with only 19% of the world's population, use about 88% of all resources and produce about 75% of the world's pollution and waste.

All other nations, in which 81% of the world's people live, are classified as **less-developed countries**, most of them in Africa, Asia, and Latin America. Some are *middle-income, moderately-developed countries* such as China, India, Brazil, Turkey, Thailand, and Mexico. Others are *low-income, least-developed countries* such as the Congo, Haiti, Nigeria, and Nicaragua. (See Figure 2, p. S32, in Supplement 8 for a map of high-, upper-middle-, lower-middle-, and low-income countries.)

1-2 How Are Our Ecological Footprints Affecting the Earth?

▶ **CONCEPT 1-2 As our ecological footprints grow, we are depleting and degrading more of the earth's natural capital.**

We Are Living Unsustainably

The bad news is that according to a massive and growing body of scientific evidence, we are living unsustainably by wasting, depleting, and degrading the earth's natural capital at an accelerating rate. The entire process is known as **environmental degradation**, summarized in Figure 1-9. We also refer to this as **natural capital degradation**.

We are a civilization in serious trouble. In many parts of the world, potentially renewable forests are

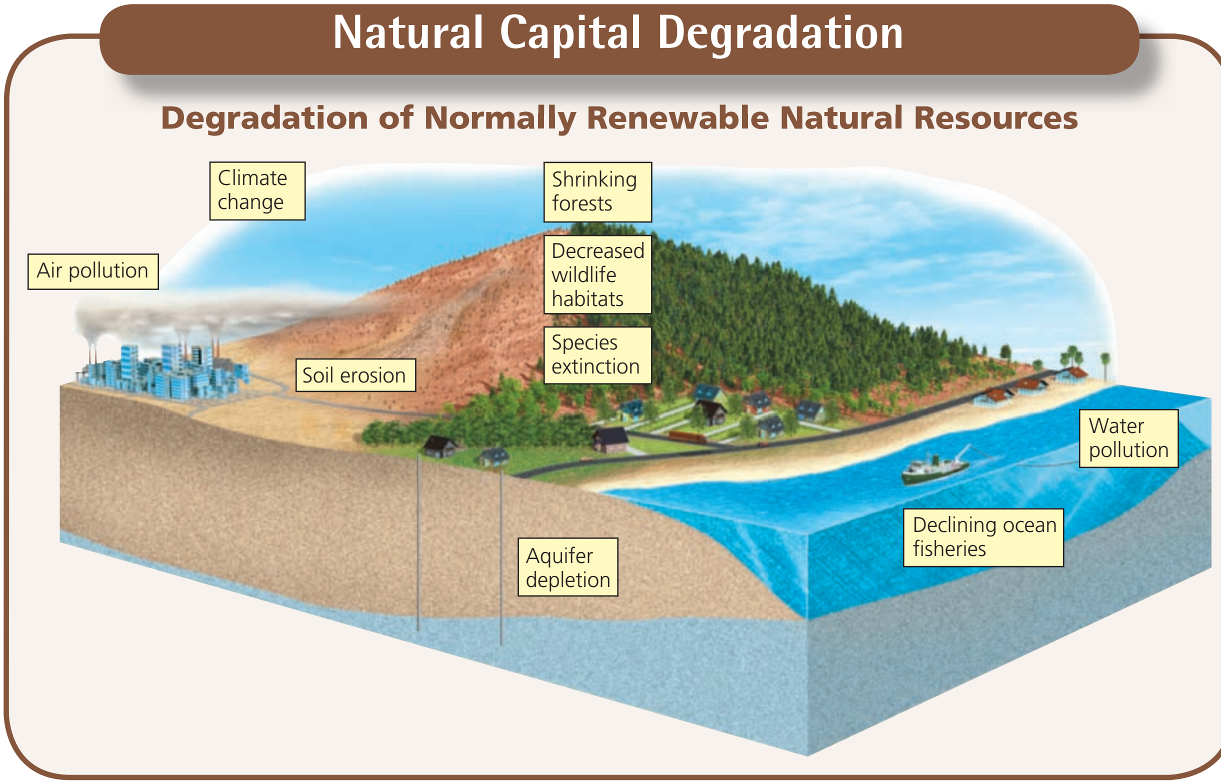

Figure 1-9 These are examples of the degradation of normally renewable natural resources and services in parts of the world, mostly as a result of rising populations and resource use per person.

shrinking, deserts are expanding, soils are eroding, and agricultural lands are deteriorating. In addition, the lower atmosphere is warming, glaciers are melting, sea levels are rising, and floods, droughts, severe weather, and forest fires are increasing in some areas. In many areas, potentially renewable rivers are running dry, harvests of many species of edible fish are dropping sharply, and coral reefs are disappearing. Species are becoming extinct at least 100 times faster than they were in prehuman times, and this rate is expected to increase.

In 2005, the UN released its *Millennium Ecosystem Assessment*. According to this 4-year study by 1,360 experts from 95 countries, human activities have degraded about 60% of the earth's natural services (Figure 1-4), mostly in the past 50 years. In its summary statement, the report warned that "human activity is putting such a strain on the natural functions of Earth that the ability of the planet's ecosystems to sustain future generations can no longer be taken for granted."

The good news, also included in the UN report, is that we have the knowledge and tools to conserve rather than degrade or destroy the planet's natural capital, and there are a number of commonsense strategies for doing so. GOOD NEWS

RESEARCH FRONTIER*

Gaining better and more comprehensive information about the state of the earth's natural capital and the health of its life-support systems; see **www.cengage.com/login**.

*Environmental science is a developing field with many exciting research frontiers that are identified throughout this book.

HOW WOULD YOU VOTE?**

Do you believe that the society you live in is on an unsustainable path? Cast your vote online at **www.cengage.com/login**.

Pollution Comes from a Number of Sources

One of the earliest problems environmental scientists have addressed, and one that is basic to many other environmental issues, is **pollution**—any presence within the environment of a chemical or other agent such as noise or heat at a level that is harmful to the health, survival, or activities of humans or other organisms. Polluting substances, or *pollutants*, can enter the environment naturally, such as from volcanic eruptions, or through human activities, such as the burning of coal or gasoline, and the dumping of chemicals into rivers and oceans.

The pollutants we produce come from two types of sources. **Point sources** are single, identifiable sources. Examples are the smokestack of a coal-burning power or industrial plant (Figure 1-10, p. 14), the drainpipe of a factory, and the exhaust pipe of an automobile. **Nonpoint sources** are dispersed and often difficult to identify. Examples are pesticides blown from the land into the air and the runoff of fertilizers, pesticides, and trash

**To cast your vote, go the website for this book and then to the appropriate chapter (in this case, Chapter 1). In most cases, you will be able to compare your vote with those of others using this book.

Figure 1-10 This *point-source air pollution* rises from a pulp mill in New York State (USA).

Figure 1-11 The trash in this river came from a large area of land and is an example of *nonpoint water pollution*.

from the land into streams and lakes (Figure 1-11). It is much easier and cheaper to identify and control or prevent pollution from point sources than from widely dispersed nonpoint sources.

There are two main types of pollutants. *Biodegradable pollutants* are harmful materials that natural processes can break down over time. Examples are human sewage and newspapers. *Nondegradable pollutants* are harmful chemicals that natural processes cannot break down. Examples are toxic chemical elements such as lead, mercury, and arsenic. (See Supplement 4, p. S11, for an introduction to basic chemistry.)

Pollutants can have three types of unwanted effects. *First,* they can disrupt or degrade life-support systems for humans and other species. *Second,* they can damage wildlife, human health, and property. *Third,* they can create nuisances such as noise and unpleasant smells, tastes, and sights.

We have tried to deal with pollution in two very different ways. One method is **pollution cleanup**, or **output pollution control**, which involves cleaning up or diluting pollutants after we have produced them. The other method is **pollution prevention**, or **input pollution control**, which reduces or eliminates the production of pollutants.

Environmental scientists have identified three problems with relying primarily on pollution cleanup. *First,* it is only a temporary bandage as long as population and consumption levels grow without corresponding improvements in pollution control technology. For example, adding catalytic converters to car exhaust systems has reduced some forms of air pollution. At the same time, increases in the number of cars and the total distance each car travels have reduced the effectiveness of this cleanup approach.

Second, cleanup often removes a pollutant from one part of the environment only to cause pollution in another. For example, we can collect garbage, but the garbage is then *burned* (possibly causing air pollution and leaving toxic ash that must be put somewhere), *dumped* on the land (possibly causing water pollution through runoff or seepage into groundwater), or *buried* (possibly causing soil and groundwater pollution).

Third, once pollutants become dispersed into the environment at harmful levels, it usually costs too much to reduce them to acceptable levels.

We need both pollution prevention (front-of-the-pipe) and pollution cleanup (end-of-the-pipe) solutions. But environmental scientists and some economists urge us to put more emphasis on prevention because it works better and in the long run is cheaper than cleanup.

The Tragedy of the Commons: Overexploiting Commonly Shared Renewable Resources

There are three types of property or resource rights. One is *private property,* where individuals or companies own the rights to land, minerals, or other resources. A second is *common property,* where the rights to certain resources are held by large groups of individuals. For example, roughly one-third of the land in the United States is owned jointly by all U.S. citizens and held and managed for them by the government.

A third category consists of *open-access renewable resources*, owned by no one and available for use by anyone at little or no charge. Examples of such shared renewable resources include the atmosphere, underground water supplies, and the open ocean and its marine life.

Many common-property and open-access renewable resources have been degraded. In 1968, biologist Garrett Hardin (1915–2003) called such degradation the *tragedy of the commons*. It occurs because each user of a shared common resource or open-access resource reasons, "If I do not use this resource, someone else will. The little bit that I use or pollute is not enough to matter, and anyway, it's a renewable resource."

When the number of users is small, this logic works. Eventually, however, the cumulative effect of many people trying to exploit a shared resource can degrade it and eventually exhaust or ruin it. Then no one can benefit from it. Such degradation threatens our ability to ensure the long-term economic and environmental sustainability of open-access resources such as the atmosphere or fish species in the ocean.

There are two major ways to deal with this difficult problem. One is to use a shared renewable resource at a rate well below its estimated sustainable yield by using less of the resource, regulating access to the resource, or doing both. For example, governments can establish laws and regulations limiting the annual harvests of various types of ocean fish that we are harvesting at unsustainable levels, and regulating the amount of pollutants we add to the atmosphere or the oceans.

The other way is to convert open-access renewable resources to private ownership. The reasoning is that if you own something, you are more likely to protect your investment. That may be so, but this approach is not practical for global open-access resources such as the atmosphere and the ocean, which cannot be divided up and sold as private property.

Ecological Footprints: A Model of Unsustainable Use of Resources

Many people in less-developed countries struggle to survive. Their individual use of resources and the resulting environmental impact is low and is devoted mostly to meeting their basic needs (Figure 1-12, top). However, altogether, people in some extremely poor countries clear virtually all available trees to get enough wood to use for heating and cooking. In such cases, short-term survival is a more urgent priority than long-term sustainability. By contrast, many individuals in more-developed nations enjoy **affluence**, or wealth, consuming large amounts of resources far beyond their basic needs (Figure 1-12, bottom).

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Figure 1-12 *Patterns of natural resource consumption:* The top photo shows a family of five subsistence farmers with all their possessions. They live in the village of Shingkhey, Bhutan, in the Himalaya Mountains, which are sandwiched between China and India in South Asia. The bottom photo shows a typical U.S. family of four living in Pearland, Texas, with their possessions.

Supplying people with renewable resources results in wastes and pollution, and can have an enormous environmental impact. We can think of it as an **ecological footprint**—the amount of biologically productive land and water needed to provide the people in a particular country or area with an indefinite supply of renewable resources and to absorb and recycle the wastes and pollution produced by such resource use. (The developers of this tool chose to focus on renewable resources, although the use of nonrenewable resources also contributes to environmental impacts.) The **per capita ecological footprint** is the average ecological footprint of an individual in a given country or area.

If a country's (or the world's) total ecological footprint is larger than its *biological capacity* to replenish its renewable resources and to absorb the resulting wastes and pollution, it is said to have an *ecological deficit*. In other words, it is living unsustainably by depleting its natural capital instead of living off the income provided by such capital. In 2008, the World Wildlife Fund (WWF) and the Global Footprint Network estimated that humanity's global ecological footprint exceeded the *earth's* biological capacity to support humans and other forms of life indefinitely by at least 30% (Figure 1-13, bottom left). That figure was about 88% in high-income countries such as the United States.

In other words, humanity is living unsustainably. According to the WWF, we need roughly the equivalent of at least 1.3 earths to provide an endless supply of renewable resources at their current average rate of use per person and to dispose of the resulting pollution and wastes indefinitely. If the number of people and the average rate of use of renewable resources per person continue growing as projected, by around 2035, we will need the equivalent of two planet Earths (Figure 1-13, bottom, right) to supply such resources indefinitely (**Concept 1-2**). (In Supplement 8, see Figure 7, pp. S38–S39, for a map of the human ecological footprint for the world, and Figure 8, p. S40, for a map of countries that are either ecological debtors or ecological creditors. For more on this subject, see the Guest Essay by Michael Cain at CengageNOW™.)

The per capita ecological footprint is an estimate of how much of the earth's renewable resources an individual consumes. Next to the oil-rich United Arab Emirates, the United States has the world's second largest per capita ecological footprint. In 2003 (the latest data available), the U.S. per capita ecological footprint was about 4.5 times the average global footprint per person, 6 times larger than China's per capita footprint, and 12 times the average per capita footprint of the world's low-income countries.

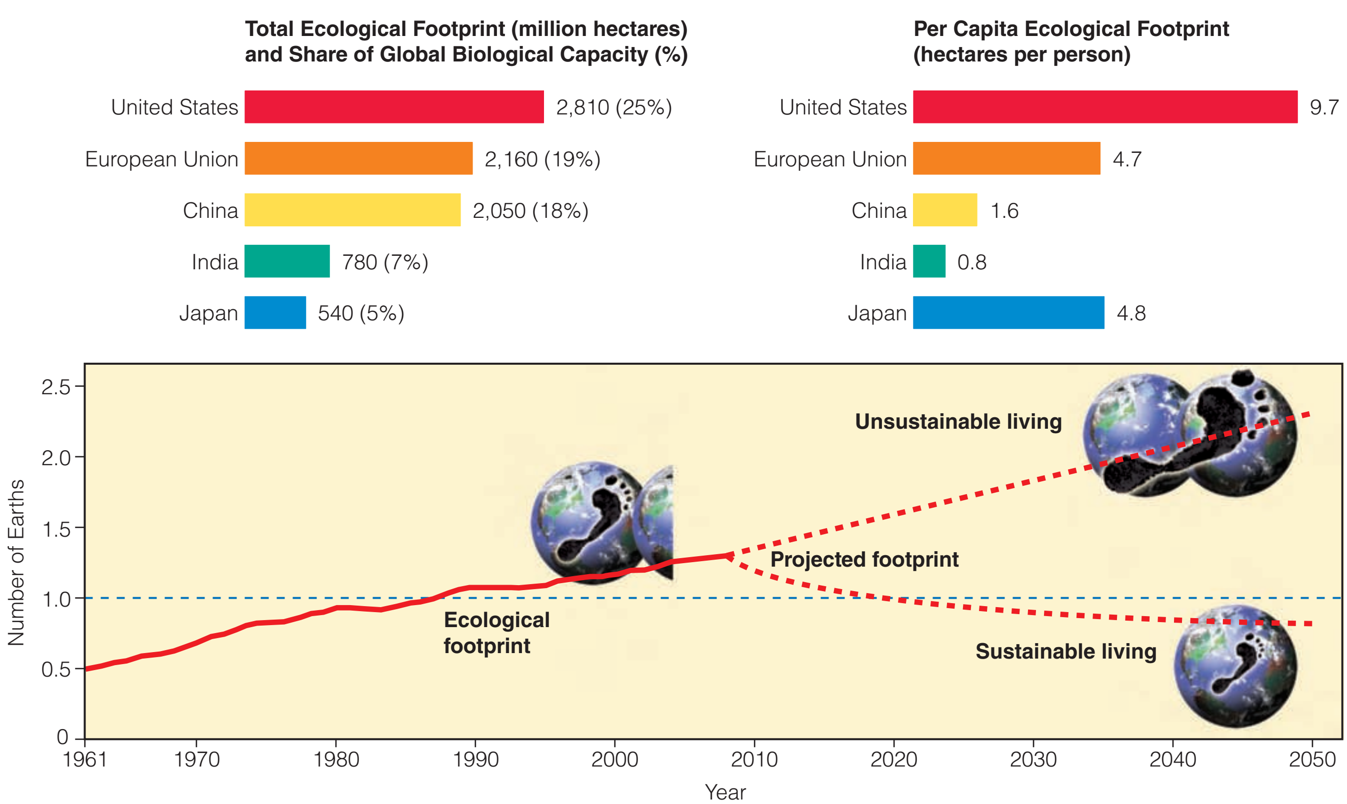

Figure 1-13 **Natural capital use and degradation:** These graphs show the total and per capita ecological footprints of selected countries (top). In 2008, humanity's total, or global, ecological footprint was at least 30% higher than the earth's biological capacity (bottom) and is projected to be twice the planet's biological capacity by around 2035. **Question:** If we are living beyond the earth's renewable biological capacity, why do you think the human population and per capita resource consumption are still growing rapidly? (Data from Worldwide Fund for Nature, Global Footprint Network, *Living Planet Report* 2008. See www.footprintnetwork.org/en/index.php/GFN/page/world_footprint/)

Some ecological footprint analysts have attempted to put these measurements in terms of actual land area. Others say that such estimates are debatable, but for rough comparison purposes, they agree that the estimates work well. According to one study, the world's per capita ecological footprint equals about 5 football fields of land. Other values are 18 football fields per person in the United States, 8 in Germany, and 4 in China.

According to William Rees and Mathis Wackernagel, the developers of the ecological footprint concept, with current technology, it would take the land area of about *five more planet Earths* for the rest of the world to reach current U.S. levels of renewable resource consumption. Put another way, if everyone consumed as much as the average American does today, the earth could indefinitely support only about 1.3 billion people—not today's 6.9 billion. At current levels of resource consumption, the land area of the United States could indefinitely sustain about 186 million people. The actual U.S. population in 2010 was 310 million—67% higher than the nation's estimated biological capacity.

THINKING ABOUT
Your Ecological Footprint

Estimate your own ecological footprint by visiting the website **www.myfootprint.org/**. Is it larger or smaller than you thought it would be, according to this estimate? Why do you think this is so?

IPAT Is Another Environmental Impact Model

In the early 1970s, scientists Paul Ehrlich and John Holdren developed a simple model showing how population size (P), affluence, or resource consumption per person (A), and the beneficial and harmful environmental effects of technologies (T) help to determine the environmental impact (I) of human activities. We can summarized this model by the simple equation $I = P \times A \times T$.

Impact (I) = Population (P) × Affluence (A) × Technology (T)

Figure 1-14 shows the relative importance of these three factors in less-developed and more-developed countries. While the ecological footprint model emphasizes the use of renewable resources, this model includes the per capita use of both renewable and nonrenewable resources. The environmental impact (I) is a rough estimate of how much humanity is degrading the natural capital it depends upon.

Note that some forms of technology such as polluting factories, coal-burning power plants, and gas-guzzling motor vehicles increase environmental impact by raising the T factor in the equation. But other technologies reduce environmental impact by decreasing the T factor. Examples are pollution control and prevention technologies, wind turbines and solar cells that generate electricity, and fuel-efficient cars. In other words, some forms of technology are *environmentally harmful* and some are *environmentally beneficial.*

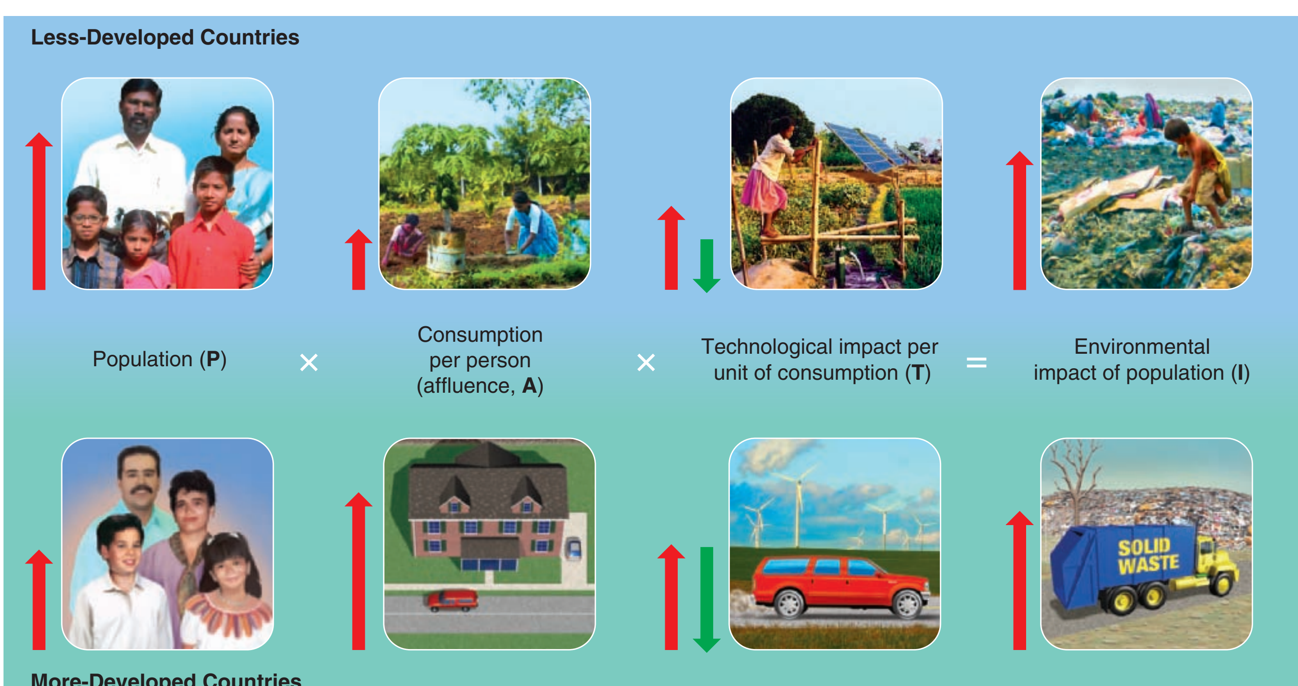

Figure 1-14 *Connections:* This simple model demonstrates how three factors—number of people, affluence (resource use per person), and technology—affect the environmental impact of populations in less-developed countries (top) and more-developed countries (bottom).

In most less-developed countries, the key factors in total environmental impact (Figure 1-14, top) are population size and the degradation of renewable resources as a large number of poor people struggle to stay alive. In such countries, where per capita resource use is low, about 1.4 billion poor people struggle to survive on the equivalent of $1.25 a day and about half of the world's people must live on the equivalent of less than $2.25 a day.

In more-developed countries, high rates of per capita resource use and the resulting high per capita levels of pollution and resource depletion and degradation usually are the key factors determining overall environmental impact (Figure 1-14, bottom). In other words, *overconsumption* by about 1 billion people is putting tremendous pressure on our life-support systems. To some analysts this factor is more important than the population growth factor.

As the human population continues to grow by more than 80 million people a year, we deplete more topsoil by increasing food production, we drill more and deeper water wells, and we use more energy and spend more money to transport fossil fuels, water, minerals, and food farther. This combination of population growth and increasing resource use per person is depleting nonrenewable mineral and energy resources and degrading renewable resources.

These processes will accelerate as countries with large populations such as China (see the Case Study that follows) and India become more developed and as their per capita resource use grows toward the per capita levels of more-developed countries such as the United States.

CASE STUDY

China's New Affluent Consumers

More than a billion super-affluent consumers in more-developed countries are putting immense pressure on the earth's potentially renewable natural capital and its nonrenewable resources. And more than a half billion new consumers are attaining middle-class, affluent lifestyles in 20 rapidly developing middle-income countries, including China, India, Brazil, South Korea, and Mexico. In China and India, the number of middle-class consumers is about 150 million—roughly equal to half of the U.S. population—and the number is growing rapidly. In 2006, the World Bank projected that by 2030 the number of middle-class consumers living in today's less-developed nations will reach 1.2 billion—about four times the current U.S. population.

China has the world's largest population and second-largest economy. It is the world's leading consumer of wheat, rice, meat, coal, fertilizer, steel, and cement, and it is the second-largest consumer of oil after the United States. China leads the world in consumption of goods such as televisions, cell phones, and refrigerators. It has built the world's largest building, the fastest train, and the biggest dam. It has produced more wind turbines than any other country and will soon become the world's largest producer of solar cells. In 2009, the number of Internet users in China was greater than the entire U.S. population and this number is growing rapidly. By 2015, China is projected to be the world's largest producer and consumer of cars, most of them more fuel-efficient than cars produced in the United States and Europe.

On the other hand, after 20 years of industrialization, China now contains two-thirds of the world's most polluted cities. Some of its major rivers are choked with waste and pollution and some areas of its coastline are basically devoid of fishes and other ocean life. A massive cloud of air pollution, largely generated in China, affects other Asian countries, the Pacific Ocean, and the West Coast of North America.

Suppose that China's economy continues to grow at a rapid rate and its population size reaches 1.5 billion by around 2025, as projected by some experts. Environmental policy expert Lester R. Brown estimates that if such projections are accurate, China will need two-thirds of the world's current grain harvest, twice the world's current paper consumption, and more than all the oil currently produced in the world. According to Brown:

> *The western economic model—the fossil fuel-based, automobile-centered, throwaway economy—is not going to work for China. Nor will it work for India, which by 2033 is projected to have a population even larger than China's, or for the other 3 billion people in developing countries who are also dreaming the "American dream."*

For more details on China's growing ecological footprint, see the Guest Essay by Norman Myers for this chapter at CengageNOW.

Natural Systems Have Tipping Points

One problem that we face in dealing with environmental degradation is the *time delay* between the unsustainable use of renewable resources and the resulting harmful environmental effects. Time delays can allow an environmental problem to build slowly until it reaches a *threshold level*, or **ecological tipping point**, which causes an often irreversible shift in the behavior of a natural system (Figure 1-15).

Reaching a tipping point is somewhat like stretching a rubber band. We can get away with stretching it to several times its original length. But at some point, we reach an irreversible tipping point where the rubber band breaks.

Three potential tipping points that we now face are the collapse of certain populations of fish due to overfishing; premature extinction of many species resulting from humans overhunting them or reducing their

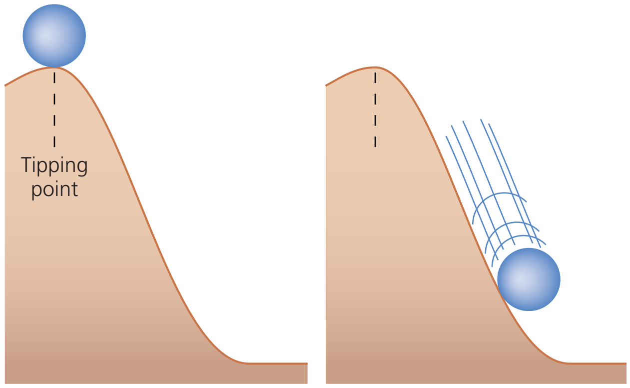

Figure 1-15 In this example of a tipping point, you can control the ball as you push it up to the tipping point. Beyond that point, you lose control. Ecological tipping points can threaten all or parts of the earth's life-support system.

habitats; and long-term climate change caused in part by the burning of oil and coal, which emits gases into the atmosphere that cause it to warm more rapidly than it would without such emissions. We examine each of these problems in later chapters.

Cultural Changes Have Increased Our Ecological Footprints

Culture is the whole of a society's knowledge, beliefs, technology, and practices, and human cultural changes have had profound effects on the earth.

Evidence of organisms from the past and studies of ancient cultures suggest that the current form of our species, *Homo sapiens sapiens,* has walked the earth for about 200,000 years—less than an eye-blink in the earth's 3.5 billion years of life (Figure 1-2). Until about 12,000 years ago, we were mostly *hunter–gatherers* who obtained food by hunting wild animals or scavenging their remains, and gathering wild plants. Early hunter–gathers lived in small groups and moved as needed to find enough food for survival.

Since then, three major cultural changes have occurred (Figure 1-16). *First* was the *agricultural revolution*, which began 10,000–12,000 years ago when humans learned how to grow and breed plants and animals for food, clothing, and other purposes. *Second* was the *industrial–medical revolution*, beginning about 275 years ago when people invented machines for the large-scale production of goods in factories. This involved learning how to get energy from fossil fuels (such as coal and oil) and how to grow large quantities of food in an efficient manner. It also included medical advances that have allowed a growing number of people to live longer and healthier lives. Finally, the *information–globalization revolution* began about 50 years ago, when we developed new technologies for gaining rapid access to much more information and resources on a global scale.

Each of these three cultural changes gave us more energy and new technologies with which to alter and control more of the planet to meet our basic needs and increasing wants. They also allowed expansion of the human population, mostly because of increased food supplies and longer life spans. In addition, they each resulted in greater resource use, pollution, and environmental degradation as they allowed us to dominate the planet and expand our ecological footprints.

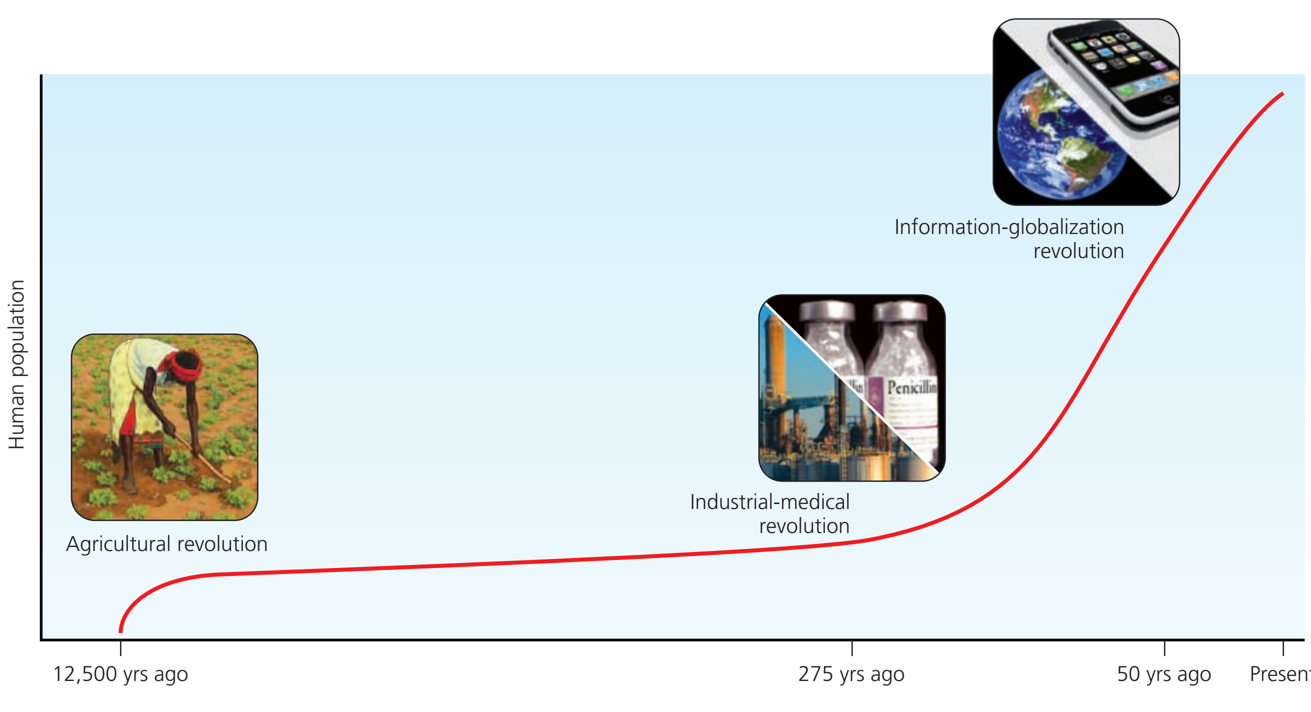

Figure 1-16 Technological innovations have led to greater human control over the rest of nature and to an expanding human population.

Many environmental scientists and other analysts now call for a fourth major cultural change in the form of a **sustainability revolution** during this century. This cultural transformation would involve learning how to reduce our ecological footprints and to live more sustainably (**Core Case Study**). One way to do this is to copy nature by using the three **principles of sustainability** (Figure 1-3) to guide our lifestyles and economies.

1-3 Why Do We Have Environmental Problems?

CONCEPT 1-3 Major causes of environmental problems are population growth, wasteful and unsustainable resource use, poverty, and exclusion of environmental costs of resource use from the market prices of goods and services.

Experts Have Identified Four Basic Causes of Environmental Problems

According to a number of environmental and social scientists, the major causes of pollution, environmental degradation, and other environmental problems are population growth, wasteful and unsustainable resource use, poverty, and failure to include the harmful environmental costs of goods and services in their market prices (Figure 1-17) (**Concept 1-3**).

We discuss in detail all of these causes in later chapters. But let us begin with a brief overview of them.

The Human Population Is Growing Exponentially at a Rapid Rate

Exponential growth occurs when a quantity such as the human population increases at a fixed percentage per unit of time, such as 2% per year. Exponential growth starts off slowly. But eventually, it causes the quantity to double again and again. After only a few doublings, it grows to enormous numbers because each doubling is twice the total of all earlier growth.

Here is an example of the immense power of exponential growth. Fold a piece of paper in half to double its thickness. If you could continue doubling the thickness of the paper 50 times, it would be thick enough to reach almost to the sun—149 million kilometers (93 million miles) away! Hard to believe, isn't it?

Because of exponential growth in the human population (Figure 1-18), in 2010 there were about 6.9 billion people on the planet. Collectively, these people consume vast amounts of food, water, raw materials, and energy, producing huge amounts of pollution and wastes in the process. Each year, we add more than 80 million people to the earth's population. Unless death rates rise sharply, there will probably be 9.5 billion of us by 2050. This projected addition of 2.6 billion more people within your lifetime is equivalent to about 8 times the current U.S. population and twice that of China, the world's most populous nation.

The exponential rate of global population growth has declined some since 1963. Even so, in 2010, we added about 83 million more people to the earth—an average of a about 227,000 people per day. This is roughly equivalent to adding a new U.S. city of Los Angeles, California, every 2 weeks, a new France every 9 months, and a new United States—the world's third most populous country—about every 4 years.

No one knows how many people the earth can support indefinitely, and at what level of resource con-

Figure 1-17 Environmental and social scientists have identified four basic causes of the environmental problems we face (**Concept 1-3**). **Question:** For each of these causes, what are two environmental problems that result?

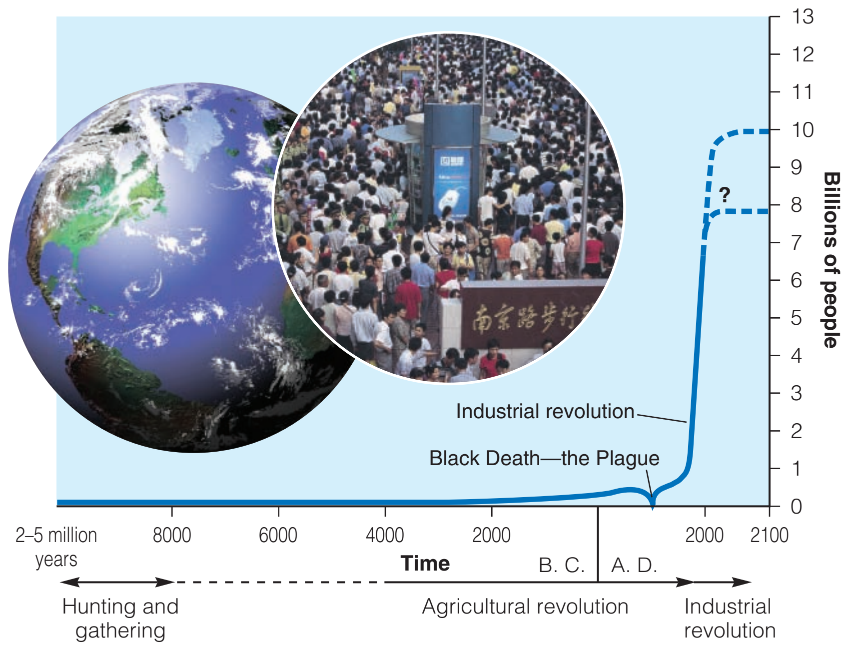

Figure 1-18 *Exponential growth:* The J-shaped curve represents past exponential world population growth, with projections to 2100 showing possible population stabilization as the J-shaped curve of growth changes to an S-shaped curve. (This figure is not to scale.) (Data from the World Bank and United Nations, 2008; photo L. Yong/UNEP/Peter Arnold, Inc.)

sumption, without seriously degrading the ability of the planet to support us, our economies, and other forms of life. But the world's expanding total and per capita ecological footprints (Figure 1-13) are disturbing warning signs.

We can slow population growth with the goal of having it level off at around 8 billion by 2040, as suggested in the **Core Case Study**. Some ways to do this include reducing poverty through economic development, promoting family planning, and elevating the status of women, as discussed in Chapter 6.

Affluence Has Harmful and Beneficial Environmental Effects

The lifestyles of many consumers in more-developed countries and in less-developed countries such as India and China (see Case Study, p. 18) are built upon growing affluence, which results in high levels of consumption and unnecessary waste of resources. Such affluence is based mostly on the assumption—fueled by mass advertising—that buying more and more material goods will bring fulfillment and happiness.

The harmful environmental effects of affluence are dramatic. The U.S. population is only about one-fourth that of India. But the average American consumes about 30 times as much as the average Indian and 100 times as much as the average person in the world's poorest countries. As a result, the average environmental impact, or ecological footprint per person, in the United States is much larger than the average impact per person in less-developed countries (Figure 1-13, top).

For example, according to some ecological footprint calculators, it takes about 27 tractor-trailer loads of resources per year to support one American, or 8.3 billion truckloads per year to support the entire U.S. population. Stretched end-to-end, each year these trucks would reach beyond the sun! In its 2006 *Living Planet Report,* the World Wildlife Fund (WWF) estimated that the United States is responsible for almost half of the global ecological footprint (Figure 1-13).

Some analysts say that many affluent consumers in the United States and other more-developed countries are afflicted with *affluenza*—an eventually unsustainable addiction to buying more and more stuff. They argue that this type of addiction fuels our currently unsustainable use of resources, even though numerous studies show that beyond a certain level, more consumption does not increase happiness. Another downside to wealth is that it allows the affluent to obtain the resources they need from almost anywhere in the world without seeing the harmful environmental impacts of their high-consumption, high-waste lifestyles.

On the other hand, affluence can allow for better education, which can lead people to become more concerned about environmental quality. It also provides money for developing technologies to reduce pollution, environmental degradation, and resource waste. As a result, in the United States and most other affluent countries, the air is clearer, drinking water is purer, and most rivers and lakes are cleaner than they were in the 1970s. In addition, the food supply is more abundant and safer, the incidence of life-threatening infectious disease has been greatly reduced, life spans are longer, and some endangered species are being rescued from extinction that may be hastened by human activities.

These improvements in environmental quality were achieved because of greatly increased scientific research and technological advances financed by affluence. And education spurred many citizens to insist that businesses and governments work toward improving environmental quality (**Core Case Study**).

CORE CASE STUDY

Poverty Has Harmful Environmental and Health Effects

Poverty occurs when people are unable to fulfill their basic needs for adequate food, water, shelter, health, and education. According to a 2008 study by the World Bank, 1.4 billion people—one of every five people on the planet and almost five times the number of people in the United States—live in *extreme poverty* (Figure 1-19) and struggle to live on the equivalent of less than $1.25 a day. (All dollar figures used in this book are in U.S. dollars.) Could you do this?

Poverty causes a number of harmful environmental and health effects (Figure 1-20). The daily lives of the world's poorest people are focused on getting enough food, water, and fuel for cooking and heating to survive. Desperate for short-term survival, some of these individuals degrade potentially renewable forests, soils, grasslands, fisheries, and wildlife at an ever-increasing rate. They do not have the luxury of worrying about long-term environmental quality or sustainability. Even though the poor in less-developed countries have no choice but to use very few resources per person, their large population size leads to a high overall environmental impact (Figure 1-14, top).

Sean Sprague/Peter Arnold, Inc.

Figure 1-19 *Extreme poverty:* This boy is searching through an open dump in Rio de Janeiro, Brazil, for items to sell. Many children of poor families who live in makeshift shantytowns in or near such dumps often scavenge most of the day for food and other items to help their families survive.

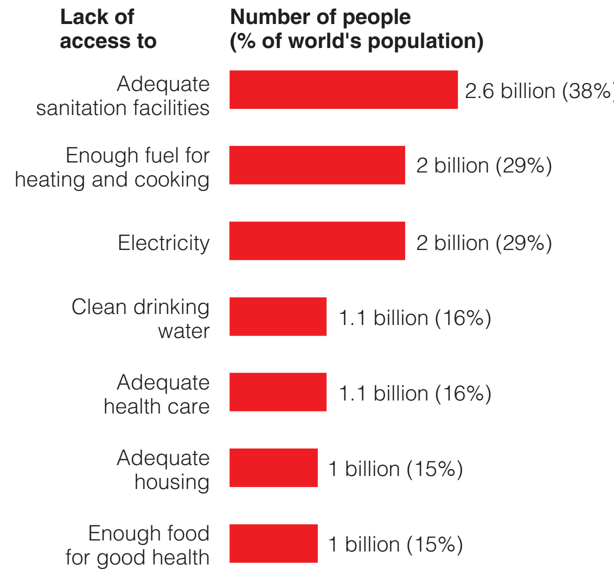

Figure 1-20 These are some of the harmful effects of poverty. **Questions:** Which two of these effects do you think are the most harmful? Why? (Data from United Nations, World Bank, and World Health Organization)

CONNECTIONS

Poverty and Population Growth

To many poor people, having more children is a matter of survival. Their children help them gather fuel (mostly wood and animal dung), haul drinking water, and tend crops and livestock. The children also help to care for their parents in their old age (their 40s or 50s in the poorest countries) because they do not have social security, health care, and retirement funds. This is largely why populations in some less-developed countries continue to grow at high rates.

While poverty can increase some types of environmental degradation, the converse is also true. Pollution and environmental degradation have a severe impact on the poor and can increase their poverty. Consequently, many of the world's poor people die prematurely from several preventable health problems. One such problem is *malnutrition* caused by a lack of protein and other nutrients needed for good health (Figure 1-21). The resulting weakened condition can increase an individual's chances of death from normally nonfatal ailments such as diarrhea and measles.

A second health problem is limited access to adequate sanitation facilities and clean drinking water. More than 2.6 billion people—more than 8 times the population of the United States—have no decent bathroom facilities. They are forced to use backyards, alleys, ditches, and streams. As a result, a large portion of these

Figure 1-21 *Global Outlook:* One of every three children younger than age 5, such as this child in Lunda, Angola, suffers from severe malnutrition caused by a lack of calories and protein. According to the World Health Organization, each day at least 16,400 children younger than age 5 die prematurely from malnutrition and from infectious diseases often caused by drinking contaminated water.

people—one of every seven in the world—get water for drinking, washing, and cooking from sources polluted by human and animal feces. A third health problem is severe respiratory disease that people get from breathing the smoke of open fires or poorly vented stoves used for heating and cooking inside their homes.

In 2008, the World Health Organization estimated that these factors, mostly related to poverty, cause premature death for at least 6 million young children each year. Some hopeful news is that this number of annual deaths is down from 12.5 million in 1990. Even so, every day an average of at least 16,400 young children die prematurely from these causes. This is equivalent to *82 fully loaded 200-passenger airliners crashing every day with no survivors!* The daily news rarely covers this ongoing human tragedy.

THINKING ABOUT

The Poor, the Affluent, and Rapidly Increasing Population Growth

Some see the rapid population growth of the poor in less-developed countries as the primary cause of our environmental problems. Others say that the much higher resource use per person in more-developed countries is a more important factor. Which factor do you think is more important? Why?

Prices Do Not Include the Value of Natural Capital

Another basic cause of environmental problems has to do with how goods and services are priced in the marketplace.

Companies using resources to provide goods for consumers generally are not required to pay for the harmful environmental costs of supplying such goods. For example, fishing companies pay the costs of catching fish but do not pay for the depletion of fish stocks. Timber companies pay the cost of clear-cutting forests but do not pay for the resulting environmental degradation and loss of wildlife habitat. The primary goal of these companies is to maximize profits for their owners or stockholders, which is how capitalism works. Indeed, it would be economic suicide for them to add these costs to their prices unless government regulations created a level economic playing field by using taxes or regulations to require all businesses to pay for the environmental costs of producing their products.

As a result, the prices of goods and services do not include their harmful environmental costs (Figure 1-22, p. 24). So consumers have no effective way to evaluate the harmful effects, on their own health and on the earth's life-support systems, of producing and using these goods and services.

Another problem arises when governments (taxpayers) give companies *subsidies* such as tax breaks and payments to assist them with using resources to run their businesses. This helps to create jobs and stimulate economies. But it can also degrade natural capital because, again, the companies do not include the value of the natural capital in the market prices of their goods and services. Indeed, environmentally harmful subsidies encourage the depletion and degradation of natural capital. (See the Guest Essay for this chapter about these subsidies by Norman Myers at CengageNOW.)

We can live more sustainably (**Core Case Study**) by including in their market prices the harmful environmental costs of the goods and services we use. Two ways to do this over the next two decades are to shift from earth-degrading government subsides to earth-sustaining subsidies, and to tax pollution and waste heavily while reducing taxes on income and wealth. We discuss such *subsidy shifts* and *tax shifts* in Chapter 23.

CORE CASE STUDY

Figure 1-22 This Hummer H3 sport utility vehicle burns a great deal of fuel compared to other, more efficient vehicles. It therefore adds more pollutants to the atmosphere and, being a very heavy vehicle, does more damage to the roads and land on which it is driven. It also requires more material and energy to build and maintain than most other vehicles on the road. These harmful costs are not included in the price of the vehicle.

Michael Shake/Shutterstock

People Have Different Views about Environmental Problems and Their Solutions

Another challenge we face is that people differ over the seriousness of the world's environmental problems and what we should do to help solve them. This can delay our dealing with these problems, which can make them harder to solve.

Differing opinions about environmental problems arise mostly out of differing environmental worldviews. Your **environmental worldview** is your set of assumptions and values reflecting how you think the world works and what you think your role in the world should be. Consciously or unconsciously, we base most of our actions on our worldviews. **Environmental ethics**, which are beliefs about what is right and wrong with how we treat the environment, are an important element in our worldviews. Here are some important ethical questions relating to the environment:

- Why should we care about the environment?
- Are we the most important beings on the planet or are we just one of the earth's millions of different life-forms?
- Do we have an obligation to see that our activities do not cause the extinction of other species? Should we try to protect all species or only some? How do we decide which ones to protect?
- Do we have an ethical obligation to pass on to future generations the extraordinary natural world in a condition that is at least as good as what we inherited?
- Should every person be entitled to equal protection from environmental hazards regardless of race, gender, age, national origin, income, social class, or any other factor? This is the central ethical and political issue for what is known as the *environmental justice* movement. (See the Guest Essay by Robert D. Bullard at CengageNOW.)
- How do we promote sustainability?

THINKING ABOUT
Our Responsibilities

How would you answer each of the questions above? Compare your answers with those of your classmates. Record your answers and, at the end of this course, return to these questions to see if your answers have changed.

People with widely differing environmental worldviews can take the same data, be logically consistent with it, and arrive at quite different conclusions because they start with different assumptions and moral, ethical, or religious beliefs. Environmental worldviews are discussed in detail in Chapter 25, but here is a brief introduction.

The **planetary management worldview** holds that we are separate from and in charge of nature, that nature exists mainly to meet our needs and increasing wants, and that we can use our ingenuity and technology to manage the earth's life-support systems, mostly for our benefit, indefinitely.

The **stewardship worldview** holds that we can and should manage the earth for our benefit, but that we have an ethical responsibility to be caring and responsible managers, or *stewards,* of the earth. It says we should encourage environmentally beneficial forms of economic growth and development and discourage environmentally harmful forms.

The **environmental wisdom worldview** holds that we are part of, and dependent on, nature and that nature exists for all species, not just for us. According to this view, our success depends on learning how life on earth sustains itself (Figure 1-3 and back cover of this book) and integrating such environmental wisdom into the ways we think and act.

1-4 What Is an Environmentally Sustainable Society?

CONCEPT 1-4 Living sustainably means living off the earth's natural income without depleting or degrading the natural capital that supplies it.

Environmentally Sustainable Societies Protect Natural Capital and Live Off Its Income

According to most environmental scientists, our ultimate goal should be to achieve an **environmentally sustainable society**—one that meets the current and future basic resource needs of its people in a just and equitable manner without compromising the ability of future generations to meet their basic needs (**Core Case Study**). CORE CASE STUDY

Imagine you win $1 million in a lottery. Suppose you invest this money (your capital) and earn 10% interest per year. If you live on just the interest, or the income made by your capital, you will have a sustainable annual income of $100,000 that you can spend each year indefinitely without depleting your capital. However, if you spend $200,000 per year, while still allowing interest to accumulate, your capital of $1 million will be gone early in the seventh year. Even if you spend only $110,000 per year and allow the interest to accumulate, you will be bankrupt early in the eighteenth year.

The lesson here is an old one: *Protect your capital and live on the income it provides.* Deplete or waste your capital and you will move from a sustainable to an unsustainable lifestyle.

The same lesson applies to our use of the earth's natural capital—the global trust fund that nature has provided for us, our children and grandchildren (Figure 1-1), and the earth's other species. *Living sustainably* means living on **natural income**, CORE CASE STUDY the renewable resources such as plants, animals, and soil provided by the earth's natural capital. It also means not depleting or degrading the earth's natural capital, which supplies this income, and providing the human population with adequate and equitable access to this natural capital and natural income for the foreseeable future (**Concept 1-4**).

There is considerable and growing evidence that we are living unsustainably. A glaring example of this is our growing total and per capita ecological footprints (Figure 1-13).

We Can Work Together to Solve Environmental Problems

Making the shift to more sustainable societies and economies includes building what sociologists call **social capital**. This involves getting people with different views and values to talk and listen to one another, to find common ground based on understanding and trust, and to work together to solve environmental and other problems facing our societies.

Solutions to environmental problems are not black and white, but rather are all shades of gray, because proponents of all sides of these issues have some legitimate and useful insights. In addition, any proposed solution has short- and long-term advantages and disadvantages that we must evaluate. This means that citizens need to work together to find *trade-off solutions* to environmental problems—an important theme of this book. They can also try to agree on shared visions of the future and work together to develop strategies for implementing such visions beginning at the local level, as the citizens of Chattanooga, Tennessee (USA), have done.

CASE STUDY
The Environmental Transformation of Chattanooga, Tennessee

Local officials, business leaders, and citizens have worked together to transform Chattanooga, Tennessee, from a highly polluted city to one of the most sustainable and livable cities in the United States (Figure 1-23, p. 26).

During the 1960s, U.S. government officials rated Chattanooga as one of the dirtiest cities in the United States. Its air was so polluted by smoke from its industries that people sometimes had to turn on their vehicle headlights in the middle of the day. The Tennessee River, flowing through the city's industrial center, bubbled with toxic waste. People and industries fled the downtown area and left a wasteland of abandoned and polluting factories, boarded-up buildings, high unemployment, and crime.

Chattanooga Area Convention and Visitors Bureau

Figure 1-23 Since 1984, citizens have worked together to make the city of Chattanooga, Tennessee, one of the best and most sustainable places to live in the United States.

In 1984, the city decided to get serious about improving its environmental quality. Civic leaders started a *Vision 2000* process with a 20-week series of community meetings in which more than 1,700 citizens from all walks of life gathered to build a consensus about what the city could be at the turn of the century. Citizens identified the city's main problems, set goals, and brainstormed thousands of ideas for solutions.

By 1995, Chattanooga had met most of its original goals. The city had encouraged zero-emission industries to locate there and replaced its diesel buses with a fleet of quiet, zero-emission electric buses, made by a new local firm.

The city also launched an innovative recycling program after environmentally concerned citizens blocked construction of a new garbage incinerator that would have emitted harmful air pollutants. These efforts paid off. Since 1989, the levels of the seven major air pollutants in Chattanooga have been lower than the levels required by federal standards.

Another project involved renovating much of the city's low-income housing and building new low-income rental units. Chattanooga also built the nation's largest freshwater aquarium, which became the centerpiece for downtown renewal. The city developed a riverfront park along both banks of the Tennessee River, where it runs through town. The park draws more than 1 million visitors per year. As property values and living conditions have improved, people and businesses have moved back downtown.

In 1993, the community began the process again in *Revision 2000.* Goals included transforming an abandoned and blighted area in South Chattanooga into a mixed community of residences, retail stores, and zero-emission industries where employees can live near their workplaces. Most of these goals have been implemented.

Chattanooga's environmental success story, based on people working together to produce a more livable and sustainable city, is a shining example of what other cities could do by building their social capital.

Individuals Matter

GOOD NEWS

Chattanooga's story shows that a key to finding solutions to environmental problems and making a transition to more sustainable societies is to recognize that most social change results from individual actions and individuals acting together to bring about change through *bottom-up* grassroots action. In other words, *individuals matter*—another important theme of this book.

Here are two pieces of good news: *First*, research by social scientists suggests that it takes only 5–10% of the population of a community, a country, or the world to bring about major social change. *Second*, such research also shows that significant social change can occur in a much shorter time than most people think.

Anthropologist Margaret Mead summarized our potential for social change: "Never doubt that a small group of thoughtful, committed citizens can change the world. Indeed, it is the only thing that ever has."

Scientific evidence indicates that we have perhaps 50 years and no more than 100 years to make a new cul-


Varina and Jay Patel/Shutterstock

Figure 1-24 Capturing wind power is one of the world's most rapidly growing and least environmentally harmful ways to produce electricity.

tural shift from unsustainable living to more sustainable living, if we start now. Many analysts argue that because these changes could take at least 50 years to implement fully, we now face a critical fork in the road where we must either choose a path toward sustainability or continue on our current unsustainable course. One of the goals of this book is to provide a realistic vision of a more environmentally sustainable future. Instead of immobilizing you with fear, gloom, and doom, we hope to energize you by inspiring realistic hope as you play your role in deciding which path to follow.

Based on the three **principles of sustainability** (Figure 1-3), we can derive three strategies for reducing our ecological footprints, helping to sustain the earth's natural capital, and making a transition to more sustainable lifestyles and economies (**Core Case Study**). Those strategies are summarized in the *three big ideas* of this chapter:

- Rely more on renewable energy from the sun, including indirect forms of solar energy such as wind (Figure 1-24) and flowing water, to meet most of our heating and electricity needs.
- Protect biodiversity by preventing the degradation of the earth's species, ecosystems, and natural processes, and by restoring areas we have degraded (Figure 1-25).
- Help to sustain the earth's natural chemical cycles by reducing the production of wastes and pollution, not overloading natural systems with harmful chemicals, and not removing natural chemicals faster than nature's cycles can replace them.


Ru Bai Le/Shutterstock

Figure 1-25 This young child—like the grandchild of Emily and Michael in our fictional scenario of a possible future (**Core Case Study**)—is promoting sustainability by preparing to plant a tree. A global program to plant and tend billions of trees each year will help to restore degraded lands, promote biodiversity, and reduce the threat of climate change from atmospheric warming.

REVISITING A Vision of a More Sustainable Earth

CORE CASE STUDY

SUSTAINABILITY

We face an array of serious environmental problems. This book is about *solutions* to these problems. A key to most solutions is to apply the three **principles of sustainability** (Figure 1-3 and the *three big ideas* listed above) to the design of our economic and social systems, and to our individual lifestyles. We can use such strategies to try to slow the rapidly increasing losses of biodiversity, switch to more sustainable sources of energy, spread more sustainable forms of agriculture and other uses of land and water, sharply reduce poverty, slow human population growth, and create a better world for ourselves and future generations.

If we make the right choices during this century, as Emily and Michael and people like them did in the **Core Case Study** that opens this chapter, we can create an extraordinary and more sustainable future for ourselves and for most other forms of life on our planetary home. If we get it wrong, we face irreversible ecological disruption that could set humanity back for centuries and wipe out as many as half of the world's species as well as much of the human population.

GOOD NEWS

You have the good fortune to be a member of the 21st century's transition generation that will decide which path humanity takes. This means confronting the urgent challenges presented by the major environmental problems discussed in this book. However, those challenges will also present you with opportunities for a promising and exciting future based on working with and for the earth that sustains us. As environmental author and entrepreneur Paul Hawken reminds us, "Working for the earth is not a way to get rich, it is a way to be rich."

What's the use of a house if you don't have a decent planet to put it on?

HENRY DAVID THOREAU

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 6. What is **sustainability** and why should we care about it? What are three principles that nature has used to sustain itself for at least 3.5 billion years, and how can we use these principles to live more sustainably?

2. Define **environment**. Distinguish among **environmental science**, **ecology**, and **environmentalism**. Distinguish between an **organism** and a **species**. What is an **ecosystem**? Define **natural capital**, **natural resources**, and **natural services**. Define **nutrient cycling** and explain why it is important. Describe how we can degrade natural capital and how finding solutions to environmental problems involves making trade-offs. Explain why individuals matter in dealing with the environmental problems we face.

3. What is a **resource**? Distinguish between a **perpetual resource** and a **renewable resource** and give an example of each. What is **sustainable yield**? Define and give two examples of a **nonrenewable resource**. Distinguish between **recycling** and **reuse** and give an example of each. What is **economic growth**? Distinguish between **gross domestic product (GDP)** and **per capita GDP**. What is **economic development**? Distinguish between **more-developed countries** and **less-developed countries**.

4. Define and give three examples of **environmental degradation (natural capital degradation)**. Define **pollution**. Distinguish between **point sources** and **nonpoint sources** of pollution. Distinguish between **pollution cleanup (output pollution control)** and **pollution prevention (input pollution control)** and give an example of each. Describe three drawbacks to solutions that rely mostly on pollution cleanup. What is the *tragedy of the commons*?

5. What is an **ecological footprint**? What is a **per capita ecological footprint**? Compare the total and per capita ecological footprints of the United States and China. Use the ecological footprint concept to explain how we are living unsustainably. What is the IPAT model for estimating our environmental impact? Explain how we can use this model to estimate the impacts of the human populations in less-developed and more-developed countries. Describe the environmental impacts of China's new affluent consumers. What is an **ecological tipping point**?

6. Define **culture**. Describe three major cultural changes that have occurred since humans were hunter–gatherers. What would a **sustainability revolution** involve?

7. Identify four basic causes of the environmental problems that we face. What is **exponential growth**? Describe the past, current, and projected exponential growth of the world's human population. What is **affluence**? How do Americans, Indians, and the average people in the poorest countries compare in terms of consumption? What are two types of environmental damage resulting from growing affluence? How can affluence help us to solve environmental problems? What is **poverty** and what are three of its harmful environmental and health effects? Describe the connection between poverty and population growth.

8. Explain how excluding from the prices of goods and services the harmful environmental costs of producing them affects the environmental problems we face. What is the connection between government subsidies, resource use, and environmental degradation? What is an **environmental worldview**? What are **environmental ethics**? Distinguish among the **planetary management**, **stewardship**, and **environmental wisdom worldviews**.

9. Describe an **environmentally sustainable society**. What is **natural income**? What is **social capital**? Describe the environmental transformation of Chattanooga, Tennessee.

10. How long do some scientists estimate that we have to make a shift to more environmentally sustainable economies and lifestyles? Based on the three **principles of sustainability**, what are the three best ways to make such a transition as summarized in this chapter's *three big ideas*? Explain how we can use these three principles to get us closer to the vision of a sustainable earth described in the **Core Case Study** that opens this chapter.

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. Do you think you are living unsustainably? Explain. If so, what are the three most environmentally unsustainable components of your lifestyle? List two ways in which you could apply each of the three **principles of sustainability** (Figure 1-3) to making your lifestyle more environmentally sustainable.

2. Do you believe a vision such as the one described in the **Core Case Study** that opens this chapter is possible? Why or why not? What, if anything, do you believe will be different from that vision? Explain. If your vision of what it will be like in 2060 is sharply different from that in the Core Case Study, write a description of your vision. Compare your answers to this question with those of your classmates.

3. For each of the following actions, state one or more of the three **principles of sustainability** (Figure 1-3) that are involved: **(a)** recycling aluminum cans; **(b)** using a rake instead of leaf blower; **(c)** walking or bicycling to class instead of driving; **(d)** taking your own reusable bags to the grocery store to carry your purchases home; **(e)** volunteering to help restore a prairie; and **(f)** lobbying elected officials to require that 20% of your country's electricity be produced with renewable wind power by 2020.

4. Explain why you agree or disagree with the following propositions:
   a. Stabilizing population is not desirable because, without more consumers, economic growth would stop.
   b. The world will never run out of resources because we can use technology to find substitutes and to help us reduce resource waste.

5. What do you think when you read that **(a)** the average American consumes 30 times more resources than the average citizen of India; and **(b)** human activities are projected to make the earth's climate warmer? Are you skeptical, indifferent, sad, helpless, guilty, concerned, or outraged? Which of these feelings can help to perpetuate such problems, and which can help to solve them?

6. When you read that at least 16,400 children age five and younger die each day (13 per minute) from preventable malnutrition and infectious disease, how does it make you feel? Can you think of something that you and others could do to address this problem? What might that be?

7. Explain why you agree or disagree with each of the following statements: **(a)** humans are superior to other forms of life; **(b)** humans are in charge of the earth; **(c)** the value of other forms of life depends only on whether they are useful to humans; **(d)** based on past extinctions and the history of life on the earth over the last 3.5 billion years, all forms of life eventually become extinct so we should not worry about whether our activities cause their premature extinction; **(e)** all forms of life have an inherent right to exist; **(f)** all economic growth is good; **(g)** nature has an almost unlimited storehouse of resources for human use; **(h)** technology can solve our environmental problems; **(i)** I do not believe I have any obligation to future generations; and **(j)** I do not believe I have any obligation to other forms of life.

8. What are the basic beliefs within your environmental worldview (pp. 24–25)? Record your answer. Then at the end of this course return to your answer to see if your environmental worldview has changed.

9. Are the beliefs included in your environmental worldview (Question 8) consistent with your answers to question 7? Are your actions that affect the environment consistent with your environmental worldview? Explain.

10. List two questions that you would like to have answered as a result of reading this chapter.

ECOLOGICAL FOOTPRINT ANALYSIS

If the *ecological footprint per person* of a country or of the world (Figure 1-13) is larger than its *biological capacity per person* to replenish its renewable resources and absorb the resulting waste products and pollution, the country or the world is said to have an *ecological deficit*. If the reverse is true, the country or the world has an *ecological credit* or *reserve*. Use the data below to calculate the ecological deficit or credit for the countries listed and for the world. (For a map of ecological creditors and debtors, see Figure 8, p. S40, in Supplement 8.)

Place	Per Capita Ecological Footprint (hectares per person)	Per Capita Biological Capacity (hectares per person)	Ecological Credit (+) or Debit (−) (hectares per person)
World	2.2	1.8	– 0.4
United States	9.8	4.7	
China	1.6	0.8	
India	0.8	0.4	
Russia	4.4	0.9	
Japan	4.4	0.7	
Brazil	2.1	9.9	
Germany	4.5	1.7	
United Kingdom	5.6	1.6	
Mexico	2.6	1.7	
Canada	7.6	14.5	

Source: Data from WWF *Living Planet Report 2006*.

1. Which two countries have the largest ecological deficits? Why do you think they have such large deficits?
2. Which two countries have an ecological credit? Why do you think each of these countries has an ecological credit?
3. Rank the countries in order from the largest to the smallest per capita ecological footprint.

LEARNING ONLINE

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Science, Matter, Energy, and Systems

2

How Do Scientists Learn about Nature? A Story about a Forest

CORE CASE STUDY

Imagine that you learn of a logging company's plans to cut down all of the trees on a hillside in back of your house. You are very concerned and want to know the possible harmful environmental effects of this action on the hillside, the stream at bottom of the hillside, and your backyard.

One way to learn about such effects is to conduct a *controlled experiment*, just as environmental scientists do. They begin by identifying key *variables* such as water loss and soil nutrient content that might change after the trees are cut down. Then, they set up two groups. One is the *experimental group*, in which a chosen variable is changed in a known way. The other is the *control group*, in which the chosen variable is not changed. The scientists' goal is to compare the two groups after the variable has been changed and to look for differences resulting from the change.

In 1963, botanist F. Herbert Bormann, forest ecologist Gene Likens, and their colleagues began carrying out such a controlled experiment. The goal was to compare the loss of water and soil nutrients from an area of uncut forest (the *control site*) with an area that had been stripped of its trees (the *experimental site*).

They built V-shaped concrete dams across the creeks at the bottoms of several forested valleys in the Hubbard Brook Experimental Forest in New Hampshire (Figure 2-1). The dams were designed so that all surface water leaving each forested valley had to flow across a dam, where scientists could measure its volume and dissolved nutrient content.

First, the investigators measured the amounts of water and dissolved soil nutrients flowing from an undisturbed forested area in one of the valleys (the control site, Figure 2-1, left). These measurements showed that an undisturbed mature forest is very efficient at storing water and retaining chemical nutrients in its soils.

Next, they set up an experimental forest area in another of the forest's valleys (the experimental site, Figure 2-1, right). One winter, they cut down all the trees and shrubs in that valley, left them where they fell, and sprayed the area with herbicides to prevent the regrowth of vegetation. Then, for 3 years, they compared the outflow of water and nutrients in this experimental site with those in the control site.

With no plants to help absorb and retain water, the amount of water flowing out of the deforested valley increased by 30–40%. As this excess water ran rapidly over the ground, it eroded soil and carried dissolved nutrients out of the deforested site. Overall, the loss of key nutrients from the experimental forest was 6 to 8 times that in the nearby uncut control forest.

This controlled experiment revealed one of the ways in which scientists can learn about the effects of our actions on natural systems such as forests. In this chapter, you will learn more about how scientists study nature and about the matter and energy that make up the physical world within and around us. You will also learn how scientists discovered three *scientific laws*, or rules of nature, governing the changes that matter and energy undergo.

Figure 2-1 This controlled field experiment measured the effects of deforestation on the loss of water and soil nutrients from a forest. V–notched dams were built at the bottoms of two forested valleys so that all water and nutrients flowing from each valley could be collected and measured for volume and mineral content. These measurements were recorded for the forested valley (left), which acted as the control site, and for the other valley, which acted as the experimental site (right). Then all the trees in the experimental valley were cut and, for 3 years, the flows of water and soil nutrients from both valleys were measured and compared.

Key Questions and Concepts

2-1 What do scientists do?

CONCEPT 2-1 Scientists collect data and develop theories, models, and laws about how nature works.

2-2 What is matter?

CONCEPT 2-2 Matter consists of elements and compounds that are in turn made up of atoms, ions, or molecules.

2-3 What happens when matter undergoes change?

CONCEPT 2-3 Whenever matter undergoes a physical or chemical change, no atoms are created or destroyed (the law of conservation of matter).

2-4 What is energy and what happens when it undergoes change?

CONCEPT 2-4A Whenever energy is converted from one form to another in a physical or chemical change, no energy is created or destroyed (first law of thermodynamics).

CONCEPT 2-4B Whenever energy is converted from one form to another in a physical or chemical change, we end up with lower-quality or less usable energy than we started with (second law of thermodynamics).

2-5 What are systems and how do they respond to change?

CONCEPT 2-5 Systems have inputs, flows, and outputs of matter and energy, and feedback can affect their behavior.

Note: Supplements 1 (p. S2), 2 (p. S3), and 4 (p. S11) can be used with this chapter.

Science is built up of facts, as a house is built of stones; but an accumulation of facts is no more a science than a heap of stones is a house.

HENRI POINCARÉ

2-1 What Do Scientists Do?

▶ **CONCEPT 2-1 Scientists collect data and develop theories, models, and laws about how nature works.**

Science Is a Search for Order in Nature

Science is a human effort to discover how the physical world works by making observations and measurements, and carrying out experiments. It is based on the assumption that events in the physical world follow orderly cause-and-effect patterns that we can understand.

You may have heard that scientists follow a specific set of steps called the *scientific method* to learn about how the physical world works. In fact, they use a variety of methods to study nature, although these methods tend to fall within a general process described in Figure 2-2.

There is nothing mysterious about this process. You use it all the time in making decisions, as shown in Figure 2-3. As the famous physicist Albert Einstein put it, "The whole of science is nothing more than a refinement of everyday thinking."

Scientists Use Observations, Experiments, and Models to Answer Questions about How Nature Works

Here is a more formal outline of the steps scientists often take in trying to understand the natural world, although they do not always follow the steps in the order listed. This outline is based on the scientific experiment carried out by Bormann and Likens (**Core Case Study**), which illustrates the nature of the scientific process shown in Figure 2-2. CORE CASE STUDY

- *Identify a problem*. Bormann and Likens identified the loss of water and soil nutrients from cutover forests as a problem worth studying.
- *Find out what is known about the problem*. Bormann and Likens searched the scientific literature to find out what scientists knew about both the retention and the loss of water and soil nutrients in forests.

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. GOOD NEWS refers to good news about the environmental challenges we face.

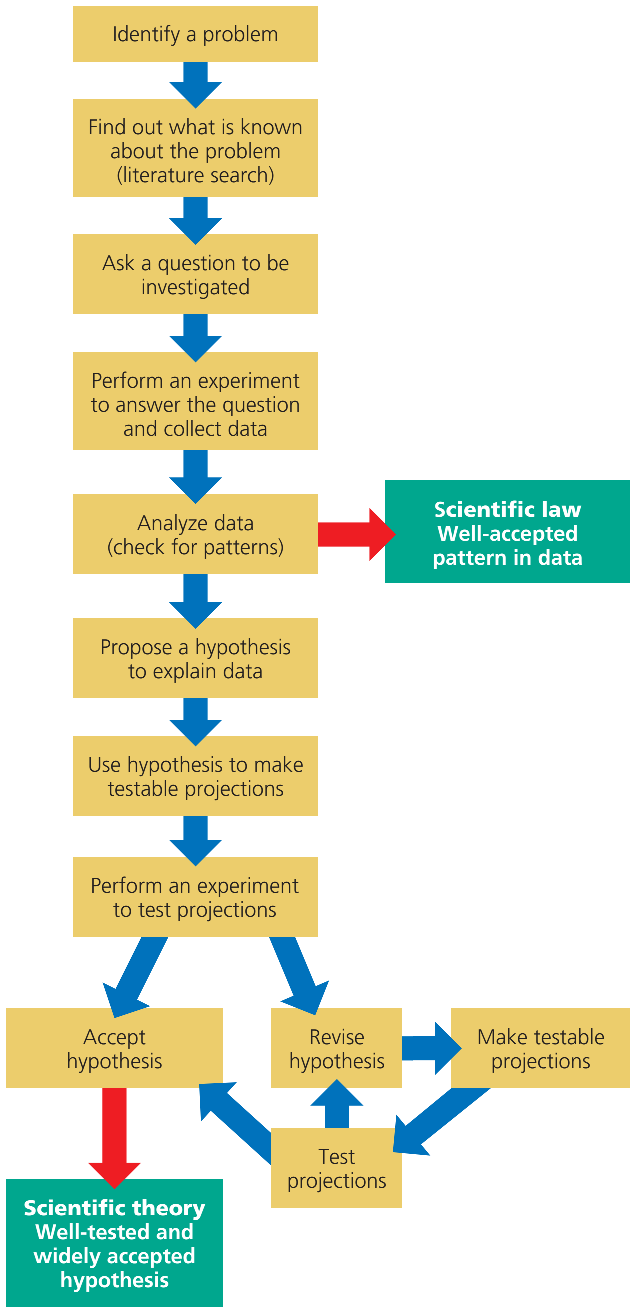


Figure 2-2 This diagram illustrates what scientists do. Scientists use this overall process for testing ideas about how the natural world works. However, they do not necessarily follow the order of steps shown here. For example, sometimes a scientist might start by coming up with a hypothesis to answer the initial question and then run experiments to test the hypothesis.

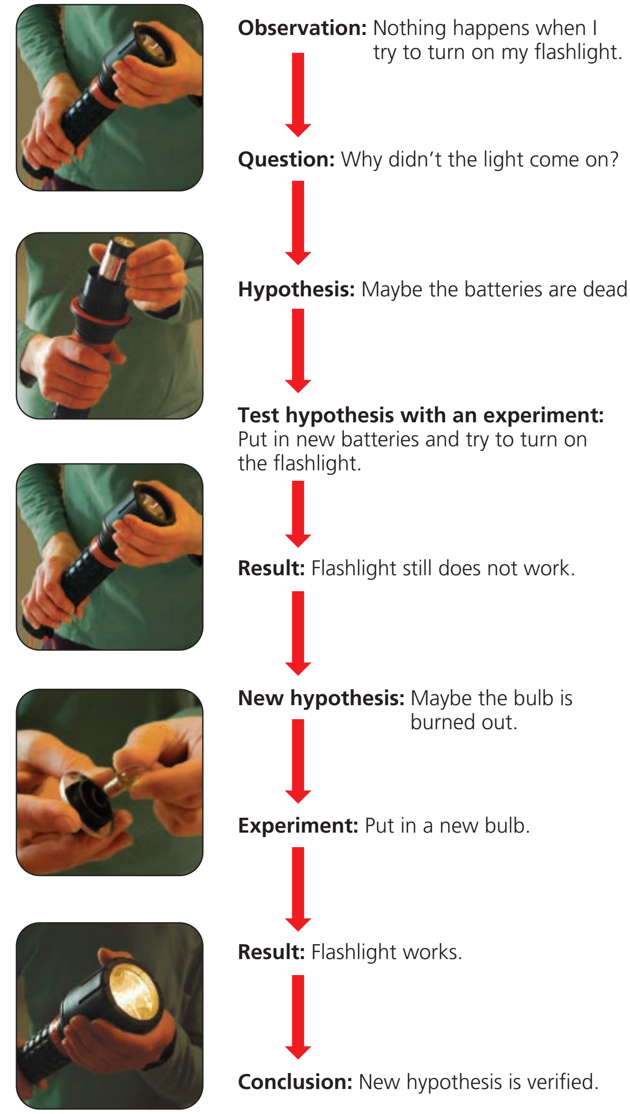


Figure 2-3 We can use the scientific process to understand and deal with an everyday problem.

- *Ask a question to investigate*. The scientists asked: "How does clearing forested land affect its ability to store water and retain soil nutrients?"
- *Collect data to answer the question*. To collect **data**—information needed to answer their questions—scientists make observations and measurements. Bormann and Likens collected and analyzed data on the water and soil nutrients flowing from a valley with an undisturbed forest (Figure 2-1, left) and from a nearby valley where they had cleared the forest for their experiment (Figure 2-1, right).
- *Propose a hypothesis to explain the data*. Scientists suggest a **scientific hypothesis**—a possible explanation of what scientists observe in nature or in the results of their experiments. The data collected by Bormann and Likens showed that clearing a forest decreases its ability to store water and retain soil nutrients such as nitrogen. They came up with the following hypothesis to explain their data: When a forest is cleared of its vegetation and exposed to rain and melting snow, it retains less water than it did before it was cleared and loses large quantities of its soil nutrients.
- *Make testable projections*. Scientists make projections about what should happen if their hypothesis is valid and then run experiments to test the projections. Bormann and Likens projected that if their hypothesis was valid for nitrogen, then a cleared forest should also lose other soil nutrients such as

phosphorus over a similar time period and under similar weather conditions.

- *Test the projections with further experiments, models, or observations*. To test their projection, Bormann and Likens repeated their controlled experiment and measured the phosphorus content of the soil. Another way to test projections is to develop a **model**, an approximate representation or simulation of a system, in this case a deforested valley, being studied. Data from the research carried out by Bormann and Likens and from other scientists' research can be fed into such models and used to project the loss of phosphorus and other types of soil nutrients. Scientists can then compare these projections with the actual measured losses to test the validity of the models.
- *Accept or reject the hypothesis*. If their new data do not support their hypothesis, scientists come up with other testable explanations. This process of proposing and testing various hypotheses goes on until there is general agreement among the scientists in this field of study that a particular hypothesis is the best explanation of the data. After Bormann and Likens confirmed that the soil in a cleared forest also loses phosphorus, they measured losses of other soil nutrients, which further supported their hypothesis. Research and models by other scientists also supported the hypothesis. A well-tested and widely accepted scientific hypothesis or a group of related hypotheses is called a **scientific theory**. Thus, Bormann and Likens and other scientists developed a theory that trees and other plants hold soil in place and help it to retain water and nutrients needed by the plants for their growth.

Scientists Are Curious and Skeptical, and Demand Lots of Evidence

Four important features of the scientific process are *curiosity, skepticism, reproducibility,* and *peer review.* Good scientists are extremely curious about how nature works. But they tend to be highly skeptical of new data, hypotheses, and models until they can test and verify them with lots of evidence. Scientists say, "Show me your evidence and explain the reasoning behind the scientific ideas or hypotheses that you propose to explain your data." They also require that any evidence gathered must be reproducible. In other words, other scientists should be able to get the same results when they run the same experiments.

Science is a community effort, and an important part of the scientific process is **peer review**. It involves scientists openly publishing details of the methods and models they used, the results of their experiments, and the reasoning behind their hypotheses for other scientists working in the same field (their peers) to evaluate.

For example, Bormann and Likens (**Core Case Study**) submitted the results of their forest experiments to a respected scientific journal. Before publishing this report, the journal's editors asked other soil and forest experts to review it. Other scientists have repeated the measurements of soil content in undisturbed and cleared forests of the same type and also for different types of forests. Their results have been subjected to peer review as well. In addition, computer models of forest systems have been used to evaluate this problem, with the results also subjected to peer review.

Scientific knowledge advances in this self-correcting way, with scientists continually questioning the measurements and data produced by their peers. They also collect new data and sometimes come up with new and better hypotheses (Science Focus, p. 35). Skepticism and debate among peers in the scientific community is essential to the scientific process—explaining why science is sometimes described as organized skepticism.

Critical Thinking and Creativity Are Important in Science

Scientists use logical reasoning and critical thinking skills (p. 2) to learn about the natural world. Such skills help scientists and the rest of us to distinguish between facts and opinions, evaluate evidence and arguments, and develop informed positions on issues.

Thinking critically involves three important steps:

1. Be skeptical about everything we read or hear.
2. Look at the evidence to evaluate it and any related information and opinions that may come from various sources. Validating information is especially important in the Internet age where we can be exposed to unreliable data, some of which may be just opinions from uninformed amateurs posing as experts.
3. Identify and evaluate our personal assumptions, biases, and beliefs. As the American psychologist and philosopher William James observed, "A great many people think they are thinking when they are merely rearranging their prejudices." We can also heed the words of the American writer Mark Twain: "It's what we know is true, but just ain't so, that hurts us."

Logic and critical thinking are very important tools in science, but imagination, creativity, and intuition are just as vital. According to physicist Albert Einstein, "There is no completely logical way to a new scientific idea." Most major scientific advances are made by creative people who come up with new and better ways to help us understand how the natural world works. As American educator John Dewey remarked, "Every great advance in science has issued from a new audacity of imagination."

SCIENCE FOCUS

Easter Island: Some Revisions in a Popular Environmental Story

For years, the story of Easter Island has been used in textbooks as an example of how humans can seriously degrade their own life-support system. It concerns a civilization that once thrived and then largely disappeared from a small, isolated island located about 3,600 kilometers (2,200 miles) off the coast of Chile in the great expanse of the South Pacific.

Scientists used anthropological evidence and scientific measurements to estimate the ages of some of the more than 300 large statues (Figure 2-A) found on Easter Island. They hypothesized that about 2,900 years ago, Polynesians used double-hulled, sea-going canoes to colonize the island. The settlers probably found a paradise with fertile soil that supported dense and diverse forests and lush grasses. According to this hypothesis, the islanders thrived, and their population increased to as many as 15,000 people.

Figure 2-A These and many other massive stone figures once lined the coasts of Easter Island and are the remains of the technology created on the island by an ancient civilization of Polynesians. Some of these statues are taller than an average five-story building and can weigh as much as 89 metric tons (98 tons).

Measurements made by scientists seemed to indicate that over time, the Polynesians began living unsustainably by using the island's forest and soil resources faster than they could be renewed. They cut down trees and used them for firewood, for building sea-going canoes, and for moving and erecting the gigantic statues. Once they had used up the large trees, the islanders could no longer build their traditional seagoing canoes for fishing in deeper offshore waters, and no one could escape the island by boat.

It was hypothesized that without the once-great forests to absorb and slowly release water, springs and streams dried up, exposed soils were eroded, crop yields plummeted, and famine struck. There was no firewood for cooking or keeping warm. According to the original hypothesis, the population and the civilization collapsed as rival clans fought one another for dwindling food supplies, and the island's population dropped sharply. By the late 1870s, only about 100 native islanders were left.

In 2006, anthropologist Terry L. Hunt, Director of the University of Hawaii Rapa Nui (Easter Island) Archaeological Field School at the University of Hawaii, evaluated the accuracy of past measurements and other evidence and carried out new measurements to estimate the ages of various statues and other artifacts. He used these data to formulate an alternative hypothesis describing the human tragedy on Easter Island.

Hunt used the data he gathered to come to several new conclusions. *First*, the Polynesians arrived on the island about 800 years ago, not 2,900 years ago. *Second*, their population size probably never exceeded 3,000, contrary to the earlier estimate of up to 15,000. *Third*, the Polynesians did use the island's trees and other vegetation in an unsustainable manner, and by 1722, visitors reported that most of the island's trees were gone.

But one question not answered by the earlier hypothesis was, why did the trees never grow back? Recent evidence and Hunt's new hypothesis suggest that rats (which either came along with the original settlers as stowaways or were brought along as a source of protein for the long voyage) played a key role in the island's permanent deforestation. Over the years, the rats multiplied rapidly into the millions and devoured the seeds that would have regenerated the forests.

Another of Hunt's conclusions was that after 1722, the population of Polynesians on the island dropped to about 100, mostly from contact with European visitors and invaders. Hunt hypothesized that these newcomers introduced fatal diseases, killed off some of the islanders, and took large numbers of them away to be sold as slaves.

This story is an excellent example of how science works. The gathering of new scientific data and the reevaluation of older data led to a revised hypothesis that challenges earlier thinking about the decline of civilization on Easter Island. As a result, the tragedy may not be as clear an example of human-caused ecological collapse as was once thought.

Critical Thinking

Does the new doubt about the original Easter Island hypothesis mean that we should not be concerned about using resources unsustainably on the island in space that we call earth? Explain.

Scientific Theories and Laws Are the Most Important and Certain Results of Science

Facts and data are essential to science, but its real goal is to develop theories and laws, based on facts, that explain how the physical world works, as illustrated in the quotation that opens this chapter.

When an overwhelming body of observations and measurements supports a scientific hypothesis or group of related hypotheses, it becomes a scientific theory. *We should never take a scientific theory lightly.* It has been tested widely, is supported by extensive evidence, and is accepted as being a useful explanation by most scientists in a particular field or related fields of study.

Because of this rigorous testing process, scientific theories are rarely overturned unless new evidence discredits them or scientists come up with better explanations. So when you hear someone say, "Oh, that's just a theory," you will know that he or she does not have a clear understanding of what a scientific theory is, how important it is, and how rigorously it has been tested before reaching this level of acceptance. In sports terms, developing a widely accepted scientific theory is roughly equivalent to winning a gold medal in the Olympics.

Another important and reliable outcome of science is a **scientific law**, or **law of nature**—a well-tested and widely accepted description of what we find happening repeatedly in nature in the same way. An example is the *law of gravity*. After making many thousands of observations and measurements of objects falling from different heights, scientists developed the following scientific law: all objects fall to the earth's surface at predictable speeds.

We can break a society's law, for example, by driving faster than the speed limit. But *we cannot break a scientific* law, unless we discover new data that lead to changes in the law.

For a superb look at how the scientific process is applied to expanding our understanding of the natural world, see the Annenberg Video series, *The Habitable Planet: A Systems Approach to Environmental Science* (see the website at **www.learner.org/resources/series209.html**). Each of the 13 videos describes how scientists working on two different problems related to each subject are learning about how nature works. We regularly cross-reference material in this book to these videos.

The Results of Science Can Be Tentative, Reliable, or Unreliable

A fundamental part of science is *testing*. Scientists insist on testing their hypotheses, models, methods, and results over and over again. In this way, they seek to establish the reliability of these scientific tools and the resulting conclusions that they reveal about how some part of the physical world works.

Sometimes, preliminary scientific results that capture news headlines are controversial because they have not been widely tested and accepted by peer review. They are not yet considered reliable, and can be thought of as **tentative science** or **frontier science**. Some of these results will be validated and classified as reliable and some will be discredited and classified as unreliable. At the frontier stage, it is normal for scientists to disagree about the meaning and accuracy of data and the validity of hypotheses and results. This is how scientific knowledge advances. But unless critics can come up with new and better data and better hypotheses, their dissent becomes unproductive. At that point, most scientists in a particular field stop listening to them and move on.

By contrast, **reliable science** consists of data, hypotheses, models, theories, and laws that are widely accepted by all or most of the scientists who are considered experts in the field under study, in what is referred to as a *scientific consensus*. The results of reliable science are based on the self-correcting process of testing, open peer review, reproducibility, and debate. New evidence and better hypotheses may discredit or alter accepted views. But until that happens, those views are considered to be the results of reliable science. **Explore More:** See a Science Focus at **www.cengage.com/login** to learn about the 30-year debate over, and development of, a scientific consensus on atmospheric warming.

Scientific hypotheses and results that are presented as reliable without having undergone the rigors of widespread peer review, or that have been discarded as a result of peer review, are considered to be **unreliable science**. Here are some critical thinking questions you can use to uncover unreliable science:

- Was the experiment well designed? Did it involve a control group? (**Core Case Study**) CORE CASE STUDY
- Have other scientists reproduced the results?
- Does the proposed hypothesis explain the data? Have scientists made and verified projections based on the hypothesis?
- Are there no other, more reasonable explanations of the data?
- Are the investigators unbiased in their interpretations of the results? Was all of their funding from unbiased sources?
- Have the data and conclusions been subjected to peer review?
- Are the conclusions of the research widely accepted by other experts in this field?

If "yes" is the answer to each of these questions, then you can classify the results as reliable science. Otherwise, the results may represent tentative science that needs further testing and evaluation, or you can classify them as unreliable science.

Science Has Some Limitations

Environmental science and science in general have five important limitations. *First*, scientists cannot prove or disprove anything absolutely, because there is always some degree of uncertainty in scientific measurements, observations, and models. Instead, scientists try to establish that a particular scientific theory or law has a very high *probability* or *certainty* (at least 90%) of being useful for understanding some aspect of nature. Many scientists don't use the word *proof* because this implies "absolute proof" to people who don't understand how science works. For example, most scientists will rarely say something like, "Cigarettes cause lung cancer." Rather, they might say, "Overwhelming evidence from thousands of studies indicates that people who smoke have a greatly increased chance of developing lung cancer."

Suppose someone tells you that some statement is not true because it has not been scientifically proven. When this happens, you can draw one of two conclusions:

1. The individual does not understand how science works, because while scientists can establish a very high degree of certainty (more than 90%) that a scientific theory is useful in explaining something about how nature works, they can never prove or disprove anything absolutely.
2. The individual is using an old debating trick to influence your thinking by telling you something that is true but irrelevant and misleading.

THINKING ABOUT
Scientific Proof

Does the fact that science can never prove anything absolutely mean that its results are not valid or useful? Explain.

A *second* limitation of science is that scientists are human and thus are not totally free of bias about their own results and hypotheses. However, the high standards of evidence required through peer review can usually uncover or greatly reduce personal bias and expose occasional cheating by scientists who falsify their results.

A *third* limitation—especially important to environmental science—is that many systems in the natural world involve a huge number of variables with complex interactions. This makes it difficult and too costly to test one variable at a time in controlled experiments such as the one described in the **Core Case Study** that opens this chapter. To try to deal with this problem, scientists develop *mathematical models* that can take into account the interactions of many variables. Running such models on high-speed computers can sometimes overcome the limitations of testing each variable individually, saving both time and money. In addition, scientists can use computer models to simulate global experiments on phenomena like climate change that are impossible to do in a controlled physical experiment.

CORE CASE STUDY

A *fourth* limitation of science involves the use of statistical tools. For example, there is no way to measure accurately how many metric tons of soil are eroded annually worldwide. Instead, scientists use statistical sampling and other mathematical methods to estimate such numbers (Science Focus, below). However, such results should not be dismissed as "only estimates" because they can indicate important trends.

SCIENCE FOCUS

Statistics and Probability

Statistics consists of mathematical tools that we can use to collect, organize, and interpret numerical data. For example, suppose we make measurements of the weight of each individual in a population of 15 rabbits. We can use statistics to calculate the *average* weight of the population. To do this we add up the combined weights of the 15 rabbits and divide the total by 15. In another example, Bormann and Likens (**Core Case Study**) made many measurements of nitrate levels in the water flowing from their undisturbed and deforested valleys (Figure 2-1) and then averaged the results to get the most reliable value.

CORE CASE STUDY

Scientists also use the statistical concept of probability to evaluate their results. **Probability** is the chance that something will happen or will be valid. For example, if you toss a nickel, what is the chance that it will come up heads? If your answer is 50%, you are correct. The probability of the nickel coming up heads is 1/2, which can also be expressed as 50% or 0.5. Probability is often expressed as a number between 0 and 1 written as a decimal (such as 0.5).

Now suppose you toss the coin ten times and it comes up heads six times. Does this mean that the probability of it coming up heads is 0.6 or 60%? The answer is no because the *sample size*—the number of objects or events studied—was too small to yield a statistically accurate result. If you increase your sample size to 1,000 by tossing the coin 1,000 times, you are almost certain to get heads 50% of the time and tails 50% of the time.

In addition to having a large enough sample size, it is also important when doing scientific research in a physical area to take samples from different places, in order to get a reasonable evaluation of the variable you are studying. For example, if you wanted to study the effects of a certain air pollutant on the needles of a pine tree species, you would need to locate different stands of the species that are exposed to the pollutant over a certain period of time. At each location, you would need to make measurements of the atmospheric levels of the pollutant at different times and average the results. You would also need to take measurements of the damage (such as needle loss) from a large enough number of trees in each location over the same time period. Then you would average the results in each location and compare the results among all locations.

If the average results were consistent in different locations, you could then say that there is a certain probability, say 60% (or 0.6), that this type of pine tree suffered a certain percentage loss of its needles when exposed to a specified average level of the pollutant over a given time. You would also need to run further experiments to determine that other factors, such as natural needle loss, extreme temperatures, insects, plant diseases, and drought did not cause the needle losses you observed. As you can see, obtaining reliable scientific results is not a simple process.

Critical Thinking

What does it mean when an international body of the world's climate experts says that there is at least a 90% chance (probability of 0.9) that human activities, primarily the burning of fossil fuels and the resulting carbon dioxide emissions, have been an important cause of the observed atmospheric warming during the past 35 years? Why is it that we would probably never see a 100% chance?

Finally, the scientific process is limited to understanding the natural world. It cannot be applied to moral or ethical questions because such questions are about matters for which scientists cannot collect data from the natural world. For example, scientists can use the scientific process to understand the effects of removing trees from an ecosystem, but this process does not tell them whether it is morally or ethically right or wrong to remove the trees.

Despite these five limitations, science is the most useful way that we have for learning about how nature works and projecting how it might behave in the future. With this important set of tools, we have made significant progress, but we still know too little about how the earth works, its present state of environmental health, and the current and future environmental impacts of our activities. These knowledge gaps point to important *research frontiers*, several of which are highlighted throughout this text.

GOOD NEWS

2-2 What Is Matter?

▶ **CONCEPT 2-2 Matter consists of elements and compounds that are in turn made up of atoms, ions, or molecules.**

Matter Consists of Elements and Compounds

To begin our study of environmental science, we look at matter—the stuff that makes up life and its environment. **Matter** is anything that has mass and takes up space. It can exist in three *physical states*—solid, liquid, and gas. Water, for example, exists as solid ice, liquid water, or water vapor depending mostly on its temperature.

Matter also exists in two *chemical forms*—elements and compounds. An **element** is a fundamental type of matter that has a unique set of properties and cannot be broken down into simpler substances by chemical means. For example, the elements gold (Figure 2-4, left), and mercury (Figure 2-4, right) cannot be broken down chemically into any other substance.

Some matter is composed of one element, such as gold or mercury (Figure 2-4). But most matter consists of **compounds**, combinations of two or more different elements held together in fixed proportions. For example, water is a compound made of the elements hydrogen and oxygen that combine chemically with one another. (See Supplement 4 on p. S11 for an expanded discussion of basic chemistry.)

To simplify things, chemists represent each element by a one- or two-letter symbol. Table 2-1 lists the elements and their symbols that you need to know to understand the material in this book.

Table 2-1 Chemical Elements Used in This Book

Element	Symbol
Arsenic	As
Bromine	Br
Calcium	Ca
Carbon	C
Chlorine	Cl
Fluorine	F
Gold	Au
Lead	Pb
Lithium	Li
Mercury	Hg
Nitrogen	N
Phosphorus	P
Sodium	Na
Sulfur	S
Uranium	U

Morgan Lane Photography/Shutterstock

Andraž Cerar/Shutterstock

Figure 2-4 Gold (left) and mercury (right) are chemical elements; each has a unique set of properties and it cannot be broken down into simpler substances.

Atoms, Molecules, and Ions Are the Building Blocks of Matter

The most basic building block of matter is an **atom**, the smallest unit of matter into which an element can be divided and still have its characteristic chemical properties. The idea that all elements are made up of atoms is called the **atomic theory** and it is the most widely accepted scientific theory in chemistry.

Atoms are incredibly small. In fact, more than 3 million hydrogen atoms could sit side by side on the period at the end of this sentence.

> **CONNECTIONS**
> **How Much Is a Million? A Billion? A Trillion?**
>
> Numbers such as millions, billions, and trillions are widely used but are often hard to comprehend. Here are a couple of ways to think about them. If you were to start counting, one number per second, and keep going 24 hours a day, it would take you 12 days (with no breaks) to get to a million. It would take you 32 years to get to a billion. And you would have to count for 32,000 years to reach a trillion. If you got paid for your efforts at a dollar per number and you stacked the bills (each set of five one-dollar bills being one millimeter high), your first million dollar bills would be 20 meters (66 feet) high—higher than a 3-story building. A stack of a billion dollar bills would reach a height of 200 kilometers (124 miles), or nearly the distance between Pittsburgh, Pennsylvania and Cleveland, Ohio (USA). A stack of a trillion dollar bills would reach about 200,000 kilometers (124,200 miles), which is more than halfway to the moon.

Atoms have an internal structure. If you could view them with a supermicroscope, you would find that each different type of atom contains a certain number of three types of *subatomic particles*: **neutrons (n)** with no electrical charge, **protons (p)** with a positive electrical charge (+), and **electrons (e)** with a negative electrical charge (−).

Each atom consists of an extremely small center called the **nucleus**—containing one or more protons and, in most cases, one or more neutrons—and one or more electrons in rapid motion somewhere around the nucleus (Figure 2-5). Each atom has equal numbers of positively charged protons and negatively charged electrons. Because these electrical charges cancel one another, *atoms as a whole have no net electrical charge*.

Each element has a unique **atomic number** equal to the number of protons in the nucleus of its atom. Carbon (C), with 6 protons in its nucleus (Figure 2-5), has an atomic number of 6, whereas uranium (U), a much larger atom, has 92 protons in its nucleus and an atomic number of 92.

Because electrons have so little mass compared to protons and neutrons, *most of an atom's mass is concentrated in its nucleus*. The mass of an atom is described by its **mass number**, the total number of neutrons and protons in its nucleus. For example, a carbon atom with 6 protons and 6 neutrons in its nucleus has a mass number of 12, and a uranium atom with 92 protons and 143 neutrons in its nucleus has a mass number of 235 (92 + 143 = 235).

Each atom of a particular element has the same number of protons in its nucleus. But the nuclei of atoms of a particular element can vary in the number of neutrons they contain, and therefore, in their mass numbers. The forms of an element having the same atomic number but different mass numbers are called **isotopes** of that element. Scientists identify isotopes by attaching their mass numbers to the name or symbol of the element. For example, the three most common isotopes of carbon are carbon-12 (Figure 2-5, with six protons and six neutrons), carbon-13 (with six protons and seven neutrons), and carbon-14 (with six protons and eight neutrons). Carbon-12 makes up about 98.9% of all naturally occurring carbon.

A second building block of matter is a **molecule**, a combination of two or more atoms of the same or different elements held together by forces called *chemical bonds*. Molecules are the basic building blocks of many compounds. Examples of molecules are water, or H_2O, which consists of two atoms of hydrogen and one atom of oxygen held together by chemical bonds. Another example is methane, or CH_4 (the major component of natural gas), which consists of four atoms of hydrogen and one atom of carbon. (See Figure 4 on p. S12 in Supplement 4 for other examples of molecules.)

A third building block of some types of matter is an **ion**—an atom or a group of atoms with one or more net positive or negative electrical charges. Like atoms, ions are made up of protons, neutrons, and electrons. A positive ion forms when an atom loses one or more of its negatively charged electrons, and a negative ion forms when an atom gains one or more negatively charged electrons. (See p. S12 in Supplement 4 for more details on how ions form.)

Chemists use a superscript after the symbol of an ion to indicate how many positive or negative electrical charges it has, as shown in Table 2-2 (p. 40). (One positive or negative charge is designated by a plus sign or a

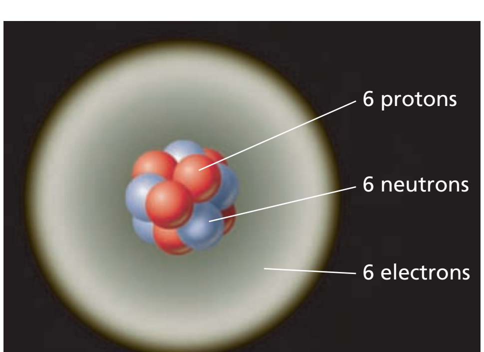


Figure 2-5 This is a greatly simplified model of a carbon-12 atom. It consists of a nucleus containing six protons, each with a positive electrical charge, and six neutrons with no electrical charge. Six negatively charged electrons are found outside its nucleus. We cannot determine the exact locations of the electrons. Instead, we can estimate the *probability* that they will be found at various locations outside the nucleus—sometimes called an *electron probability cloud*. This is somewhat like saying that there are six airplanes flying around inside a cloud. We do not know their exact location, but the cloud represents an area in which we can probably find them.

Table 2-2 Chemical Ions Used in This Book

Positive Ion	Symbol	Components
hydrogen ion	H^+	One H atom, one positive charge
sodium ion	Na^+	One Na atom, one positive charge
calcium ion	Ca^{2+}	One Ca atom, two positive charges
aluminum ion	Al^{3+}	One Al atom, three positive charges
ammonium ion	NH_4^+	One N atom, four H atoms, one positive charge
Negative Ion	**Symbol**	**Components**
chloride ion	Cl^-	One chlorine atom, one negative charge
hydroxide ion	OH^-	One oxygen atom, one hydrogen atom, one negative charge
nitrate ion	NO_3^-	One nitrogen atom, three oxygen atoms, one negative charge
carbonate ion	CO_3^{2-}	One carbon atom, three oxygen atoms, two negative charges
sulfate ion	SO_4^{2-}	One sulfur atom, four oxygen atoms, two negative charges
phosphate ion	PO_4^{3-}	One phosphorus atom, four oxygen atoms, three negative charges

minus sign, respectively.) Note in the table that some ions are forms of one element, like hydrogen (H^+), and some are combinations of more than one, such as oxygen and hydrogen (OH^-).

One example of the importance of ions in our study of environmental science is the nitrate ion (NO_3^-), a nutrient essential for plant growth. Figure 2-6 shows measurements of the loss of nitrate ions from the deforested area (Figure 2-1, right) in the controlled experiment run by Bormann and Likens (**Core Case Study**). Numerous chemical analyses of the water flowing through the dam at the cleared forest site showed an average 60-fold rise in the concentration of NO_3^- compared to water running off the forested site. After a few years, however, vegetation began growing back on the cleared valley and nitrate levels in its runoff returned to normal levels.

Ions are also important for measuring a substance's **acidity** in a water solution, a chemical characteristic that helps determine how a substance dissolved in water will interact with and affect its environment. The acidity of a water solution is based on the comparative amounts of hydrogen ions (H^+) and hydroxide ions (OH^-) contained in a particular volume of the solution. Scientists use **pH** as a measure of acidity. Pure water (not tap water or rainwater) has an equal number of H^+ and OH^- ions. It is called a neutral solution and has a pH of 7. An *acidic solution* has more hydrogen ions than hydroxide ions and has a pH less than 7. A *basic solution* has more hydroxide ions than hydrogen ions and has a pH greater than 7. (See Figure 5, p. S13, in Supplement 4 for more details.)

Chemists use a **chemical formula** to show the number of each type of atom or ion in a compound. This shorthand contains the symbol for each element present (Table 2-1) and uses subscripts to show the number of atoms or ions of each element in the compound's basic structural unit. For example, water is a *molecular compound* that is made up of H_2O molecules. Sodium chloride (NaCl) is an *ionic compound* that is made up of a regular network of positively charged sodium ions (Na^+) and negatively charged chloride ions (Cl^-), (as shown in Figure 2 on p. S12 of Supplement 4). These and other compounds important to our study of environmental science are listed in Table 2-3.

You might want to mark these pages containing Tables 2-1, 2-2, and 2-3, because they show the key elements, ions, and compounds used in this book. Think

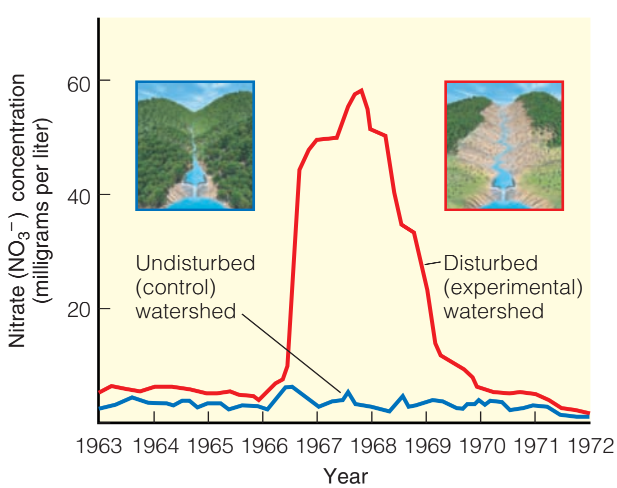


Figure 2-6 This graph shows the loss of nitrate ions (NO_3^-) from a deforested watershed in the Hubbard Brook Experimental Forest (Figure 2-1, right). The average concentration of nitrate ions in runoff from the experimental deforested watershed was about 60 times greater than in a nearby unlogged watershed used as a control (Figure 2-1, left). (Data from F. H. Bormann and Gene Likens)

Table 2-3 Compounds Used in This Book

Compound	Formula
sodium chloride	NaCl
sodium hydroxide	NaOH
carbon monoxide	CO
oxygen	O_2
nitrogen	N_2
chlorine	Cl_2
carbon dioxide	CO_2
nitric oxide	NO
nitrogen dioxide	NO_2
nitrous oxide	N_2O
nitric acid	HNO_3
methane	CH_4
glucose	$C_6H_{12}O_6$
water	H_2O
hydrogen sulfide	H_2S
sulfur dioxide	SO_2
sulfuric acid	H_2SO_4
ammonia	NH_3
calcium carbonate	$CaCO_3$

of them as lists of the main chemical characters in the story of matter that makes up the natural world.

CENGAGENOW™ Examine atoms—their parts, how they work, and how they bond together to form molecules—at CengageNOW.

Organic Compounds Are the Chemicals of Life

Plastics, as well as table sugar, vitamins, aspirin, penicillin, and most of the chemicals in your body are called **organic compounds** because they contain at least two carbon atoms combined with atoms of one or more other elements. All other compounds are called **inorganic compounds**. One exception, methane (CH_4), has only one carbon atom but is considered an organic compound.

The millions of known organic (carbon-based) compounds include the following:

- *Hydrocarbons*: compounds of carbon and hydrogen atoms. One example is methane (CH_4), the main component of natural gas, and the simplest organic compound. Another is octane (C_8H_{18}), a major component of gasoline.
- *Chlorinated hydrocarbons*: compounds of carbon, hydrogen, and chlorine atoms. An example is the insecticide DDT ($C_{14}H_9Cl_5$).
- *Simple carbohydrates (simple sugars)*: certain types of compounds of carbon, hydrogen, and oxygen atoms. An example is glucose ($C_6H_{12}O_6$), which most plants and animals break down in their cells to obtain energy. (For more details, see Figure 7 on p. S14 in Supplement 4.)

Larger and more complex organic compounds, essential to life, are composed of *macromolecules*. Some of these molecules are called *polymers*, formed when a number of simple organic molecules (*monomers)* are linked together by chemical bonds—somewhat like rail cars linked in a freight train. The three major types of organic polymers are

- *Complex carbohydrates* such as cellulose and starch, which consist of two or more monomers of simple sugars such as glucose (see Figure 7, p. S14, in Supplement 4),
- *Proteins* formed by monomers called *amino acids* (see Figure 8, p. S14, in Supplement 4), and
- *Nucleic acids* (DNA and RNA) formed by monomers called *nucleotides* (see Figures 9 and 10, pp. S14 and S15, in Supplement 4).

Lipids, which include fats and waxes, are not made of monomers but are a fourth type of macromolecule essential for life (see Figure 11, p. S15, in Supplement 4).

Matter Comes to Life through Genes, Chromosomes, and Cells

The story of matter, starting with the hydrogen atom, becomes more complex as molecules grow in complexity. This is no less true when we examine the fundamental components of life. The bridge between nonliving and living matter lies somewhere between large molecules and **cells**—the fundamental structural and functional units of life.

All organisms are composed of cells. They are minute compartments covered with a thin membrane, and within them, the processes of life occur. The idea that all living things are composed of cells is called the *cell theory* and it is the most widely accepted scientific theory in biology.

Above, we mentioned nucleotides in DNA (see Figures 9 and 10, pp. S14 and S15, in Supplement 4). Within some DNA molecules are certain sequences of nucleotides called **genes**. Each of these distinct pieces of DNA contains instructions, or codes, called *genetic information*, for making specific proteins. Each of these coded units of genetic information leads to a specific **trait**, or characteristic, passed on from parents to offspring during reproduction in an animal or plant.

In turn, thousands of genes make up a single **chromosome**, a double helix DNA molecule (see Figure 10, p. S15, in Supplement 4) wrapped around some proteins. Humans have 46 chromosomes, mosquitoes have 8, and a fish known as a carp has 104. Genetic information coded in your chromosomal DNA is what makes you different from an oak leaf, an alligator, or a mosquito, and from your parents. In other words, it makes you human, but it also makes you unique. The relationships among genetic material and cells are depicted in Figure 2-7, p. 42).

Some Forms of Matter Are More Useful than Others

Matter quality is a measure of how useful a form of matter is to humans as a resource, based on its availability and *concentration*—the amount of it that is contained in a given area or volume. **High-quality matter** is highly concentrated, is typically found near the earth's surface, and has great potential for use as a resource. **Low-quality matter** is not highly concentrated, is often located deep underground or dispersed in the ocean or atmosphere, and usually has little potential for use as a resource. Figure 2-8 (p. 42) illustrates examples of differences in matter quality.

In summary, matter consists of elements and compounds that in turn are made up of atoms, ions, or molecules (**Concept 2-2**). Some forms of matter are more useful as resources than others because of their availability and concentrations.

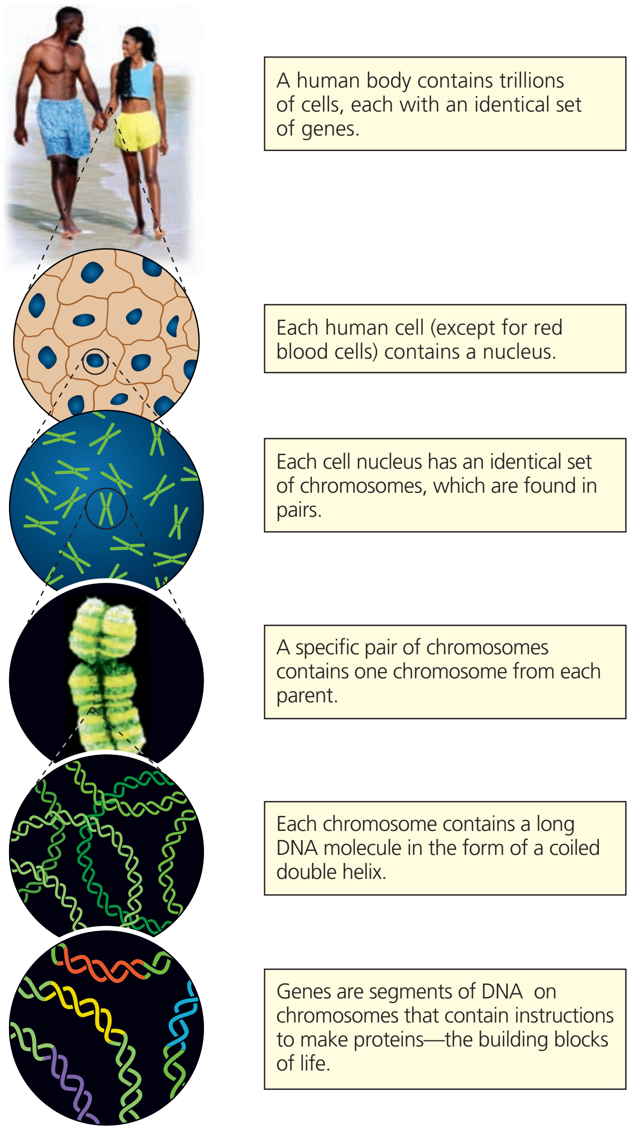


Figure 2-7 This diagram shows the relationships among cells, nuclei, chromosomes, DNA, and genes.

Figure 2-8 These examples illustrate the differences in matter quality. *High-quality matter* (left column) is fairly easy to extract and is highly concentrated; *low-quality matter* (right column) is not highly concentrated and is more difficult to extract than high-quality matter.

2-3 What Happens When Matter Undergoes Change?

▶ **CONCEPT 2-3 Whenever matter undergoes a physical or chemical change, no atoms are created or destroyed (the law of conservation of matter).**

Matter Undergoes Physical, Chemical, and Nuclear Changes

When a sample of matter undergoes a **physical change**, there is no change in its *chemical composition*. A piece of aluminum foil cut into small pieces is still aluminum foil. When solid water (ice) melts and when liquid water boils, the resulting liquid water and water vapor are still made up of H_2O molecules.

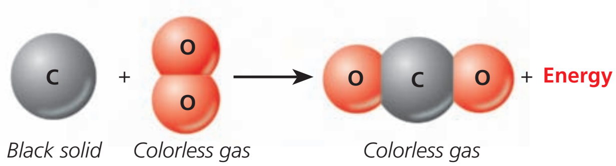
THINKING ABOUT
Controlled Experiments and Physical Changes

CORE CASE STUDY

How would you set up a controlled experiment (**Core Case Study**) to verify that when water changes from one physical state to another, its chemical composition does not change?

When a **chemical change**, or **chemical reaction**, takes place, there is a change in the chemical composition of the substances involved. Chemists use a *chemical equation* to show how chemicals are rearranged in a chemical reaction. For example, coal is made up almost entirely of the element carbon (C). When coal is burned completely in a power plant, the solid carbon (C) in the coal combines with oxygen gas (O_2) from the atmosphere to form the gaseous compound carbon dioxide (CO_2). Chemists use the following shorthand chemical equation to represent this chemical reaction:

Reactant(s)			→	Product(s)		
Carbon	+	Oxygen	→	Carbon dioxide	+	**Energy**
C	+	O_2	→	CO_2	+	**Energy**



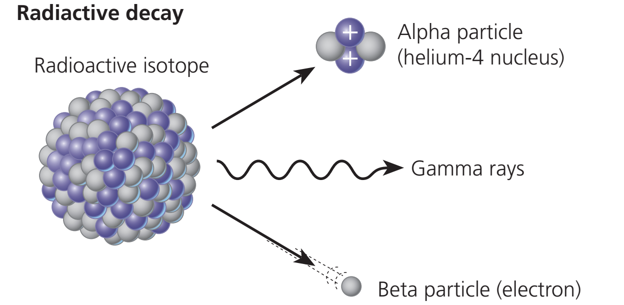
In addition to physical and chemical changes, matter can undergo three types of **nuclear change**, or change in the nuclei of its atoms: radioactive decay, nuclear fission, and nuclear fusion, which are described and defined in Figure 2-9.

We Cannot Create or Destroy Atoms: The Law of Conservation of Matter

We can change elements and compounds from one physical or chemical form to another, but we can never create or destroy any of the atoms involved in any physical or chemical change. All we can do is rearrange the atoms, ions, or molecules into different spatial patterns (physical changes) or chemical combinations (chemical changes). These facts, based on many thousands of measurements, describe a scientific law known as the **law of conservation of matter**: Whenever matter undergoes a physical or chemical change, no atoms are created or destroyed (**Concept 2-3**).

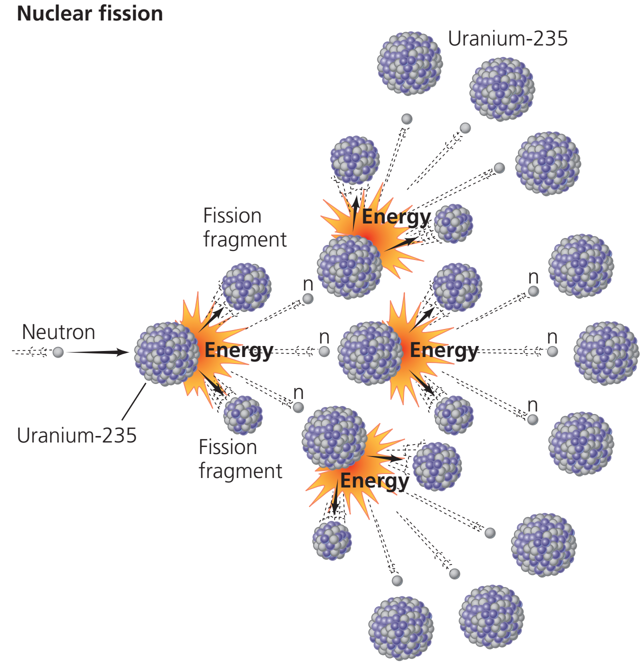
> **CONNECTIONS**
>
> **Waste and the Law of Conservation of Matter**
>
> The law of conservation of matter means we can never really throw anything away because the atoms in any form of matter cannot be destroyed as it undergoes physical or chemical changes. Stuff that we put out in the trash may be buried in a sanitary landfill, but we have not really thrown it away because the atoms in this waste material will always be around in one form or another. We can burn trash, but we then end up with ash that must be put somewhere, and with gases emitted by the burning that can pollute the air. We can reuse or recycle some materials and chemicals, but the law of conservation of matter means we will always face the problem of what to do with some quantity of the wastes and pollutants we produce because their atoms cannot be destroyed.

Radiactive decay



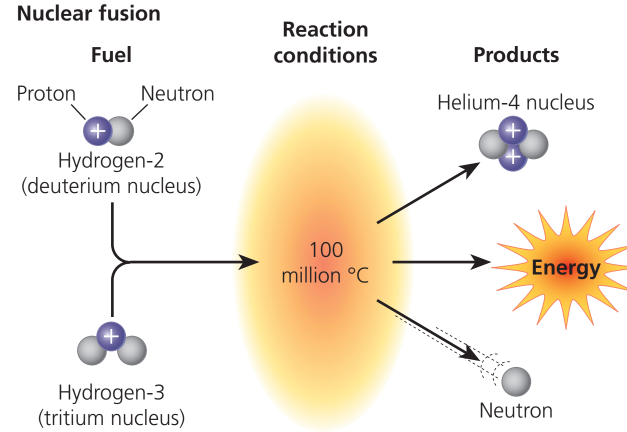
Radioactive decay occurs when nuclei of unstable isotopes spontaneously emit fast-moving chunks of matter (alpha particles or beta particles), high-energy radiation (gamma rays), or both at a fixed rate. A particular radioactive isotope may emit any one or a combination of the three items shown in the diagram.

Nuclear fission



Nuclear fission occurs when the nuclei of certain isotopes with large mass numbers (such as uranium-235) are split apart into lighter nuclei when struck by a neutron and release energy plus two or three more neutrons. Each neutron can trigger an additional fission reaction and lead to a *chain reaction*, which releases an enormous amount of energy very quickly.

Nuclear fusion



Nuclear fusion occurs when two isotopes of light elements, such as hydrogen, are forced together at extremely high temperatures until they fuse to form a heavier nucleus and release a tremendous amount of energy.

Figure 2-9 There are three types of nuclear changes: natural radioactive decay (top), nuclear fission (middle), and nuclear fusion (bottom).

2-4 What Is Energy and What Happens When It Undergoes Change?

▶ **CONCEPT 2-4A Whenever energy is converted from one form to another in a physical or chemical change, no energy is created or destroyed (first law of thermodynamics).**

▶ **CONCEPT 2-4B Whenever energy is converted from one form to another in a physical or chemical change, we end up with lower-quality or less usable energy than we started with (second law of thermodynamics).**

Energy Comes in Many Forms

Suppose you find this book on the floor and you pick it up and put it on your desktop. In doing this you have to use a certain amount of muscular force to move the book, and you have done work. In scientific terms, work is done when any object is moved a certain distance (work = force × distance). Also, whenever you touch a hot object such as a stove, heat flows from the stove to your finger. Both of these examples involve **energy**: the capacity to do work or to transfer heat.

There are two major types of energy: *moving energy* (called kinetic energy) and *stored energy* (called potential energy). Matter in motion has **kinetic energy**, which is energy associated with motion. Examples are flowing water, electricity (electrons flowing through a wire or other conducting material), and wind (a mass of moving air that we can use to produce electricity, as shown in Figure 2-10).

Another form of kinetic energy is **heat**, the total kinetic energy of all moving atoms, ions, or molecules within a given substance. When two objects at different temperatures contact one another, heat flows from the warmer object to the cooler object. You learned this the first time you touched a hot stove.

Another form of kinetic energy is called **electromagnetic radiation**, in which energy travels in the form of a *wave* as a result of changes in electrical and magnetic fields. There are many different forms of electromagnetic radiation (Figure 2-11), each having a different *wavelength* (the distance between successive peaks or troughs in the wave) and *energy content*. Forms of electromagnetic radiation with short wavelengths, such as gamma rays, X rays, and ultraviolet (UV) radiation, have more energy than do forms with longer wavelengths, such as visible light and infrared (IR) radiation. Visible light makes up most of the spectrum of electromagnetic radiation emitted by the sun.

CENGAGE**NOW**™ Find out how the color, wavelengths, and energy intensities of visible light are related at CengageNOW.

The other major type of energy is **potential energy**, which is stored and potentially available for use. Examples of this type of energy include a rock held in your hand, the water in a reservoir behind a dam, and the chemical energy stored in the carbon atoms of coal.

We can change potential energy to kinetic energy. If you hold this book in your hand, it has potential energy. However, if you drop it on your foot, the book's potential energy changes to kinetic energy. When a car engine burns gasoline, the potential energy stored in the chemical bonds of the gasoline molecules changes into kinetic energy that propels the car, and into heat that flows into the environment. When water in a reservoir (Figure 2-12) flows through channels in a dam, its potential energy becomes kinetic energy that we can use to spin turbines in the dam to produce electricity—another form of kinetic energy.

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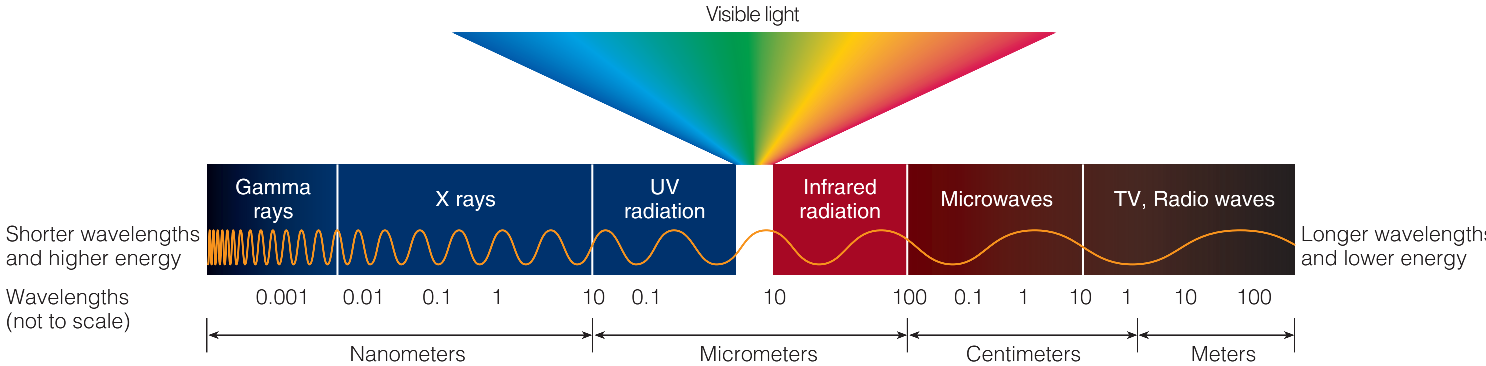
Figure 2-10 Kinetic energy, created by the gaseous molecules in a mass of moving air, turns the blades of this wind turbine. The turbine then converts this kinetic energy to electrical energy, which is another form of kinetic energy.



CENGAGENOW™ **Active Figure 2-11** The *electromagnetic spectrum* consists of a range of electromagnetic waves, which differ in wavelength (the distance between successive peaks or troughs) and energy content. *See an animation based on this figure at* CengageNOW.

About 99% of the energy that heats the earth and our buildings, and that supports plants (through a process called photosynthesis) that provide us and other organisms with food, comes from the sun (Figure 2-13, p. 46) at no cost to us. This is in keeping with the solar energy **principle of sustainability** (see back cover). Without this essentially inexhaustible solar energy, the earth's average temperature would be −240° C (−400° F), and life as we know it would not exist.

This direct input of solar energy produces several other indirect forms of renewable solar energy. Examples are *wind* (Figure 2-10), *hydropower* (falling and flowing water, Figure 2-12), and *biomass* (solar energy converted to chemical energy and stored in the chemical bonds of organic compounds in trees and other plants).

Commercial energy sold in the marketplace makes up the remaining 1% of the energy we use to supplement the earth's direct input of solar energy. About 79% of the commercial energy used in the world and 85% of the commercial energy that is used in the United States comes from burning oil, coal, and natural gas (Figure 2-14, p. 46). These fuels are called **fossil fuels** because they were formed over millions of years as

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Figure 2-12 The water stored in this reservoir behind a dam in the U.S. state of Tennessee has potential energy, which becomes kinetic energy when the water flows through channels built into the dam where it spins a turbine and produces electricity—another form of kinetic energy.

Figure 2-13 Energy from the sun supports life and human economies. This energy is produced far away from the earth by *nuclear fusion* (Figure 2-9, bottom). In this process, nuclei of light elements such as hydrogen are forced together at extremely high temperatures until they fuse to form a heavier nucleus. This results in the release of a massive amount of energy that is radiated out through space.

Galyna Andrushko/Shutterstock

layers of the decaying remains of ancient plants and animals (fossils) were exposed to intense heat and pressure within the earth's crust.

CENGAGENOW™ Witness how a Martian might use kinetic and potential energy at CengageNOW.

Some Types of Energy Are More Useful Than Others

Energy quality is a measure of the capacity of a type of energy to do useful work. **High-quality energy** has a great capacity to do useful work because it is concentrated. Examples are very high-temperature heat, concentrated sunlight, high-speed wind (Figure 2-10), and the energy released when we burn gasoline or coal.

By contrast, **low-quality energy** is so dispersed that it has little capacity to do useful work. For example, the low-temperature heat generated by the enormous number of moving molecules in the atmosphere or in an ocean (Figure 2-15) is of such low quality that we cannot use it to heat things to high temperatures.

Energy Changes Are Governed by Two Scientific Laws

Thermodynamics is the study of energy transformations. After observing and measuring energy being changed from one form to another in millions of physical and chemical changes, scientists have summarized their results in the **first law of thermodynamics**, also known as the **law of conservation of energy**. According to this scientific law, whenever energy is

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Figure 2-14 *Fossil fuels:* Oil, coal, and natural gas (left, center, and right, respectively) supply most of the commercial energy that we use to supplement energy from the sun. Burning fossil fuels provides us with many benefits such as heat, electricity, air conditioning, manufacturing, and mobility. But when we burn these fuels, we automatically add carbon dioxide and various other pollutants to the atmosphere.

Figure 2-15 A huge amount of the sun's energy is stored as heat in the world's oceans. But the temperature of this widely dispersed energy is so low that we cannot use it to heat matter to a high temperature. Thus, the ocean's stored heat is low-quality energy. **Question:** Why is direct solar energy a higher-quality form of energy than the ocean's heat is?

converted from one form to another in a physical or chemical change, no energy is created or destroyed (**Concept 2-4A**).

This scientific law tells us that no matter how hard we try or how clever we are, we cannot get more energy out of a physical or chemical change than we put in. This is one of nature's basic rules that has never been violated.

Because the first law of thermodynamics states that energy cannot be created or destroyed, but only converted from one form to another, you may be tempted to think we will never have to worry about running out of energy. Yet if you fill a car's tank with gasoline and drive around or use a flashlight battery until it is dead, something has been lost. What is it? The answer is *energy quality,* the amount of energy available for performing useful work.

Thousands of experiments have shown that whenever energy is converted from one form to another in a physical or chemical change, we end up with lower-quality or less useable energy than we started with (**Concept 2-4B**). This is a statement of the **second law of thermodynamics**. The resulting low-quality energy usually takes the form of heat that flows into the environment. In the environment, the random motion of air or water molecules further disperses this heat, decreasing its temperature to the point where its energy quality is too low to do much useful work.

In other words, *when energy is changed from one form to another, it always goes from a more useful to a less useful form*. No one has ever found a violation of this fundamental scientific law.

We can recycle various forms of matter such as paper and aluminum. However, because of the second law of thermodynamics we can never recycle or reuse high-quality energy to perform useful work. Once the concentrated energy in a serving of food, a liter of gasoline, or a chunk of uranium is released, it is degraded to low-quality heat that is dispersed into the environment at a low temperature. According to British astrophysicist Arthur S. Eddington (1882–1944): "The second law of thermodynamics holds, I think, the supreme position among laws of nature. . . . If your theory is found to be against the second law of thermodynamics, I can give you no hope."

Two widely used technologies—the incandescent lightbulb and the internal combustion engine found in most motor vehicles—waste enormous amounts of energy (Figure 2-16, p. 48). Up to half of this waste occurs automatically because the high-quality energy in electricity and gasoline is degraded to low-quality heat that flows into the environment, as required by the second law of thermodynamics. But most of the remaining high-quality energy is wasted unnecessarily because of the poor design of these increasingly outdated technologies.

CENGAGE**NOW**™ See examples of how the first and second laws of thermodynamics apply in our world at CengageNOW.

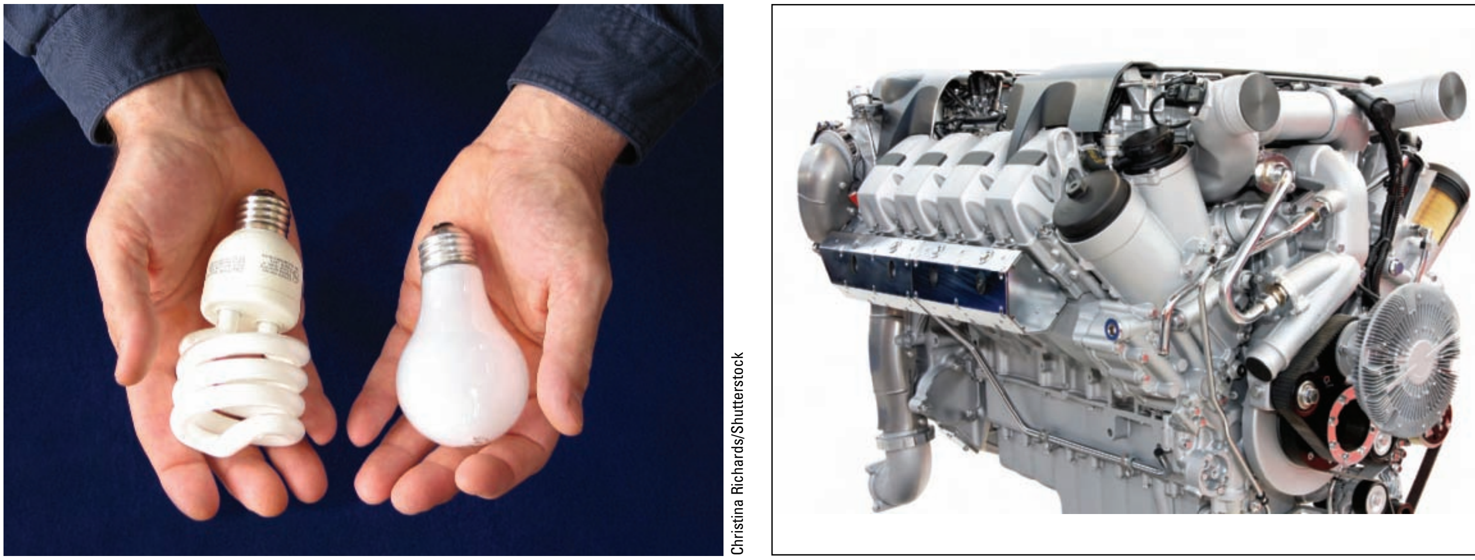

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Figure 2-16 Two widely used technologies waste enormous amounts of energy. In an incandescent lightbulb (right), about 95% of the electrical energy flowing into it becomes heat; just 5% becomes light. By comparison, in a compact fluorescent bulb (left) with the same brightness, about 20% of the energy input becomes light. In the internal combustion engine (right photo) found in most motor vehicles, about 87% of the chemical energy provided in its gasoline fuel flows into the environment as low-quality heat. (Data from U.S. Department of Energy and Amory Lovins; see his Guest Essay at CengageNOW.)

2-5 What Are Systems and How Do They Respond to Change?

▶ **CONCEPT 2-5 Systems have inputs, flows, and outputs of matter and energy, and feedback can affect their behavior.**

Systems Have Inputs, Flows, and Outputs

A **system** is a set of components that function and interact in some regular way. The human body, a river, an economy, and the earth are all systems.

Most systems have the following key components: **inputs** from the environment, **flows** or **throughputs** of matter and energy within the system, and **outputs** to the environment (Figure 2-17) (**Concept 2-5**). One of the most powerful tools used by environmental scientists to study how these components of systems interact is computer modeling (Science Focus, p. 49).

Systems Respond to Change through Feedback Loops

When people ask you for feedback, they are usually seeking your response to something they said or did. They might feed your response back into their mental processes to help them decide whether and how to change what they are saying or doing.

Similarly, most systems are affected in one way or another by **feedback**, any process that increases (posi-

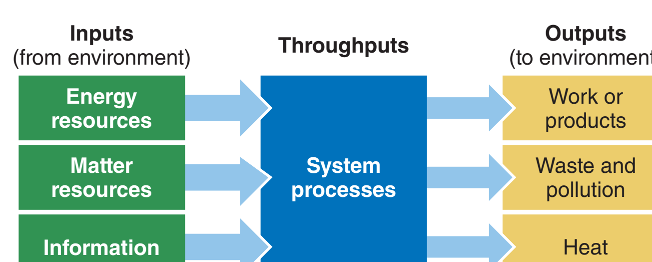


Figure 2-17 This diagram illustrates a greatly simplified model of a system. Most systems depend on inputs of matter and energy resources, and outputs of wastes, pollutants, and heat to the environment. A system can become unsustainable if the throughputs of matter and energy resources exceed the abilities of the system's environment to provide the required resource inputs and to absorb or dilute the resulting wastes, pollutants, and heat.

SCIENCE FOCUS

The Usefulness of Models

Scientists use *models*, or simulations, to learn how systems work. Mathematical models are especially useful when there are many interacting variables, when the time frame of events we are modeling is long, and when controlled experiments are impossible or too expensive to conduct. Some of our most powerful and useful technologies are mathematical models that are run on high-speed supercomputers.

Making a mathematical model usually requires that the modelers go through three steps many times. *First*, identify the major components of the system and how they interact, and develop mathematical equations that summarize this information. In succeeding runs, these equations are steadily refined. *Second*, use a high-speed computer to describe the likely behavior of the system based on the equations. *Third*, compare the system's projected behavior with known information about its actual behavior. Keep doing this until the model mimics the past and current behavior of the system.

After building and testing a mathematical model, scientists can use it to project what is *likely* to happen under a variety of conditions. In effect, they use mathematical models to answer *if–then* questions: "*If* we do such and such, *then* what is likely to happen now and in the future?" This process can give us a variety of projections of possible outcomes based on different assumptions. Mathematical models (like all other models) are no better than the assumptions on which they are built and the data we feed into them.

This process of model building was applied to the data collected by Bormann and Likens in their Hubbard Brook experiment (**Core Case Study**). Other scientists created mathematical models based on this data to describe a forest and to project what might happen to soil nutrients and other variables when the forest is disturbed or cut down.

CORE CASE STUDY

Other areas of environmental science in which computer modeling is becoming increasingly important include studies of the complex systems that govern climate change, deforestation, biodiversity loss, and the oceans.

Critical Thinking

What are two limitations of computer models? Does this mean that we should not rely on such models? Explain.

tive feedback) or decreases (negative feedback) a change to a system (**Concept 2-5**). Such a process, called a **feedback loop**, occurs when an output of matter, energy, or information is fed back into the system as an input and leads to changes in that system. Note that, unlike the human brain, most systems do not consciously decide how to respond to feedback. Nevertheless, feedback can affect the behavior of systems.

A **positive feedback loop** causes a system to change further in the same direction (Figure 2-18). In the Hubbard Brook experiments, for example (**Core Case Study**), researchers found that when vegetation was removed from a stream valley, flowing water from precipitation caused erosion and loss of nutrients, which caused more vegetation to die. With even less vegetation to hold soil in place, flowing water caused even more erosion and nutrient loss, which caused even more plants to die.

CORE CASE STUDY

Such accelerating positive feedback loops are of great concern in several areas of environmental science. One of the most alarming is the melting of polar ice, which has occurred as the temperature of the atmosphere has risen during the past few decades. As that ice melts, there is less of it to reflect sunlight, and more water that is exposed to sunlight. Because water is darker than ice, it absorbs more solar energy, making the polar areas warmer and causing the ice to melt faster, thus exposing more water. The melting of polar ice is therefore accelerating, causing a number of serious problems that we explore further in Chapter 19. If a system gets locked into an accelerating positive feedback loop, it can reach a breaking point that can destroy the system or change its behavior irreversibly.

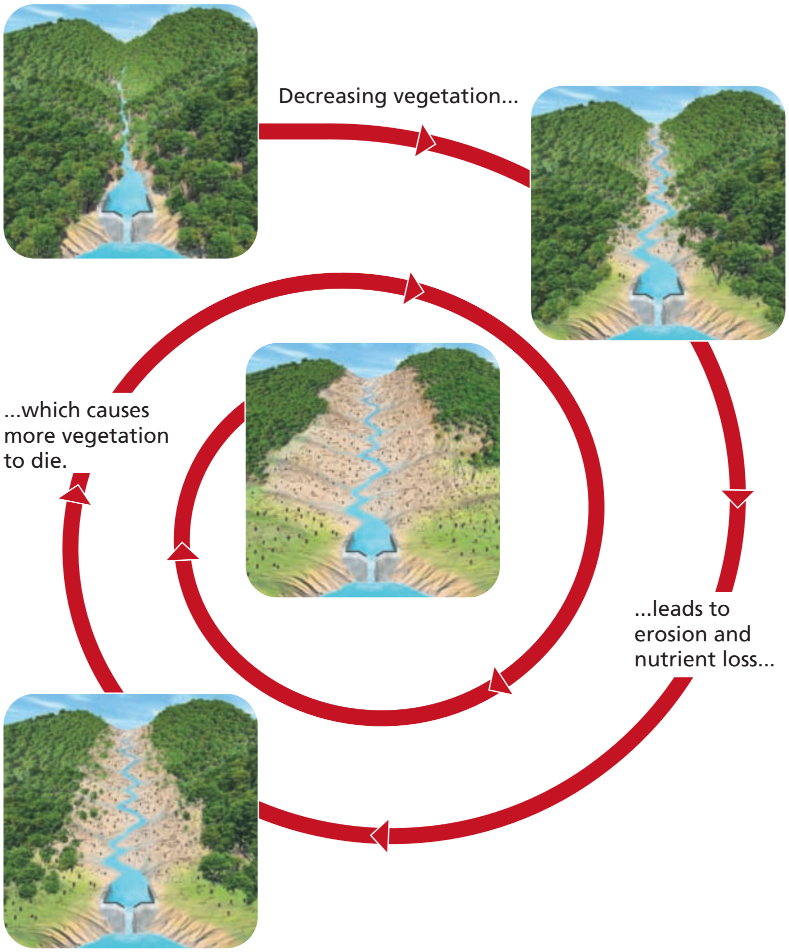


Figure 2-18 This diagram represents a *positive feedback loop*. Decreasing vegetation in a valley causes increasing erosion and nutrient losses that in turn cause more vegetation to die, resulting in more erosion and nutrient losses. **Question:** Can you think of another positive feedback loop in nature?

A **negative**, or **corrective, feedback loop** causes a system to change in the opposite direction from which is it moving. A simple example is a thermostat, a device that controls how often and how long a heating or cooling system runs (Figure 2-19). When the furnace in a house turns on and begins heating the house, we can set the thermostat to turn the furnace off when the temperature in the house reaches the set number. The house then stops getting warmer and starts to cool.

THINKING ABOUT
The Hubbard Brook Experiments and Feedback Loops

How might experimenters have employed a negative feedback loop to stop, or correct, the positive feedback loop that resulted in increasing erosion and nutrient losses in the Hubbard Brook experimental forest?

An important example of a negative feedback loop is the recycling and reuse of some resources such as aluminum and copper. For example, an aluminum can is an output of a mining and manufacturing system. When we recycle the can, that output becomes an input. This reduces the amount of aluminum ore that we must mine and process to make aluminum cans. It also reduces the harmful environmental impacts from mining and processing the aluminum ore. Such a negative feedback loop therefore can help reduce the harmful environmental impacts of human activities by decreasing the use of matter and energy resources, and the amount of pollution and solid waste produced by the use of such resources.

It Can Take a Long Time for a System to Respond to Feedback

A complex system will often show a **time delay**, or a lack of response during a period of time between the input of a feedback stimulus and the system's response to it. For example, scientists could plant trees in a degraded area such as the Hubbard Brook experimental forest to slow erosion and nutrient losses (**Core Case Study**). But it would take years for the trees and other vegetation to grow in order to accomplish this purpose.

Time delays can allow an environmental problem to build slowly until it reaches a *threshold level*, or **tipping point**—the point at which a fundamental shift in the behavior of a system occurs. Prolonged delays dampen the negative feedback mechanisms that might slow, prevent, or halt environmental problems. In the Hubbard Brook example, if soil erosion and nutrient losses reached a certain point where the land could no longer support vegetation, then a tipping point would have been reached and it would be futile to plant trees alone to try to restore the system. Other environmental prob-

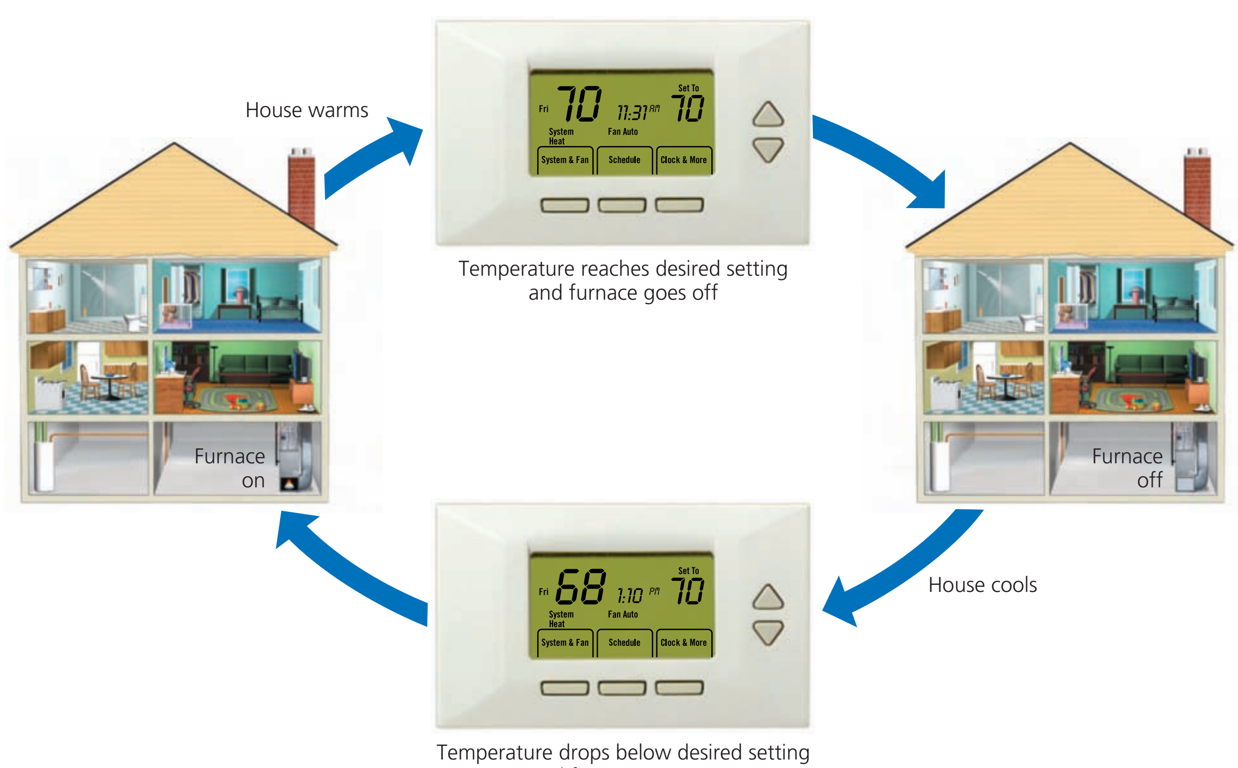


Figure 2-19 This diagram illustrates a *negative feedback loop*. When a house being heated by a furnace gets to a certain temperature, its thermostat is set to turn off the furnace, and the house begins to cool instead of continuing to get warmer. When the house temperature drops below the set point, this information is fed back to turn the furnace on until the desired temperature is reached again.

lems that can reach tipping-point levels are the melting of polar ice (as described above), population growth, and depletion of fish populations due to overfishing.

System Effects Can Be Amplified through Synergy

A **synergistic interaction**, or **synergy**, occurs when two or more processes interact so that the combined effect is greater than the sum of their separate effects. For example, scientific studies reveal such an interaction between smoking and inhaling asbestos particles. Nonsmokers who are exposed to asbestos particles for long periods of time increase their risk of getting lung cancer fivefold. But people who smoke and are exposed to asbestos have 50 times the risk that nonsmokers have of getting lung cancer.

On the other hand, synergy can be helpful. You may find that you are able to study longer or run farther if you do these activities with a studying or running partner. Your physical and mental systems can do a certain amount of work on their own. But the synergistic effect of you and your partner working together can make your individual systems capable of accomplishing more in the same amount of time.

RESEARCH FRONTIER

Identifying environmentally harmful and beneficial synergistic interactions; see **www.cengage.com/login**.

The following scientific laws of matter and energy are the *three big ideas* of this chapter:

- **There is no away.** According to the *law of conservation of matter*, no atoms are created or destroyed whenever matter undergoes a physical or chemical change. Thus, we cannot do away with matter; we can only change it from one physical state or chemical form to another.
- **You cannot get something for nothing.** According to the *first law of thermodynamics*, or the *law of conservation of energy*, whenever energy is converted from one form to another in a physical or chemical change, no energy is created or destroyed. This means that in such changes, we cannot get more energy out than we put in.
- **You cannot break even.** According to the *second law of thermodynamics*, whenever energy is converted from one form to another in a physical or chemical change, we always end up with lower-quality or less usable energy than we started with.

No matter how clever we are or how hard we try, we cannot violate these three basic scientific laws of nature that place limits on what we can do with matter and energy resources.

A Look Ahead

In the next six chapters, we apply the three basic laws of matter and thermodynamics and the three principles of sustainability (see back cover) to living systems. Chapter 3 shows how the sustainability principles related to solar energy and nutrient cycling apply in ecosystems. Chapter 4 focuses on using the biodiversity principle to understand the relationships between species diversity and evolution. Chapter 5 examines how the biodiversity principle relates to interactions among species and how such interactions regulate population size. In Chapter 6, we apply the principles of sustainability to the growth of the human population. In Chapter 7, we look more closely at terrestrial biodiversity and nutrient cycling in different types of deserts, grasslands, and forests. Chapter 8 examines biodiversity in aquatic systems such as oceans, lakes, wetlands, and rivers.

REVISITING The Hubbard Brook Experimental Forest and Sustainability

CORE CASE STUDY

SUSTAINABILITY

The controlled experiment discussed in the **Core Case Study** that opened this chapter revealed that clearing a mature forest degrades some of its natural capital (see Figure 1-4, p. 9). Specifically, the loss of trees and vegetation altered the ability of the forest to retain and recycle water and other critical plant nutrients—a crucial ecological function based on one of the three **principles of sustainability** (see Figure 1-3, p. 8, or the back cover). In other words, the uncleared forest was a more sustainable system than a similar area of cleared forest (Figure 2-1).

This clearing of vegetation also violated the other two principles of sustainability. For example, the cleared forest lost most of its plants that had used solar energy to produce food for animals. And the loss of plants and the resulting loss of animals reduced the life-sustaining biodiversity of the cleared forest.

Humans clear forests to grow crops, build settlements, and expand cities. The key question is, how far can we go in expanding our ecological footprints (see Figure 1-13, p. 16, and **Concept 1-2**, p. 13) without threatening the quality of life for our own species and for the other species that keep us alive and support our economies? To live more sustainably, we need to find and maintain a balance between preserving undisturbed natural systems and modifying other natural systems for our use.

Logic will get you from A to B. Imagination will take you everywhere.

ALBERT EINSTEIN

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 32. Describe the *controlled scientific experiment* carried out in the Hubbard Brook Experimental Forest.

2. What is **science**? Describe the steps involved in a scientific process. What is **data**? What is a **model**? Distinguish among a **scientific hypothesis**, a **scientific theory**, and a **scientific law (law of nature)**. What is **peer review** and why is it important? Explain why scientific theories are not to be taken lightly and why people often use the term *theory* incorrectly. Describe how a hypothesis about the decline of a civilization on Easter Island has been challenged by new data.

3. Explain why scientific theories and laws are the most important and most certain results of science.

4. Distinguish among **tentative science (frontier science)**, **reliable science**, and **unreliable science**. What is **statistics**? What is **probability** and what is its role in scientific conclusions and proof? What are three limitations of science in general and environmental science in particular?

5. What is **matter**? Distinguish between an **element** and a **compound** and give an example of each. Distinguish among **atoms**, **molecules**, and **ions** and give an example of each. What is the **atomic theory**? Distinguish among **protons**, **neutrons**, and **electrons**. What is the **nucleus** of an atom? Distinguish between the **atomic number** and the **mass number** of an element. What is an **isotope**? What is **acidity**? What is **pH**?

6. What is a **chemical formula**? Distinguish between **organic compounds** and **inorganic compounds** and give an example of each. Distinguish among complex carbohydrates, proteins, nucleic acids, and lipids. What is a **cell**? Distinguish among a **gene**, a **trait**, and a **chromosome**. What is **matter quality**? Distinguish between **high-quality matter** and **low-quality matter** and give an example of each.

7. Distinguish between a **physical change** and a **chemical change (chemical reaction)** and give an example of each. What is a **nuclear change**? Explain the differences among **radioactive decay, nuclear fission**, and **nuclear fusion**. What is the **law of conservation of matter** and why is it important?

8. What is **energy**? Distinguish between **kinetic energy** and **potential energy** and give an example of each. What is **heat**? Define and give two examples of **electromagnetic radiation**. What are **fossil fuels** and what three fossil fuels do we use most to supplement energy from the sun? What is **energy quality**? Distinguish between **high-quality energy** and **low-quality energy** and give an example of each. What is the **first law of thermodynamics (law of conservation of energy)** and why is it important? What is the **second law of thermodynamics** and why is it important? Explain why the second law means that we can never recycle or reuse high-quality energy.

9. Define and give an example of a **system**. Distinguish among the **input, flow (throughput)**, and **output** of a system. Why are scientific models useful? What is **feedback**? What is a **feedback loop**? Distinguish between a **positive feedback loop** and a **negative (corrective) feedback loop** in a system, and give an example of each. Distinguish between a **time delay** and a **synergistic interaction (synergy)** in a system and give an example of each. What is a **tipping point**?

10. What are this chapter's *three big ideas*? Relate the three **principles of sustainability** to the Hubbard Brook Experimental Forest controlled experiment. SUSTAINABILITY

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. What ecological lesson can we learn from the controlled experiment on the clearing of forests described in the **Core Case Study** that opened this chapter? CORE CASE STUDY

2. You observe that all of the fish in a pond have disappeared. Describe how you might use the scientific process described in the **Core Case Study** and on p. 32 to determine the cause of this fish kill. CORE CASE STUDY

3. Describe a way in which you have applied the scientific process described in this chapter (see Figure 2-2) in your own life, and state the conclusion you drew from this process. Describe a new problem that you would like to solve using this process.

4. Respond to the following statements:
   a. Scientists have not absolutely proven that anyone has ever died from smoking cigarettes.
   b. The natural greenhouse theory—that certain gases such as water vapor and carbon dioxide warm the lower atmosphere—is not a reliable idea because it is just a scientific theory.

5. A tree grows and increases its mass. Explain why this is not a violation of the law of conservation of matter.

6. If there is no "away" where organisms can get rid of their wastes because of the law of conservation of matter, why is the world not filled with waste matter?

7. Someone wants you to invest money in an automobile engine, claiming that it will produce more energy than the energy in the fuel used to run it. What is your response? Explain.

8. Use the second law of thermodynamics to explain why we can use oil only once as a fuel, or in other words, why we cannot recycle its high-quality energy.

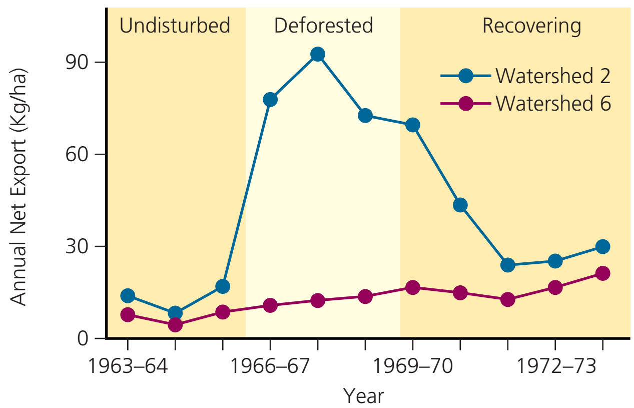
9. a. Imagine you have the power to revoke the law of conservation of matter for one day. What are three things you would do with this power? Explain your choices.
   b. Imagine you have the power to violate the first law of thermodynamics for one day. What are three things you would do with this power? Explain your choices.

10. List two questions that you would like to have answered as a result of reading this chapter.

DATA ANALYSIS

Consider the graph below that shows loss of calcium from the experimental cutover site of the Hubbard Brook Experimental Forest compared with that of the control site. Note that this figure is very similar to Figure 2-6, which compares loss of nitrates from the two sites (**Core Case Study**). After studying this graph, answer the questions below.

CORE CASE STUDY



1. In what year did the calcium loss from the experimental site begin a sharp increase? In what year did it peak? In what year did it again level off?

2. In what year were the calcium losses from the two sites closest together? In the span of time between 1963 and 1972, did they ever get that close again?

3. Does this graph support the hypothesis that cutting the trees from a forested area causes the area to lose nutrients more quickly than leaving the trees in place? Explain.

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengagebrain.com/shop/ISBN/0538735341** and choose Chapter 2 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

For students with access to premium online resources, log on to **www.cengage.com/login**.

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3 Ecosystems: What Are They and How Do They Work?

CORE CASE STUDY Tropical Rain Forests Are Disappearing

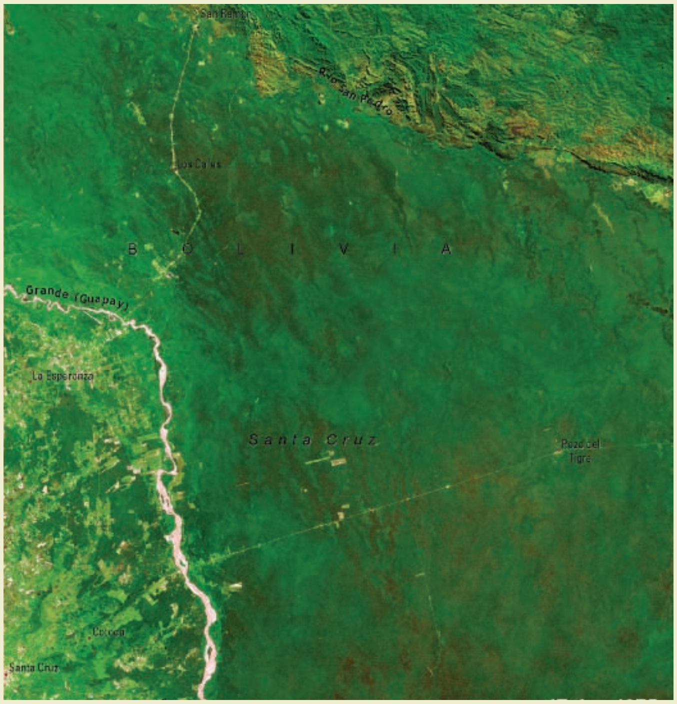
Tropical rain forests are found near the earth's equator and contain an incredible variety of life. These lush forests are warm year round and have high humidity and heavy rainfall almost daily. Although they cover only about 2% of the earth's land surface, studies indicate that they contain up to half of the world's known terrestrial plant and animal species. For these reasons, they make an excellent natural laboratory for the study of *ecosystems*—communities of organisms interacting with one another and with the physical environment of matter and energy in which they live.

So far, at least half of these forests have been destroyed or disturbed by humans cutting down trees, growing crops, grazing cattle, and building settlements (Figure 3-1), and the degradation of these centers of biodiversity is increasing. Ecologists warn that without strong protective measures, most of these forests will probably be gone or severely degraded within your lifetime.

So why should we care that tropical rain forests are disappearing? Scientists give three reasons. *First*, clearing these forests will reduce the earth's vital biodiversity by destroying or degrading the habitats of many of the unique plant and animal species that live there, which could lead to their early extinction. *Second*, it is helping to accelerate atmospheric warming, and thus climate change (as discussed in more detail in Chapter 19), because by eliminating large areas of trees faster than they can grow back, we are degrading the forests' ability to remove the greenhouse gas carbon dioxide (CO_2) from the atmosphere.

Third, it will change regional weather patterns in ways that could prevent the return of diverse tropical rain forests in cleared or severely degraded areas. If this irreversible *ecological tipping point* is reached, tropical rain forests in such areas will become much less diverse tropical grasslands.

In this chapter, we look more closely at how tropical rain forests, and ecosystems in general, work. We also examine how human activities such as the clear-cutting of forests can disrupt the cycling of nutrients within ecosystems and the flow of energy through them.



United Nations Environment Programme

United Nations Environment Programme

Figure 3-1 **Natural capital degradation:** This satellite image shows the loss of topical rain forest, cleared for farming, cattle grazing, and settlements, near the Bolivian city of Santa Cruz between June 1975 (left) and May 2003 (right).

Key Questions and Concepts

3-1 What keeps us and other organisms alive?

CONCEPT 3-1A The four major components of the earth's life-support system are the atmosphere (air), the hydrosphere (water), the geosphere (rock, soil, and sediment), and the biosphere (living things).

CONCEPT 3-1B Life is sustained by the flow of energy from the sun through the biosphere, the cycling of nutrients within the biosphere, and gravity.

3-2 What are the major components of an ecosystem?

CONCEPT 3-2 Some organisms produce the nutrients they need, others get the nutrients they need by consuming other organisms, and some recycle nutrients back to producers by decomposing the wastes and remains of other organisms.

3-3 What happens to energy in an ecosystem?

CONCEPT 3-3 As energy flows through ecosystems in food chains and webs, the amount of chemical energy available to organisms at each successive feeding level decreases.

3-4 What happens to matter in an ecosystem?

CONCEPT 3-4 Matter, in the form of nutrients, cycles within and among ecosystems and the biosphere, and human activities are altering these chemical cycles.

3-5 How do scientists study ecosystems?

CONCEPT 3-5 Scientists use both field research and laboratory research, as well as mathematical and other models to learn about ecosystems.

Note: Supplements 1 (p. S2), 2 (p. S3), 3 (p. S6), 4 (p. S11), 5 (p. S18), 6 (p. S20), 8 (p. S30), and 9 (p. S57) can be used with this chapter.

To halt the decline of an ecosystem, it is necessary to think like an ecosystem.

DOUGLAS WHEELER

3-1 What Keeps Us and Other Organisms Alive?

CONCEPT 3-1A The four major components of the earth's life-support system are the atmosphere (air), the hydrosphere (water), the geosphere (rock, soil, and sediment), and the biosphere (living things).

CONCEPT 3-1B Life is sustained by the flow of energy from the sun through the biosphere, the cycling of nutrients within the biosphere, and gravity.

Earth's Life-Support System Has Four Major Components

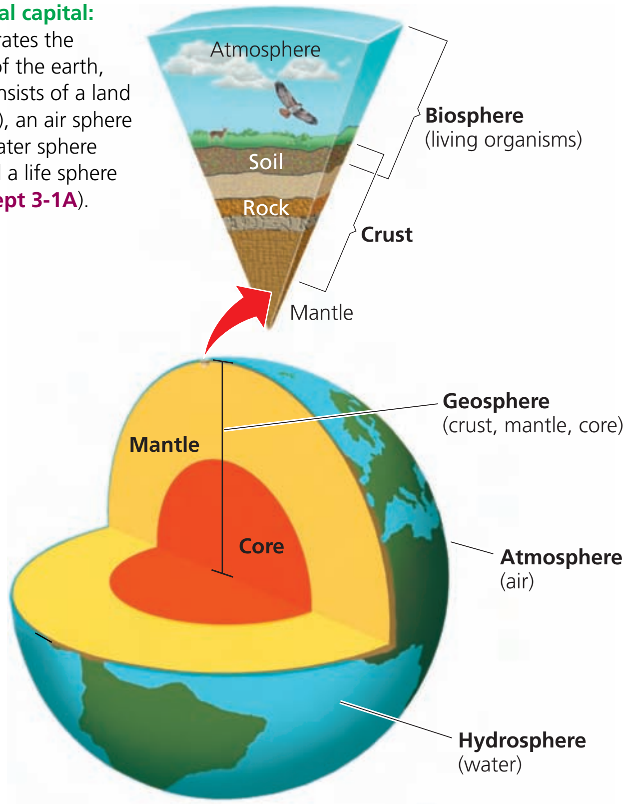
The earth's life-support system consists of four main spherical systems that interact with one another—the atmosphere (air), the hydrosphere (water), the geosphere (rock, soil, and sediment), and the biosphere (living things) (Figures 3-2 and 3-3, p. 56, and Concept 3-1A).

The **atmosphere** is a thin spherical envelope of gases surrounding the earth's surface. Its inner layer, the **troposphere**, extends only about 17 kilometers (11 miles) above sea level at the tropics and about 7 kilometers (4 miles) above the earth's north and south poles. It contains air that we breathe, consisting mostly of nitrogen (78% of the total volume) and oxygen (21%). The remaining 1% of the air includes water vapor, carbon dioxide, and methane, all of which are called **greenhouse gases**, which absorb and release energy that warms the lower atmosphere. Without these gases, the earth would be too cold for the existence of life as we know it. Almost all of the earth's weather occurs within this layer.

The next layer, stretching 17–50 kilometers (11–31 miles) above the earth's surface, is called the **stratosphere**. Its lower portion holds enough ozone (O_3) gas to filter out about 95% of the sun's harmful *ultraviolet (UV) radiation*. This global sunscreen allows life to exist on land and in the surface layers of bodies of water.

The **hydrosphere** consists of all of the water on or near the earth's surface. It is found as *water vapor* in the atmosphere, *liquid water* on the surface and underground, and *ice*—polar ice, icebergs, glaciers, and ice in frozen soil layers called *permafrost*. The oceans, which

Figure 3-2 Natural capital: This diagram illustrates the general structure of the earth, showing that it consists of a land sphere (*geosphere*), an air sphere (*atmosphere*), a water sphere (*hydrosphere*), and a life sphere (*biosphere*) (**Concept 3-1A**).



cover about 71% of the globe, contain about 97% of the earth's water.

The **geosphere** consists of the earth's intensely hot *core*, a thick *mantle* composed mostly of rock, and a thin outer *crust*. Most of the geosphere is located in the earth's interior. Its upper portion contains nonrenewable fossil fuels and minerals that we use, as well as renewable soil chemicals (nutrients) that organisms need in order to live, grow, and reproduce.

The **biosphere** consists of the parts of the atmosphere, hydrosphere, and geosphere where life is found. If the earth were an apple, the biosphere would be no thicker than the apple's skin. *One important goal of environmental science is to understand the interactions that occur within this thin layer of air, water, soil, and organisms.*

Three Factors Sustain the Earth's Life

Life on the earth depends on three interconnected factors (**Concept 3-1B**):

1. The *one-way flow of high-quality energy* from the sun, through living things in their feeding interactions, into the environment as low-quality energy (mostly heat dispersed into air or water at a low temperature), and eventually back into space as heat. No round trips are allowed because high-quality energy cannot be recycled. The two laws of thermodynamics (see Chapter 2, pp. 46–48) govern this energy flow.
2. The *cycling of nutrients* (the atoms, ions, and molecules needed for survival by living organisms) through parts of the biosphere. Because the earth is closed to significant inputs of matter from space,

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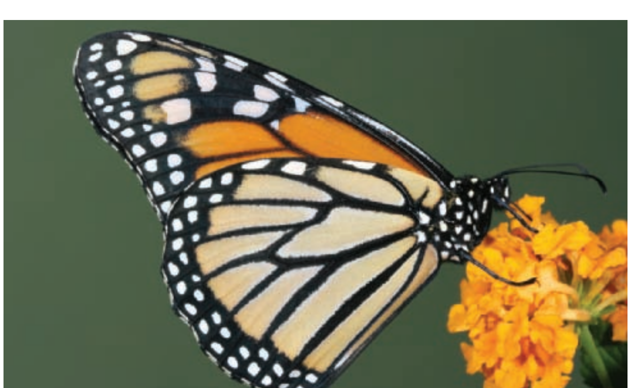
(a) Land, air, water, and plants in Siberia

Andrey Ushakov/Shutterstock

(c) Endangered Siberian tiger



Goran Kapor/Shutterstock

(b) Monarch butterfly and flower

PBorowka/Shutterstock

(d) Coral reef in Hawaii

Figure 3-3 Natural capital: Land, air, water, and a variety of plants and animals sustain the earth's diversity of life and human economies.

its essentially fixed supply of nutrients must be continually recycled to support life (see Figure 1-5, p. 10). Nutrient cycles in ecosystems and in the biosphere are round trips, which can take from seconds to centuries to complete. The law of conservation of matter (see Chapter 2, p. 43) governs this nutrient cycling process.

3. *Gravity,* which allows the planet to hold onto its atmosphere and helps to enable the movement and cycling of chemicals through air, water, soil, and organisms.

Sun, Earth, Life, and Climate

Millions of kilometers from the earth, there is an immense nuclear fusion reactor that we call the sun (see Figure 2-13, p. 46). In this star, nuclei of hydrogen fuse together to form larger helium nuclei (see Figure 2-9, bottom, p. 43), releasing tremendous amounts of energy into space.

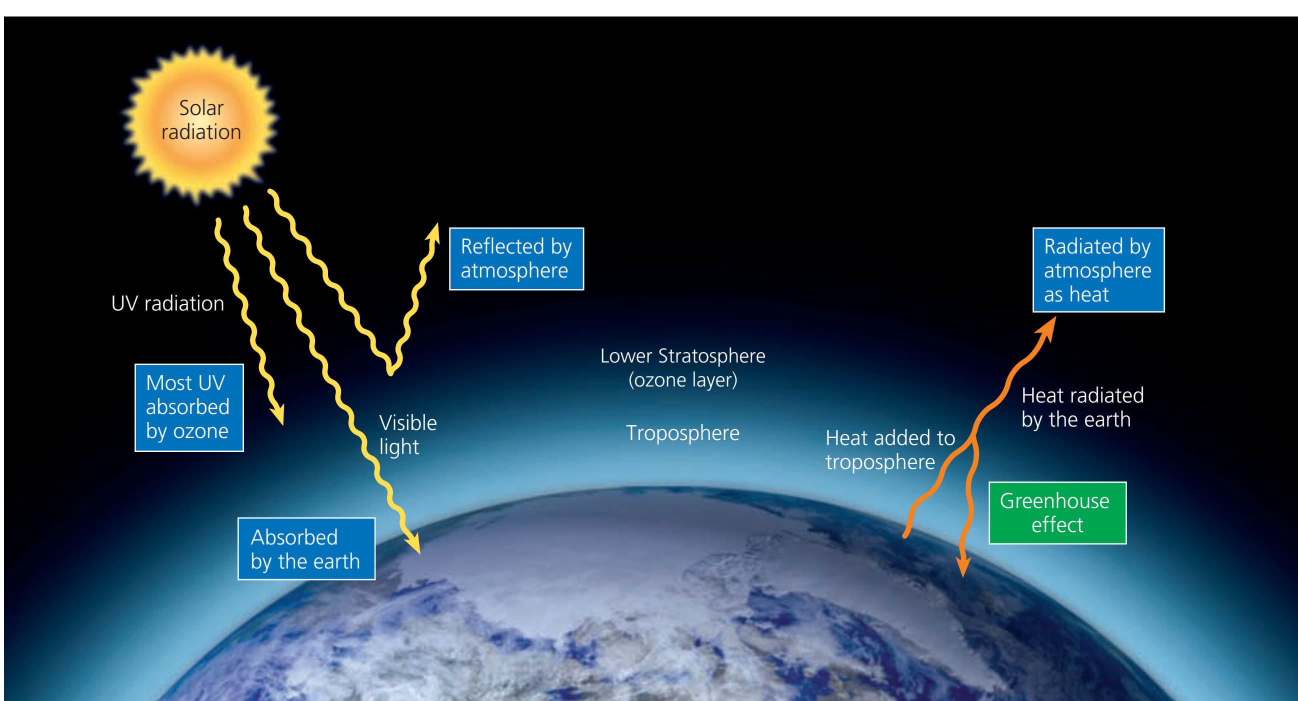
Only a very small amount of this output of energy reaches the earth—a tiny sphere in the vastness of space. This energy reaches the earth in the form of electromagnetic waves, composed mostly of visible light, ultraviolet (UV) radiation, and heat (infrared radiation) (see Figure 2-11, p. 45). Much of this energy is absorbed or reflected back into space by the earth's atmosphere and surface (Figure 3-4).

The solar energy that reaches the atmosphere lights the earth during daytime, warms the air, and evaporates and cycles water through the biosphere. Approximately 1% of this incoming energy goes to generating winds. And green plants, algae, and some types of bacteria use less than 0.1% of it to produce the nutrients they need through photosynthesis, and in turn, to feed animals.

Much of the high-quality solar radiation that reaches our planet is reflected by its atmosphere back into space as lower-quality energy in the form of longer-wavelength infrared radiation. About half of all the solar radiation intercepted by the earth reaches the planet's surface. There it interacts with the earth's land, water, and life and is degraded to lower-quality infrared radiation.

As this infrared radiation travels back from the earth's surface into the lower atmosphere, it encounters greenhouse gases such as water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Some of it flows back into space as heat. The rest of it causes the greenhouse gas molecules to vibrate and release infrared radiation with even longer wavelengths. The vibrating gaseous molecules then have higher kinetic energy, which helps to warm the lower atmosphere and the earth's surface. Without this **natural greenhouse effect**, the earth would be too cold to support the forms of life we find here today (see *The Habitable Planet*, Video 2, at **www.learner.org/resources/series209.html**).

Human activities add greenhouse gases to the atmosphere. For example, burning carbon-containing fuels such as coal, gasoline, and natural gas (see Figure 2-14, p. 46) releases huge amounts of carbon dioxide (CO_2) into the atmosphere. Growing crops and raising livestock release large amounts of methane (CH_4) and nitrous oxide (N_2O). There is considerable and growing evidence that these inputs are intensifying the natural greenhouse effect and the warming of the earth's



CENGAGENOW™ **Active Figure 3-4** High-quality solar energy flows from the sun to the earth. As it interacts with the earth's air, water, soil, and life, it is degraded into lower-quality energy (heat) that flows back into space. *See an animation based on this figure at* CengageNOW.

atmosphere and surface. This, in turn, is projected to alter the earth's climate during this century, as discussed at length in Chapter 19.

CENGAGENOW™ Learn more about the flow of energy—from sun to earth and within the earth's systems—at CengageNOW.

3-2 What Are the Major Components of an Ecosystem?

CONCEPT 3-2 Some organisms produce the nutrients they need, others get the nutrients they need by consuming other organisms, and some recycle nutrients back to producers by decomposing the wastes and remains of other organisms.

Ecologists Study Interactions in Nature

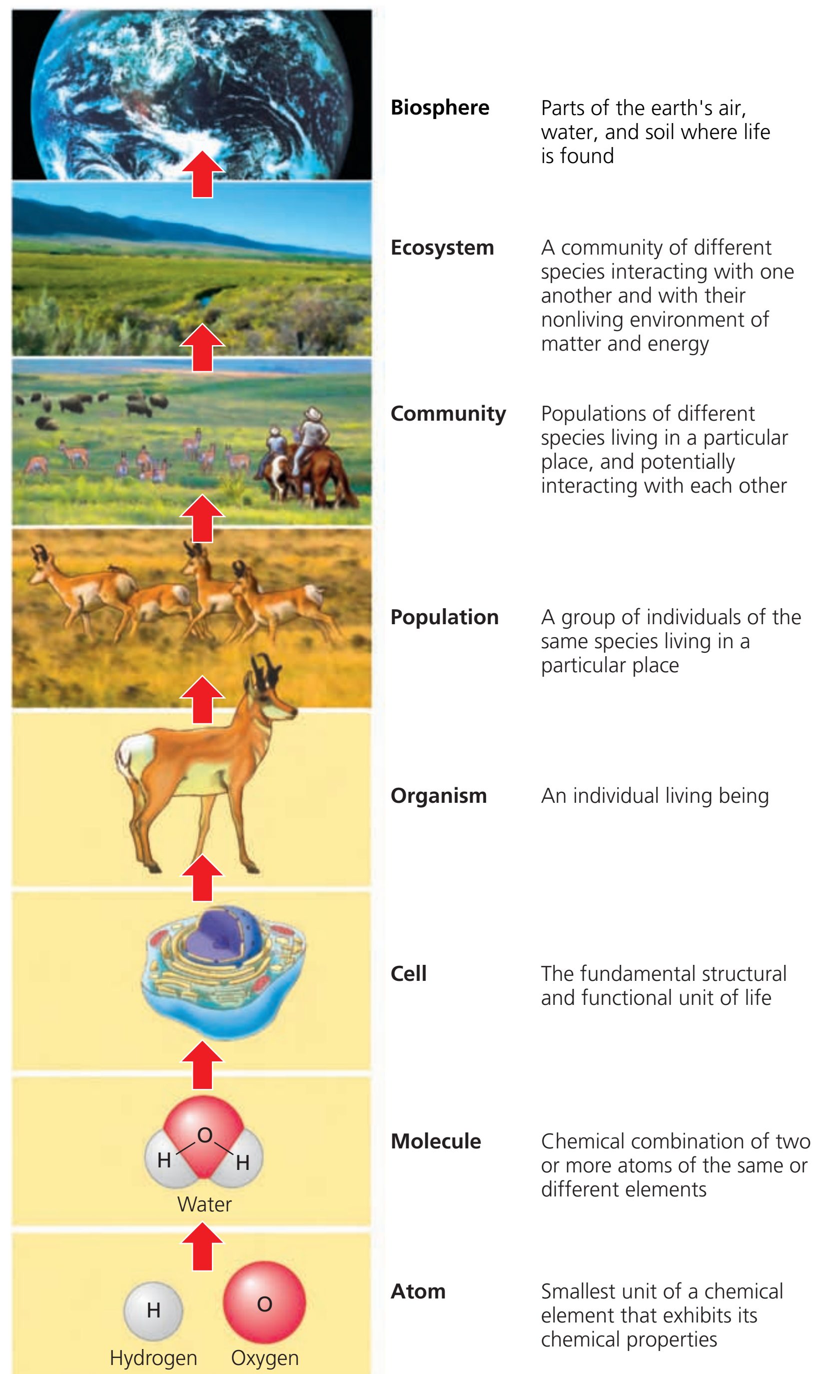
Ecology is the science that focuses on how organisms interact with one another and with their nonliving environment of matter and energy. Scientists classify matter into levels of organization ranging from atoms to galaxies. Ecologists study interactions within and among five of these levels—**organisms**, **populations** (see Photo 2 in the Detailed Contents), **communities**, **ecosystems**, and the **biosphere**, which are illustrated and defined in Figure 3-5.

CENGAGENOW™ Learn more about how the earth's life is organized on five levels in the study of ecology at CengageNOW.

Ecosystems Have Living and Nonliving Components

The biosphere and its ecosystems are made up of living (*biotic*) and nonliving (*abiotic*) components. Examples of nonliving components are water, air, nutrients, rocks, heat, and solar energy. Living components include plants, animals, microbes, and all other organisms. Figure 3-6 is a greatly simplified diagram of some of the living and nonliving components of a terrestrial ecosystem.

Ecologists assign every type of organism in an ecosystem to a *feeding level*, or **trophic level**, depending on its source of food or nutrients. We can broadly classify



CENGAGENOW™ **Active Figure 3-5** This diagram illustrates some levels of the organization of matter in nature. Ecology focuses on the top five of these levels. *See an animation based on this figure at* CengageNOW.

the living organisms that transfer energy and nutrients from one trophic level to another within an ecosystem as producers and consumers.

Producers, sometimes called **autotrophs** (self-feeders), make the nutrients they need from compounds and energy obtained from their environment (**Concept 3-2**). In a process called **photosynthesis**, plants typically capture about 1% of the solar energy that falls on their leaves and use it in combination with carbon dioxide and water to form organic molecules, including energy-rich carbohydrates (such as glucose, $C_6H_{12}O_6$), which store the chemical energy they need. Although hundreds of chemical changes take place during photosynthesis, we can summarize the overall reaction as follows:

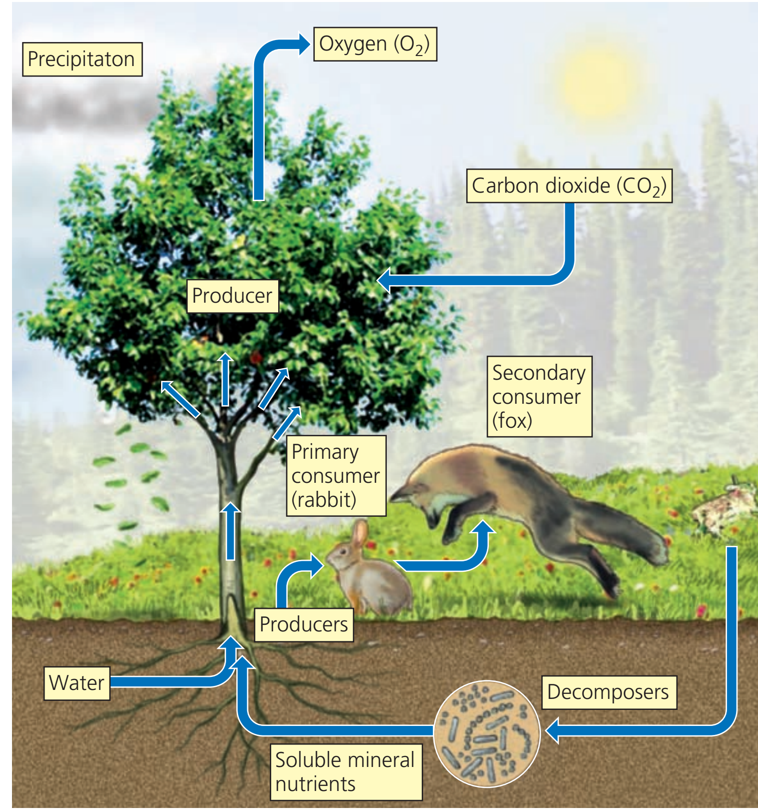
carbon dioxide + water + solar energy → glucose + oxygen

$$6\ CO_2 + 6\ H_2O + \text{solar energy} \rightarrow C_6H_{12}O_6 + 6\ O_2$$

(In Supplement 4, see p. S16 for information on how to balance chemical equations such as this one, and p. S16 for more details on photosynthesis.)

On land, most producers are green plants (Figure 3-7, left). In freshwater and ocean ecosystems, algae and aquatic plants growing near shorelines are the major producers (Figure 3-7, right). In open water, the dominant producers are *phytoplankton*—mostly microscopic organisms that float or drift in the water (see *The Habitable Planet*, Video 3, at **http://www.learner.org/resources/series209.html**).

Through a process called **chemosynthesis**, a few producers, mostly specialized bacteria, can convert simple inorganic compounds from their environment into more complex nutrient compounds without using sunlight. In 1977, scientists discovered communities of bacteria living in the extremely hot water around *hydrothermal vents*—fissures deep under water on the ocean floor through which heat and pressurized gases from the earth's mantle vent to the surface. These bacteria, beyond the reach of sunlight, survive by chemosynthesis and serve as producers for their ecosystems. They draw energy and produce carbohydrates from hydrogen sulfide (H_2S) gas escaping through the hydrothermal



CENGAGENOW™ **Active Figure 3-6** Key living and nonliving components of an ecosystem in a field are shown in this diagram. *See an animation based on this figure at* CengageNOW.

Figure 3-7 Some producers live on land, such as this large tree and other plants in an Amazon rain forest (**Core Case Study**) in Brazil (left). Others, such as green algae (right), live in water.

vents. Most of the earth's producers are photosynthetic organisms that get their energy from the sun and convert it to chemical energy stored in their cells. But chemosynthetic producer organisms in these dark, deep-sea habitats survive on *geothermal energy* from the earth's interior and represent an exception to the first principle of sustainability.

All other organisms in an ecosystem are **consumers**, or **heterotrophs** ("other-feeders"), that cannot produce the nutrients they need through photosynthesis or other processes (**Concept 3-2**). They must obtain their energy-storing organic molecules and many other nutrients by feeding on other organisms (producers or other consumers) or their remains. In other words, all consumers (including humans) depend on producers for their nutrients.

There are several types of consumers. **Primary consumers**, or **herbivores** (plant eaters), are animals that eat mostly green plants. Examples are caterpillars, giraffes (Figure 3-8, left), and *zooplankton*, or tiny sea animals that feed on phytoplankton. **Carnivore**s (meat eaters) are animals that feed on the flesh of other animals. Some carnivores such as spiders, lions (Figure 3-8, right), and most small fishes are **secondary consumers** that feed on the flesh of herbivores. Other carnivores such as tigers, hawks, and killer whales (orcas) are **tertiary** (or higher-level) **consumers** that feed on the flesh of other carnivores. Some of these relationships are shown in Figure 3-6. **Omnivores** such as pigs, rats, and humans eat plants and other animals.

THINKING ABOUT
What You Eat

When you ate your most recent meal, were you an herbivore, a carnivore, or an omnivore?

CENGAGENOW™ Explore the components of ecosystems, how they interact, the roles of bugs and plants, and what a fox will eat at CengageNOW.

Decomposers are consumers that, in the process of obtaining their own nutrients, release nutrients from the wastes or remains of plants and animals and then return those nutrients to the soil, water, and air for reuse by producers (**Concept 3-2**). Most decomposers are bacteria and fungi (Figure 3-9, left). Other consumers, called **detritus feeders**, or **detritivores**, feed on the wastes or dead bodies of other organisms; these wastes are called *detritus* (dee-TRI-tus), which means debris. Examples are earthworms, some insects, and vultures (Figure 3-9, right).

Hordes of detritus feeders and decomposers can transform a fallen tree trunk into wood particles and, finally, into simple inorganic molecules that plants can absorb as nutrients (Figure 3-10). Thus, in natural ecosystems the wastes and dead bodies of organisms serve as resources for other organisms, as the nutrients that make life possible are continuously recycled, in keeping with one of the three **principles of sustainability** (see back cover). As a result, *there is very little waste of nutrients in nature*.

Decomposers and detritus feeders, many of which are microscopic organisms (Science Focus, p. 62), are the key to nutrient cycling. Without them, the planet would be overwhelmed with plant litter, animal wastes, dead animal bodies, and garbage.

Producers, consumers, and decomposers use the chemical energy stored in glucose and other organic compounds to fuel their life processes. In most cells, this energy is released by **aerobic respiration**, which uses oxygen to convert glucose (or other organic nutrient

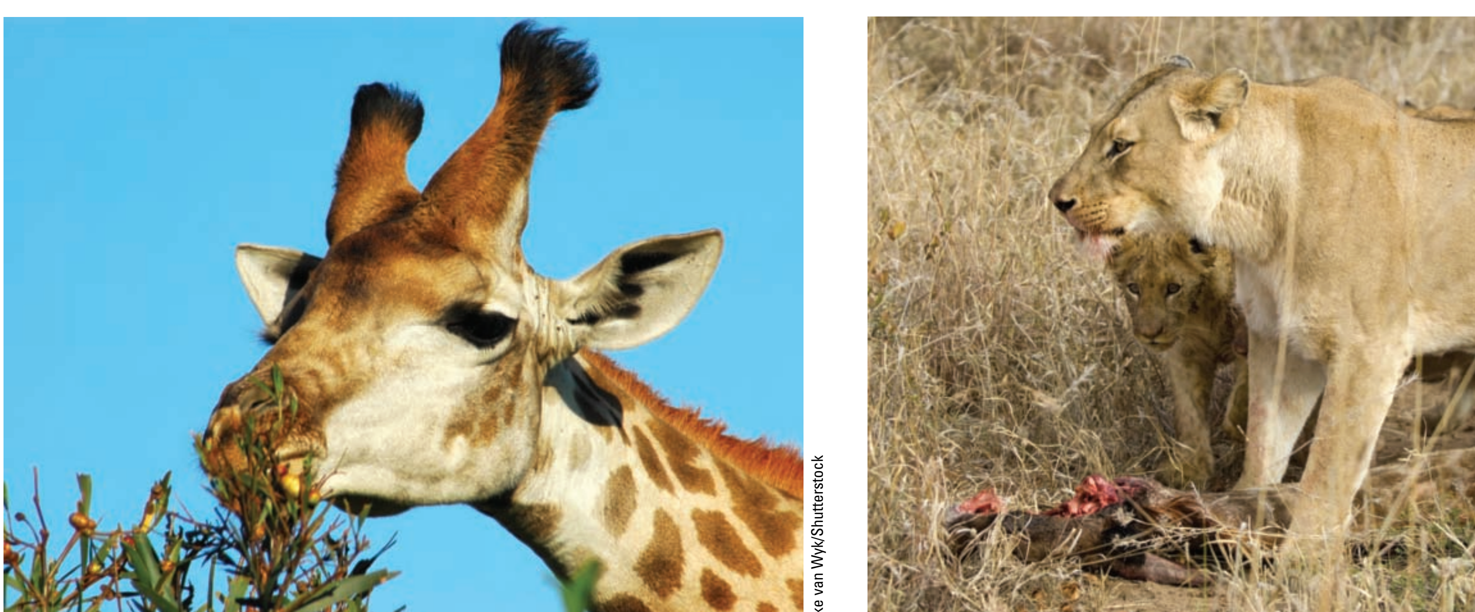


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Figure 3-8 The giraffe (left) feeding on the leaves of a tree is an herbivore. The lions (right) are carnivores feeding on the dead body of a giraffe that they have killed.

Arie v.d. Wolde/Shutterstock

javaman/Shutterstock

Figure 3-9 This saddle fungus feeding on a dead tree (left) is a decomposer. Three vultures and two Marabou storks (right), classified as detritivores, are eating the carcass of an animal that was killed by other animals.

molecules) back into carbon dioxide and water. The net effect of the hundreds of steps in this complex process is represented by the following chemical reaction:

glucose + oxygen → carbon dioxide + water + energy

$$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O + \text{energy}$$

Although the detailed steps differ, the net chemical change for aerobic respiration is the opposite of that for photosynthesis.

Some decomposers get the energy they need by breaking down glucose (or other organic compounds) in the *absence* of oxygen. This form of cellular respiration is called **anaerobic respiration,** or **fermentation**. Instead of carbon dioxide and water, the end products of this process are compounds such as methane gas (CH_4, the main component of natural gas), ethyl alcohol (C_2H_6O), acetic acid ($C_2H_4O_2$, the key component of vinegar), and hydrogen sulfide (H_2S, when sulfur compounds are broken down). Note that all organisms get

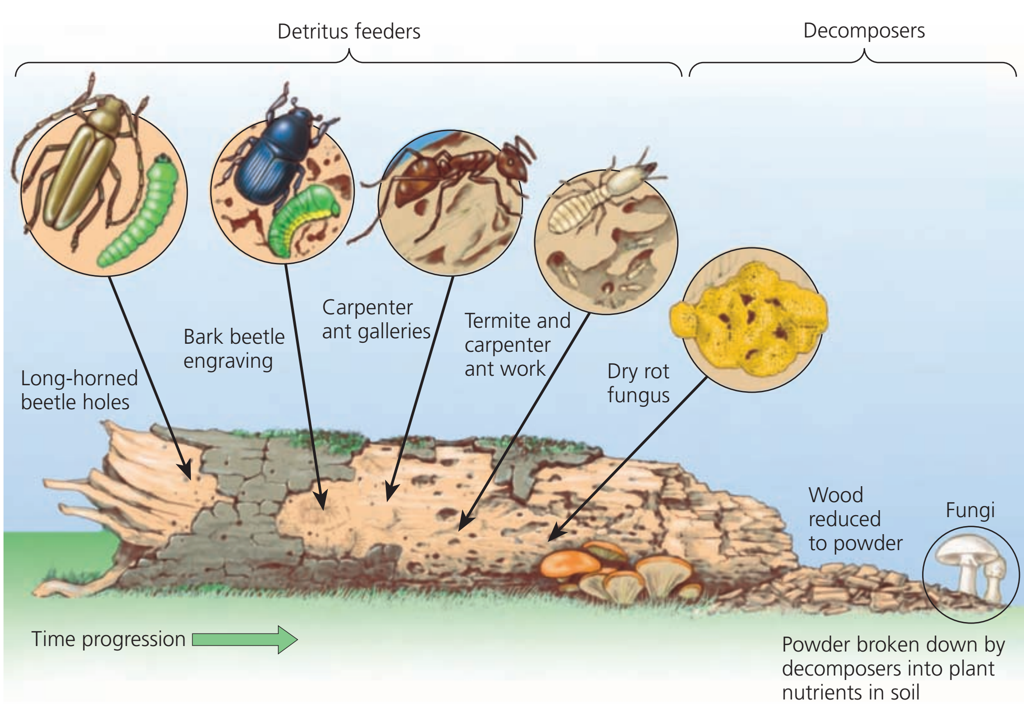


Figure 3-10 Various detritivores and decomposers (mostly fungi and bacteria) can "feed on" or digest parts of a log and eventually convert its complex organic chemicals into simpler inorganic nutrients that can be taken up by producers.

SCIENCE FOCUS

Many of the World's Most Important Organisms Are Invisible to Us

They are everywhere. Billions can be found inside your body, on your body, in a handful of soil, and in a cup of ocean water.

These mostly invisible rulers of the earth are *microbes*, or *microorganisms*, catchall terms for many thousands of species of bacteria, protozoa, fungi, and floating phytoplankton—most too small to be seen with the naked eye.

Microbes do not get the respect they deserve. Most of us view them primarily as threats to our health in the form of infectious bacteria or "germs," fungi that cause athlete's foot and other skin diseases, and protozoa that cause diseases such as malaria. But these harmful microbes are in the minority.

We are alive because of multitudes of microbes toiling away completely out of sight. Bacteria in our intestinal tracts help break down the food we eat, and microbes in our noses help prevent harmful bacteria from reaching our lungs.

Bacteria and other microbes help to purify the water we drink by breaking down plant and animal wastes that may be in the water. Bacteria and fungi (such as yeast) also help to produce foods such as bread, cheese, yogurt, soy sauce, beer, and wine. Bacteria and fungi in the soil decompose organic wastes into nutrients that can be taken up by plants that humans and most other animals eat. Without these tiny creatures, we would go hungry and be up to our necks in waste matter.

Microbes, particularly phytoplankton in the ocean, provide much of the planet's oxygen, and help to regulate the earth's temperature by removing some of the carbon dioxide produced when we burn coal, natural gas, and gasoline (see *The Habitable Planet*, Video 3, at www.learner.org/resources/series209.html). Scientists are working on using microbes to develop new medicines and fuels. Genetic engineers are inserting genetic material into existing microorganisms to convert them to microbes that can be used to clean up polluted water and soils.

Some microorganisms assist us in controlling diseases that affect plants and controlling populations of insect species that attack our food crops. Relying more on these microbes for pest control could reduce the use of potentially harmful chemical pesticides. In other words, microbes are a vital part of the earth's natural capital.

Critical Thinking

What are three advantages that microbes have over humans for thriving in the world?

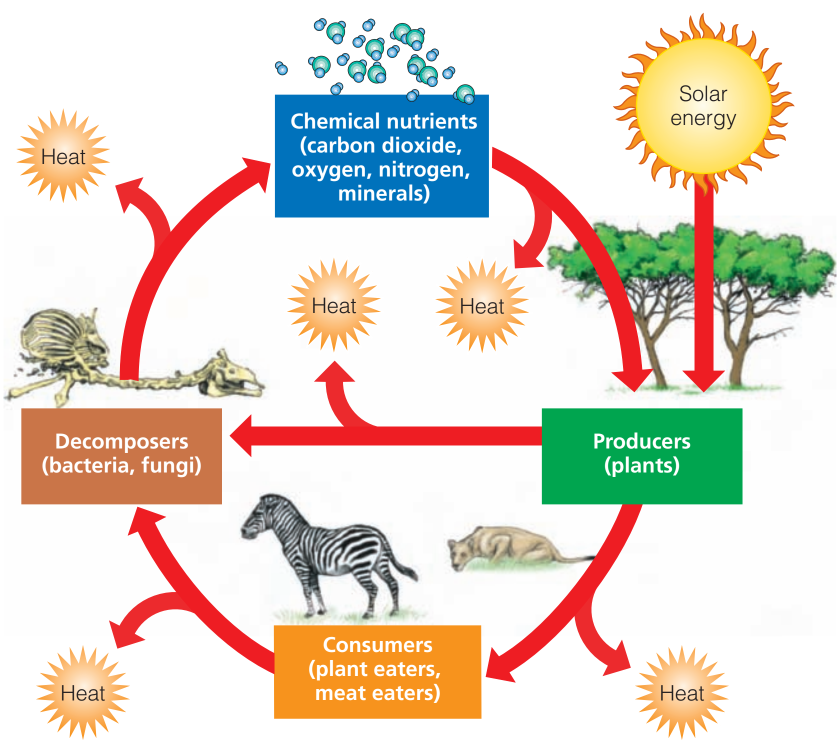
their energy from aerobic or anaerobic respiration but only plants carry out photosynthesis.

To summarize, ecosystems and the biosphere are sustained through a combination of *one-way energy flow* from the sun through these systems and the *nutrient cycling* of key materials within them (**Concept 3-1B**)—in keeping with two of the **principles of sustainability** (Figure 3-11).

THINKING ABOUT
Chemical Cycling and the Law of Conservation of Matter

Explain the relationship between chemical cycling in ecosystems and the law of conservation of matter (Chapter 2, p. 43).

Let us look at the flow of energy and the cycling of chemicals in ecosystems in more detail.



CENGAGENOW™ **Active Figure 3-11** **Natural capital:** This diagram shows the main structural components of an ecosystem (energy, chemicals, and organisms). Nutrient cycling and the flow of energy—first from the sun, then through organisms, and finally into the environment as low-quality heat—link these components. *See an animation based on this figure at* CengageNOW.

3-3 What Happens to Energy in an Ecosystem?

▶ **CONCEPT 3-3 As energy flows through ecosystems in food chains and webs, the amount of chemical energy available to organisms at each successive feeding level decreases.**

Energy Flows through Ecosystems in Food Chains and Food Webs

The chemical energy stored as nutrients in the bodies and wastes of organisms flows through ecosystems from one trophic (feeding) level to another. For example, a plant uses solar energy to store chemical energy in a leaf. A caterpillar eats the leaf, a robin eats the caterpillar, and a hawk eats the robin. Decomposers and detritus feeders consume the wastes and remains of all members of this and other food chains and return their nutrients to the soil for reuse by producers.

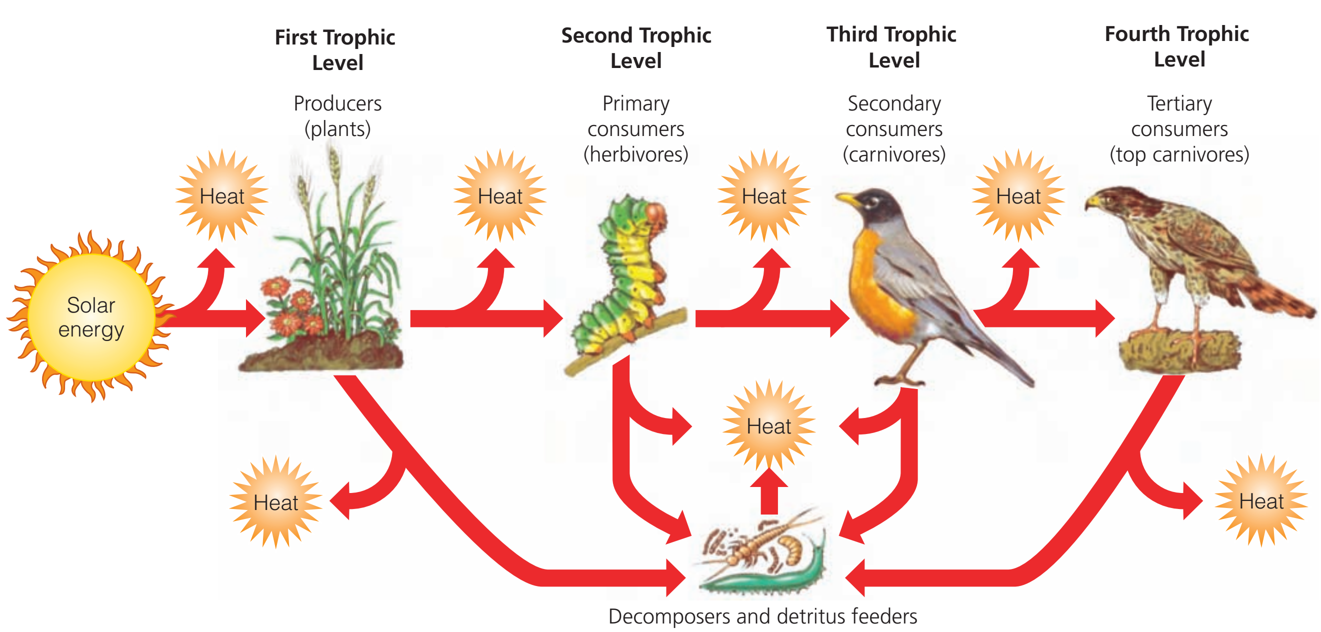
A sequence of organisms, each of which serves as a source of food or energy for the next, is called a **food chain**. It determines how chemical energy and nutrients move along the same pathways from one organism to another through the trophic levels in an ecosystem—primarily through photosynthesis, feeding, and decomposition—as shown in Figure 3-12. Every use and transfer of energy by organisms involves a loss of some degraded high-quality energy to the environment as heat.

In natural ecosystems, most consumers feed on more than one type of organism, and most organisms are eaten or decomposed by more than one type of consumer. Because of this, organisms in most ecosystems form a complex network of interconnected food chains called a **food web** (Figure 3-13, p. 64). We can assign trophic levels in food webs just as we can in food chains. Food chains and webs show how producers, consumers, and decomposers are connected to one another as energy flows through trophic levels in an ecosystem.

Usable Energy Decreases with Each Link in a Food Chain or Web

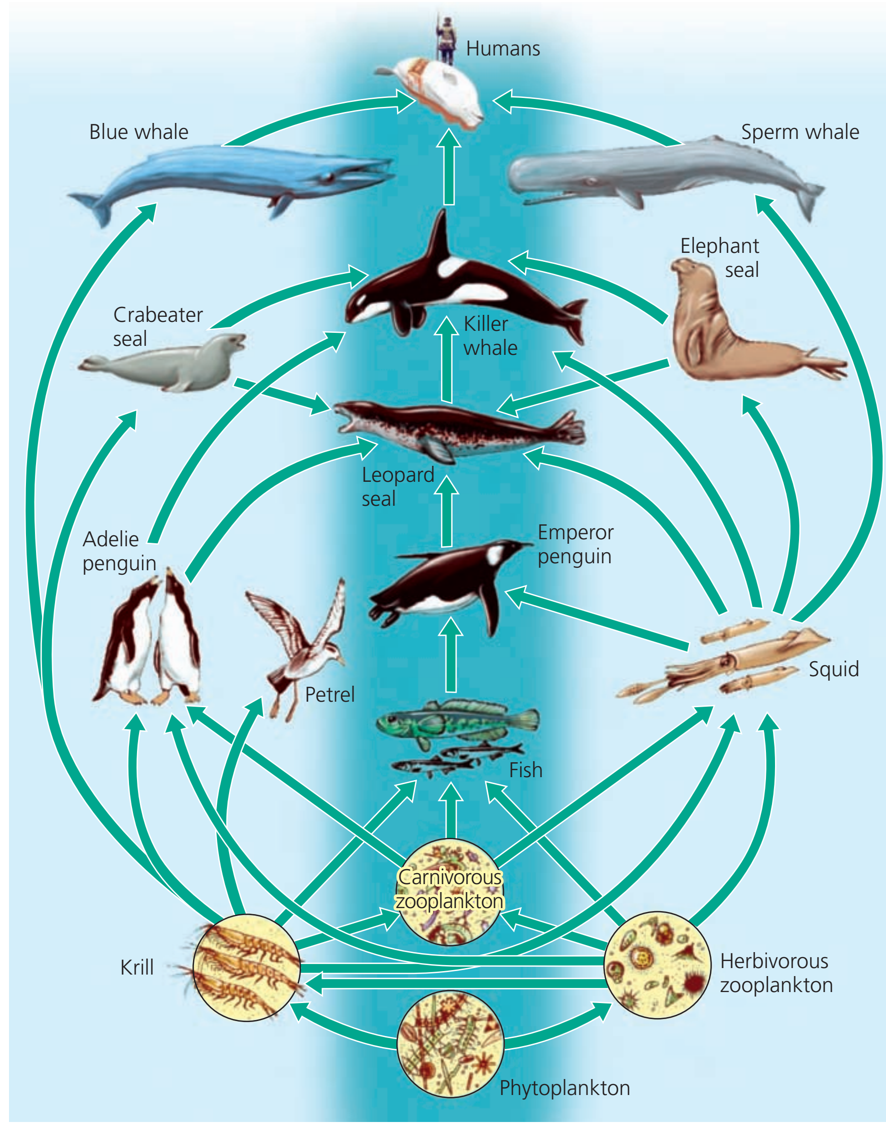
Each trophic level in a food chain or web contains a certain amount of **biomass**, the dry weight of all organic matter contained in its organisms. In a food chain or web, chemical energy stored in biomass is transferred from one trophic level to another.

As a result of the second law of thermodynamics, energy transfer through food chains and food webs is not very efficient because, with each transfer, some usable chemical energy is degraded and lost to the environment as low-quality heat. In other words, as energy flows through ecosystems in food chains and webs, there is a decrease in the amount of high-quality chemical energy available to organisms at each succeeding feeding level (**Concept 3-3**).



CENGAGENOW™ **Active Figure 3-12** This diagram illustrates a *food chain.* The arrows show how the chemical energy in nutrients flows through various *trophic levels* in energy transfers; most of the energy is degraded to heat, in accordance with the second law of thermodynamics (see Chapter 2, p. 47). *See an animation based on this figure at* CengageNOW. **Question:** Think about what you ate for breakfast. At what level or levels on a food chain were you eating?

CENGAGENOW™ **Active Figure 3-13** This diagram illustrates a greatly simplified *food web* in the southern hemisphere. The shaded middle area shows a simple food chain. Its participants interact in feeding relationships to form the more complex food web shown here. Many more participants in the web, including an array of decomposer and detritus feeder organisms, are not shown here. *See an animation based on this figure at* CengageNOW. **Question:** Can you imagine a food web of which you are a part? Try drawing a simple diagram of it.



The percentage of usable chemical energy transferred as biomass from one trophic level to the next varies, depending on what types of species and ecosystems are involved. The more trophic levels there are in a food chain or web, the greater is the cumulative loss of usable chemical energy as it flows through the trophic levels. The **pyramid of energy flow** in Figure 3-14 illustrates this energy loss for a simple food chain, assuming a 90% energy loss with each transfer.

THINKING ABOUT

Energy Flow and the Second Law of Thermodynamics

Explain the relationship between the second law of thermodynamics (see Chapter 2, p. 47) and the flow of energy through a food chain or web.

The large loss in chemical energy between successive trophic levels explains why food chains and webs rarely have more than four or five trophic levels. In most cases, too little chemical energy is left after four or five transfers to support organisms feeding at these high trophic levels. Thus, there are far fewer tigers (Figure 3-3c) in tropical rain forests (**Core Case Study**) and other areas than there are insects.

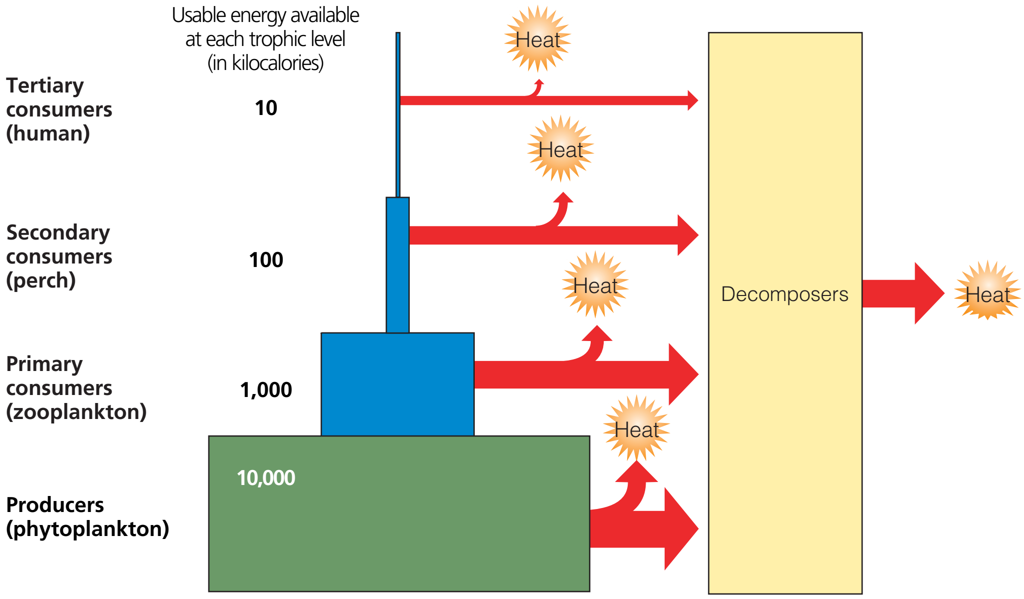
CORE CASE STUDY

CONNECTIONS

Energy Flow and Feeding People

Energy flow pyramids explain why the earth could support more people if they all ate at lower trophic levels by consuming grains, vegetables, and fruits directly rather than passing such crops through another trophic level and eating grain eaters or herbivores such as cattle. About two-thirds of the world's people survive primarily by eating wheat, rice, and corn at the first trophic level because most of them cannot afford to eat much meat.

CENGAGENOW™ Examine how energy flows among organisms at different trophic levels and through food webs in tropical rain forests, prairies, and other ecosystems at CengageNOW.



CENGAGENOW™ **Active Figure 3-14** This model is a generalized *pyramid of energy flow* that shows the decrease in usable chemical energy available at each succeeding trophic level in a food chain or web. The model assumes that with each transfer from one trophic level to another, there is a 90% loss in usable energy to the environment in the form of low-quality heat. (Calories and joules are used to measure energy. 1 kilocalorie = 1,000 calories = 4,184 joules.) *See an animation based on this figure at* CengageNOW. **Question:** Why is a vegetarian diet more energy efficient than a meat-based diet?

Some Ecosystems Produce Plant Matter Faster Than Others Do

The amount, or mass, of living organic material (biomass) that a particular ecosystem can support is determined by how much solar energy its producers can capture and store as chemical energy and by how rapidly they can do so. **Gross primary productivity** (**GPP**) is the *rate* at which an ecosystem's producers (usually plants) convert solar energy into chemical energy in the form of biomass found in their tissues. It is usually measured in terms of energy production per unit area over a given time span, such as kilocalories per square meter per year (kcal/m^2/yr).

To stay alive, grow, and reproduce, producers must use some of the chemical energy stored in the biomass they make for their own respiration. **Net primary productivity** (**NPP**) is the *rate* at which producers use photosynthesis to produce and store chemical energy *minus* the *rate* at which they use some of this stored chemical energy through aerobic respiration. NPP measures how fast producers can make the chemical energy that is stored in their tissues and that is potentially available to other organisms (consumers) in an ecosystem.

Primary productivity is similar to the *rate* at which you make money, or the number of dollars you earn per year. *Net primary productivity* is similar to the amount of money earned per year that you can spend after subtracting your work expenses such as transportation, clothes, food, and supplies.

Ecosystems and aquatic life zones differ in their NPP as illustrated in Figure 3-15 (p. 66). Despite its low NPP, the open ocean produces more of the earth's biomass per year than any other ecosystem or life zone, simply because there is so much open ocean containing huge numbers of producers such as tiny phytoplankon.

On land, tropical rain forests have a very high net primary productivity because of their large number and variety of producer trees and other plants (Figure 3-7, left). When such forests are cleared (**Core Case Study**, Figure 3-1, right) or burned to plant crops (see Figure 1-6, p. 10) or graze cattle, there is a sharp drop in the net primary productivity and a loss of many of the diverse array of plant and animal species.

CORE CASE STUDY

As we have seen, producers are the source of all nutrients in an ecosystem that are available for the producers themselves and for the consumers and decomposers that feed on them. Only the biomass represented by NPP is available as nutrients for consumers, and they use only a portion of this amount. Thus, *the planet's NPP ultimately limits the number of consumers (including humans) that can survive on the earth.* This is an important lesson from nature.

CONNECTIONS

Humans and Earth's Net Primary Productivity

Peter Vitousek, Stuart Rojstaczer, and other ecologists estimate that humans now use, waste, or destroy 10–55% of the earth's total potential NPP. This is a remarkably high value, considering that the human population makes up less than 1% of the total biomass of all of the earth's consumers that depend on producers for their nutrients.

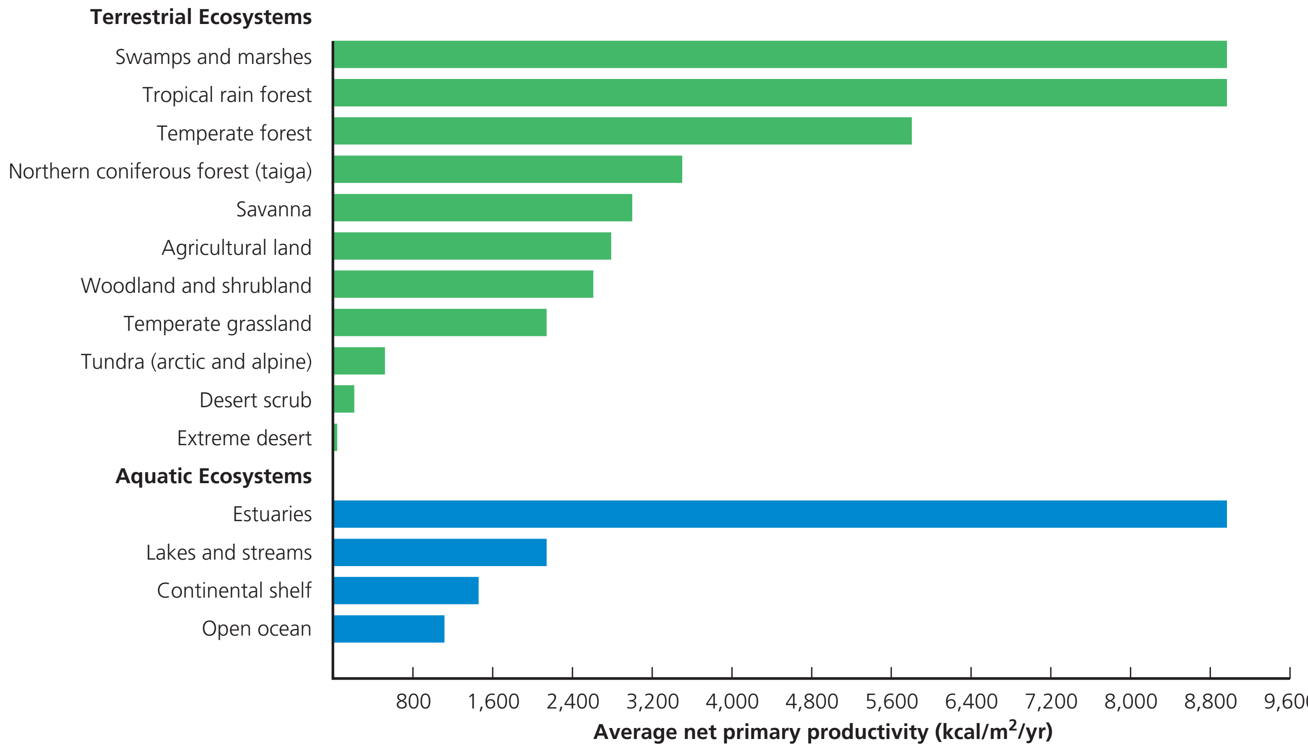


Figure 3-15 The estimated annual average *net primary productivity* in major life zones and ecosystems is expressed in this graph as kilocalories of energy produced per square meter per year (kcal/m^2/yr). **Question:** What are nature's three most productive and three least productive systems? (Data from R. H. Whittaker, *Communities and Ecosystems*, 2nd ed., New York: Macmillan, 1975)

3-4 What Happens to Matter in an Ecosystem?

▶ **CONCEPT 3-4 Matter, in the form of nutrients, cycles within and among ecosystems and the biosphere, and human activities are altering these chemical cycles.**

Nutrients Cycle within and among Ecosystems

The elements and compounds that make up nutrients move continually through air, water, soil, rock, and living organisms within ecosystems, as well as in the biosphere in cycles called **biogeochemical cycles** (literally, life-earth-chemical cycles), or **nutrient cycles**. This is in keeping with one of the three **principles of sustainability** (see back cover). These cycles, driven directly or indirectly by incoming solar energy and the earth's gravity, include the hydrologic (water), carbon, nitrogen, phosphorus, and sulfur cycles. They are an important component of the earth's natural capital (see Figure 1-4, p. 9), and human activities are altering them (**Concept 3-4**).

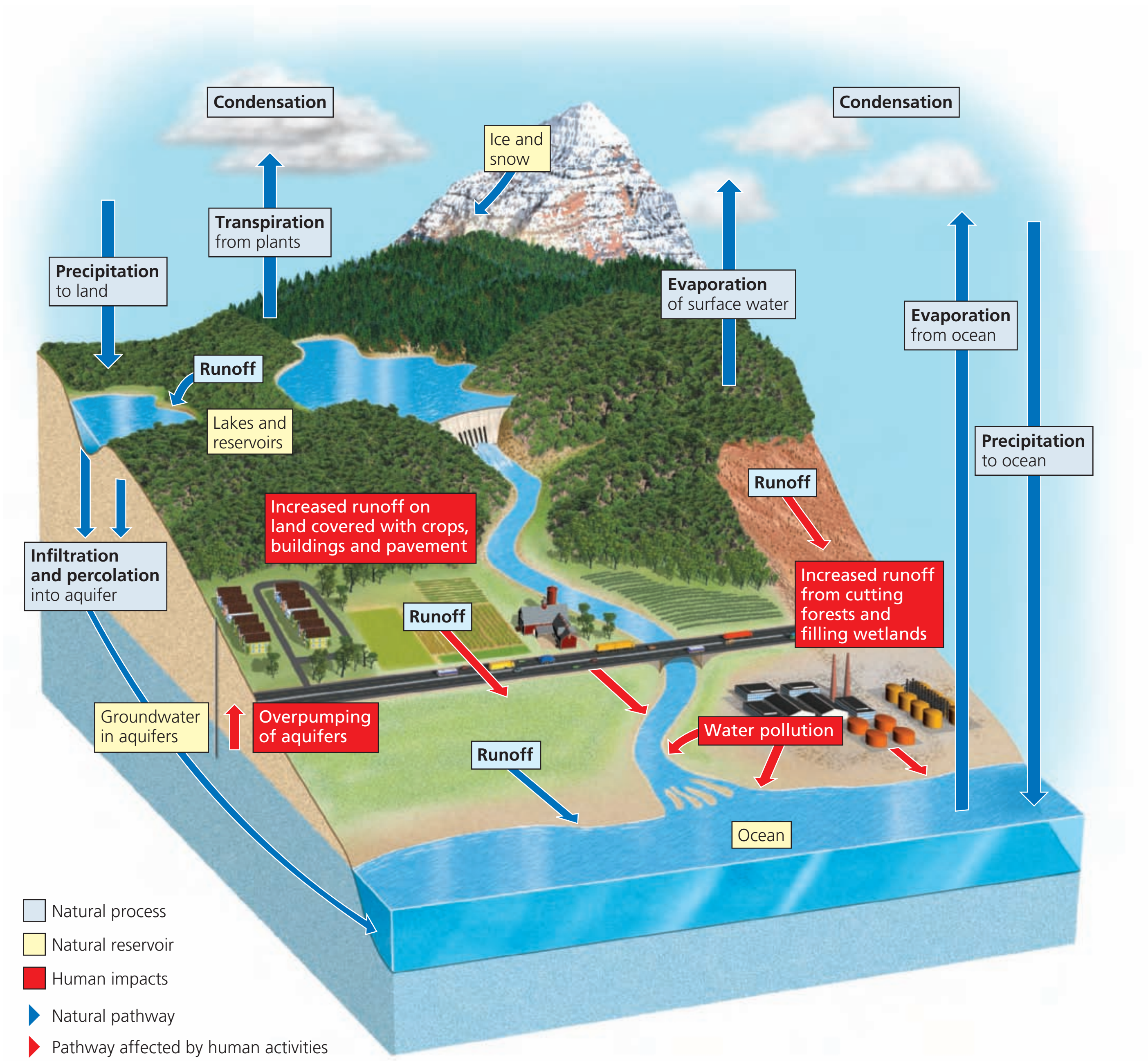
As nutrients move through their biogeochemical cycles, they may accumulate in certain portions of the cycles and remain there for different periods of time. These temporary storage sites such as the atmosphere, the oceans and other bodies of water, and underground deposits are called *reservoirs*.

CONNECTIONS
Nutrient Cycles and Life

Nutrient cycles connect past, present, and future forms of life. Some of the carbon atoms in your skin may once have been part of an oak leaf, a dinosaur's skin, or a layer of limestone rock. Your grandmother, rock star Bono, or a hunter–gatherer who lived 25,000 years ago may have inhaled some of the nitrogen molecules you just inhaled.

The Water Cycle

Water is an amazing substance (Science Focus, p. 68) that is necessary for life on the earth. The **hydrologic cycle**, or **water cycle**, collects, purifies, and distributes the earth's fixed supply of water, as shown in Figure 3-16.



CENGAGENOW™ **Active Figure 3-16 Natural capital:** This diagram is a simplified model of the *water cycle*, or *hydrologic cycle*, in which water circulates in various physical forms within the biosphere. Major harmful impacts of human activities are shown by the red arrows and boxes. *See an animation based on this figure at* CengageNOW. **Question:** What are three ways in which your lifestyle directly or indirectly affects the hydrologic cycle?

The water cycle is powered by energy from the sun and involves three major processes—evaporation, precipitation, and transpiration. Incoming solar energy causes *evaporation* of water from the earth's oceans, lakes, rivers, and soil. Evaporation changes liquid water into water vapor in the atmosphere, and gravity draws the water back to the earth's surface as *precipitation* (rain, snow, sleet, and dew). Over land, about 90% of the water that reaches the atmosphere evaporates from the surfaces of plants, through a process called *transpiration*, and from the soil.

Water returning to the earth's surface as precipitation takes various paths. Most precipitation falling on terrestrial ecosystems becomes *surface runoff*. This water flows into streams, which eventually carry water back to lakes and oceans, from which it can evaporate to repeat the cycle. Some surface water also seeps into the upper layers of soils where it is used by plants, and some evaporates from the soils back into the atmosphere.

Some precipitation is converted to ice that is stored in *glaciers* (Figure 3-17, p. 68), usually for long periods of time. Some precipitation sinks through soil and

SCIENCE FOCUS

Water's Unique Properties

Water is a remarkable substance with a unique combination of properties:

- *Forces of attraction*, called *hydrogen bonds* (see Figure 6, p. S13, in Supplement 4), *hold water molecules together*—the major factor determining water's distinctive properties.
- *Water exists as a liquid over a wide temperature range because of the forces of attraction between its molecules.* Without water's high boiling point, the oceans would have evaporated long ago.
- *Liquid water changes temperature slowly because it can store a large amount of heat without a large change in its own temperature.* This high heat storage capacity helps protect living organisms from temperature changes, moderates the earth's climate, and makes water an excellent coolant for car engines and power plants.
- *It takes a large amount of energy to evaporate water because of the forces of attraction between its molecules.* Water absorbs large amounts of heat as it changes into water vapor and releases this heat as the vapor condenses back to liquid water. This helps to distribute heat throughout the world and to determine regional and local climates. It also makes evaporation a cooling process—explaining why you feel cooler when perspiration evaporates from your skin.
- *Liquid water can dissolve a variety of compounds* (see Figure 3, p. S12, in Supplement 4). It carries dissolved nutrients into the tissues of living organisms, flushes waste products out of those tissues, serves as an all-purpose cleanser, and helps to remove and dilute the water-soluble wastes of civilization. This property also means that water-soluble wastes can easily pollute water.
- *Water filters out wavelengths of the sun's ultraviolet radiation that would harm some aquatic organisms.* However, down to a certain depth, it is transparent to sunlight needed for photosynthesis.
- *The forces of attraction between water molecules also allow liquid water to adhere to a solid surface.* This enables narrow columns of water to rise through a plant from its roots to its leaves (a process called *capillary action*).
- *Unlike most liquids, water expands when it freezes.* This means that ice floats on water because it has a lower density (mass per unit of volume) than liquid water has. Otherwise, lakes and streams in cold climates would freeze solid, losing most of their aquatic life. Because water expands upon freezing, it can break pipes, crack a car's engine block (if it doesn't contain antifreeze), break up pavement, and fracture rocks.

Critical Thinking

What are three ways in which your life would be different if there were no special forces of attraction (hydrogen bonds) between water molecules?

permeable rock formations to underground layers of rock, sand, and gravel called *aquifers*, where it is stored as *groundwater*.

A small amount of the earth's water ends up in the living components of ecosystems. As producers, plants absorb some of this water through their roots, most of which evaporates from plant leaves back into the atmosphere during transpiration; some of the water combines with carbon dioxide during photosynthesis to produce high-energy organic compounds such as carbohydrates. Eventually these compounds are broken down in plant cells, which release the water back into the environment. Consumers get their water from their food and by drinking it.

MaxFX/Shutterstock

Figure 3-17 Hubbard glacier in the U.S. state of Alaska stores water for a long time as part of the hydrologic cycle. However, mostly because of recent atmospheric warming, many of the world's glaciers are slowly melting.

Can Balcioglu/Shutterstock

Figure 3-18 Water flowing over the earth's surfaces for millions of years played a major role in the formation of the Antelope Canyon in the U.S. state of Arizona.

Because water dissolves many nutrient compounds, it is a major medium for transporting nutrients within and between ecosystems. Water is also the primary sculptor of the earth's landscape as it flows over and wears down rock over millions of years (Figure 3-18).

Throughout the hydrologic cycle, many natural processes purify water. Evaporation and subsequent precipitation act as a natural distillation process that removes impurities dissolved in water. Water flowing above ground through streams and lakes, and below ground in aquifers is naturally filtered and partially purified by chemical and biological processes—mostly by the actions of decomposer bacteria—as long as these natural processes are not overloaded. Thus, *the hydrologic cycle can be viewed as a cycle of natural renewal of water quality.*

Only about 0.024% of the earth's vast water supply is available to humans and other species as liquid freshwater in accessible groundwater deposits and in lakes, rivers, and streams. The rest is too salty for us to use, is stored as ice, or is too deep underground to extract at affordable prices using current technology.

We alter the water cycle in three major ways (see the red arrows and boxes in Figure 3-16). *First,* we withdraw large quantities of freshwater from streams, lakes, and aquifers sometimes at rates faster than nature can replace it.

Second, we clear vegetation from land for agriculture, mining, road building, and other activities, and cover much of the land with buildings, concrete, and asphalt. This increases runoff, reduces infiltration that would normally recharge groundwater supplies, accelerates topsoil erosion, and increases the risk of flooding.

CONNECTIONS

Clearing a Rain Forest Can Affect Local Weather

CORE CASE STUDY

Clearing vegetation (see Figure 1-6, p. 10) can alter weather patterns by reducing transpiration, especially in dense tropical rain forests (**Core Case Study** and Figure 3-1). Because so many plants in such a forest transpire water into the atmosphere, vegetation is the primary source of local rainfall. Cutting down the forest raises ground temperatures (because it reduces shade) and can reduce local rainfall so much that the forest cannot grow back. When such an *ecological tipping point* is reached, these biologically diverse forests are converted into much less diverse tropical grasslands.

Third, we also increase flooding when we drain and fill wetlands for farming and urban development. Left undisturbed, wetlands provide the natural service of flood control, acting like sponges to absorb and hold overflows of water from drenching rains or rapidly melting snow.

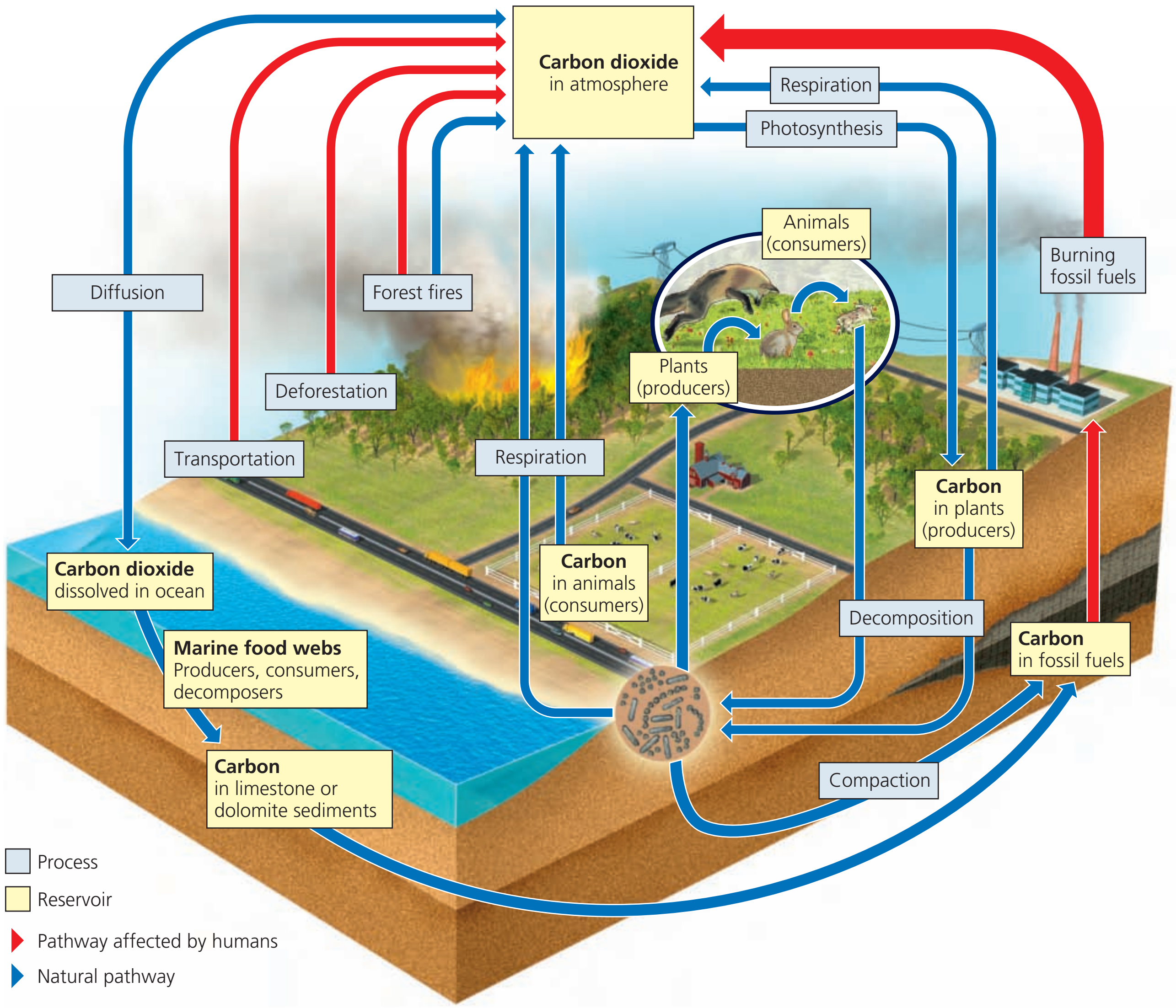
The Carbon Cycle

Carbon is the basic building block of the carbohydrates, fats, proteins, DNA, and other organic compounds necessary for life. Various compounds of carbon circulate through the biosphere, the atmosphere, and parts of the hydrosphere, in the **carbon cycle** shown in Figure 3-19 (p. 70).

The carbon cycle is based on carbon dioxide (CO_2) gas, which makes up 0.039% of the volume of the earth's atmosphere and is also dissolved in water. Carbon dioxide (along with water vapor in the water cycle) is a key component of the atmosphere's thermostat. If the carbon cycle removes too much CO_2 from the atmosphere, the atmosphere will cool, and if it generates too much CO_2, the atmosphere will get warmer. Thus, even slight changes in this cycle caused by natural or human factors can affect the earth's climate and ultimately help to determine the types of life that can exist in various places.

Terrestrial producers remove CO_2 from the atmosphere and aquatic producers remove it from the water. (See *The Habitable Planet*, Video 3, at **www.learner.org/resources/series209.html** for information on the effects of phytoplankton on the carbon cycle and the earth's climate.) These producers then use photosynthesis to convert CO_2 into complex carbohydrates such as glucose ($C_6H_{12}O_6$).

The cells in oxygen-consuming producers, consumers, and decomposers then carry out aerobic respiration.



CENGAGENOW™ **Active Figure 3-19** **Natural capital:** This simplified model illustrates the circulation of various chemical forms of carbon in the global *carbon cycle*, with major harmful impacts of human activities shown by the red arrows. *See an animation based on this figure at* CengageNOW. **Question:** What are three ways in which you directly or indirectly affect the carbon cycle?

This process breaks down glucose and other complex organic compounds to produce CO_2 in the atmosphere and water for reuse by producers. This linkage between *photosynthesis* in producers and *aerobic respiration* in producers, consumers, and decomposers circulates carbon in the biosphere. Oxygen and hydrogen—the other elements in carbohydrates—cycle almost in step with carbon.

Some carbon atoms take a long time to recycle. Decomposers release the carbon stored in the bodies of dead organisms on land back into the air as CO_2. However, in water, decomposers release carbon that can be stored as insoluble carbonates in bottom sediment. Indeed, marine sediments are the earth's largest store of carbon. Over millions of years, buried deposits of dead plant matter and bacteria are compressed between layers of sediment, where high pressure and heat convert them to carbon-containing *fossil fuels* such as coal, oil, and natural gas (see Figure 2-14, p. 46, and Figure 3-19). This carbon is not released to the atmosphere as CO_2 for recycling until these fuels are extracted and burned, or until long-term geological processes expose these deposits to air. In only a few hundred years, we have extracted and burned huge quantities of fossil fuels that took millions of years to form. This is why, on a human time scale, fossil fuels are nonrenewable resources.

We are altering the carbon cycle (see the red arrows in Figure 3-19) mostly by adding large amounts of carbon dioxide to the atmosphere (see Figure 14, p. S63, Supplement 9) when we burn carbon-containing fossil fuels (especially coal to produce electricity). We also alter the cycle by clearing carbon-absorbing vegetation from forests (especially tropical forests, Figures 3-1, right and 1-6, p. 10) faster than it can grow back (**Core Case Study**). Human activities are altering CORE CASE STUDY both the rate of energy flow and the cycling of nutrients within the carbon cycle (Figure 3-11). In other words, humanity has a large and growing *carbon footprint* that makes up a significant part of our overall ecological footprint (see Figure 1-13, p. 16).

Computer models of the earth's climate systems indicate that increased concentrations of atmospheric CO_2 (see Figure 14, p. S63, Supplement 9) and other greenhouse gases such as methane (CH_4) are very likely to warm the atmosphere by enhancing the planet's natural greenhouse effect, and thus to change the earth's climate during this century, as discussed in Chapter 19.

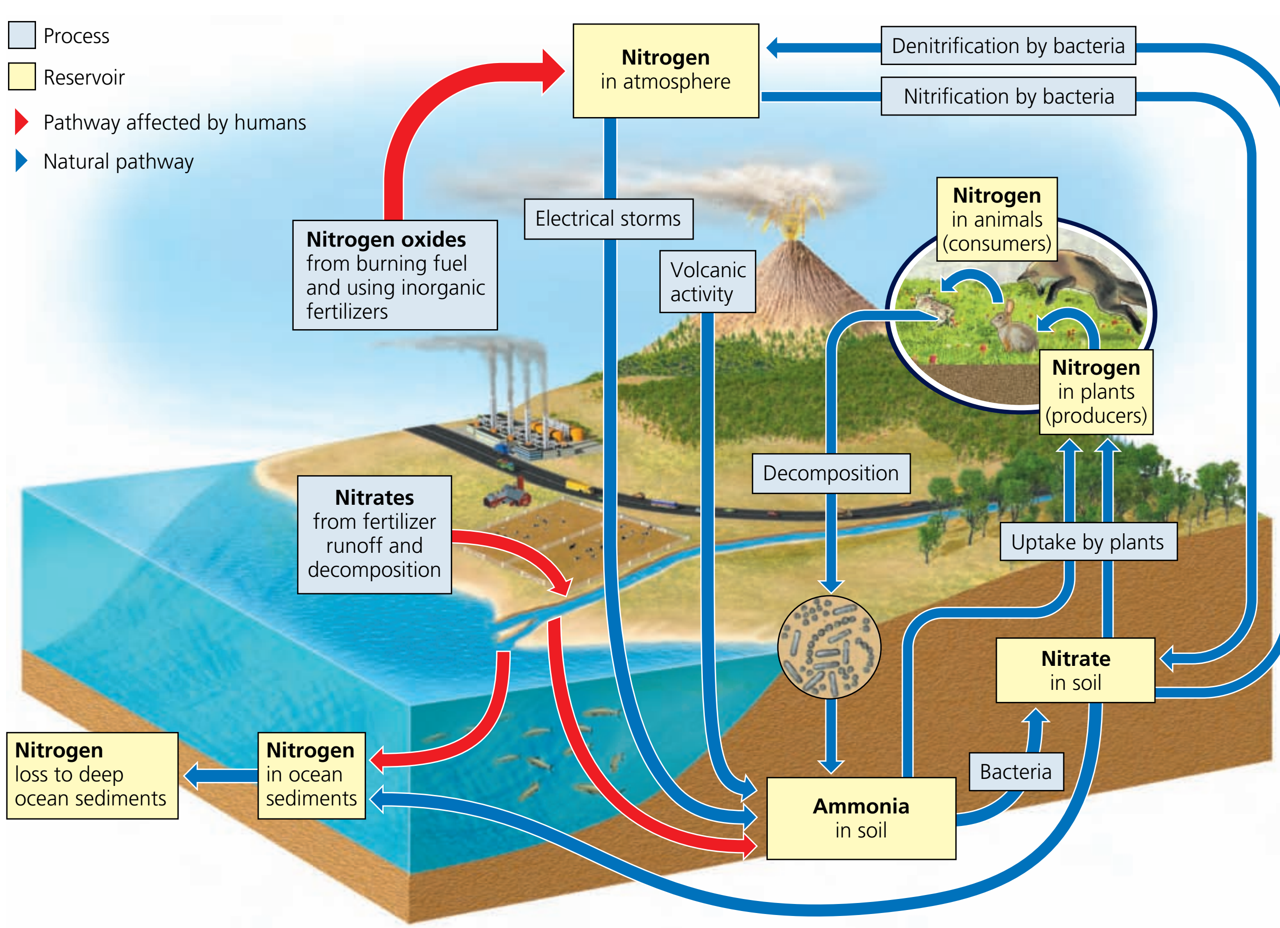
The Nitrogen Cycle: Bacteria in Action

The major reservoir for nitrogen is the atmosphere. Chemically unreactive nitrogen gas (N_2) makes up 78% of the volume of the atmosphere. Nitrogen is a crucial component of proteins, many vitamins, and nucleic acids such as DNA (see Figure 10, p. S15, in Supplement 4). However, N_2 cannot be absorbed and used directly as a nutrient by multicellular plants or animals.

Fortunately, two natural processes convert, or *fix*, N_2 into compounds that plants and animals can use as nutrients. One is electrical discharges, or lightning, taking place in the atmosphere. The other takes place in aquatic systems, in soil, and in the roots of some plants, where specialized bacteria, called *nitrogen-fixing bacteria*, complete this conversion as part of the **nitrogen cycle**, which is depicted in Figure 3-20.

The nitrogen cycle consists of several major steps. In *nitrogen fixation*, specialized bacteria in soil as well as blue-green algae (cyanobacteria) in aquatic environments combine gaseous N_2 with hydrogen to make ammonia (NH_3). The bacteria use some of the ammonia they produce as a nutrient and excrete the rest into the soil or water. Some of the ammonia is converted to ammonium ions (NH_4^+) that plants can use as a nutrient.

Ammonia not taken up by plants may undergo *nitrification*. In this process, specialized soil bacteria convert most of the NH_3 and NH_4^+ in soil to *nitrate ions* (NO_3^-), which are easily taken up by the roots of plants. The plants then use these forms of nitrogen to produce



CENGAGENOW™ **Active Figure 3-20** **Natural capital:** This diagram is a simplified model of the circulation of various chemical forms of nitrogen in the *nitrogen cycle* in a terrestrial ecosystem, with major harmful human impacts shown by the red arrows. *See an animation based on this figure at* CengageNOW. **Question:** What are three ways in which you directly or indirectly affect the nitrogen cycle?

various amino acids, proteins, nucleic acids, and vitamins. Animals that eat plants eventually consume these nitrogen-containing compounds, as do detritus feeders and decomposers.

Plants and animals return nitrogen-rich organic compounds to the environment as both wastes and cast-off particles of tissues such as leaves, skin, or hair, and through their bodies when they die and are decomposed or eaten by detritus feeders. In *ammonification*, vast armies of specialized decomposer bacteria convert this detritus into simpler nitrogen-containing inorganic compounds such as ammonia (NH_3) and water-soluble salts containing ammonium ions (NH_4^+).

In *denitrification*, specialized bacteria in waterlogged soil and in the bottom sediments of lakes, oceans, swamps, and bogs convert NH_3 and NH_4^+ back into nitrate ions, and then into nitrogen gas (N_2) and nitrous oxide gas (N_2O). These gases are released to the atmosphere to begin the nitrogen cycle again.

We intervene in the nitrogen cycle in five ways (see the red arrows in Figure 3-20). *First*, we add large amounts of nitric oxide (NO) into the atmosphere when N_2 and O_2 combine as we burn any fuel at high temperatures, such as in car, truck, and jet engines. In the atmosphere, this gas can be converted to nitrogen dioxide gas (NO_2) and nitric acid vapor (HNO_3), which can return to the earth's surface as damaging *acid deposition*, commonly called *acid rain*.

Second, we add nitrous oxide (N_2O) to the atmosphere through the action of anaerobic bacteria on commercial inorganic fertilizer or organic animal manure applied to the soil. This greenhouse gas can warm the atmosphere and deplete stratospheric ozone, which keeps most of the sun's harmful ultraviolet radiation from reaching the earth's surface.

Third, we release large quantities of nitrogen stored in soils and plants as gaseous compounds into the atmosphere through destruction of forests (Figure 3-1, **Core Case Study**), grasslands, and wetlands. CORE CASE STUDY

Fourth, we upset the nitrogen cycle in aquatic ecosystems by adding excess nitrates (NO_3^-) to bodies of water through agricultural runoff of fertilizers and animal manure and through discharges from municipal sewage systems. This can cause excess growth of algae (see Figure 3-7, right).

And *fifth*, we remove nitrogen from topsoil when we harvest nitrogen-rich crops, irrigate crops (washing nitrates out of the soil), and burn or clear grasslands and forests before planting crops.

According to the 2005 Millennium Ecosystem Assessment, since 1950, human activities have more than doubled the annual release of nitrogen from the land into the rest of the environment—most of this from the greatly increased use of inorganic fertilizers to grow crops—and the amount released is projected to double again by 2050 (see Figure 16, p. S64, in Supplement 9). This excessive input of nitrogen into the air and water contributes to pollution and other problems to be discussed in later chapters. Nitrogen overload is a serious and growing local, regional, and global environmental problem that has attracted little attention. Princeton University physicist Robert Socolow calls for countries around the world to work out some type of nitrogen management agreement to help prevent this problem from reaching crisis levels.

THINKING ABOUT

The Nitrogen Cycle and Tropical Deforestation CORE CASE STUDY

What effects might the clearing and degrading of tropical rain forests (**Core Case Study**) have on the nitrogen cycle in these forest ecosystems and on any nearby aquatic systems? (See Figure 2-1, p. 31, and Figure 2-6, p. 40.)

The Phosphorus Cycle

Compounds of phosphorous (P) circulate through water, the earth's crust, and living organisms in the **phosphorus cycle**, depicted in Figure 3-21. Most of these compounds contain *phosphate* ions (PO_4^{3-}), which are a combination of phosphorus and oxygen and which serve as an important nutrient. In contrast to the cycles of water, carbon, and nitrogen, the phosphorus cycle does not include the atmosphere. The major reservoir for phosphorous is phosphate salts containing phosphate ions (PO_4^{3-}) in terrestrial rock formations and ocean bottom sediments. The phosphorus cycle is slow compared to the water, carbon, and nitrogen cycles.

As water runs over exposed rocks, it slowly erodes away inorganic compounds that contain phosphate ions. The running water carries these dissolved phosphate ions into the soil where they can be absorbed by the roots of plants and by other producers. Phosphate compounds are also transferred by food webs from producers to consumers, eventually including detritus feeders and decomposers. In both producers and consumers, phosphates are a component of biologically important molecules such as nucleic acids (see Figure 9, p. S14, in Supplement 4) and energy transfer molecules such as ADP and ATP (see Figure 13, p. S16, in Supplement 4). Phosphate is also a major component of vertebrate bones and teeth.

Phosphate can be lost from the cycle for long periods of time when it is washed from the land into streams and rivers and is carried to the ocean. There it can be deposited as marine sediment and remain trapped for millions of years. Someday, geological processes may uplift and expose these seafloor deposits, from which phosphate can be eroded to start the cycle again.

Because most soils contain little phosphate, the lack of it often limits plant growth on land unless phosphorus (as phosphate salts mined from the earth) is applied to the soil as a fertilizer. Lack of phosphorus also limits the growth of producer populations in many freshwater streams and lakes because phosphate salts are only slightly soluble in water and thus do not release many phosphate ions that producers need as nutrients.

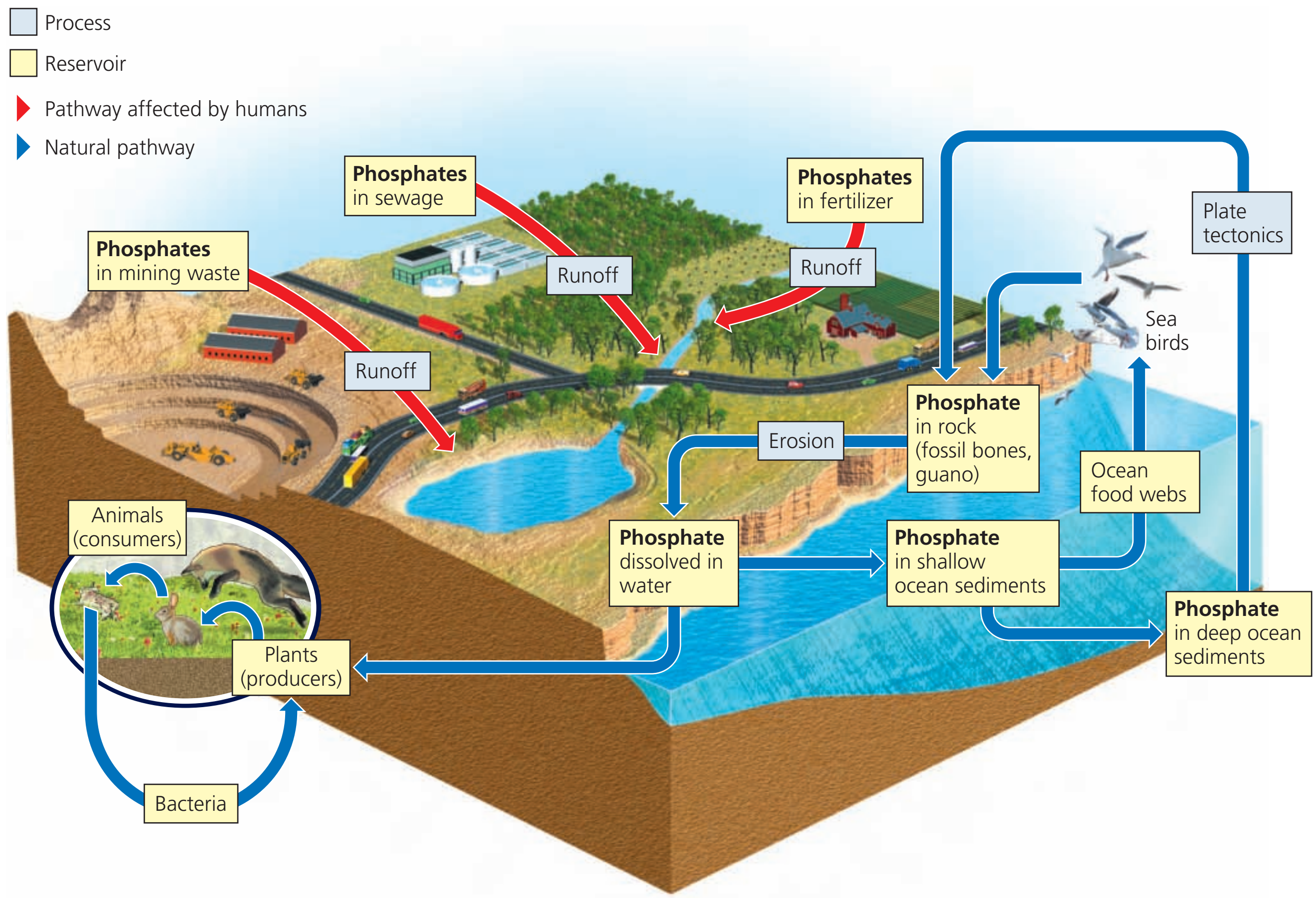


Figure 3-21 **Natural capital:** This is a simplified model of the circulation of various chemical forms of phosphorus (mostly phosphates) in the *phosphorus cycle*, with major harmful human impacts shown by the red arrows. **Question:** What are three ways in which you directly or indirectly affect the phosphorus cycle?

Human activities are affecting the phosphorous cycle (as shown by the red arrows in Figure 3-21). This includes removing large amounts of phosphate from the earth to make fertilizer and reducing phosphate levels in tropical soils by clearing forests (**Core Case Study**). CORE CASE STUDY Topsoil that is eroded from fertilized crop fields, lawns, and golf courses carries large quantities of phosphate ions into streams, lakes, and oceans; there they stimulate the growth of producers such as algae and various aquatic plants. Phosphate-rich runoff from the land can produce huge populations of algae (Figure 3-7, right), which can upset chemical cycling and other processes in lakes. In other words, we are altering the phosphorous cycle by removing fairly scarce phosphate ions from land areas where they are needed by plants and feeding them in excessive amounts to producers in aquatic systems, causing these producer populations to explode.

The Sulfur Cycle

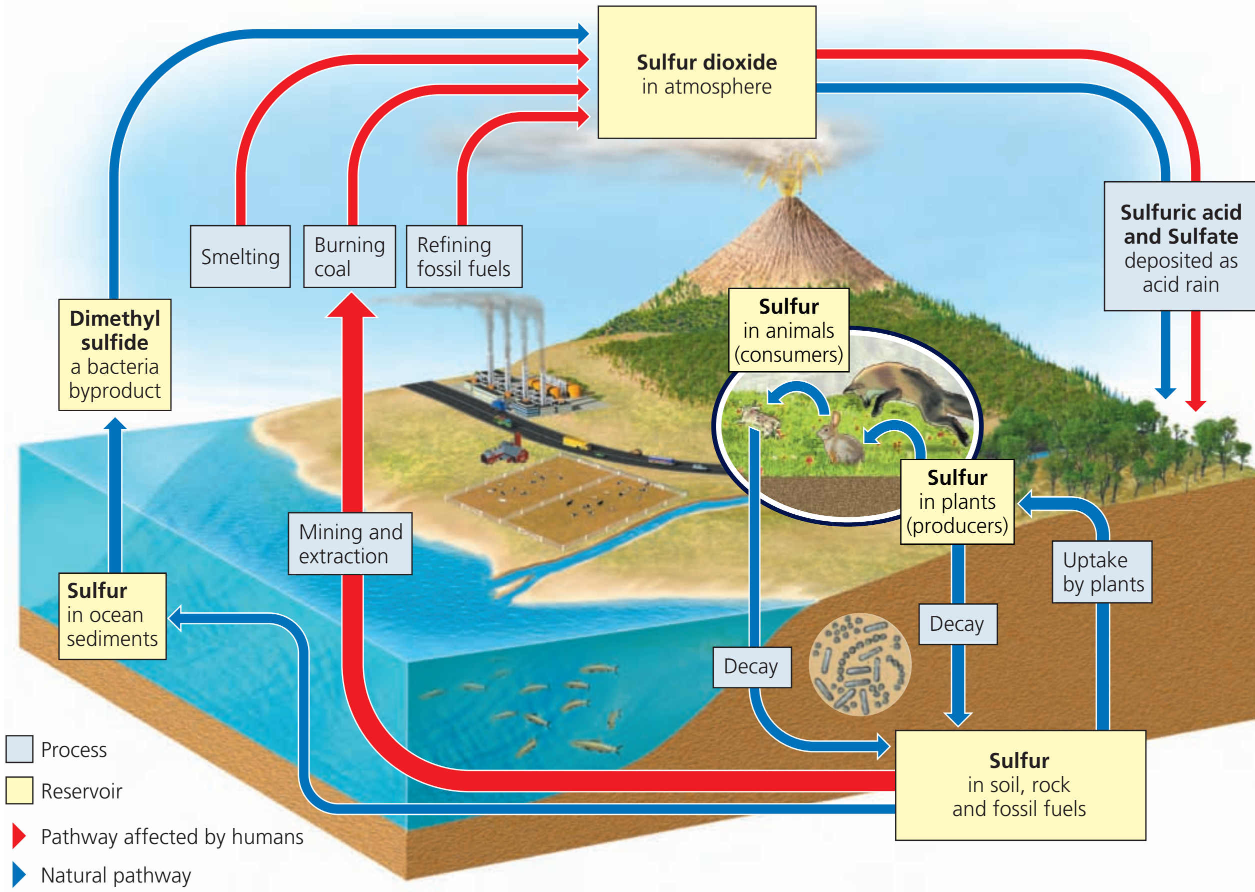
Sulfur circulates through the biosphere in the **sulfur cycle**, shown in Figure 3-22 (p. 74). Much of the earth's sulfur is stored underground in rocks and minerals and in the form of sulfate (SO_4^{2-}) salts buried deep under ocean sediments.

Sulfur also enters the atmosphere from several natural sources. Hydrogen sulfide (H_2S)—a colorless, highly poisonous gas with a rotten-egg smell—is released from active volcanoes and from organic matter broken down by anaerobic decomposers in flooded swamps, bogs, and tidal flats. Sulfur dioxide (SO_2), a colorless and suffocating gas, also comes from volcanoes.

Particles of sulfate (SO_4^{2-}) salts, such as ammonium sulfate, enter the atmosphere from sea spray, dust storms, and forest fires. Plant roots absorb sulfate ions and incorporate the sulfur as an essential component of many proteins.

Certain marine algae produce large amounts of volatile dimethyl sulfide, or DMS (CH_3SCH_3). Tiny droplets of DMS serve as nuclei for the condensation of water into droplets found in clouds. In this way, changes in DMS emissions can affect cloud cover and climate.

In the atmosphere, DMS is converted to sulfur dioxide, some of which in turn is converted to sulfur trioxide gas (SO_3) and to tiny droplets of sulfuric acid (H_2SO_4). DMS also reacts with other atmospheric chemicals such as ammonia to produce tiny particles of sulfate salts. These droplets and particles fall to the



CENGAGENOW™ **Active Figure 3-22** **Natural capital:** This is a simplified model of the circulation of various chemical forms of sulfur in the *sulfur cycle*, with major harmful impacts of human activities shown by the red arrows. *See an animation based on this figure at* CengageNOW. **Question:** What are three ways in which your lifestyle directly or indirectly affects the sulfur cycle?

earth as components of *acid deposition*, which along with other air pollutants can harm trees and aquatic life.

In the oxygen-deficient environments of flooded soils, freshwater wetlands, and tidal flats, specialized bacteria convert sulfate ions to sulfide ions (S^{2-}). The sulfide ions can then react with metal ions to form insoluble metallic sulfides, which are deposited as rock or metal ores (often extracted by mining and converted to various metals), and the cycle continues.

Human activities have affected the sulfur cycle primarily by releasing large amounts of sulfur dioxide (SO_2) into the atmosphere (as shown by the red arrows in Figure 3-22). We release sulfur to the atmosphere in three ways. *First*, we burn sulfur-containing coal and oil to produce electric power. *Second*, we refine sulfur-containing oil (petroleum) to make gasoline, heating oil, and other useful products. *Third*, we extract metals such as copper, lead, and zinc from sulfur-containing compounds in rocks that are mined for these metals. Once the sulfur is in the atmosphere, SO_2 is converted to droplets of sulfuric acid (H_2SO_4) and particles of sulfate (SO_4^{2-}) salts, which return to the earth as acid deposition.

RESEARCH FRONTIER

The effects of human activities on the major nutrient cycles and how we can reduce these effects; see **www.cengage.com/login**.

Most forms of life get supplies of critical nutrients from compounds containing carbon, nitrogen, phosphorus, and sulfur that are circulated in their respective chemical cycles. These cycles are driven by gravity and by the one-way flow of energy from the sun. Human activities are degrading the earth's natural capital by increasingly altering the rates at which energy flows through these cycles and the rates at which critical chemicals are recycled. This is a major intrusion into the processes of energy flow and nutrient cycling (Figure 3-11) that support life on the earth.

CENGAGENOW™ Learn more about the water, carbon, nitrogen, phosphorus, and sulfur cycles using interactive animations at CengageNow.

3-5 How Do Scientists Study Ecosystems?

▶ **CONCEPT 3-5 Scientists use both field research and laboratory research, as well as mathematical and other models to learn about ecosystems.**

Some Scientists Study Nature Directly

Scientists use both field research and laboratory research, as well as mathematical and other models to learn about ecosystems (**Concept 3-5**). *Field research*, sometimes called "muddy-boots biology," involves going into natural settings to observe and measure the structure of ecosystems and what happens in them. Most of what we know about ecosystems has come from such research. **GREEN CAREER:** ecologist

Sometimes ecologists carry out controlled experiments by isolating and changing a variable in part of an area and comparing the results with nearby unchanged areas (see Chapter 2 **Core Case Study**, p. 31, and *The Habitable Planet*, Videos 4 and 9, at **www.learner.org/resources/series209.html**). In a few cases, tropical ecologists have erected tall construction cranes that provide them access to the canopies of tropical forests. This, along with rope walkways between treetops, has helped them to identify and observe the rich diversity of species living or feeding in these treetop habitats.

Increasingly, we are using new technologies to collect ecological data. Scientists use aircraft and satellites equipped with sophisticated cameras and other *remote sensing* devices to scan and collect data on the earth's surface (Science Focus, p. 76). Then they use *geographic information system (GIS)* software to capture, store, analyze, and display such information.

The software in a GIS can electronically store geographic and ecological spatial data as numbers or as images in computer databases. For example, a GIS can convert digital satellite images generated through remote sensing into global, regional, and local maps showing variations in vegetation (see Figure 6, pp. S36–S37, in Supplement 8), gross primary productivity, temperature patterns, air pollution emissions, and many other variables.

Scientists can also attach tiny radio transmitters to animals and use global positioning systems (GPS) to learn about the animals by tracking where they go and how far they go. This technology is very important for studying endangered species. **GREEN CAREERS:** GIS analyst; remote sensing analyst

Some Scientists Study Ecosystems in the Laboratory

Since the 1960s, ecologists have increasingly supplemented field research by using *laboratory research*, setting up, observing, and making measurements of model ecosystems and populations under laboratory conditions. They have created such simplified systems in containers such as culture tubes, bottles, aquariums, and greenhouses, and in indoor and outdoor chambers where they can control temperature, light, CO_2, humidity, and other variables.

Such systems make it easier for scientists to carry out controlled experiments. In addition, laboratory experiments often are quicker and less costly than similar experiments in the field. But there is a catch: scientists must consider how well their scientific observations and measurements in a simplified, controlled system under laboratory conditions reflect what actually takes place under more complex and dynamic conditions found in nature. Thus, the results of laboratory research must be coupled with and supported by field research (see *The Habitable Planet*, Videos 4, 9, and 12, at **www.learner.org/resources/series209.html**).

THINKING ABOUT
Greenhouse Experiments and Tropical Rain Forests

CORE CASE STUDY

How would you design an experiment that includes an experimental group and a control group and uses a greenhouse to determine how clearing a patch of tropical rain forest vegetation (**Core Case Study**) affects the temperature above the cleared patch?

Some Scientists Use Models to Simulate Ecosystems

Since the late 1960s, ecologists have developed mathematical and other models that simulate ecosystems. Computer simulations can help scientists understand large and very complex systems, such as lakes, oceans, forests, and the earth's climate system, that cannot be adequately studied and modeled in field and laboratory research. (see *The Habitable Planet*, Videos 2, 3, and 12, at **www.learner.org/resources/series209.html**.) Scientists are learning a lot about how the earth works by feeding data into increasingly sophisticated models of the earth's systems and running them on high-speed supercomputers. **GREEN CAREER:** ecosystem modeler

Of course, simulations and projections made with ecosystem models are no better than the data and assumptions used to develop the models. Ecologists must do careful field and laboratory research to get *baseline data*, or beginning measurements, of the variables they are studying. They also must determine the

SCIENCE FOCUS

Satellites, Google Earth, and the Environment

The use of satellites as remote sensing devices is an important and rapidly expanding type of environmental research for scientists and for citizens who have learned to use Google Earth (see **http://earth.google.com/**) to monitor the planet. Within the last decade, free Google Earth software has allowed individuals to virtually fly anywhere over the earth to view high-resolution satellite imagery (Figure 3-A, images a and b) and maps of particular areas. One can also zoom in to get a 3-D view of vegetation, buildings, oceans, canyons, and other features of the earth's surface. Google Earth allows anyone with an Internet connection to view the earth's surface from different altitudes (Figure 3-A, image c).

Today's satellites use increasingly sophisticated cameras, with microwave sensors that can penetrate clouds and infrared sensors that can measure temperatures at different elevations and in different parts of the world.

Scientists and environmental groups now use this technology to help indigenous people in the Amazon map and protect their land from illegal logging and mining and to monitor the growth of cropland and irrigation in the Amazon. Others use these tools to uncover and monitor deforestation, oil spills, air pollution from various sources, overgrazing by livestock, illegal fishing, the melting of Arctic sea ice, and the concentration of ozone in the stratosphere over Antarctica. Scientists, governments, and ordinary citizens are developing many other uses for Google Earth, such as following the spread of harmful invasive plant species and diseases that affect humans, tracking the movements of elephants across Africa, and studying the effects of urbanization.

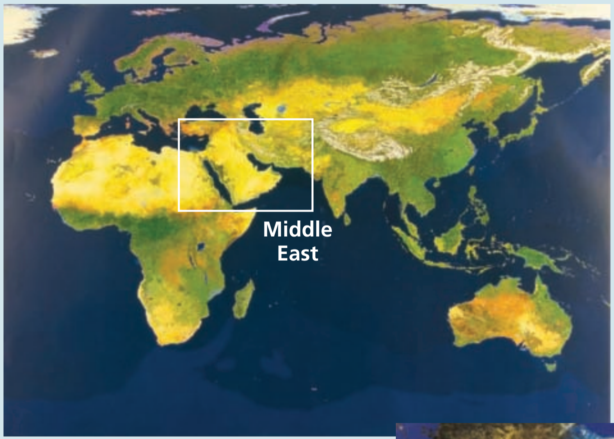
For example, in 2008, British scientists used this technology to find a previously unknown center of biodiversity in a remote mountain forest in the African country of Mozambique. Scientists who then visited this difficult-to-reach area found hundreds of species of plants, animals, and insects, including three new butterfly species.

Remote sensing expert Mark Mulligan at London's King's College has used satellite technology to allow individuals to get a close look at all of the earth's 77,000 protected areas (see **http://healthyplanet.org/**). David Tryse, an ordinary citizen, developed a software program for the Zoological Society of London that allows anyone to surf the world to see and learn about endangered species, to track deforestation, and to view the world's major threatened biodiversity hot spots.

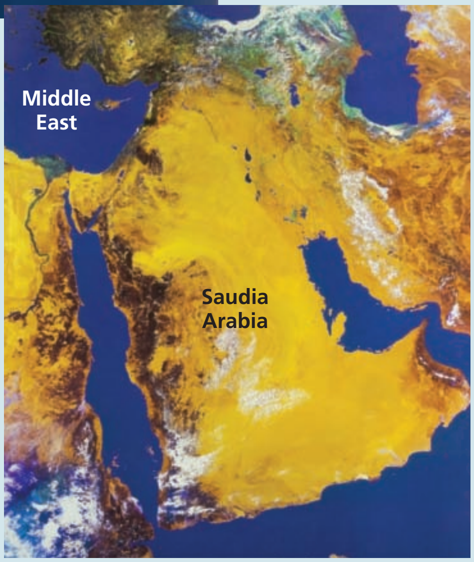
If you have not yet used this technology, give it a try. Fly around the planet and zoom in to see for yourself what we are doing to some of the planet's natural capital that is so important for our survival. Happy surfing.

Critical Thinking

Explain how this technology can help ordinary citizens throughout the world to carry out their own biological and environmental investigations and to help improve the environmental quality of the planet and of the places where they live.



(a) This is a satellite view of the Eastern Hemisphere from space.



(b) This satellite view shows the Middle East from space.

(c) This is a satellite view of Jeddah, Saudi Arabia's second largest city.

Figure 3-A Anyone with an Internet connection can now use Google Earth software to learn about, monitor, or support scientific research on almost any place on the earth's surface. High-resolution satellite imagery was used to produce these photos **(a)** the Eastern Hemisphere and **(b)** the Middle East at different zoom levels. You can also use Google Earth to zoom in on the rooftops and streets of **(c)** Jeddah, Saudi Arabia and many other cities throughout the world.

relationships among key variables that they will use to develop and test ecosystem models.

RESEARCH FRONTIER

Improved computer modeling for understanding complex environmental systems; see **www.cengage.com/login**.

We Need to Learn More about the Health of the World's Ecosystems

We need baseline data on the condition of world's ecosystems to see how they are changing and to develop effective strategies for preventing or slowing their degradation.

By analogy, your doctor needs baseline data on your blood pressure, weight, and functioning of your organs and other systems, which can be obtained through basic tests. If your health declines in some way, the doctor can run new tests and compare the results with the baseline data to identify changes and come up with a cause and a treatment.

According to a 2002 ecological study published by the Heinz Foundation and the 2005 Millennium Ecosystem Assessment, scientists have less than half of the basic ecological data they need to evaluate the status of ecosystems in the United States. Even fewer data are available for most other parts of the world. Ecologists have called for a massive program to develop baseline data for the world's ecosystems. In 2009, NASA and Cisco teamed up to develop a global nervous system, or *planetary skin*, that will integrate land, air, and space-based sensors throughout the word. This pilot project will help scientists, the public, government agencies, and private businesses to make decisions on how to reduce our environmental impacts.

GOOD NEWS

RESEARCH FRONTIER

A crash program to gather and evaluate baseline data for all of the world's major terrestrial and aquatic systems; see **www.cengage.com/login**.

Here are this chapter's *three big ideas*:

- Life is sustained by the flow of energy from the sun through the biosphere, the cycling of nutrients within the biosphere, and gravity.
- Some organisms produce the nutrients they need, others survive by consuming other organisms, and some recycle nutrients back to producer organisms.
- Human activities are altering the flow of energy through food chains and webs and the cycling of nutrients within ecosystems and the biosphere.

REVISTING Tropical Rain Forests and Sustainability

CORE CASE STUDY

SUSTAINABILITY

This chapter applied two of the **principles of sustainability** (see back cover) by which the biosphere and the ecosystems it contains have been sustained over the long term. *First*, the source of energy for the biosphere and almost all of its ecosystems is *solar energy*, which flows through these systems. *Second*, the ecosystems *recycle the chemical nutrients* that their organisms need for survival, growth, and reproduction. These two major processes support and are enhanced by *biodiversity*, in keeping with the third sustainability principle.

This chapter started with a discussion of the importance of incredibly diverse tropical rain forests (**Core Case Study**, p. 54), which showcase the functioning of the three **principles of sustainability**. Producers within rain forests rely on solar energy to produce a vast amount of biomass through photosynthesis. Species living in the forests take part in, and depend on, the cycling of nutrients in the biosphere and the flow of energy through the biosphere. Tropical rain forests contain a huge and vital part of the earth's biodiversity, and interactions among species living in these forests help to sustain these complex ecosystems. We explore biodiversity and these important species interactions more deeply in the next two chapters.

All things come from earth, and to earth they all return.

MENANDER (342–290 BC)

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 55. What are three harmful effects resulting from the clearing and degradation of tropical rain forests?
2. Distinguish among the **atmosphere**, **troposphere**, **stratosphere**, **hydrosphere**, **geosphere**, and **biosphere**. What are **greenhouse gases** and why are they important? What three interconnected factors sustain life on earth?

3. Describe the flow of energy to and from the earth. What is the **natural greenhouse effect** and why is it important? Define **ecology**. Define **organism**, **population**, and **community**. Define and distinguish between an **ecosystem** and the **biosphere**.

4. Distinguish between the living and nonliving components in ecosystems and give two examples of each.

5. What is a **trophic level**? Distinguish among **producers (autotrophs)**, **consumers (heterotrophs)**, **decomposers** and **detritus feeders (detritivores)**, and give an example of each in an ecosystem. Distinguish among **primary consumers (herbivores)**, **secondary consumers**, **carnivores**, **tertiary consumers**, and **omnivores**, and give an example of each.

6. Distinguish between **photosynthesis** and **chemosynthesis**. Distinguish between **aerobic respiration** and **anaerobic respiration (fermentation)**. What two processes sustain ecosystems and the biosphere and how are they linked? Explain the importance of microbes.

7. Distinguish between a **food chain** and a **food web**. Explain what happens to energy as it flows through the food chains and webs. What is **biomass**? What is the **pyramid of energy flow**? Why are there more insects than tigers in the world?

8. Distinguish between **gross primary productivity (GPP)** and **net primary productivity (NPP)**, and explain their importance.

9. What happens to matter in an ecosystem? What is a **biogeochemical cycle (nutrient cycle)**? Describe the **hydrologic**, or **water cycle**. What are its three major processes? Summarize the unique properties of water. Explain how clearing a rain forest can affect local weather (**Core Case Study**). Explain how human activities are affecting the water cycle. Describe the **carbon**, **nitrogen**, **phosphorus**, and **sulfur cycles**, and explain how human activities are affecting each cycle. Explain how nutrient cycles connect past, present, and future life. CORE CASE STUDY

10. Describe three ways in which scientists study ecosystems. Describe how satellite and Google Earth technology can be used to help us understand and monitor the natural world and how we are affecting it. Explain why we need much more basic data about the structure and condition of the world's ecosystems. What are this chapter's *three big ideas*? How are the three **principles of sustainability** showcased in tropical rain forests? SUSTAINABILITY

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. How would you explain the importance of tropical rain forests (**Core Case Study**) to people who think that such forests have no connection to their lives? CORE CASE STUDY

2. Explain why **(a)** the flow of energy through the biosphere depends on the cycling of nutrients, and **(b)** the cycling of nutrients depends on gravity (**Concept 3-1B**).

3. Explain why microbes are so important. List two beneficial and two harmful effects of microbes on your health and lifestyle. Write a brief description of what you think would happen to you if microbes were eliminated from the earth.

4. Make a list of the foods you ate for lunch or dinner today. Trace each type of food back to a particular producer species. Describe the sequence of feeding levels that led to your feeding.

5. Use the second law of thermodynamics (see Chapter 2, p. 47) to explain why many poor people in less-developed countries live on a mostly vegetarian diet.

6. Why do farmers not need to apply carbon to grow their crops but often need to add fertilizer containing nitrogen and phosphorus?

7. What changes might take place in the hydrologic cycle if the earth's climate becomes **(a)** hotter or **(b)** cooler? In each case, what are two ways in which these changes might affect your lifestyle?

8. What would happen to an ecosystem if **(a)** all of its decomposers and detritus feeders were eliminated, **(b)** all of its producers were eliminated, or **(c)** all of its insects were eliminated? Could a balanced ecosystem exist with only producers and decomposers and no consumers such as humans and other animals? Explain.

9. List three ways in which you could apply **Concept 3-3** and **Concept 3-4** to making your lifestyle more environmentally sustainable.

10. List two questions that you would like to have answered as a result of reading this chapter.

ECOLOGICAL FOOTPRINT ANALYSIS

Based on the following carbon dioxide emissions data and 2010 population data, answer the questions below.

Country	Total Carbon Footprint—Carbon Dioxide Emissions in Metric Gigatons per Year*	Population in billions (2010)	Per Capita Carbon Footprint—Per Capita Carbon Dioxide Emissions per Year
China	5.0	1.3	
India	1.3	1.2	
Japan	1.3	0.13	
Russia	1.5	0.14	
United States	6.0	0.31	
WORLD	29	6.9	

(Data from the World Resources Institute and the International Energy Agency)
*The prefix giga stands for 1 billion.

1. Calculate the per capita carbon footprint for each country and for the world, and complete the table.
2. It has been suggested that a sustainable average worldwide carbon footprint per person should be no more than 2.0 metric tons per person per year. How many times larger is the U.S. carbon footprint per person than **(a)** the sustainable level, and **(b)** the world average?
3. By what percentage will China, Japan, Russia, the United States, and the world each have to reduce their carbon footprints per person to achieve the estimated maximum sustainable carbon footprint per person of 2.0 metric tons per person per year?

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengagebrain.com/shop/ISBN/0538735341** and choose Chapter 3 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

For students with access to premium online resources, log on to **www.cengage.com/login**.

Find the latest news and research, (including videos and podcasts), at the GLOBAL ENVIRONMENT WATCH. Visit **www.CengageBrain.com** for more information.

4 Biodiversity and Evolution

CORE CASE STUDY Why Should We Protect Sharks?

More than 400 known species of sharks (Figure 4-1) inhabit the world's oceans. They vary widely in size and behavior, from the goldfish-sized dwarf dog shark to the whale shark (Figure 4-1, left), which can grow to a length of 18 meters (60 feet) and weigh as much as two full-grown African elephants.

Many people, influenced by movies, popular novels, and widespread media coverage of shark attacks, think of sharks as people-eating monsters. In reality, the three largest species—the whale shark (Figure 4-1, left), basking shark, and megamouth shark—are gentle giants. These plant-eating sharks swim through the water with their mouths open, filtering out and swallowing huge quantities of phytoplankton.

Media coverage of shark attacks greatly exaggerates the danger from sharks. Every year, members of a few species such as the great white, bull, tiger, oceanic white tip, and hammerhead sharks (Figure 4-1, right) injure 60–75 people worldwide. Between 1998 and 2008, there were an average of six deaths per year from such attacks. Some of these sharks feed on sea lions and other marine mammals and sometimes mistake swimmers and surfers for their usual prey.

However, *for every shark that injures or kills a person every year, people kill about 1.2 million sharks. This amounts to 79–97 million shark deaths each year*, according to Australia's Shark Research Institute. Many sharks are caught for their valuable fins and then thrown back alive into the water, fins removed, to bleed to death or drown because they can no longer swim. This practice is called *finning*. The fins are widely used in Asia as a soup ingredient and as a pharmaceutical cure-all. Sharks are also killed for their livers, meat, hides, and jaws, and because we fear them. Some sharks die when they are trapped by fishing lines and nets.

According to a 2009 study by the International Union for Conservation of Nature (IUCN), 32% of the world's open-ocean shark species are threatened with extinction. One of the most endangered species is the scalloped hammerhead shark (Figure 4-1, right). Sharks are especially vulnerable to population declines because they grow slowly, mature late, and have only a few offspring per generation. Today, they are among the earth's most vulnerable and least protected animals.

Sharks have been around for more than 400 million years. As *keystone species*, some shark species play crucial roles in helping to keep their ecosystems functioning. Feeding at or near the tops of food webs, they remove injured and sick animals from the ocean. Without this service provided by sharks, the oceans would be teeming with dead and dying fish and marine mammals.

In addition to playing their important ecological roles, sharks could help to save human lives. If we can learn why they almost never get cancer, we could possibly use this information to fight cancer in our own species. Scientists are also studying their highly effective immune systems, which allow wounds in sharks to heal without becoming infected.

Many people argue that we should protect sharks simply because they, like any other species, have a right to exist. But another reason for the importance of sustaining this threatened portion of the earth's biodiversity is that some sharks are keystone species, which means that we and other species need them. In this chapter we explore the keystone species' role and other special roles played by species in the story of the earth's vital biodiversity.

fAndy Murch/Tom Stack and Associates

Westend61/SuperStock

Figure 4-1 The threatened whale shark (left), which feeds on plankton, is the largest fish in the ocean. The endangered scalloped hammerhead shark (right) is swimming in waters near the Galapagos Islands, Ecuador. They are known for eating stingrays, which are related to sharks.

Key Questions and Concepts

4-1 What is biodiversity and why is it important?

CONCEPT 4-1 The biodiversity found in genes, species, ecosystems, and ecosystem processes is vital to sustaining life on earth.

4-2 How does the earth's life change over time?

CONCEPT 4-2A The scientific theory of evolution explains how life on earth changes over time through changes in the genes of populations.

CONCEPT 4-2B Populations evolve when genes mutate and give some individuals genetic traits that enhance their abilities to survive and to produce offspring with these traits (natural selection).

4-3 How do geological processes and climate change affect evolution?

CONCEPT 4-3 Tectonic plate movements, volcanic eruptions, earthquakes, and climate change have shifted wildlife habitats, wiped out large numbers of species, and created opportunities for the evolution of new species.

4-4 How do speciation, extinction, and human activities affect biodiversity?

CONCEPT 4-4A As environmental conditions change, the balance between the formation of new species and the extinction of existing species determines the earth's biodiversity.

CONCEPT 4-4B Human activities are decreasing biodiversity by causing the extinction of many species and by destroying or degrading habitats needed for the development of new species.

4-5 What is species diversity and why is it important?

CONCEPT 4-5 Species diversity is a major component of biodiversity and tends to increase the sustainability of some ecosystems.

4-6 What roles do species play in an ecosystem?

CONCEPT 4-6A Each species plays a specific ecological role called its niche.

CONCEPT 4-6B Any given species may play one or more of five important roles—native, nonnative, indicator, keystone, or foundation—in a particular ecosystem.

Note: Supplements 2 (p. S3), 4 (p. S11), and 5 (p. S18) can be used with this chapter.

There is grandeur to this view of life . . . that, whilst this planet has gone cycling on . . . endless forms most beautiful and most wonderful have been, and are being, evolved.

CHARLES DARWIN

4-1 What Is Biodiversity and Why Is It Important?

▶ **CONCEPT 4-1 The biodiversity found in genes, species, ecosystems, and ecosystem processes is vital to sustaining life on earth.**

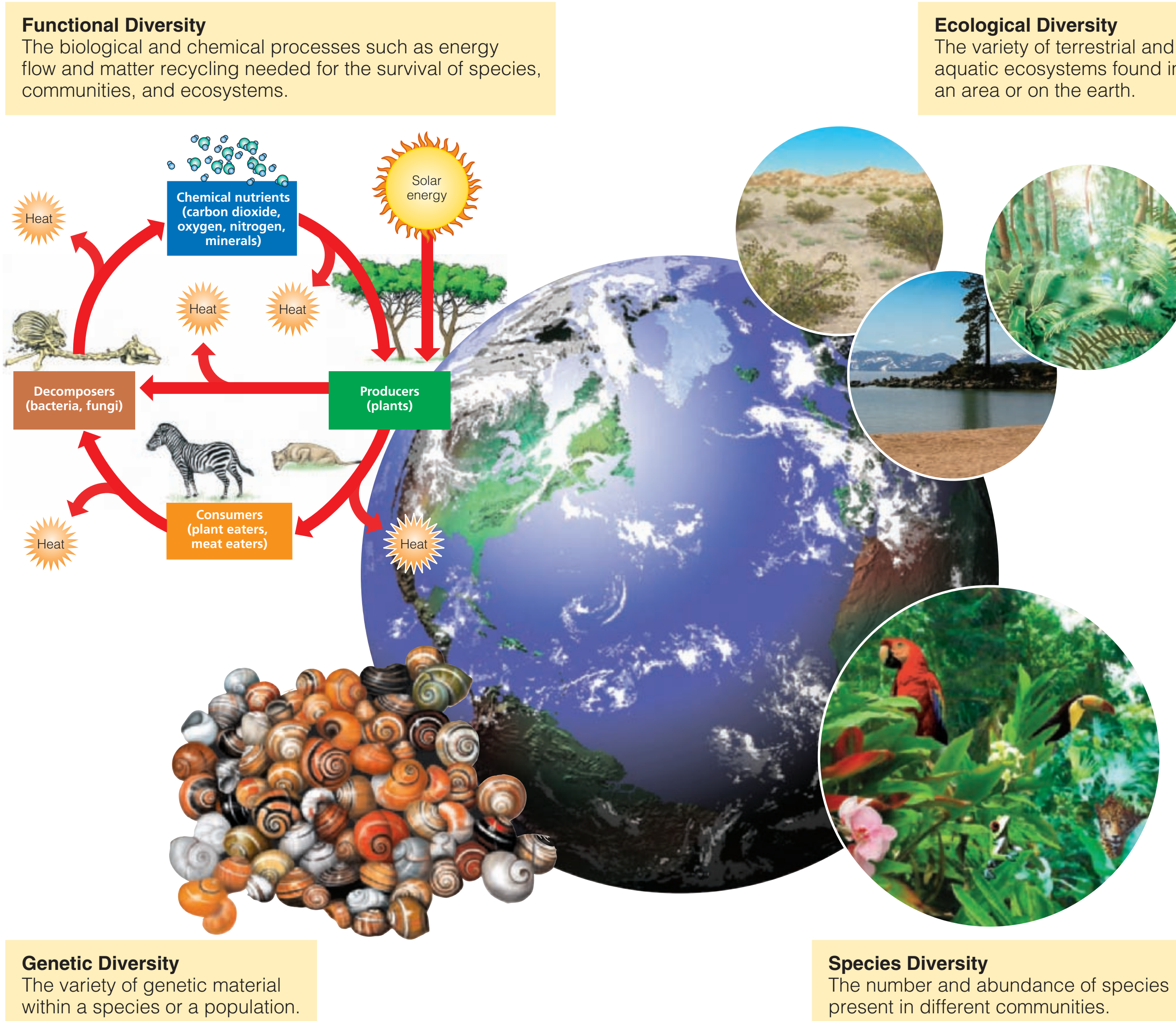
Biodiversity Is a Crucial Part of the Earth's Natural Capital

Biological diversity, or **biodiversity**, is the variety of the earth's *species*, or varying life-forms, the genes they contain, the ecosystems in which they live, and the ecosystem processes of energy flow and nutrient cycling that sustain all life (Figure 4-2, p. 82).

For a group of sexually reproducing organisms, a **species** is a set of individuals that can mate and produce fertile offspring. Every organism is a member of a certain species with certain distinctive traits. For example, all humans are members of the species *Homo sapiens sapiens*. Scientists have developed a system for classifying and naming each species, as discussed on p. S19 in Supplement 5.

We do not know how many species there are on the earth. Estimates range from 8 million to 100 million. The best guess is that there are 10–14 million species. So far, biologists have identified about 1.9 million (Figure 4-3, p. 82). Up to half of the world's plant and animal species live in tropical rain forests that humans are

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. GOOD NEWS refers to good news about the environmental challenges we face.



CENGAGENOW™ **Active Figure 4-2** **Natural capital:** This diagram illustrates the major components of the earth's *biodiversity*—one of the earth's most important renewable resources and a key component of the planet's natural capital (see Figure 1-4, p. 9). *See an animation based on this figure at* CengageNOW. **Question:** What role do you play in such degradation?

Figure 4-3 Two of the world's 1.9 million known species are the Columbia lily (left) and the great egret (right). In 1953, the National Audubon Society adopted an image of this egret in flight as its symbol. The society was formed in 1905, partly to help prevent the widespread killing of this bird for its feathers.

SCIENCE FOCUS

Have You Thanked the Insects Today?

Insects are an important part of the earth's natural capital, although they generally have a bad reputation. We classify many insect species as *pests* because they compete with us for food, spread human diseases such as malaria, bite or sting us, and invade our lawns, gardens, and houses. Some people fear insects and think the only good bug is a dead bug. They fail to recognize the vital roles insects play in helping to sustain life on earth.

For example, pollination is a natural service that allows flowering plants to reproduce sexually when pollen grains are transferred from the flower of one plant to a receptive part of the flower of another plant of the same species. Many of the earth's plant species depend on insects to pollinate their flowers (Figure 4-A, left).

John Henry Williams/Bruce Coleman USA

Peter J. Bryant/Biological Photo Service

Figure 4-A *Importance of insects:* The monarch butterfly, like bees and numerous other insects, feeds on pollen in a flower (left), and pollinates flowering plants that serve as food for many plant eaters, including humans. The praying mantis, which is eating a house cricket (right), and many other insect species help to control the populations of most of the insect species we classify as pests.

Insects that eat other insects—such as the praying mantis (Figure 4-A, right)—help to control the populations of at least half the species of insects we call pests. This free pest control service is an important part of the earth's natural capital. Some insects also play a key role in loosening and renewing the soil that supports plant life on land.

Insects have been around for at least 400 million years—about 2,000 times longer than the latest version of the human species. They are phenomenally successful forms of life. Some reproduce at an astounding rate and can rapidly develop new genetic traits such as resistance to pesticides. They also have an exceptional ability to evolve into new species when faced with changing environmental conditions, and they are very resistant to extinction. This is fortunate because, according to ant specialist and biodiversity expert E. O. Wilson, if all insects disappeared, the life-support systems for us and other species would be seriously disrupted.

The environmental lesson: although insects do not need newcomer species such as humans, we and most other land organisms need them.

Critical Thinking

Identify three insect species not discussed above that benefit your life.

rapidly clearing (see Figure 3-1, p. 54). Insects make up most of the world's known species (see Science Focus, above). Scientists believe that most of the unidentified species live in the planet's rain forests and largely unexplored oceans.

Scientists are creating the *Encyclopedia of Life*, a website devoted to eventually summarizing all the basic information on the world's known and named species. It will be continually updated as more species are discovered (see **http://www.eol.org/**).

Species diversity is the most obvious, but not the only, component of biodiversity. We discuss species diversity in greater detail in Section 4-5 of this chapter. Another important component is *genetic diversity* (Figure 4-4). The earth's variety of species contains an even greater variety of genes. This genetic diversity enables life on the earth to adapt to and survive dramatic environmental changes.

Ecosystem diversity—the earth's variety of deserts, grasslands, forests, mountains, oceans, lakes, rivers, and wetlands is another major component of biodiversity. Each of these ecosystems is a storehouse of genetic and species diversity.

Figure 4-4 *Genetic diversity* among individuals in a population of a species of Caribbean snail is reflected in the variations in shell color and banding patterns. Genetic diversity can also include other variations such as slight differences in chemical makeup, sensitivity to various chemicals, and behavior.

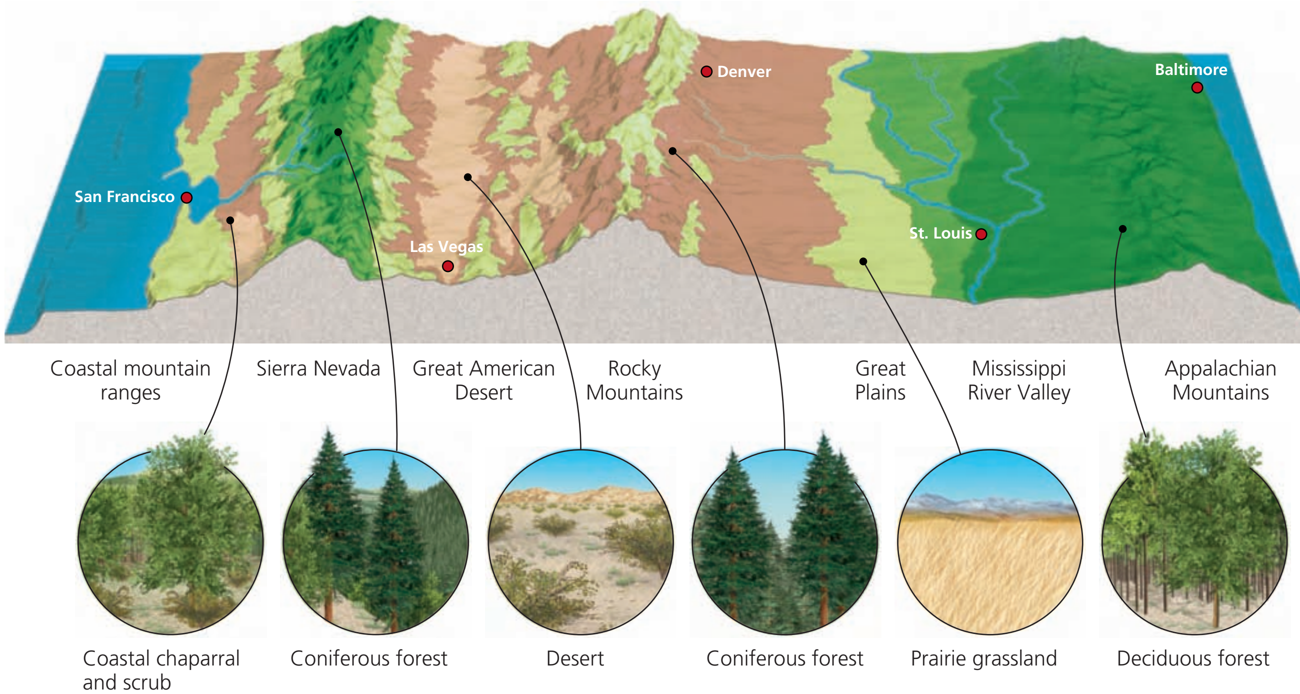


Figure 4-5 The major biomes found along the 39th parallel across the United States are shown in this diagram. The differences in tree and other plant species reflect changes in climate, mainly differences in average annual precipitation and temperature.

Biologists have classified the terrestrial (land) portion of the biosphere into **biomes**—large regions such as forests, deserts, and grasslands with distinct climates and certain species (especially vegetation) adapted to them. Figure 4-5 shows different major biomes along the 39th parallel spanning the United States. We discuss biomes in more detail in Chapter 7.

Yet another important component of biodiversity is *functional diversity*—the variety of processes such as energy flow and matter cycling that occur within ecosystems (see Figure 3-11, p. 62) as species interact with one another in food chains and webs. Part of the importance of some shark species (**Core Case Study**) is their role in supporting these processes within their ecosystems, which helps to maintain other species of animals and plants that live in those ecosystems.

CORE CASE STUDY

THINKING ABOUT
Sharks and Biodiversity

CORE CASE STUDY

What are three ways in which sharks (**Core Case Study**) support one or more of the four components of biodiversity within their environment?

The earth's biodiversity is a vital part of the natural capital that helps keep us alive and supports our economies. With the help of technology, we use biodiversity to provide us with food, wood, fibers, energy from wood and biofuels, and medicines. Biodiversity also plays critical roles in preserving the quality of the air and water, maintaining the fertility of topsoil, decomposing and recycling waste, and controlling populations of species that humans consider to be pests. In carrying out these free ecological services, which are also part of the earth's natural capital (see Figure 1-4, p. 9), biodiversity helps to sustain life on the earth. We owe much of what we know about biodiversity to a fairly small number of researchers, one of whom is Edward O. Wilson (see Individuals Matter, at right).

RESEARCH FRONTIER

Identifying and cataloging information on biodiversity; see **www.cengage.com/login**.

Because biodiversity is such an important concept and so vital to sustainability, we are going to take a grand tour of biodiversity in this and the next seven chapters. This chapter focuses on the earth's variety of species, how these species evolved, and the major roles that species play in ecosystems. Chapter 5 examines how different interactions between species help to control population sizes and promote biodiversity. Chapter 6 uses principles of population dynamics developed in Chapter 5 to look at human population growth and its effects on biodiversity. Chapters 7 and 8 look at the major types of terrestrial and aquatic ecosystems, respectively, that are key components of biodiversity. Then, the next three chapters examine major threats to species biodiversity (Chapter 9), terrestrial biodiversity (Chapter 10), and aquatic biodiversity (Chapter 11), and solutions for dealing with these threats.

INDIVIDUALS MATTER

Edward O. Wilson: A Champion of Biodiversity

As a boy growing up in the southeastern United States, Edward O. Wilson (Figure 4-B) became interested in insects at the age of nine. He has said, "Every kid has a bug period. I never grew out of mine."

Before entering college, Wilson had decided he would specialize in the study of ants. After he grew fascinated with that tiny organism, and throughout his long career, he steadily widened his focus to include the entire biosphere. He now spends much of his time studying, writing, and speaking about all of life—the earth's *biodiversity*—and working on Harvard University's *Encyclopedia of Life*, an online database for the planet's known and named species (see **http://www.eol.org/**).

During his long career of researching, writing, and teaching, Wilson has taken on many challenges. He and other researchers working together discovered how ants communicate using chemicals called pheromones. He also studied the complex social behavior of ants and has compiled much of his work into the epic volume, *The Ants*, published in 1990. His ant research has been applied to the study and understanding of other social organisms.

In the 1960s, Wilson and other scientists developed the *theory of island biogeography* (Science Focus, p. 94), which deals with how species diversity on islands is affected by the sizes and locations of the islands. It has been applied to areas that resemble islands, such as mountain forests surrounded by developed land. It has also been important in the creation of wildlife preserves.

Wilson is sometimes credited with coining the term "biodiversity." He was not actually the inventor of the term but was the first to use it in a scientific paper. And he fleshed out the meaning of the term and essentially christened a new field of science. Another of his landmark works is *The Diversity of Life*, published in 1992, in which he put together the principles and practical issues of biodiversity more completely than anyone had to that point.

Since then he has become deeply involved in writing and lecturing about the need for global conservation efforts. Wilson has won more than 100 awards, including the U.S. National Medal of Science, as well as similar national awards from many other countries. He has written 25 books, two of which won the Pulitzer Prize for General Nonfiction. About the study of biodiversity, he writes:

> "Until we get serious about exploring biological diversity . . . science and humanity at large will be flying blind inside the biosphere. How can we fully understand the ecology of a pond or forest patch without knowledge of the thousands of species . . . the principal channels of materials and energy flow? How can we anticipate and control the spread of new crop diseases and human diseases if we do not know . . . the identity of the insect and other [species] that carry them? And, finally, . . . how can we save Earth's life forms from extinction if we don't even know what most of them are?"

Learn more at the website of the Edward O. Wilson Biodiversity Foundation (**www.eowilson.org**).

Figure 4-B Edward O. Wilson

4-2 How Does the Earth's Life Change over Time?

▶ **CONCEPT 4-2A The scientific theory of evolution explains how life on earth changes over time through changes in the genes of populations.**

▶ **CONCEPT 4-2B Populations evolve when genes mutate and give some individuals genetic traits that enhance their abilities to survive and to produce offspring with these traits (natural selection).**

Biological Evolution by Natural Selection Explains How Life Changes over Time

The history of life on earth is colorful, deep, and complex. Most of what we know of this story comes from **fossils**: mineralized or petrified replicas of skeletons, bones, teeth, shells, leaves, and seeds, or impressions of such items found in rocks (Figure 4-6, p. 86). Scientists also drill core samples from glacial ice at the earth's poles and on mountaintops, and examine the signs of ancient life found at different layers in these cores.

The entire body of evidence gathered using these methods, which is called the *fossil record*, is uneven and incomplete. Some forms of life left no fossils, and some

Figure 4-6 This fossilized skeleton is the mineralized remains of an herbivore that lived during the Cenozoic era from 26 to 66 million years ago.

fossils have decomposed. The fossils found so far represent probably only 1% of all species that have ever lived. Trying to reconstruct the development of life with so little evidence is the work of *paleontology*—a challenging scientific detective game. **GREEN CAREER:** paleontologist

How did we end up with the current amazing array of species? The scientific answer involves **biological evolution** (or simply **evolution**): the process whereby earth's life changes over time through changes in the genetic characteristics of populations (**Concept 4-2A**). According to the **theory of evolution**, all species descended from earlier, ancestral species. In other words, life comes from life.

The idea that organisms change over time and are descended from a single common ancestor has been around in one form or another since the early Greek philosophers. But no one had developed a convincing explanation of how this could happen until 1858 when naturalists Charles Darwin (1809–1882) and Alfred Russel Wallace (1823–1913) independently proposed the concept of *natural selection* as a mechanism for biological evolution. It was Darwin who meticulously gathered evidence for this idea and published it in 1859 in his book, *On the Origin of Species by Means of Natural Selection*.

Darwin and Wallace observed that individual organisms must struggle constantly to survive by getting enough food, water, and other resources, to avoid being eaten, and to reproduce. They also observed that individuals in a population with a specific advantage over other individuals in that population were more likely to survive and produce offspring that had the same specific advantage. The advantage was due to a characteristic, or *trait*, possessed by these individuals but not by others of their kind.

Based on these observations, Darwin and Wallace described a process called **natural selection**, in which individuals with certain traits are more likely to survive and reproduce under a particular set of environmental conditions than are those without the traits (**Concept 4-2B**). The scientists concluded that these survival traits would become more prevalent in future populations of the species as individuals with those traits became more numerous and passed their traits on to their offspring.

A huge body of evidence has supported this idea. As a result, *biological evolution through natural selection* has become an important scientific theory that generally explains how life has changed over the past 3.5 billion years and why life is so diverse today (see Figure 1, p. S18, in Supplement 5). However, there are still many unanswered questions that generate scientific debate about the details of evolution by natural selection.

CENGAGE**NOW**™ Get a detailed look at early biological evolution by natural selection—the roots of the tree of life—at CengageNOW.

Evolution by Natural Selection Works through Mutations and Adaptations

The process of biological evolution by natural selection involves changes in a population's genetic makeup through successive generations. Note that *populations—not individuals—evolve by becoming genetically different.*

The first step in this process is the development of *genetic variability*, or variety in the genetic makeup of individuals in a population. This occurs through **mutations**: *random* changes in the DNA molecules (see Figure 10, p. S15, in Supplement 4) of a gene in any cell that can be inherited by offspring. Most mutations result from random changes that occur in coded genetic instructions when DNA molecules are copied each time a cell divides and whenever an organism reproduces. In other words, this copying process is subject to random errors. Some mutations also occur from exposure to external agents such as radioactivity, X rays, and natural and human-made chemicals (called *mutagens*).

Mutations can occur in any cell, but only those taking place in genes of reproductive cells are passed on to offspring. Sometimes, such a mutation can result in a new genetic trait, called a *heritable trait*, which can be passed from one generation to the next. In this way, populations develop differences among individuals, including genetic variability.

The next step in biological evolution is *natural selection*, in which environmental conditions favor some individuals over others. The favored individuals possess heritable traits that give them some advantage over other individuals in a given population. Such a trait is called an **adaptation**, or **adaptive trait**—any heritable trait that improves the ability of an individual organism to survive and to reproduce at a higher rate than other individuals in a population are able to do under prevailing environmental conditions. For natural selection to occur, the heritable trait must also lead to **differential reproduction**, which enables individuals with the trait to produce more surviving offspring than other members of the population produce.

For example, in the face of snow and cold, a few gray wolves in a population that have thicker fur might live longer and thus produce more offspring than do those without thicker fur. As those longer-lived wolves mate, genes for thicker fur spread throughout the population and individuals with those genes increase in number and pass this helpful trait on to more offspring. Thus, the scientific concept of natural selection explains how populations adapt to changes in environmental conditions.

CENGAGE**NOW**™ How many moths can you eat? Find out and learn more about adaptation at CengageNOW.

Genetic resistance is the ability of one or more organisms in a population to tolerate a chemical designed to kill it. For example, the organism might have a gene that allows it to break the chemical down into other harmless chemicals. Another important example of natural selection at work is the evolution of genetic resistance to widely used antibacterial drugs, or antibiotics.

Doctors use these drugs to help control disease-causing bacteria, but they have become a force of natural selection. When such a drug is used, the few bacteria that are genetically resistant to it (because of some trait they possess) survive and rapidly produce more offspring than the bacteria that were killed by the drug could have produced. Thus, the antibiotic eventually loses its effectiveness as genetically resistant bacteria rapidly reproduce and those that are susceptible to the drug die off (Figure 4-7).

One way to summarize the process of biological evolution by natural selection is: *Genes mutate, individuals are selected, and populations evolve such that they are better adapted to survive and reproduce under existing environmental conditions* (**Concept 4-2B**).

A remarkable example of species evolution by natural selection is *Homo sapiens sapiens*. We have evolved certain traits that have allowed us to take over much of the world (see the following Case Study).

■ CASE STUDY

How Did Humans Become Such a Powerful Species?

Like many other species, humans have survived and thrived because we have certain traits that allow us to adapt to and modify parts of the environment to increase our survival chances.

Evolutionary biologists attribute our success to three adaptations: *strong opposable thumbs* that allowed us to grip and use tools better than the few other animals that have thumbs could do; an *ability to walk upright*, which gave us agility and freed up our hands for many uses; and a *complex brain*, which allowed us to develop many skills, including the ability to use speech to transmit complex ideas.

These adaptations have helped us to develop tools, weapons, protective devices, and technologies that extend our limited senses of sight, hearing, and smell and make up for some of our deficiencies. Thus, in an eyeblink of the 3.5-billion-year history of life on earth, we have developed powerful technologies and taken over much of the earth's net primary productivity for our own use. At the same time, we have degraded much of the planet's life-support system as our ecological footprints have grown (see Figure 1-13, p. 16).

But adaptations that make a species successful during one period of time may not be enough to ensure the species' survival when environmental conditions

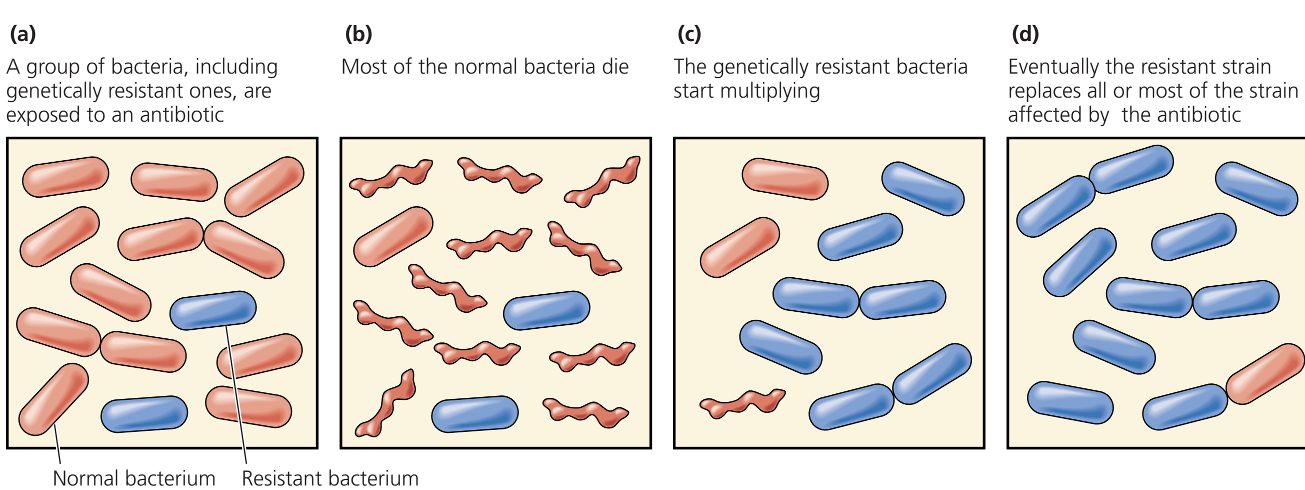


Figure 4-7 *Evolution by natural selection.* **(a)** A population of bacteria is exposed to an antibiotic, which **(b)** kills all individuals except those possessing a trait that makes them resistant to the drug. **(c)** The resistant bacteria multiply and eventually **(d)** replace all or most of the nonresistant bacteria.

change. This is no less true for humans, and some environmental conditions are now changing rapidly, largely due to our own actions.

One of our adaptations—our powerful brain—may enable us to live more sustainably by understanding and copying the ways in which nature has sustained itself for billions of years, despite major changes in environmental conditions. GOOD NEWS

THINKING ABOUT
Human Adaptations

An important adaptation of humans is strong opposable thumbs, which allow us to grip and manipulate things with our hands. Make a list of the things you could not do if you did not have opposable thumbs.

Adaptation through Natural Selection Has Limits

In the not-too-distant future, will adaptations to new environmental conditions through natural selection allow our skin to become more resistant to the harmful effects of UV radiation (see Figure 2-11, p. 45), our lungs to cope with air pollutants, and our livers to better detoxify pollutants?

According to scientists in this field, the answer is *no* because of two limitations on adaptation through natural selection. *First*, a change in environmental conditions can lead to such an adaptation only for genetic traits already present in a population's gene pool or for traits resulting from mutations, which occur randomly.

Second, even if a beneficial heritable trait is present in a population, the population's ability to adapt may be limited by its reproductive capacity. Populations of genetically diverse species that reproduce quickly—such as weeds, mosquitoes, rats, cockroaches, and bacteria—often adapt to a change in environmental conditions in a short time (days to years). By contrast, species that cannot produce large numbers of offspring rapidly—such as elephants, tigers, sharks, and humans—take a much longer time (typically thousands or even millions of years) to adapt through natural selection.

Three Common Myths about Evolution through Natural Selection

According to evolution experts, there are three common misconceptions about biological evolution through natural selection. One is that "survival of the fittest" means "survival of the strongest." To biologists, *fitness* is a measure of reproductive success, not strength. Thus, the fittest individuals are those that leave the most descendants.

Another misconception is that organisms develop certain traits because they need them. A giraffe has a very long neck not because it needs it to feed on vegetation high in trees. Rather, some ancestor had a gene for long necks that gave it an advantage over other members of its population in getting food, and that giraffe produced more offspring with long necks.

A third misconception is that evolution by natural selection involves some grand plan of nature in which species become more perfectly adapted. From a scientific standpoint, no plan or goal for genetic perfection has been identified in the evolutionary process.

4-3 How Do Geological Processes and Climate Change Affect Evolution?

▶ **CONCEPT 4-3 Tectonic plate movements, volcanic eruptions, earthquakes, and climate change have shifted wildlife habitats, wiped out large numbers of species, and created opportunities for the evolution of new species.**

Geological Processes Affect Natural Selection

The earth's surface has changed dramatically over its long history. Scientists have discovered that huge flows of molten rock within the earth's interior break its surface into a series of gigantic solid plates, called *tectonic plates*. For hundreds of millions of years, these plates have drifted slowly on the planet's mantle (Figure 4-8).

This fact that tectonic plates drift has had two important effects on the evolution and distribution of life on the earth. *First*, the locations (latitudes) of continents and oceanic basins have greatly influenced the earth's climate and thus helped to determine where plants and animals can live.

Second, the movement of continents has allowed species to move, adapt to new environments, and form new species through natural selection. When continents join together, populations can disperse to new areas and adapt to new environmental conditions. When continents separate and when islands are formed, populations must evolve under isolated conditions or become extinct.

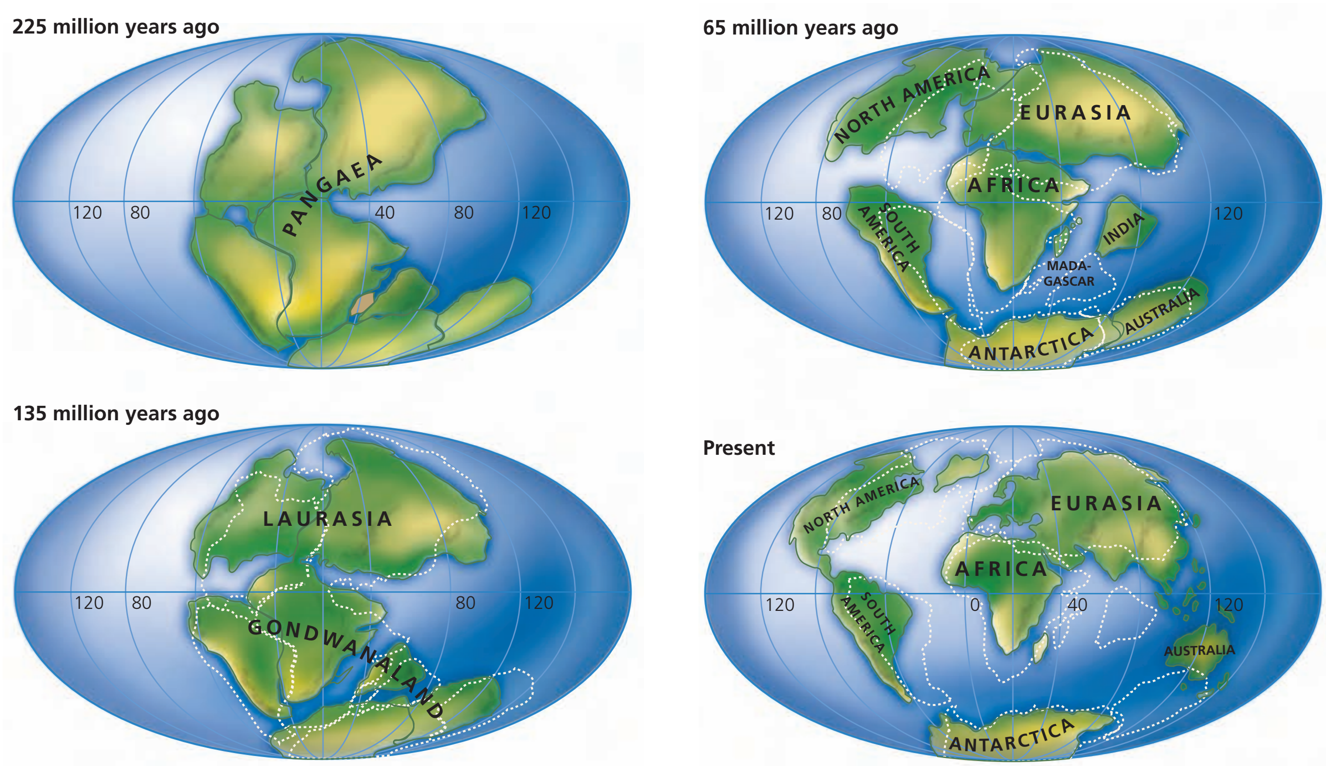


Figure 4-8 Over millions of years, the earth's continents have moved very slowly on several gigantic tectonic plates. This process plays a role in the extinction of species, as continental areas split apart, and also in the rise of new species when isolated island areas such as the Hawaiian Islands and the Galapagos Islands are created. Rock and fossil evidence indicates that 200–250 million years ago, all of the earth's present-day continents were connected in a supercontinent called Pangaea (top left). About 180 million years ago, Pangaea began splitting apart as the earth's tectonic plates moved, eventually resulting in the present-day locations of the continents (bottom right). **Question:** How might an area of land splitting apart cause the extinction of a species?

Adjoining tectonic plates that are moving slowly past one another sometimes shift quickly. Such sudden movement of tectonic plates can cause *earthquakes*. Such an event can also affect biological evolution by causing fissures in the earth's crust that can separate and isolate populations of species. Over long periods of time, this can lead to the formation of new species as each isolated population changes genetically in response to new environmental conditions. *Volcanic eruptions* also occur along the boundaries of tectonic plates. They can affect biological evolution by destroying habitats and reducing or wiping out populations of species (**Concept 4-3**).

Climate Change and Catastrophes Affect Natural Selection

Throughout its long history, the earth's climate has changed drastically. Sometimes it has cooled and covered much of the earth with glacial ice. At other times it has warmed, melted that ice, and drastically raised sea levels, which in turn increased the total area covered by the oceans and decreased the earth's total land area. Such alternating periods of cooling and heating have led to the advance and retreat of ice sheets at high latitudes over much of the northern hemisphere, most recently about 18,000 years ago (Figure 4-9).

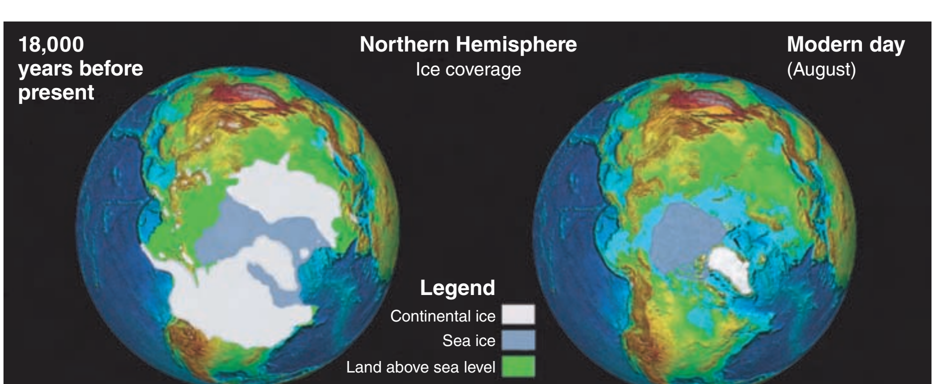


Figure 4-9 These maps of the northern hemisphere show the large-scale changes in glacial ice coverage during the past 18,000 years. Other smaller changes in glacial ice on mountain ranges such as the European Alps are not shown. **Question:** What are two characteristics of an animal and two characteristics of a plant that natural selection would have favored as these ice sheets (left) advanced? (Data from the National Oceanic and Atmospheric Administration)

SCIENCE FOCUS

Earth Is Just Right for Life to Thrive

Life on the earth, as we know it, can thrive only within a certain temperature range related to properties of the liquid water that dominates the earth's surface. Most life on the earth requires average temperatures between the freezing and boiling points of water.

The earth's orbit is the right distance from the sun to provide these conditions. If the earth were much closer to the sun, it would be too hot—like Venus—for water vapor to condense and form rain. If it were much farther away, the earth's surface would be so cold—like Mars—that water would exist only as ice. The earth also spins fast enough to keep the sun from overheating any part of it. If it did not, most life could not exist.

The size of the earth is also just right for life. It has enough gravitational mass to keep the atmosphere—made up of light gaseous molecules required for life (such as N_2, O_2, CO_2, and H_2O vapor)—from flying off into space.

Although life on earth has been enormously adaptive, it has benefited from a favorable temperature range. During the 3.5 billion years since life arose, the average surface temperature of the earth has remained within the narrow range of 10–20 °C (50–68 °F), even with a 30–40% increase in the sun's energy output. One reason for this is the evolution of organisms that modify atmospheric levels of the temperature-regulating gas carbon dioxide as a part of the carbon cycle (see Figure 3-19, p. 70).

For several hundred million years, oxygen has made up about 21% of the volume of earth's atmosphere. If this oxygen content dropped to about 15%, it would be lethal for most forms of life. If it increased to about 25%, oxygen in the atmosphere would probably ignite into a giant fireball. The current oxygen content of the atmosphere is largely the result of producer and consumer organisms (especially phytoplankton and certain types of bacteria) interacting in the carbon cycle. Also, because of the development of photosynthesizing bacteria that have been adding oxygen to the atmosphere for more than 2 billion years, a sunscreen of ozone (O_3) molecules in the stratosphere protects us and many other forms of life from an overdose of ultraviolet radiation.

In short, this remarkable planet we live on is uniquely suited for life as we know it.

Critical Thinking

Suppose the oxygen content of the atmosphere dropped to 13%. What types of organisms might eventually arise on the earth?

These long-term climate changes have a major effect on biological evolution by determining where different types of plants and animals can survive and thrive, and by changing the locations of different types of ecosystems such as deserts, grasslands, and forests (**Concept 4-3**). Some species became extinct because the climate changed too rapidly for them to adapt and survive, and new species evolved to fill their ecological roles.

Another force affecting natural selection has been catastrophic events such as collisions between the earth and large asteroids. There have probably been many of these collisions during the 3.5 billion years of life on earth. Such impacts have caused widespread destruction of ecosystems and wiped out large numbers of species. But they have also caused shifts in the locations of ecosystems and created opportunities for the evolution of new species.

On a long-term basis, the three **principles of sustainability** (see back cover), especially the biodiversity principle (Figure 4-2), have enabled life on earth to adapt to drastic changes in environmental conditions (see Science Focus, above, and *The Habitable Planet*, Video 1, at **www.learner.org/resources/series209.html**).

4-4 How Do Speciation, Extinction, and Human Activities Affect Biodiversity?

CONCEPT 4-4A As environmental conditions change, the balance between the formation of new species and the extinction of existing species determines the earth's biodiversity.

CONCEPT 4-4B Human activities are decreasing biodiversity by causing the extinction of many species and by destroying or degrading habitats needed for the development of new species.

How Do New Species Evolve?

Under certain circumstances, natural selection can lead to an entirely new species. In this process, called **speciation**, one species splits into two or more different species. For sexually reproducing organisms, a new species forms when one population of a species has evolved to the point where its members no longer can breed and produce fertile offspring with members of another population that did not change or that evolved differently.

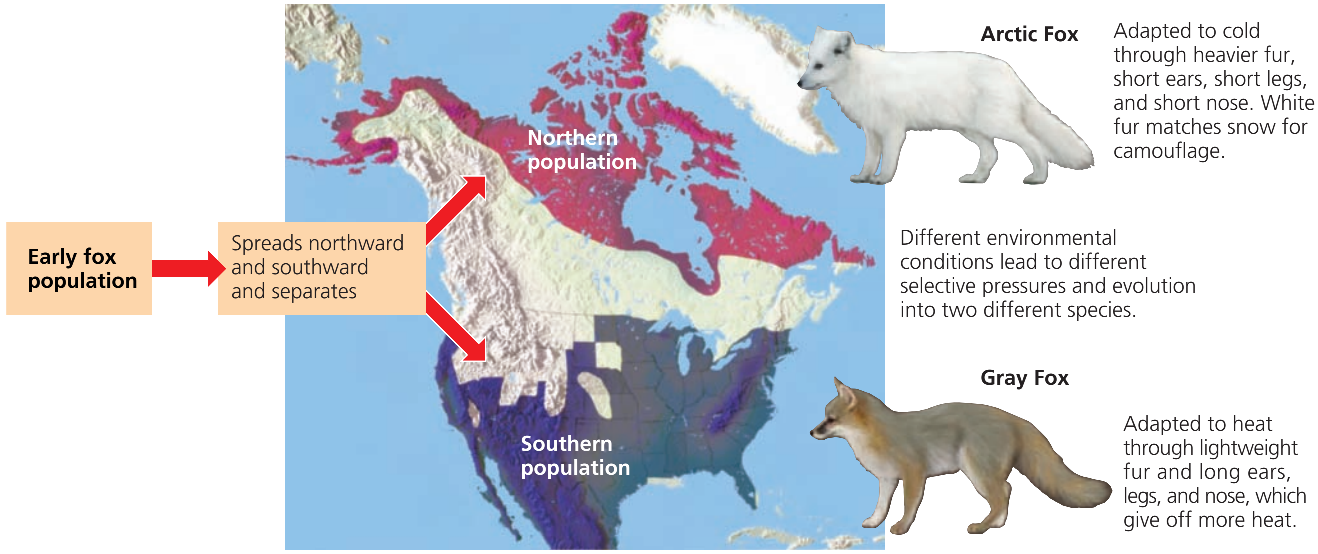


Figure 4-10 *Geographic isolation* can lead to reproductive isolation, divergence of gene pools, and speciation.

The most common way in which speciation occurs, especially among sexually reproducing species, is when a barrier or distant migration prevents the flow of genes between two or more populations of a species. This happens in two phases: first, geographic isolation and then reproductive isolation.

Geographic isolation occurs when different groups of the same population of a species become physically isolated from one another for a long period of time. For example, part of a population may migrate in search of food and then begin living as a separate population in another area with different environmental conditions. Populations can also be separated by a physical barrier (such as a mountain range, stream, or road), a volcanic eruption, tectonic plate movements, or winds or flowing water that carry a few individuals to a distant area.

In **reproductive isolation**, mutation and change by natural selection operate independently in the gene pools of geographically isolated populations. If this process continues long enough, members of the geographically and reproductively isolated populations of sexually reproducing species may become so different in genetic makeup that they cannot produce live, fertile offspring if they are rejoined and attempt to interbreed. Then, one species has become two, and speciation has occurred (Figure 4-10).

For some rapidly reproducing organisms, this type of speciation may occur within hundreds of years. For most species, it takes from tens of thousands to millions of years—making it difficult to observe and document the appearance of a new species.

CENGAGE**NOW**™ Learn more about different types of speciation and the ways in which they occur at CengageNOW.

Humans are playing an increasing role in the process of speciation. We have learned to shuffle genes from one species to another through artificial selection and, more recently, through genetic engineering (see Science Focus, p. 92).

Extinction Is Forever

Another process affecting the number and types of species on the earth is **extinction**, a process in which an entire species ceases to exist (*biological extinction*) or a population of a species becomes extinct over a large region, but not globally (*local extinction*). When environmental conditions change, a population of a species faces three possible futures: *adapt* to the new conditions through natural selection, *move* (if possible) to an area with more favorable conditions, or *become extinct*.

Species that are found in only one area are called **endemic species** and are especially vulnerable to extinction. They exist on islands and in other unique areas, especially in tropical rain forests where most species have highly specialized roles. For these reasons, they are unlikely to be able to migrate or adapt in the face of rapidly changing environmental conditions. One example is the golden toad (Figure 4-11, p. 92), which apparently became extinct in 1989 even though it lived in the well-protected Monteverde Cloud Forest Reserve in the mountains of Costa Rica.

All species eventually become extinct, but drastic changes in environmental conditions can eliminate large groups of species in a relatively short period of time. Throughout most of the earth's long history, species have disappeared at a low rate, called **background extinction**. Based on the fossil record and analysis of ice cores, biologists estimate that the average annual background extinction rate has been one to five species for each million species on the earth.

In contrast, **mass extinction** is a significant rise in extinction rates above the background level. In such a

SCIENCE FOCUS

Changing the Genetic Traits of Populations

We have used **artificial selection** to change the genetic characteristics of populations with similar genes. In this process, we select one or more desirable genetic traits in the population of a plant or animal such as a type of wheat, fruit (Figure 4-C), or dog. Then we use *selective breeding*, or *crossbreeding*, to generate populations of the species containing large numbers of individuals with the desired traits.

Note that artificial selection involves crossbreeding between genetic varieties of the same species or between species that are genetically close to one another, and thus it is not a form of speciation. Most of the grains, fruits, and vegetables we eat are produced by artificial selection.

Artificial selection has given us food crops with higher yields, cows that give more milk, trees that grow faster, and many different types of dogs and cats. But traditional crossbreeding is a slow process. Also, it can be used only on species that are close to one another genetically.

Now scientists are using genetic engineering to speed up our ability to manipulate genes. **Genetic engineering** is the alteration of an organism's genetic material, by adding, deleting, or changing segments of its DNA to produce desirable traits or to eliminate undesirable ones. It enables scientists to transfer genes between different species that would not interbreed in nature. Thus, genetic engineering, unlike artificial selection, can combine genetic material from very different species. For example, we can put genes from a fish species into a tomato plant to give it certain properties.

Scientists have used genetic engineering to develop modified crop plants, new drugs, pest-resistant plants, and animals that grow rapidly (Figure 4-D). They have also created genetically engineered bacteria to extract minerals such as copper from their underground ores and to clean up spills of oil and other toxic pollutants.

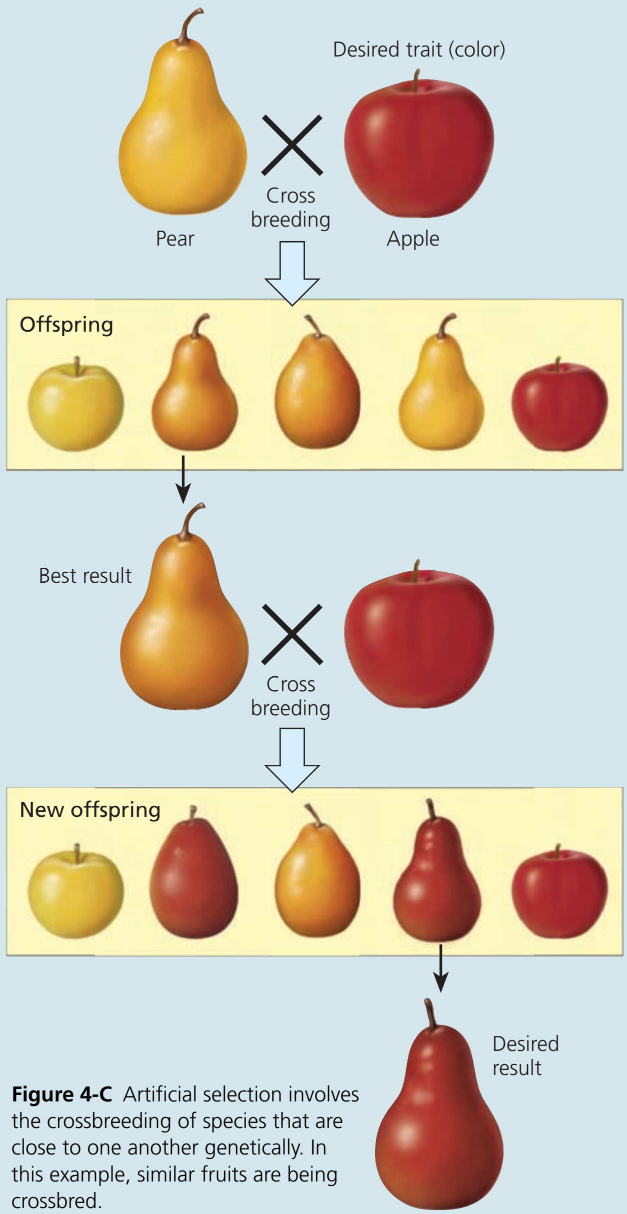


Figure 4-C Artificial selection involves the crossbreeding of species that are close to one another genetically. In this example, similar fruits are being crossbred.


R. L. Brinster and R. E. Hammer/School of Veterinary Medicine, University of Pennsylvania

Figure 4-D These mice are an example of genetic engineering. The 6-month-old mouse on the left is normal; the same-age mouse on the right had a human growth hormone gene inserted into its cells. Mice with this gene grow two to three times faster than, and twice as large as, mice without it. **Question:** How do you think the creation of such species might change the process of evolution by natural selection?

Critical Thinking

What might be some beneficial and harmful effects on the evolutionary process if genetic engineering is widely applied to plants and animals?


Michael P. Fogden/Bruce Coleman USA

Figure 4-11 This male golden toad lived in Costa Rica's high-altitude Monteverde Cloud Forest Reserve. The species became extinct in 1989 apparently because its habitat dried up.

catastrophic, widespread, and often global event, large groups of species (25–95% of all species) are wiped out worldwide in a few million years or less. Fossil and geological evidence indicate that the earth's species have experienced at least three and probably five mass extinctions (20–60 million years apart) during the past 500 million years.

Some biologists argue that a mass extinction should be distinguished by a low speciation rate as well as a high rate of extinction. Under this more strict definition, there have been only three mass extinctions. Either way, there is substantial evidence that large numbers of species have become extinct three or more times in the past.

A mass extinction provides an opportunity for the evolution of new species that can fill unoccupied ecological roles or newly created ones. As a result, evidence indicates that each occurrence of mass extinction has been followed by an increase in species diversity over several million years as new species have arisen to occupy new habitats or to exploit newly available resources. As environmental conditions change, the balance between formation of new species (speciation) and extinction of existing species determines the earth's biodiversity (**Concept 4-4A**).

The existence of millions of species today means that speciation, on average, has kept ahead of extinction, and thus species diversity has increased over time. However there is evidence that the rate of extinction is now higher than at any time during the past 65 million years and that much of this loss of biodiversity is due to human activities (**Concept 4-4B**). We examine this further in Chapter 9.

HOW WOULD YOU VOTE?

Do we have an ethical obligation to protect shark species from extinction caused mostly by our environmental impact (**Core Case Study**)? Cast your vote online at **www.cengage.com/login**.

CORE CASE STUDY

4-5 What Is Species Diversity and Why Is It Important?

CONCEPT 4-5 Species diversity is a major component of biodiversity and tends to increase the sustainability of some ecosystems.

Species Diversity Includes the Variety and Abundance of Species in a Particular Place

An important characteristic of a community and the ecosystem to which it belongs is its **species diversity**, or the number and variety of species it contains. One important component of species diversity is *species richness*, the number of different species present. For example, a biologically diverse community such as a coral reef (Figure 4-12, left) with a large number of species has high species richness, while an aspen forest community (Figure 4-12, right) may have only ten plant species, or low species richness.

For any given community, another component of species diversity is *species evenness*, the comparative numbers of individuals of each species present. The more even the numbers of individuals in each species are, the higher is the species evenness in that community. For example, the aspen forest in Figure 4-12 (right), containing a large number of aspens and relatively low numbers of individuals from the other species, has low species evenness. But most tropical forests have high species evenness, because they contain similar numbers of individuals from each of many different species.

Reinhard Dirscherl/Bruce Coleman USA

Alan Majchrowicz/Peter Arnold

Figure 4-12 These two types of ecosystems vary greatly in species richness. An example of high species richness is a coral reef (left), with a large number of different species. On the other hand, this grove of aspen trees in Alberta, Canada (right) has a small number of different species, or low species richness.

SCIENCE FOCUS

Species Richness on Islands

In the 1960s, Robert MacArthur and Edward O. Wilson began studying communities on islands to discover why large islands tend to have more species of a certain category such as insects, birds, or ferns than do small islands.

To explain these differences in species richness among islands of different sizes, MacArthur and Wilson carried out research and used their findings to propose what is called the **species equilibrium model**, or the **theory of island biogeography**. According to this widely accepted scientific theory, the number of different species (species richness) found on an island is determined by the interactions of two factors: the rate at which new species immigrate to the island and the rate at which species become locally extinct, or cease to exist, on the island.

The model projects that, at some point, the rates of species immigration and species extinction should balance so that neither rate is increasing or decreasing sharply. This balance point is the equilibrium point that determines the island's average number of different species (species richness) over time.

(The website **CengageNOW** has a great interactive animation of this model. Go to the end of this or any chapter for instructions on how to access it.)

According to the model, two features of an island affect the immigration and extinction rates of its species and thus its species diversity. One is the island's *size*. Small islands tend to have fewer species than large islands do because, for one thing, they make smaller targets for potential colonizers flying or floating toward them. Thus, they have lower immigration rates than larger islands do. In addition, a small island should have a higher extinction rate because it usually has fewer resources and less diverse habitats for its species.

A second factor is an island's *distance from the nearest mainland*. Suppose we have two islands about equal in size, extinction rates, and other factors. According to the model, the island closer to a mainland source of immigrant species should have the higher immigration rate and thus a higher species richness. The farther a potential colonizing species has to travel, the less likely it is to reach the island.

These factors interact to influence the relative species richness of different islands. Thus, larger islands closer to a mainland tend to have the most species, while smaller islands farther away from a mainland tend to have the fewest. Since MacArthur and Wilson presented their hypothesis and did their experiments, others have conducted more scientific studies that have born out their hypothesis, making it a widely accepted scientific theory.

Scientists have used this theory to study and make predictions about wildlife in *habitat islands*—areas of natural habitat, such as national parks and mountain ecosystems, surrounded by developed and fragmented land. These studies and predictions have helped scientists to preserve these ecosystems and protect their resident wildlife.

Critical Thinking

Suppose we have two national parks surrounded by development, one being a large park, the other much smaller. Which park is likely to have the higher species richness? Why?

The species diversity of communities varies with their *geographical location*. For most terrestrial plants and animals, species diversity (primarily species richness) is highest in the tropics and declines as we move from the equator toward the poles (see Figure 6, pp. S36–S37, in Supplement 8). The most species-rich environments are tropical rain forests, large tropical lakes, coral reefs, and the ocean-bottom zone.

Edward O. Wilson (Individuals Matter, p. 85) and other scientists have sought to learn more about species richness by studying species on islands (see Science Focus, above). Islands make good study areas because they are relatively isolated and it is easier to observe species arriving and disappearing from islands than it would be to make such a study in other less isolated ecosystems.

CENGAGE**NOW**™ Learn about how latitude affects species diversity and about the differences between big and small islands at CengageNOW.

Species-Rich Ecosystems Tend to Be Productive and Sustainable

What effects does species richness have on an ecosystem? In trying to answer this question, ecologists have been conducting research to answer two related questions: *First*, is plant productivity higher in species-rich ecosystems? *Second*, does species richness enhance the *stability*, or *sustainability*, of an ecosystem? Research suggests that the answers to both questions may be *yes*, but more research is needed before these scientific hypotheses can be accepted as scientific theories.

According to the first hypothesis, the more diverse an ecosystem is, the more productive it will be. That is, with a greater variety of producer species, an ecosystem will produce more plant biomass, which in turn will support a greater variety of consumer species.

A related hypothesis is that greater species richness and productivity will make an ecosystem more stable or sustainable. In other words, the greater the species richness and the accompanying web of feeding and biotic interactions in an ecosystem, the greater its sustainability, or its ability to withstand environmental disturbances such as drought or insect infestations. According to this hypothesis, a complex ecosystem, with many different species (high species richness) and the resulting variety of feeding paths, has more ways to respond to most environmental stresses because it does not have "all its eggs in one basket." According to biologist Edward O. Wilson, "There's a common sense element to this: the more species you have, the more likely you're going to have an insurance policy for the whole ecosystem."

There are exceptions, but many studies support the idea that some level of species richness and productivity can provide insurance against catastrophe. Ecologist David Tilman and his colleagues at the University of Minnesota found that communities with high plant species richness produced a certain amount of biomass more consistently than did communities with fewer species. The species-rich communities were also less affected by drought and more resistant to invasions by insect species. Because of their higher level of biomass, the species-rich communities also consumed more carbon dioxide and took up more nitrogen, thus playing more robust roles in the carbon and nitrogen cycles.

Later laboratory studies involved setting up artificial ecosystems in growth chambers where researchers could control and manipulate key variables such as temperature, light, and atmospheric gas concentrations. These studies have supported Tilman's findings.

Ecologists hypothesize that in a species-rich ecosystem, each species can exploit a different portion of the resources available. For example, some plants will bloom early and others will bloom late. Some have shallow roots to absorb water and nutrients in topsoil, and others use longer roots to tap into deeper soils. A number of studies support this hypothesis, although some do not.

There is debate among scientists about how much species richness is needed to help sustain various ecosystems. Some research suggests that the average annual net primary productivity of an ecosystem reaches a peak with 10–40 producer species. Many ecosystems contain more than 40 producer species, but do not necessarily produce more biomass or reach a higher level of stability. Scientists will continue trying to determine how many producer species are needed to enhance the sustainability of particular ecosystems and which producer species are the most important for providing such stability.

Bottom line: species richness appears to increase the productivity and stability, or sustainability, of an ecosystem (**Concept 4-5**). While there may be some exceptions to this, most ecologists now accept it as a useful hypothesis.

RESEARCH FRONTIER

Learning more about how biodiversity is related to ecosystem stability and sustainability; see **www.cengage.com/login**.

4-6 What Roles Do Species Play in an Ecosystem?

▶ **CONCEPT 4-6A Each species plays a specific ecological role called its niche.**

▶ **CONCEPT 4-6B Any given species may play one or more of five important roles—native, nonnative, indicator, keystone, or foundation—in a particular ecosystem.**

Each Species Plays a Role in Its Ecosystem

An important principle of ecology is that *each species has a specific role to play in the ecosystems where it is found* (**Concept 4-6A**). Scientists describe the role that a species plays in its ecosystem as its **ecological niche**, or simply **niche** (often pronounced "nitch"). It is a species' way of life in a community and includes everything that affects its survival and reproduction, such as how much water and sunlight it needs, how much space it requires, what it feeds on, what feeds on it, and the temperatures it can tolerate. A species' niche should not be confused with its *habitat*, which is the place where it lives. Its niche is its pattern of living.

Scientists use the niches of species to classify them broadly as *generalists* or *specialists*. **Generalist species** have broad niches (Figure 4-13, right curve). They can live in many different places, eat a variety of foods, and often tolerate a wide range of environmental conditions. Flies, cockroaches (see Case Study, p. 96), mice, rats, white-tailed deer, raccoons, and humans are generalist species.

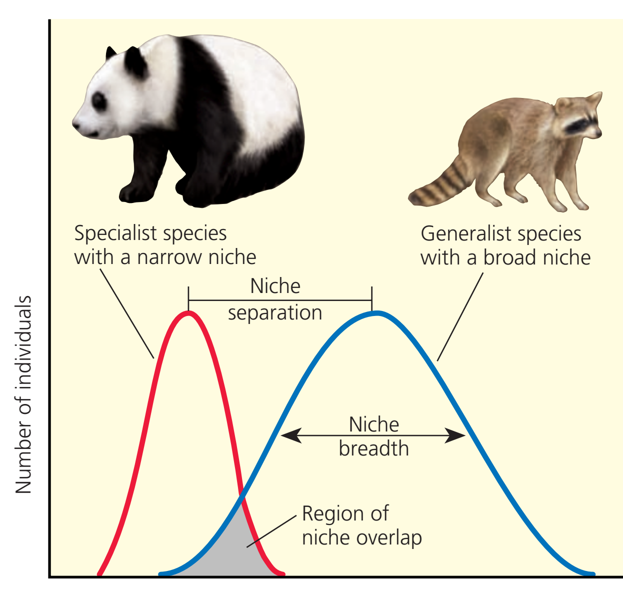


Figure 4-13 Specialist species such as the giant panda have a narrow niche (left) and generalist species such as the raccoon have a broad niche (right).

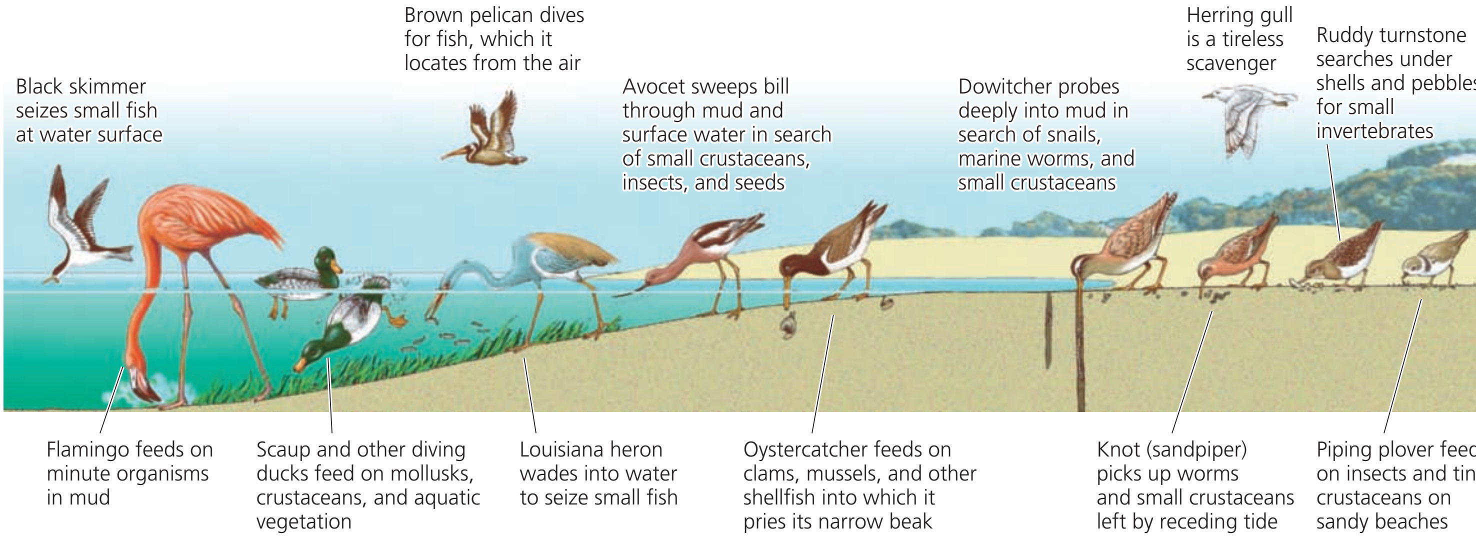


Figure 4-14 This diagram illustrates the specialized feeding niches of various bird species in a coastal wetland. This specialization reduces competition and allows sharing of limited resources.

In contrast, **specialist species** occupy narrow niches (Figure 4-13, left curve). They may be able to live in only one type of habitat, use just one or only a few types of food, or tolerate a narrow range of climatic and other environmental conditions. For example, some shorebirds occupy specialized niches, feeding on crustaceans, insects, and other organisms found on sandy beaches and their adjoining coastal wetlands (Figure 4-14).

Because of their narrow niches, specialists are more prone to extinction when environmental conditions change. For example, China's *giant panda* is highly endangered because of a combination of habitat loss, low birth rate, and its specialized diet consisting mostly of bamboo.

Is it better to be a generalist or a specialist? It depends. When environmental conditions are fairly constant, as in a tropical rain forest, specialists have an advantage because they have fewer competitors. But under rapidly changing environmental conditions, the generalist usually is better off than the specialist.

■ CASE STUDY

Cockroaches: Nature's Ultimate Survivors

Cockroaches (Figure 4-15), the bugs many people love to hate, have been around for 350 million years, outliving the dinosaurs. One of evolution's great success stories, they have thrived because they are *generalists*.

The earth's 3,500 cockroach species can eat almost anything, including algae, dead insects, fingernail clippings, salts deposited by sweat in tennis shoes, electrical cords, glue, paper, and soap. They can also live and breed almost anywhere except in polar regions.

Some cockroach species can go for a month without food, survive for weeks on a drop of water, and withstand massive doses of radiation. One species can survive being frozen for 48 hours.

Cockroaches usually can evade their predators—and a human foot in hot pursuit—because most species have antennae that can detect minute movements of air. They also have vibration sensors in their knee joints, and they can respond faster than you can blink your eye. Some even have wings. They have compound eyes that allow them to see in almost all directions at once. Each eye has about 2,000 lenses, compared to just one in each of your eyes.

And, perhaps most significantly, they have high reproductive rates. In only a year, a single Asian cockroach and its offspring can add about 10 million new cockroaches to the world. Their high reproductive rate also helps them to quickly develop genetic resistance to almost any poison we throw at them.

Clemson University–USDA Cooperative Extension Slide Series

Figure 4-15 As generalists, cockroaches are among the earth's most adaptable and prolific species. This is a photo of an American cockroach.

Most cockroaches sample food before it enters their mouths and learn to shun foul-tasting poisons. They also clean up after themselves by eating their own dead and, if food is scarce enough, their living.

About 25 species of cockroach live in homes and can carry viruses and bacteria that cause diseases. On the other hand, cockroaches play a role in nature's food webs. They make a tasty meal for birds and lizards.

THINKING ABOUT
A Shark's Niche

CORE CASE STUDY

Do you think that most sharks (**Core Case Study**) occupy specialist or generalist niches? Explain.

Species Can Play Five Major Roles within Ecosystems

Niches can be classified further in terms of specific roles that certain species play within ecosystems. Ecologists describe *native*, *nonnative*, *indicator*, *keystone*, and *foundation species*. Any given species may play one or more of these five roles in a particular ecosystem (**Concept 4-6B**).

Native species are those species that normally live and thrive in a particular ecosystem. Other species that migrate into, or are deliberately or accidentally introduced into, an ecosystem are called **nonnative species**, also referred to as *invasive*, *alien*, and *exotic species*.

Some people tend to think of nonnative species as threatening. In fact, most introduced and domesticated plant species such as food crops and flowers and animals such as chickens, cattle, and fish from around the world are beneficial to us. However, some nonnative species can compete with and reduce a community's native species, causing unintended and unexpected consequences. In 1957, for example, Brazil imported wild African honeybees (Figure 4-16) to help increase honey production. Instead, the bees displaced domestic honeybees and reduced the honey supply.

John Lindsay-Smith/Shutterstock

Figure 4-16 Wild African honeybees, popularly known as "killer bees," were imported into Brazil. These nonnative species caused problems, including the displacement of native honeybees and the deaths of people and domestic animals.

Since then, these nonnative honeybee species—popularly known as "killer bees"—have moved northward into Central America and parts of the southwestern and southeastern United States. The wild African bees are not the fearsome killers portrayed in some horror movies, but they are aggressive and unpredictable. They have killed thousands of domesticated animals and an estimated 1,000 people in the western hemisphere, many of whom were allergic to bee stings.

Nonnative species can spread rapidly if they find a new location that is favorable. In their new niches, these species often do not face the predators and diseases they face in their native niches, or they may be able to out-compete some native species in their new locations. We will examine this environmental threat in greater detail in Chapter 8.

Indicator Species Serve as Biological Smoke Alarms

Species that provide early warnings of damage to a community or an ecosystem are called **indicator species**. Birds are excellent biological indicators because they are found almost everywhere and are affected quickly by environmental changes such as the loss or fragmentation of their habitats and the introduction of chemical pesticides. The populations of many bird species are declining.

Butterflies are also good indicator species because their association with various plant species makes them vulnerable to habitat loss and fragmentation. Some amphibians are also classified as indicator species (see the following Case Study).

CASE STUDY
Why Are Amphibians Vanishing?

Amphibians (frogs, toads, and salamanders) live part of their lives in water and part on land. Populations of some amphibians, also believed to be indicator species, are declining throughout the world.

Amphibians were the first vertebrates (animals with backbones) to set foot on the earth. Historically, they have also been better at adapting to environmental changes through evolution than many other species have been. Some amphibian species are not in danger (Figure 4-17, p. 98, left). But many amphibian species (Figure 4-17, right) are having difficulty adapting to some of the rapid environmental changes that have taken place in the air and water and on the land during the past few decades—changes resulting mostly from human activities.

Since 1980, populations of hundreds of the world's almost 6,000 amphibian species have been vanishing or declining in almost every part of the world, even in

Sascha Burkard/Shutterstock

Abhindia/Shutterstock

Figure 4-17 The well-known red-eyed tree frog (left) found in tropical rain forests in Mexico and Central America is currently not threatened with extinction. However, some species of the poison dart frog (right) found in the tropical forests of Brazil and southern Suriname are threatened with extinction, mostly because of an infectious fungus and habitat loss from logging and farming. This frog's bright blue color warns predators that it is poisonous to eat. The toxic secretions of at least three of these species are used to poison the tips of blow darts that native peoples in the frog's tropical habitat use for hunting.

protected wildlife reserves and parks (Figure 4-11). According to a 2008 assessment by the International Union for Conservation of Nature and Natural Resources (IUCN), about 32% of all known amphibian species (and more than 80% of those in the Caribbean) are threatened with extinction, and populations of another 43% of the species are declining.

Frogs are especially sensitive and vulnerable to environmental disruption at various points in their life cycle. As tadpoles, frogs live in water and eat plants; as adults, they live mostly on land and eat insects that can expose them to pesticides. The eggs of frogs have no protective shells to block harmful UV radiation or pollution. As adults, they take in water and air through their thin, permeable skins, which can readily absorb pollutants from water, air, or soil. And they have no hair, feathers, or scales to protect them.

No single cause has been identified to explain these amphibian declines. However, scientists have identified a number of factors that can affect frogs and other amphibians at various points in their life cycles:

- *Habitat loss and fragmentation*, especially from the draining and filling of freshwater wetlands, deforestation, farming, and urban development.
- *Prolonged drought*, which can dry up breeding pools so that few tadpoles survive.
- *Increases in UV radiation* resulting from reductions in stratospheric ozone during the past few decades, which were caused by chemicals we put into the air that ended up in the stratosphere. Higher doses of UV radiation can harm embryos of amphibians in shallow ponds and adults exposing themselves to the sun for warmth.
- *Parasites* such as flatworms, which feed on the amphibian eggs laid in water, apparently have caused an increase in births of amphibians with missing or extra limbs.
- *Viral and fungal diseases*, especially the chytrid fungus that attacks the skin of frogs, apparently reducing their ability to take in water and leading to death from dehydration. Such diseases can spread because adults of many amphibian species congregate in large numbers to breed.
- *Pollution*, especially exposure to pesticides in ponds and in the bodies of insects consumed by frogs, which can make them more vulnerable to bacterial, viral, and fungal diseases and to some parasites.
- *Climate change*. A 2005 study found an apparent correlation between climate change caused by atmospheric warming and the extinction of about two-thirds of the 110 known species of harlequin frog in tropical forests in Central and South America. Climate change or at least short-term weather patterns such as El Niño (see pp. S27–S28 in Supplement 7) played an important role in the extinction of the golden toad in Costa Rica (Figure 4-11).
- *Overhunting*, especially in Asia and France, where frog legs are a delicacy.
- *Natural immigration of, or deliberate introduction of, nonnative predators and competitors* (such as certain fish species).

A combination of such factors, which vary from place to place, probably is responsible for most of the decline and disappearances among amphibian species.

Why should we care if some amphibian species become extinct? Scientists give three reasons. *First,* amphibians are sensitive biological indicators of changes in environmental conditions such as habitat loss and degradation, air and water pollution, UV radiation, and climate change. The more intense threats to their survival suggest that environmental health is deteriorating in many parts of the world.

Second, adult amphibians play important ecological roles in biological communities. For example, amphibians eat more insects (including mosquitoes) than do birds. In some habitats, the extinction of certain amphibian species could lead to extinction of other species, such as reptiles, birds, aquatic insects, fish, mammals, and other amphibians that feed on them or their larvae.

Third, amphibians are a genetic storehouse of pharmaceutical products waiting to be discovered. For example, compounds in secretions from amphibian skin have been isolated and used as painkillers and antibiotics, and in treatments for burns and heart disease.

Many scientists believe that the rapidly increasing chances for global extinction of a variety of amphibian species is a warning about the harmful effects of an array of environmental threats to biodiversity, mostly resulting from human activities.

RESEARCH FRONTIER

Learning more about why amphibians are disappearing and applying this knowledge to other threatened species; see **www.cengage.com/login**.

Keystone Species Play Critical Roles in Their Ecosystems

A keystone is the wedge-shaped stone placed at the top of a stone archway. Remove this stone and the arch collapses. In some communities and ecosystems, ecologists hypothesize that certain species play a similar role. **Keystone species** are species whose roles have a large effect on the types and abundance of other species in an ecosystem.

Keystone species often exist in relatively limited numbers in their ecosystems, but the effects that they have there are often much larger than their numbers would suggest. And because of their often smaller numbers, some keystone species are more vulnerable to extinction than other species are.

Keystone species can play several critical roles in helping to sustain ecosystems. One such role is the *pollination* of flowering plant species by butterflies (Figure 4-A), bees (Figure 4-16), hummingbirds, bats, and other species. In addition, *top predator* keystone species feed on and help to regulate the populations of other species. Examples are the wolf, leopard, lion, some shark species, and the American alligator (see the following Case Study).

CONNECTIONS

Shark Declines and Other Species CORE CASE STUDY

Various shark species (**Core Case Study**) help to keep the populations of some species in check, while supporting the populations of other species. In 2007, scientists reported that the decline in certain shark populations along the U.S. Atlantic coast led to an explosion in populations of rays and skates, which sharks normally feed on. Now the rays and skates are feasting on bay scallops, resulting in a sharp decline in their population and in the area's bay scallop fishing business.

The loss of a keystone species can lead to population crashes and extinctions of other species in a community that depends on them for certain ecological services. This is why it so important for scientists to identify and protect keystone species.

THINKING ABOUT

Sharks and Biodiversity CORE CASE STUDY

Why are some shark species (**Core Case Study**) considered to be keystone species?

CASE STUDY

The American Alligator—A Keystone Species That Almost Went Extinct

The American alligator (Figure 4-18), North America's largest reptile, has no natural predators except for humans and it plays a number of important roles in the ecosystems where it is found. This species has outlived the dinosaurs and survived many challenges to its existence.

A. & J. Visage/Peter Arnold, Inc.

Figure 4-18 *Keystone species:* The American alligator plays an important ecological role in its marsh and swamp habitats in the southeastern United States. Since being classified as an endangered species in 1967, it has recovered enough to have its status changed from endangered to threatened—an outstanding success story in wildlife conservation.

However, starting in the 1930s, alligators in the United States faced a new challenge; hunters began killing large numbers of these animals for their exotic meat and their supple belly skin, used to make expensive shoes, belts, and pocketbooks. Other people hunted alligators for sport or out of dislike for the large reptile. By the 1960s, hunters and poachers had wiped out 90% of the alligators in the U.S. state of Louisiana, and the alligator population in the Florida Everglades was also near extinction.

Those who did not care much for the alligator were probably not aware of its important ecological role—its *niche*—in subtropical wetland ecosystems. Alligators dig deep depressions, or gator holes, using their jaws and claws. These depressions hold freshwater during dry spells, serve as refuges for aquatic life, and supply freshwater and food for fishes, insects, snakes, turtles, birds, and other animals. Large alligator nesting mounds also provide nesting and feeding sites for some herons and egrets (Figure 4-3, right), and red-bellied turtles use old gator nests for incubating their eggs. In addition, alligators eat large numbers of gar, a predatory fish, which helps to maintain populations of game fish such as bass and bream that the gar like to eat.

As alligators create gator holes and nesting mounds, they help to keep shore and open water areas free of invading vegetation. Without this free ecosystem service, freshwater ponds and coastal wetlands where alligators live would be filled in with shrubs and trees, and dozens of species would disappear from these ecosystems.

For these reasons, some ecologists classify the American alligator as a *keystone species* because of its important ecological role in helping to maintain the sustainability of the ecosystems in which it is found.

In 1967, the U.S. government placed the American alligator on the endangered species list. Protected from hunters, by 1975, the population had made a strong comeback in many areas—too strong, according to homeowners who now find alligators in their backyards and swimming pools, and to duck hunters whose retriever dogs are sometimes eaten by alligators.

In 1977, the U.S. Fish and Wildlife Service reclassified the American alligator as a *threatened* species in the U.S. states of Florida, Louisiana, and Texas, where 90% of the animals live. Today, there are well over a million alligators in Florida, and the state now allows property owners to kill alligators that stray onto their land. To conservation biologists, the comeback of the American alligator is an important success story in wildlife conservation.

THINKING ABOUT
The American Alligator and Biodiversity

What are two ways in which the American alligator supports one or more of the four components of biodiversity (Figure 4-2) within its environment?

Foundation Species Help to Form the Bases of Ecosystems

Another important type of species in some ecosystems is a **foundation species**, species that play a major role in shaping their communities by creating and enhancing their habitats in ways that benefit other species. For example, elephants push over, break, or uproot trees, creating openings in the grasslands and woodlands of Africa. This promotes the growth of grasses and other forage plants that benefit smaller grazing species such as antelope. It also accelerates nutrient cycling rates.

Beavers (Figure 4-19a) are another good example of a foundation species. Acting as "ecological engineers," they build dams (Figure 4-19b) in streams to create ponds and wetlands that they and other species use (Figure 4-19c). Their large front teeth enable them to


Oleg Kozlov/Shutterstock
(a)


Coia Hubert/Shutterstock
(b)


Ryan Morgan/Shutterstock
(c)

Figure 4-19 *Foundation species:* beavers **(a)** built a dam **(b)** to create this pond in Canada. They create such ponds and other wetlands so that they can build their own shelters, called lodges, on the water **(c)**, which help to protect them from predators. The pond also provides a "foundation" for many other species of plants, waterfowl, and other animals that can thrive in aquatic settings such as this one. However, beavers cut down large numbers of trees on land near streams to build their dams and lodges. This decreases terrestrial biodiversity and can increase soil erosion, which adds sediment pollution to streams. Flooding from beaver dams can also damage crops, roads, and buildings.

cut down medium-size trees that they use to build dams and the lodges where they live. They also work at night and sleep during the day, which helps them to avoid predators.

There are other examples of foundation species. Some bat and bird species, for example, help to regenerate deforested areas and spread fruit plants by depositing plant seeds with their droppings.

Keystone and foundation species play similar roles. In general, the major difference between the two types of species is that foundation species help to create habitats and ecosystems. They often do this by almost literally providing the foundation for the ecosystem (as beavers do, for example). However, keystone species can do this and more. They sometimes play this foundation role (as do alligators), but also play an active role in maintaining the ecosystem and keeping it functioning.

RESEARCH FRONTIER

Identifying and protecting keystone and foundation species; see **www.cengage.com/login**.

Here are this chapter's *three big ideas*.

- Populations evolve when genes mutate and give some individuals genetic traits that enhance their abilities to survive and to produce offspring with these traits (natural selection).
- Human activities are decreasing the earth's vital biodiversity by causing the extinction of species and by disrupting habitats needed for the development of new species.
- Each species plays a specific ecological role (ecological niche) in the ecosystem where it is found.

REVISITING Sharks and Sustainability

CORE CASE STUDY

SUSTAINABILITY

The **Core Case Study** on sharks at the beginning of this chapter shows that the importance of a species does not always match the public's perception of it. While many people worry about the fates of panda bears and polar bears (both facing threats of extinction), most people fear sharks and do not view them as cute and cuddly or worthy of protection. Yet they are no less important to their ecosystems. If they disappeared, ocean ecosystems would be severely damaged and some might even collapse. This could greatly disrupt the earth's climates and food supplies for billions of people. And like the polar bears, almost a third of the world's sharks face serious threats of extinction due to human activities.

In this chapter, we studied the importance of biodiversity, especially the numbers and varieties of species found in different parts of the world, along with the other forms of biodiversity—genetic, ecosystem, and functional diversity. We also studied the process whereby all species came to be, according to the scientific theory of biological evolution through natural selection. Taken together, these two great assets, biodiversity and evolution, represent irreplaceable natural capital. Each depends upon the other and upon whether humans can respect and preserve this natural capital.

Finally, we examined the variety of roles played by species in ecosystems. For example, we saw that some shark species and other species are keystone species on which their ecosystems depend for survival and health. When keystone species are threatened, whole ecosystems are threatened.

Ecosystems and the variety of species they contain are functioning examples of the three **principles of sustainability** (see back cover) in action. They depend on solar energy and on the chemical cycling of nutrients. Ecosystems also help to sustain *biodiversity* in all its forms. In the next chapter, we delve further into how species interact and how their interactions result in the natural regulation of populations and the maintenance of biodiversity.

All we have yet discovered is but a trifle in comparison with what lies hid in the great treasury of nature.

ANTOINE VAN LEEUWENHOCK

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 81. Describe the threats to many of the world's shark species (**Core Case Study**) and explain why we should protect sharks from extinction as a result of our activities. CORE CASE STUDY
2. What are the four major components of **biodiversity (biological diversity)**? What is the importance of biodiversity? What are **species**? Describe the importance of insects. Define and give three examples of **biomes**.
3. What is a **fossil** and why are fossils important for understanding the history of life? What is **biological evolution**? Summarize the theory of evolution. What is **natural selection**? What is a **mutation** and what role do mutations play in evolution by natural selection? What

is an **adaptation (adaptive trait)**? What is **differential reproduction** and why is it important? How did we become such a powerful species? What are two limits to evolution by natural selection? What are three myths about evolution through natural selection?

4. Describe how geologic processes can affect natural selection. How can climate change and catastrophes such as asteroid impacts affect natural selection? Describe conditions on the earth that favor the development of life as we know it.

5. What is **speciation**? Distinguish between **geographic isolation** and **reproductive isolation** and explain how they can lead to the formation of a new species. Distinguish between **artificial selection** and **genetic engineering** and give an example of each.

6. What is **extinction**? What is an **endemic species** and why can such a species be vulnerable to extinction? Distinguish between **background extinction** and **mass extinction**.

7. What is **species diversity**? Distinguish between species richness and species evenness and give an example of each. Summarize the **theory of island biogeography (species equilibrium model)**. According to this theory, what two factors affect the immigration and extinction rates of species on an island? What are habitat islands? Explain why species-rich ecosystems tend to be productive and sustainable.

8. What is an **ecological niche**? Distinguish between **specialist species** and **generalist species** and give an example of each. Why do some scientists consider the cockroach to be one of evolution's greatest success stories?

9. Distinguish among **native**, **nonnative**, and **indicator species** and give an example of each type. What major ecological roles do amphibian species play? List nine factors that help to threaten frogs and other amphibians with extinction. What are three reasons for protecting amphibians? Distinguish between **keystone** and **foundation species**. Describe the role of some sharks as a keystone species. Describe the role of the American alligator as a keystone species and how it was brought back from near extinction. Describe the role of beavers as a foundation species.

10. What are this chapter's *three big ideas*? How are ecosystems and the variety of species they contain related to the three **principles of sustainability**?

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. How might we and other species be affected if all of the world's sharks were to go extinct? (CORE CASE STUDY)

2. What role does each of the following processes play in helping to implement the three **principles of sustainability** (see back cover): **(a)** natural selection, **(b)** speciation, and **(c)** extinction?

3. How would you respond to someone who tells you:
   a. that he or she does not believe in biological evolution because it is "just a theory"?
   b. that we should not worry about air pollution because natural selection will enable humans to develop lungs that can detoxify pollutants?

4. Describe the major differences between the ecological niches of humans and cockroaches. Are these two species in competition? If so, how do they manage to coexist?

5. How would you experimentally determine whether an organism is **(a)** a keystone species and **(b)** a foundation species?

6. Is the human species a keystone species? Explain. If humans were to become extinct, what are three species that might also become extinct and three species whose populations would probably grow?

7. How would you respond to someone who says that because extinction is a natural process, we should not worry about the loss of biodiversity when species become extinct as a result of our activities?

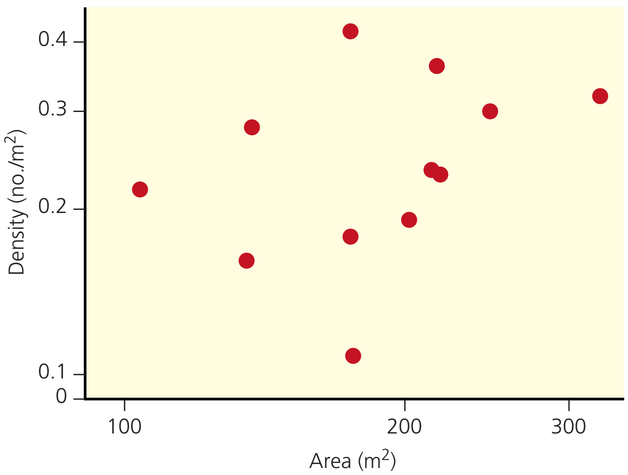
8. List three ways in which you could apply **Concept 4-4B** to making your lifestyle more environmentally sustainable.

9. Congratulations! You are in charge of the future evolution of life on the earth. What are the three things that you would consider to be the most important to do?

10. List two questions that you would like to have answered as a result of reading this chapter.

DATA ANALYSIS

This graph shows data collected by scientists investigating island biogeography. It shows measurements taken for two variables: the area within which measurements were taken, and the population density of a certain species of lizard found in each area. Note that the areas studied varied from 100 square meters (m^2) (1,076 square feet) to 300 m^2 (3,228 square feet) (x-axis). Densities measured varied from 0.1 to 0.4 individuals per m^2 (y-axis). Study the data and answer the following questions.



1. How many measurements below 0.2 individuals per m^2 were made? How many of these measurements were made in areas smaller than 200 m^2? How many were made in areas larger than 200 m^2?
2. How many measurements above 0.2 individuals per m^2 were made? How many of these measurements were made in areas smaller than 200 m^2? How many were made in areas larger than 200 m^2?
3. Do your answers support the hypothesis that larger islands tend to have higher species densities? Explain.

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5 Biodiversity, Species Interactions, and Population Control

CORE CASE STUDY The Southern Sea Otter: A Species in Recovery

Southern sea otters (Figure 5-1, left) live in giant kelp forests (Figure 5-1, right) in shallow waters along part of the Pacific coast of North America. Most remaining members of this endangered species are found off the western coast of the United States between the cities of Santa Cruz and Santa Barbara, California.

Southern sea otters are fast and agile swimmers that dive to the ocean bottom looking for shellfish and other prey. These marine mammals use stones as tools to pry shellfish off rocks under water. When they return to the surface they swim on their backs, and using their bellies as a table, break open the shells by cracking them against a stone (Figure 5-1, left). Each day, a sea otter consumes about a fourth of its weight in clams, mussels, crabs, sea urchins, abalone, and about 40 other species of bottom-dwelling organisms.

It is believed that between 16,000 and 17,000 southern sea otters once lived in the waters of their habitat area along the California coast. But by the early 1900s, the species was hunted almost to extinction in this region by fur traders who killed them for their thick, luxurious fur. Commercial fisherman also killed otters that were competing with them for valuable abalone and other shellfish.

Between 1938 and 2009, the population of southern sea otters off California's coast increased from about 50 to about 2,654. Their partial recovery had gotten a boost in 1977 when the U.S. Fish and Wildlife Service declared the species endangered in most of its range with a population of only 1,850 individuals. But this species has a long way to go before its population will be large enough to justify removing it from the endangered species list.

Why should we care about the southern sea otters of California? One reason is *ethical*: many people believe it is wrong to allow human activities to cause the extinction of any species. Another reason is that people love to look at these appealing and highly intelligent animals as they play in the water. As a result, they help to generate millions of dollars a year in tourism revenues in coastal areas where they are found.

A third reason to care about otters—and a key reason in our study of environmental science—is that biologists classify them as a *keystone species* (see Chapter 4, p. 99). Without southern sea otters, scientists hypothsize that sea urchins and other kelp-eating species would probably destroy the kelp forests and much of the rich biodiversity associated with them.

Biodiversity is an important part of the earth's natural capital and is the focus of one of the three **principles of sustainability** (see back cover). In this chapter, we will look at two factors that affect biodiversity: how species interact and help control one another's population sizes and how biological communities and populations respond to changes in environmental conditions.

Tom and Pat Leeson, Ardea London Ltd

Paul Whitted/Shutterstock

Figure 5-1 An endangered southern sea otter in Monterey Bay, California (USA), uses a stone to crack the shell of a clam (left). It lives in a giant kelp bed (right). Scientific studies indicate that the otters act as a keystone species in a kelp forest system by helping to control the populations of sea urchins and other kelp-eating species.

Key Questions and Concepts

5-1 How do species interact?

CONCEPT 5-1 Five types of species interactions—competition, predation, parasitism, mutualism, and commensalism—affect the resource use and population sizes of the species in an ecosystem.

5-2 What limits the growth of populations?

CONCEPT 5-2 No population can continue to grow indefinitely because of limitations on resources and because of competition among species for those resources.

5-3 How do communities and ecosystems respond to changing environmental conditions?

CONCEPT 5-3 The structure and species composition of communities and ecosystems change in response to changing environmental conditions through a process called ecological succession.

Note: Supplements 2 (p. S3), 5 (p. S18), and 8 (p. S30) can be used with this chapter.

In looking at nature, never forget that every single organic being around us may be said to be striving to increase its numbers.

CHARLES DARWIN, 1859

5-1 How Do Species Interact?

CONCEPT 5-1 Five types of species interactions—competition, predation, parasitism, mutualism, and commensalism—affect the resource use and population sizes of the species in an ecosystem.

Species Interact in Five Major Ways

Ecologists identify five basic types of interactions between species as they share limited resources such as food, shelter, and space:

- **Interspecific competition** occurs when members of two or more species interact to gain access to the same limited resources such as food, water, light, and space.
- **Predation** occurs when a member of one species (the *predator*) feeds directly on all or part of a member of another species (the *prey*).
- **Parasitism** occurs when one organism (the *parasite*) feeds on another organism (the *host*), usually by living on or in the host.
- **Mutualism** is an interaction that benefits both species by providing each with food, shelter, or some other resource.
- **Commensalism** is an interaction that benefits one species but has little or no effect on the other.

These interactions have significant effects on the resource use and population sizes of the species in an ecosystem (**Concept 5-1**).

Most Species Compete with One Another for Certain Resources

The most common interaction between species is *competition* for limited resources. While fighting for resources does occur, most competition involves the ability of one species to become more efficient than another species in getting food, space, light, or other resources.

Recall that each species plays a role in its ecosystem called its *ecological niche* (see Chapter 4, p. 95). Some species are specialists with a narrow niche (see Figure 4-13, left, p. 95) and some are generalists with a broad niche (see Figure 4-13, right, p. 95). When two species compete with one another for the same resources such as food, light, or space, their niches *overlap*. The greater this overlap, the more intense their competition for key resources. If one species can take over the largest share of one or more key resources, each of the other competing species must move to another area (if possible), adapt by shifting its feeding habits or behavior through natural selection to reduce or alter its niche, suffer a sharp population decline, or become extinct in that area.

Humans compete with many other species for space, food, and other resources. As our ecological footprints grow and spread (see Figure 1-13, p. 16) and we convert more of the earth's land, aquatic resources, and net primary productivity (see Figure 3-15, p. 66) to our uses, we are taking over the habitats of many other species and depriving them of resources they need to survive.

THINKING ABOUT
Humans and the Southern Sea Otter

CORE CASE STUDY

What human activities have interfered with the ecological niche of the southern sea otter (**Core Case Study**)?

Some Species Evolve Ways to Share Resources

Over a time scale long enough for natural selection to occur, populations of some species develop adaptations that allow them to reduce or avoid competition with other species for resources. One way this happens is through **resource partitioning**. It occurs when species competing for similar scarce resources evolve specialized traits that allow them to share resources by using parts of them, using them at different times, or using them in different ways.

Figure 5-2 shows resource partitioning by some insect-eating bird species. In this case, their adaptations allow them to reduce competition by feeding in different portions of certain spruce trees and by feeding on different insect species. Figure 4-14 (p. 96) shows how the evolution of specialized feeding niches has reduced competition for resources among bird species in a coastal wetland.

Another example of resource partitioning through natural selection involves birds called honeycreepers that live in the U.S. state of Hawaii. Long ago these birds started from a single ancestral species. But through evolution by natural selection there are now numerous honeycreeper species. Each has a different type of specialized beak for feeding on certain food sources such as specific types of insects, nectar from particular types of flowers, and certain types of seeds and fruits (Figure 5-3).

Most Consumer Species Feed on Live Organisms of Other Species

In **predation**, a member of one species (the **predator**) feeds directly on all or part of a living organism (the **prey**) as part of a food web. Together, the two different species, such as a brown bear (the predator, or hunter) and a salmon (the prey, or hunted), form a **predator–prey relationship** (Figure 5-4). Such relationships are also shown in Figures 3-12 (p. 63) and 3-13 (p. 64).

Sometimes predator–prey relationships can surprise us. During the summer months, the grizzly bears of the Greater Yellowstone ecosystem in the western United States eat huge amounts of army cutworm moths, which huddle in masses high on remote mountain slopes. One grizzly bear can dig out and lap up as many as 40,000 of the moths in a day. Consisting of 50–70% fat, the moths

Figure 5-2 *Sharing the wealth:* This diagram illustrates *resource partitioning* among five species of insect-eating warblers in the spruce forests of the U.S. state of Maine. Each species minimizes competition with the others for food by spending at least half its feeding time in a distinct portion (yellow highlighted areas) of the spruce trees, and by consuming somewhat different insect species. (After R. H. MacArthur, "Population Ecology of Some Warblers in Northeastern Coniferous Forests," *Ecology* 36 (1958): 533–536.)

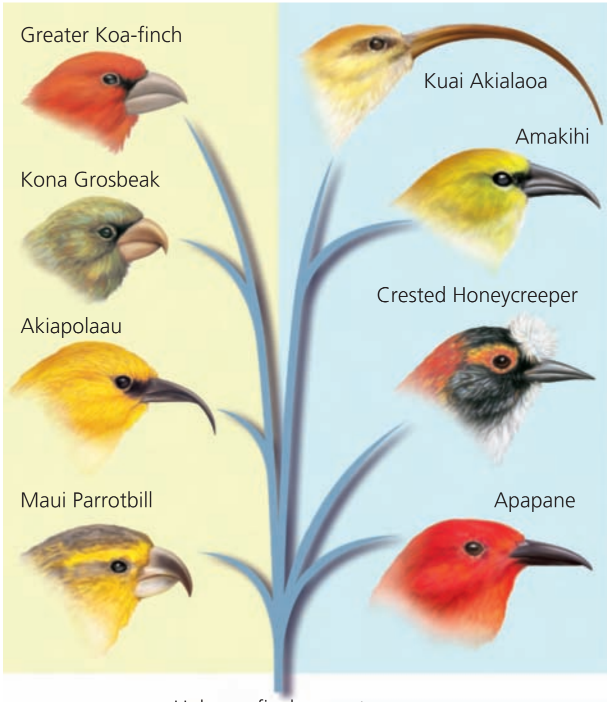


Figure 5-3 *Specialist species of honeycreepers:* Through natural selection, different species of honeycreepers developed specialized ecological niches that reduced competition between these species. Each species has evolved a specialized beak to take advantage of certain types of food resources.

offer a nutrient that the bear can store in its fatty tissues and draw on during its winter hibernation.

In giant kelp forest ecosystems, sea urchins (Science Focus, Figure 5-A, p. 108) prey on kelp, a form of seaweed. However, as keystone species, southern sea otters (**Core Case Study**, Figure 5-1, left) prey on the sea urchins and thus keep them from destroying the kelp forests.

CORE CASE STUDY

Predators have a variety of methods that help them to capture prey. *Herbivores* can simply walk, swim, or fly up to the plants they feed on. *Carnivores* feeding on mobile prey have two main options: *pursuit* and *ambush*. Some such as the cheetah catch prey by running fast; others such as the American bald eagle can fly and have keen eyesight; still others cooperate in capturing their prey. For example, African lions capture giraffes by hunting in packs.

Other predators use *camouflage* to hide in plain sight and ambush their prey. For example, praying mantises (see Figure 4-A, right, p. 83) sit on flowers or plants of a color similar to their own and ambush visiting insects. White ermines (a type of weasel) and snowy owls hunt in snow-covered areas. People camouflage themselves to hunt wild game and use camouflaged traps to capture wild animals.

Some predators use *chemical warfare* to attack their prey. For example, some spiders and poisonous snakes use venom to paralyze their prey and to deter their predators.

Steve Hilebrand/U.S. Fish and Wildlife Service

Figure 5-4 *Predator-prey relationship:* This brown bear (the predator) in the U.S. state of Alaska has captured and will feed on this salmon (the prey).

SCIENCE FOCUS

Threats to Kelp Forests

A kelp forest is composed of large concentrations of a seaweed called *giant kelp* whose long blades grow straight to the surface (Figure 5-1, right). Under good conditions, its blades can grow 0.6 meter (2 feet) a day. A gas-filled bladder at its base holds up each blade. The blades are very flexible and can survive all but the most violent storms and waves.

Kelp forests are one of the most biologically diverse ecosystems found in marine waters, supporting large numbers of marine plants and animals. These forests help reduce shore erosion by blunting the force of incoming waves and trapping some of the outgoing sand. People harvest kelp as a renewable resource, extracting a substance called algin from its blades. This substance is used to make toothpaste, cosmetics, ice cream, and hundreds of other products.

Sea urchins and pollution are major threats to kelp forests. Acting as predators, large populations of sea urchins (Figure 5-A) can rapidly devastate a kelp forest because they eat the bases of young kelp plants. Southern sea otters, a keystone species, help to control populations of sea urchins. An adult southern sea otter (Figure 5-1, left) can eat up to 50 sea urchins a day—equivalent to a 68-kilogram (150-pound) person eating 160 quarter-pound hamburgers a day. Scientific studies indicate that without southern sea otters, giant kelp-forest ecosystems off the coast of California would collapse, thereby reducing aquatic biodiversity.


Deborah Meeks/SuperStock

Figure 5-A This purple sea urchin inhabits the coastal waters of the U.S. state of California.

A second threat to kelp forests is polluted water running off of the land and into the coastal waters where kelp forests grow. The pollutants in this runoff include pesticides and herbicides, which can kill kelp plants and other kelp forest species and upset the food webs in these forests. Another runoff pollutant is fertilizer. Its plant nutrients (mostly nitrates) can cause excessive growth of algae and other plants, which block some of the sunlight needed to support the growth of giant kelp, and thus fertilizer in runoff upsets these aquatic ecosystems.

A looming threat to kelp forests is the warming of the world's oceans. Giant kelp forests require fairly cool water. If coastal waters warm up during this century, as projected by climate models, many—perhaps most—of the kelp forests off the coast of California will disappear. If this happens, the southern sea otter and many other species will also disappear, unless they can migrate to other suitable locations, which are few and far between on the earth.

Critical Thinking

List three ways to protect giant kelp forests and southern sea otters.

Prey species have evolved many ways to avoid predators, including abilities to run, swim, or fly fast, and highly developed senses of sight or smell that alert some prey to the presence of predators. Other avoidance adaptations include protective shells (as on armadillos and turtles), thick bark (on giant sequoia), spines (on porcupines), and thorns (on cacti and rose bushes). Many lizards have brightly colored tails that break off when they are attacked, often giving them enough time to escape.

Other prey species use the camouflage of certain shapes or colors. Chameleons and cuttlefish have the ability to change color. Some insect species have shapes that look like twigs (Figure 5-5a), bark, thorns, or even bird droppings on leaves. A leaf insect can be almost invisible against its background (Figure 5-5b), as can an arctic hare in its white winter fur.

Chemical warfare is another common strategy. Some prey species discourage predators with chemicals that are *poisonous* (oleander plants), *irritating* (stinging nettles and bombardier beetles, Figure 5-5c), *foul smelling* (skunks, skunk cabbages, and stinkbugs), or *bad tasting* (buttercups and monarch butterflies, Figure 5-5d). When attacked, some species of squid and octopus emit clouds of black ink, allowing them to escape by confusing their predators.

Many bad-tasting, bad-smelling, toxic, or stinging prey species have evolved *warning coloration*, brightly colored advertising that helps experienced predators to recognize and avoid them. They flash a warning: "Eating me is risky." Examples are brilliantly colored poisonous frogs (Figure 5-5e and Figure 4-17, right, p. 98) and foul-tasting monarch butterflies (Figure 5-5d). When a bird such as a blue jay eats a monarch butterfly, it usually vomits and learns to avoid them.

CONNECTIONS

Coloration and Dangerous Species

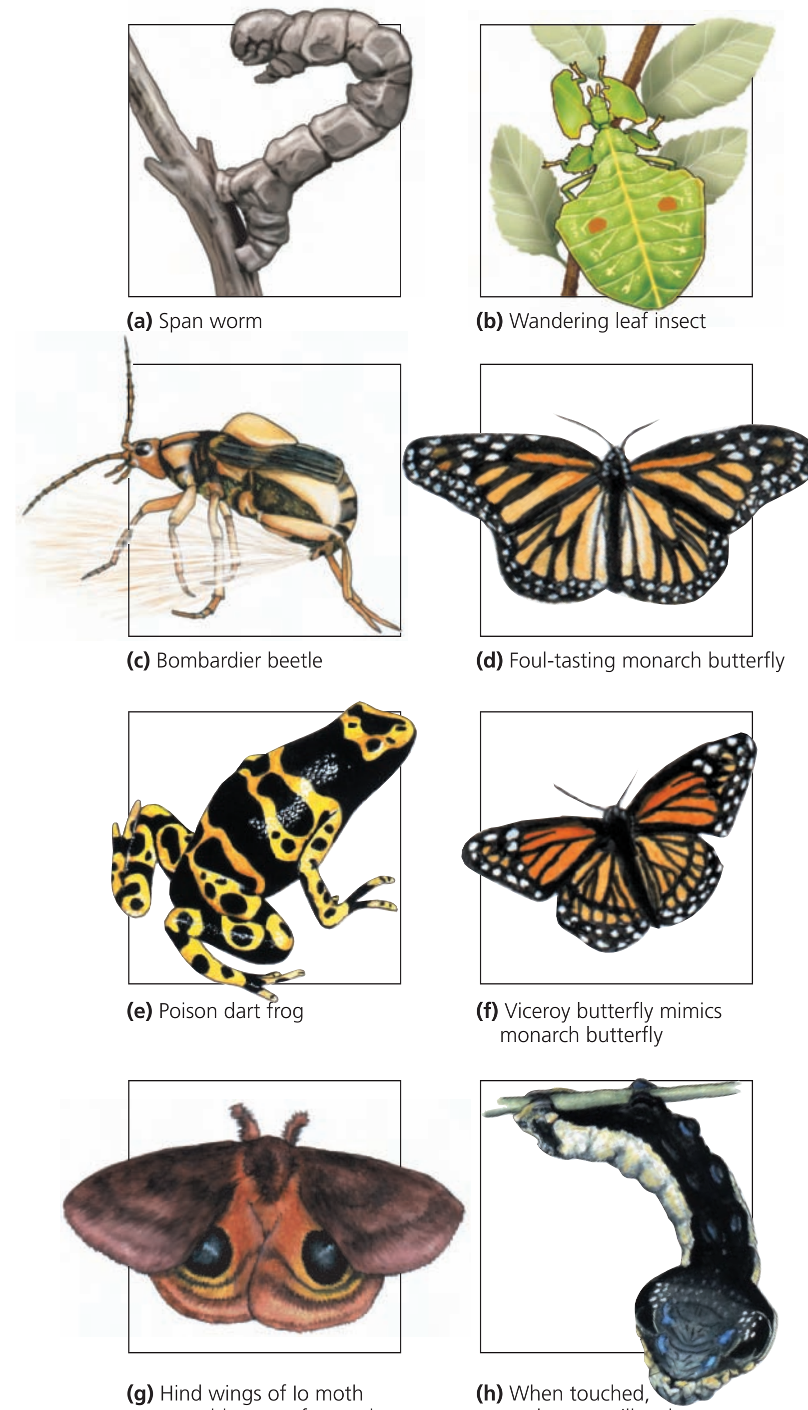
Biologist Edward O. Wilson gives us two rules, based on coloration, for evaluating possible danger from any unknown animal species we encounter in nature. *First*, if it is small and strikingly beautiful, it is probably poisonous. *Second*, if it is strikingly beautiful and easy to catch, it is probably deadly.

Some butterfly species such as the nonpoisonous viceroy (Figure 5-5f) gain protection by looking and acting like the monarch, a protective device known as *mimicry*. Other prey species use *behavioral strategies* to avoid predation. Some attempt to scare off predators by puffing up (blowfish), spreading their wings (peacocks), or mimicking a predator (Figure 5-5h). Some moths have wings that look like the eyes of much larger animals (Figure 5-5g). Other prey species gain some protection by living in large groups such as schools of fish and herds of antelope.

THINKING ABOUT
Predation and the Southern Sea Otter

CORE CASE STUDY

Describe **(a)** a trait possessed by the southern sea otter (**Core Case Study**) that helps it to catch prey and **(b)** a trait that helps it to avoid being preyed upon.



(a) Span worm **(b)** Wandering leaf insect **(c)** Bombardier beetle **(d)** Foul-tasting monarch butterfly **(e)** Poison dart frog **(f)** Viceroy butterfly mimics monarch butterfly **(g)** Hind wings of Io moth resemble eyes of a much larger animal. **(h)** When touched, snake caterpillar changes shape to look like head of snake.

Figure 5-5 These prey species have developed specialized ways to avoid their predators: **(a, b)** *camouflage*, **(c–e)** *chemical warfare*, **(d, e)** *warning coloration*, **(f)** *mimicry*, **(g)** *deceptive looks*, and **(h)** deceptive behavior.

At the individual level, members of the predator species benefit and members of the prey species are harmed. At the population level, predation plays a role in evolution by natural selection (see Chapter 4, p. 86). Animal predators, for example, tend to kill the sick, weak, aged, and least fit members of a population because they are the easiest to catch. This leaves behind individuals with better defenses against predation. Such individuals tend to survive longer and leave more offspring with adaptations that can help them avoid predation.

Some people tend to view certain animal predators with contempt. When a hawk tries to capture and feed on a rabbit, some root for the rabbit. Yet the hawk, like all predators, is merely trying to get enough food for itself and its young. In doing so, it plays an important ecological role in controlling rabbit populations.

Interactions between Predator and Prey Species Can Drive Each Other's Evolution

Predator and prey populations can exert intense natural selection pressures on one another. Over time, as prey develop traits that make them more difficult to catch, predators face selection pressures that favor traits increasing their ability to catch prey. Then prey must get better at eluding the more effective predators.

When populations of two different species interact in such a way over a long period of time, changes in the gene pool of one species can lead to changes in the gene pool of the other. Such changes can help both sides to become more competitive or to avoid or reduce competition. Biologists call this process **coevolution**.

Consider the species interaction between bats (the predator) and certain species of moths (the prey). Bats like to eat moths, and they hunt at night (Figure 5-6, p. 110) using *echolocation* to navigate and to locate their prey. This means that they emit pulses of extremely high-frequency and high-intensity sound which bounces off objects, and then they capture the returning echoes that tell them where their prey is located.

As a countermeasure to this effective prey-detection system, certain moth species have evolved ears that are especially sensitive to the sound frequencies that bats use to find them. When the moths hear the bat frequencies, they try to escape by dropping to the ground or flying evasively.

Figure 5-6 *Coevolution.* This Langohrfledermaus bat is hunting a moth. Long-term interactions between bats and their prey such as moths and butterflies can lead to coevolution, as the bats evolve traits to increase their chance of getting a meal and the moths evolve traits to help them avoid being eaten.

Some bat species have evolved ways to counter this defense by switching the frequency of their sound pulses. In turn, some moths have evolved their own high-frequency clicks to jam the bats' echolocation systems. Some bat species have then adapted by turning off their echolocation systems and using the moths' clicks to locate their prey.

Some Species Feed off Other Species by Living on or inside Them

Parasitism occurs when one species (the *parasite*) feeds on another organism (the *host*), usually by living on or inside the host. In this relationship, the parasite benefits and the host is often harmed but not immediately killed.

A parasite usually is much smaller than its host and rarely kills it. However, most parasites remain closely associated with their hosts, draw nourishment from them, and may gradually weaken them over time.

Some parasites such as tapeworms live *inside* their hosts. Other parasites such as mistletoe plants (see Photo 3 in the Detailed Contents) and sea lampreys (Figure 5-7) attach themselves to the *outsides* of their hosts. Some parasites such as fleas and ticks move from one host to another while others, such as tapeworms, spend their adult lives within a single host.

From the host's point of view, parasites are harmful. But from the population perspective, parasites can promote biodiversity by contributing to species richness, and in some cases, they help to keep the populations of their hosts in check.

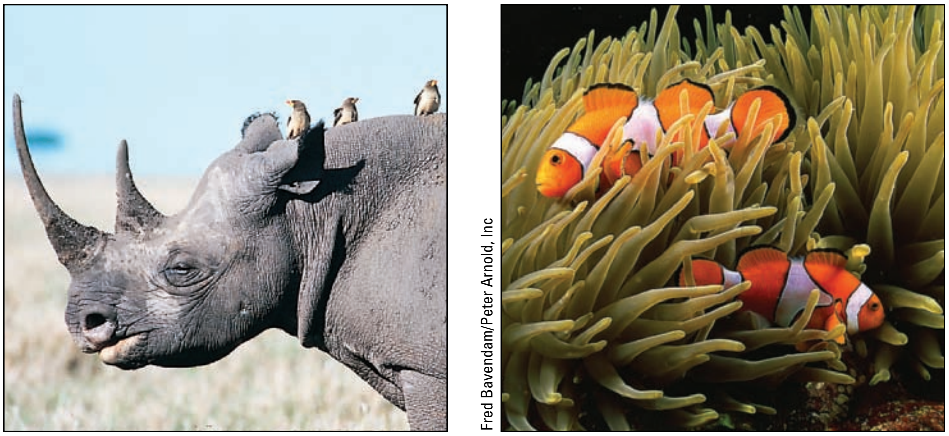
Figure 5-7 *Parasitism:* This blood-sucking parasitic sea lamprey has attached itself to an adult lake trout from the Great Lakes (USA).

In Some Interactions, Both Species Benefit

In **mutualism**, two species behave in ways that benefit both by providing each with food, shelter, or some other resource. One example is pollination of a flower by species such as honeybees (see Figure 4-16, p. 97), hummingbirds (Figure 5-8), and butterflies that feed on the flower's nectar (see Figure 4-A, right, p. 83).

Figure 5-9 shows two examples of mutualistic relationships that combine *nutrition* and *protection*. One involves birds that ride on the backs of large animals like African buffalo, elephants, and rhinoceroses (Figure 5-9a). The birds remove and eat parasites and pests (such as ticks and flies) from the animal's body and often make noises warning the larger animals when predators are approaching.

Figure 5-8 *Mutualism:* This hummingbird benefits by feeding on nectar in this flower, and it benefits the flower by pollinating it.



Joe McDonald/Tom Stack & Associates

Fred Bavendam/Peter Arnold, Inc

(a) Oxpeckers and black rhinoceros

(b) Clownfish and sea anemone

Figure 5-9 Examples of *mutualism:* **(a)** Oxpeckers (or tickbirds) feed on parasitic ticks that infest large, thick-skinned animals such as the endangered black rhinoceros. **(b)** A clownfish gains protection and food by living among deadly, stinging sea anemones and helps to protect the anemones from some of their predators.

A second example involves the clownfish species (Figure 5-9b). Clownfish usually live in a group within sea anemones, whose tentacles sting and paralyze most fish that touch them. The clownfish, which are not harmed by the tentacles, gain protection from predators and feed on the detritus left from the anemones' meals. The sea anemones benefit because the clownfish protect them from some of their predators and parasites.

In *gut inhabitant mutualism,* vast armies of bacteria in the digestive systems of animals help to break down (digest) the animals' food. In turn, the bacteria receive a sheltered habitat and food from their hosts. Hundreds of millions of bacteria in your gut secrete enzymes that help you digest the food you eat. Cows and termites are able to digest cellulose in the plant tissues they eat because of the large number of microorganisms, mostly certain types of bacteria, that live in their guts.

It is tempting to think of mutualism as an example of cooperation between species. In reality, each species benefits by unintentionally exploiting the other as a result of traits they obtained through natural selection. Both species in a mutualistic pair are in it for themselves.

In Some Interactions, One Species Benefits and the Other Is Not Harmed

Commensalism is an interaction that benefits one species but has little, if any, beneficial or harmful effect on the other. One example involves plants called *epiphytes* (such as certain types of orchids and bromeliads), which attach themselves to the trunks or branches of large trees in tropical and subtropical forests (Figure 5-10). These *air plants* benefit by having a solid base on which to grow. They also live in an elevated spot that gives them better access to sunlight, water from the humid air and rain, and nutrients falling from the tree's upper leaves and limbs. Their presence apparently does not harm the tree. Similarly, birds benefit by nesting in trees, generally without harming them.

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Luiz C. Marigo/Peter Arnold, Inc.

Figure 5-10 In an example of *commensalism*, this bromeliad—an epiphyte, or air plant—in Brazil's Atlantic tropical rain forest roots on the trunk of a tree, rather than in soil, without penetrating or harming the tree. In this interaction, the epiphyte gains access to sunlight, water, and nutrients from the tree's debris; the tree apparently remains unharmed and gains no benefit.

5-2 What Limits the Growth of Populations?

▶ **CONCEPT 5-2 No population can continue to grow indefinitely because of limitations on resources and because of competition among species for those resources.**

Most Populations Live in Clumps

A **population** is a group of interbreeding individuals of the same species (Figure 5-11 and Photo 2 in the Detailed Contents). Figure 5-12 shows three ways in which the members of a population are typically distributed, or *dispersed*, in their habitat. Most populations live together in *clumps* (Figure 5-12a) such as packs of wolves, schools of fish, and flocks of birds (Figure 5-11). Southern sea otters (Figure 5-1, left), for example, are usually found in groups known as rafts or pods ranging in size from a few to several hundred animals.

CORE CASE STUDY

Lee Karney/U.S. Fish and Wildlife Service

Figure 5-11 This large group of birds is a population, or flock, of snow geese.

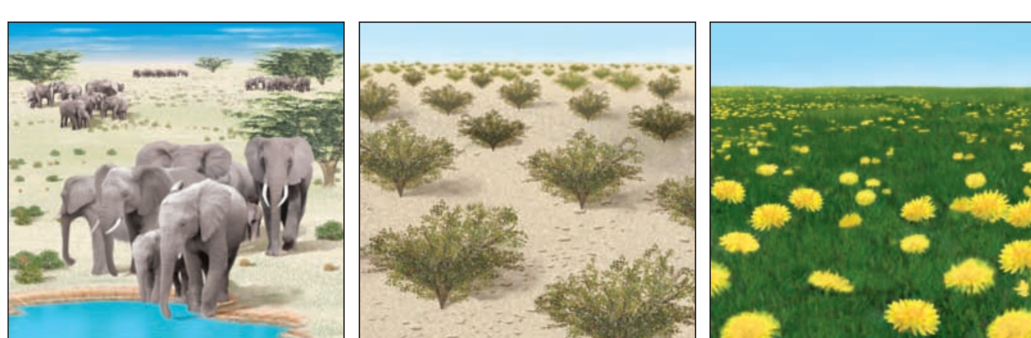
Why clumps? Several reasons: *First*, the resources a species needs vary greatly in availability from place to place, so the species tends to cluster where the resources are available. *Second*, individuals moving in groups have a better chance of encountering patches or clumps of resources, such as water and vegetation, than they would searching for the resources on their own. *Third*, living in groups can help to protect some individuals from predators. *Fourth*, living in packs gives some predator species a better chance of getting a meal.

Populations Can Grow, Shrink, or Remain Stable

Over time, the number of individuals in a population may increase, decrease, remain about the same, or go up and down in cycles in response to changes in environmental conditions. Four variables—*births*, *deaths*, *immigration*, and *emigration*—govern changes in population size. A population increases by birth and immigration (arrival of individuals from outside the population) and decreases by death and emigration (departure of individuals from the population):

$$\text{Population change} = (\text{Births} + \text{Immigration}) - (\text{Deaths} + \text{Emigration})$$

A population's **age structure**—its distribution of individuals among various age groups—can have a strong effect on how rapidly it increases or decreases in size. Age groups are usually described in terms of organisms not mature enough to reproduce (the *pre-reproductive age*), those capable of reproduction (the *reproductive stage*), and those too old to reproduce (the *post-reproductive stage*).



(a) Clumped (elephants) **(b)** Uniform (creosote bush) **(c)** Random (dandelions)

Figure 5-12 This diagram illustrates three general *dispersion patterns* for populations. *Clumps* **(a)** are the most common dispersion pattern, mostly because resources such as grass and water are usually found in patches. Where such resources are scarce, uniform dispersion **(b)** is more common. Where they are plentiful, a random dispersion **(c)** is more likely. **Question:** Why do you think elephants live in clumps or groups?

The size of a population will likely increase if it is made up mostly of individuals in their reproductive stage, or soon to enter this stage. In contrast, a population dominated by individuals past their reproductive stage will tend to decrease over time. Excluding emigration and immigration, the size of a population with a fairly even distribution among these three age groups tends to remain stable because reproduction by younger individuals will be roughly balanced by the deaths of older individuals.

Some Factors Can Limit Population Size

Different species and their populations thrive under different physical and chemical conditions. Some need bright sunlight; others flourish in shade. Some need a hot environment; others prefer a cool or cold one. Some do best under wet conditions; others thrive in dry conditions.

Each population in an ecosystem has a **range of tolerance** to variations in its physical and chemical environment, as shown in Figure 5-13. Individuals within a population may also have slightly different tolerance ranges for temperature or other physical or chemical factors because of small differences in their genetic makeup, health, and age. For example, a trout population may do best within a narrow band of temperatures (*optimum level* or *range*), but a few individuals can survive above and below that band. Of course, if the water becomes much too hot or too cold, none of the trout can survive.

A number of physical or chemical factors can help to determine the number of organisms in a population. Sometimes one or more factors, known as **limiting factors**, are more important than other factors in regulating population growth. This ecological principle is called the **limiting factor principle**: *Too much or too little of any physical or chemical factor can limit or prevent growth of a population, even if all other factors are at or near the optimal range of tolerance.*

On land, precipitation often is the limiting factor. Lack of water in a desert limits plant growth. Soil nutrients also can act as a limiting factor on land. Suppose a farmer plants corn in phosphorus-poor soil. Even if water, nitrogen, potassium, and other nutrients are at optimal levels, the corn will stop growing when it uses up the available phosphorus. Too much of a physical or chemical factor can also be limiting. For example, too much water or fertilizer can kill plants. Temperature can be a limiting factor as well. Both high and low temperatures can limit the survival and population sizes of various terrestrial species, especially plants.

Important limiting physical factors for popuations in *aquatic life zones*, or water-filled areas that support life, include temperature (Figure 5-13), sunlight, nutrient availability, and the low levels of oxygen gas in the water (*dissolved oxygen content*). Another limiting factor in aquatic life zones is *salinity*—the amounts of various inorganic minerals or salts dissolved in a given volume of water.

No Population Can Grow Indefinitely: J-Curves and S-Curves

Some species have an incredible ability to increase their numbers. Members of such populations typically reproduce at an early age, have many offspring each time they reproduce, and reproduce many times, with short intervals between successive generations. For example, with no controls on its population growth, a species of bacteria that can reproduce every 20 minutes would generate enough offspring to form a layer 0.3 meter (1 foot) deep over the entire earth's surface in only 36 hours!

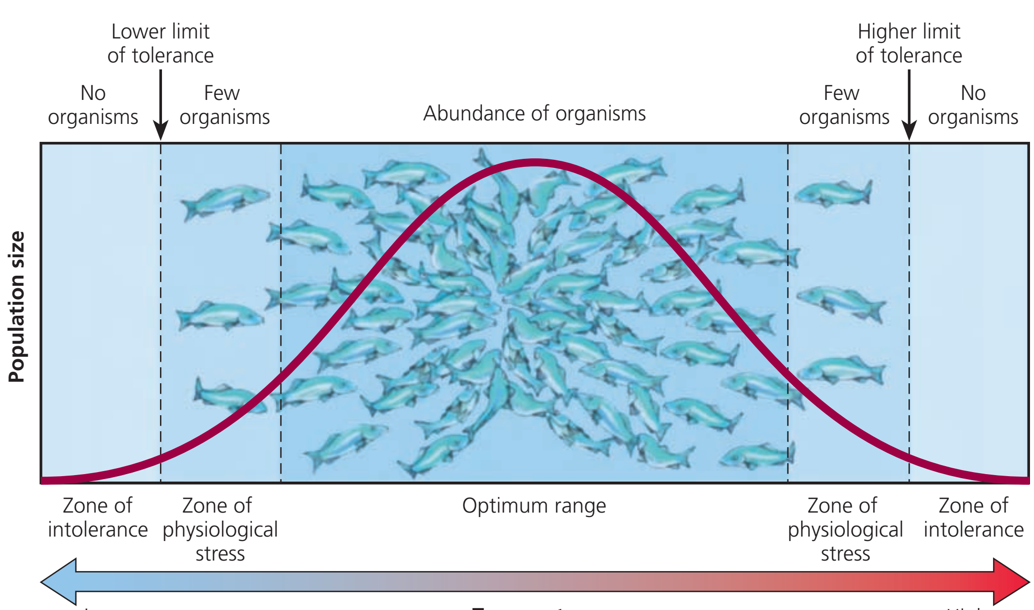


Figure 5-13 This diagram illustrates the range of tolerance for a population of organisms, such as trout, to a physical environmental factor—in this case, water temperature. Range of tolerance restrictions prevent particular species from taking over an ecosystem by keeping their population size in check. **Question:** For humans, what is an example of a range of tolerance for a physical environmental factor?

SCIENCE FOCUS

Why Do California's Sea Otters Face an Uncertain Future?

The southern sea otter (**Core Case Study**) cannot rapidly increase its numbers for several reasons. Female southern sea otters reach sexual maturity between 2 and 5 years of age, can reproduce until age 15, and typically each produce only one pup a year.

The population size of southern sea otters has fluctuated in response to changes in environmental conditions. One such change has been a rise in populations of orcas (killer whales) that feed on them. Scientists hypothesize that orcas began feeding more on southern sea otters when populations of their normal prey, sea lions and seals, began declining.

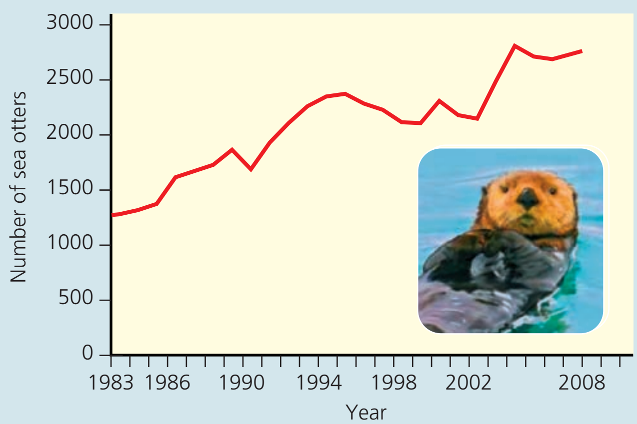


Figure 5-B This graph tracks the population size of southern sea otters off the coast of the U.S. state of California, 1983–2009. According to the U.S. Geological Survey, the California southern sea otter population would have to reach at least 3,090 animals for 3 years in a row before it could be considered for removal from the endangered species list. (Data from U.S. Geological Survey)

Another factor may be parasites known to breed in cats. Scientists hypothesize that some sea otters may be dying because coastal area cat owners flush used, feces-laden cat litter down their toilets or dump it in storm drains that empty into coastal waters. The feces contain the parasites, which then infect the otters.

Thorny-headed worms from seabirds also are known to be killing sea otters, as are toxic algae blooms triggered by urea, a key ingredient in fertilizer that washes into coastal waters. PCBs and other fat-soluble toxic chemicals released by human activities can accumulate in the tissues of the shellfish on which otters feed, and this proves fatal to otters. The facts that sea otters feed at high trophic levels and live close to the shore makes them vulnerable to these and other pollutants in coastal waters. In other words, as an *indicator* species, sea otters reveal the condition of coastal waters in their habitat.

Some southern sea otters die when they encounter oil spilled from ships. The entire California southern sea otter population could be wiped out by a large oil spill from a single tanker off the state's central coast or from an oil well, should drilling for oil be allowed off this coast. These factors, mostly resulting from human activities, plus a fairly low reproductive rate, have hindered the ability of the endangered southern sea otter to rebuild its population (Figure 5-B).

Critical Thinking

How would you design a controlled experiment to test the hypothesis that cat litter flushed down toilets may be killing sea otters?

Fortunately, this will not happen. Research reveals that regardless of their reproductive strategy, no population of a species can grow indefinitely because of limitations on resources and competition with populations of other species for those resources (**Concept 5-2**). In the real world, a rapidly growing population of any species eventually reaches some size limit imposed by the availability of one or more *limiting factors* such as light, water, temperature, space, or nutrients, or by exposure to predators or infectious diseases.

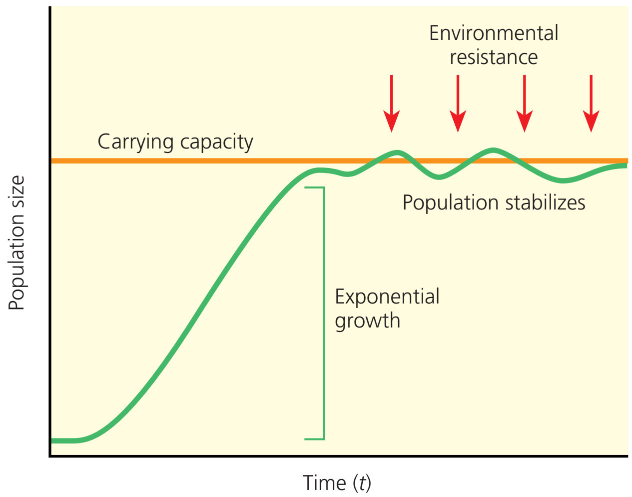
There are always limits to population growth in nature. For example, one reason California's southern sea otters (**Core Case Study**) face extinction is that they cannot reproduce rapidly (Science Focus, above).

Environmental resistance is the combination of all factors that act to limit the growth of a population. It largely determines an area's **carrying capacity**: the maximum population of a given species that a particular habitat can sustain indefinitely. The growth rate of a population decreases as its size nears the carrying capacity of its environment because resources such as food, water, and space begin to dwindle.

A population with few, if any, limitations on its resource supplies can grow exponentially at a fixed rate such as 1% or 2% per year. *Exponential growth* starts slowly but then accelerates as the population increases, because the base size of the population is increasing. Plotting the number of individuals against time yields a J-shaped growth curve (Figure 5-14, left half of curve). Figure 5-15 depicts such a curve for sheep on the island of Tasmania, south of Australia, in the early 19th century.

CENGAGENOW™ Learn how to estimate a population of butterflies and see a mouse population growing exponentially at CengageNOW.

Changes in the population sizes of keystone species such as the southern sea otter (**Core Case Study**) can alter the species composition and biodiversity of an ecosystem. For example, a decline in the population of the California southern sea otter caused a decline in the populations of species dependent on them, including the giant kelp (Science Focus, above). This reduced the species diversity of the kelp forest and altered its functional biodiversity by upsetting its food web and reducing energy flows and nutrient cycling within the forest.



CENGAGENOW™ **Active Figure 5-14** No population can continue to increase in size indefinitely (**Concept 5-2**). *Exponential growth* (left half of the curve) occurs when a population has essentially unlimited resources to support its growth (see Case Study below). Such exponential growth is eventually converted to *logistic growth*, in which the growth rate decreases as the population becomes larger and faces environmental resistance (right half of the curve). Over time, the population size stabilizes at or near the *carrying capacity* of its environment, which results in a sigmoid (S-shaped) population growth curve. Depending on resource availability, the size of a population often fluctuates around its carrying capacity. However, a population may temporarily exceed its carrying capacity and then suffer a sharp decline or crash in its numbers. *See an animation based on this figure at* CengageNOW. **Question:** What is an example of environmental resistance that humans have not been able to overcome?

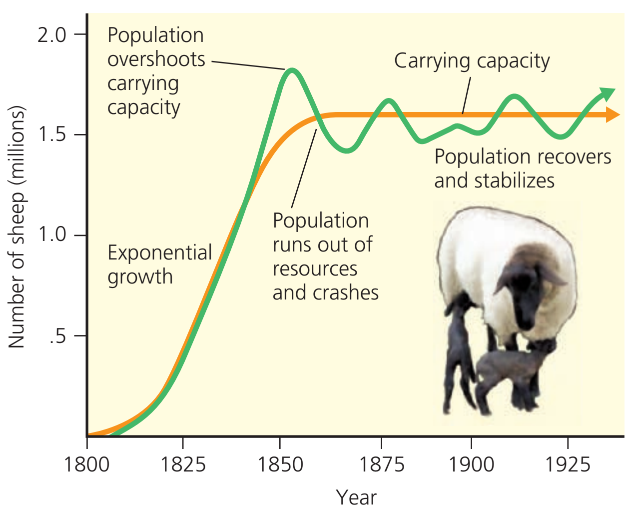


Figure 5-15 This graph tracks the *logistic growth* of a sheep population on the island of Tasmania between 1800 and 1925. After sheep were introduced in 1800, their population grew exponentially, thanks to an ample food supply and few predators. By 1855, they had overshot the land's carrying capacity. Their numbers then stabilized and fluctuated around a carrying capacity of about 1.6 million sheep.

THINKING ABOUT
California Southern Sea Otters

CORE CASE STUDY

Name a species whose population is likely to decline if the population of California southern sea otters living in kelp forests declines sharply. Name a species whose population would increase if this happened.

CASE STUDY

Exploding White-Tailed Deer Populations in the United States

By 1900, habitat destruction and uncontrolled hunting had reduced the white-tailed deer (Figure 5-16) population in the United States to about 500,000 animals. In the 1920s and 1930s, laws were passed to protect the remaining deer. Hunting was restricted and predators such as wolves and mountain lions that preyed on the deer were nearly eliminated.

These protections worked, and for some suburbanites and farmers, perhaps too well. Today there are over 25 million white-tailed deer in the United States. During the last 50 years, large numbers of Americans have moved into the wooded habitat of deer where suburban areas have expanded. With the landscaping around their homes, they have provided deer with flowers, shrubs, garden crops, and other plants that deer like to eat.

Deer prefer to live in the edge areas of forests and wooded areas for security, and they go to nearby fields, orchards, lawns, and gardens for food. Thus, a suburban neighborhood can be an all-you-can-eat paradise for white-tailed deer. Their populations in such areas have soared. In some woodlands, they are consuming native ground-cover vegetation and this has allowed nonnative weed species to take over. Deer also spread Lyme disease (carried by deer ticks) to humans.

Howard Sandler/Shutterstock

Figure 5-16 This is a mature male (buck) white-tailed deer.

In addition, in deer–vehicle collisions, deer accidentally injure and kill more people each year in the United States than do any other wild animals. Such accidents number around 1.5 million per year and annually injure at least 25,000 people, kill at least 200 people, and cause $1.1 billion in property damage. Most of these accidents occur during October, November, and December in the early morning or at dusk when deer are moving back and forth between fields or suburban areas and nearby woods.

There are no easy answers to the deer population problem in the suburbs. Changes in hunting regulations that allow for the killing of more female deer have cut down the overall deer population. But these actions have little effect on deer in suburban areas because it is too dangerous to allow widespread hunting with guns in such populated communities. Some areas have hired experienced and licensed archers who use bows and arrows to help reduce deer numbers. To protect nearby residents the archers hunt from elevated tree stands and only shoot their arrows downward.

Animal rights activists strongly oppose killing deer, arguing that it is cruel and inhumane. On the other hand, some feel that controlled hunting of deer is more humane than allowing them to starve to death in large numbers during winter. They argue that by removing the deer's chief predator (the wolf) and much of its original habitat, humans have contributed to winter deer starvation in many areas.

Some communities spray the scent of deer predators or of rotting deer meat in edge areas to scare off deer. Others use electronic equipment that emits high-frequency sounds, which humans cannot hear, for the same purpose. Some homeowners surround their gardens and yards with high, black plastic mesh fencing that is invisible from a distance. Such deterrents may protect one area, but cause the deer to seek food in someone else's yard or garden.

Deer can be trapped and moved from one area to another, but this is expensive and must be repeated whenever they move back into an area. Also, there are questions concerning where to move the deer and how to pay for such programs.

Should we put deer on birth control? Darts loaded with contraceptives could be shot into female deer to hold down their birth rates. But this is expensive and must be repeated every year. One possibility is an experimental, single-shot contraceptive vaccine that causes females to stop producing eggs for several years. Another approach is to trap dominant males and use chemical injections to sterilize them. Both these approaches will require years of testing.

Meanwhile, suburbanites can expect deer to chow down on their shrubs, flowers, and garden plants unless they can protect their properties with high, deer-proof fences, repellants, or other methods. Deer have to eat every day just as we do. Suburban dwellers might consider not planting trees, shrubs, and flowers that attract deer around their homes.

THINKING ABOUT
White-Tailed Deer

Some people blame the white-tailed deer for invading farms and suburban yards and gardens to eat food that humans have made easily available to them. Others say humans are mostly to blame because they have invaded deer territory, eliminated most of the predators that kept deer populations under control, and provided the deer with plenty to eat in their lawns and gardens. Which view do you hold? Why? Do you see a solution to this problem?

When a Population Exceeds Its Carrying Capacity It Can Crash

Some species do not make a smooth transition from *exponential growth* to *logistic growth* (Figure 5-14). Such populations use up their resource supplies and temporarily *overshoot*, or exceed, the carrying capacity of their environment. This occurs because of a *reproductive time lag*: the period needed for the birth rate to fall and for the death rate to rise in response to resource overconsumption.

In such cases, the population suffers a sharp decline, called *dieback*, or **population crash**, unless the excess individuals can switch to new resources or move to an area that has more resources. Such a crash occurred when reindeer were introduced onto a small island in the Bering Sea (Figure 5-17).

The carrying capacity of any given area is not fixed. In some areas, it can increase or decrease seasonally and from year to year because of variations in weather, such as a drought that causes decreases in available vegeta-

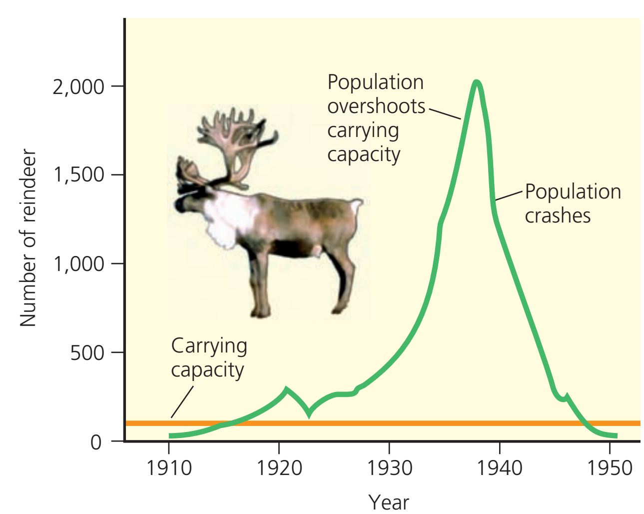


Figure 5-17 This graph tracks the exponential growth, overshoot, and population crash of reindeer introduced onto the small Bering Sea island of St. Paul. When 26 reindeer (24 of them female) were introduced in 1910, lichens, mosses, and other food sources were plentiful. By 1935, the herd size had soared to 2,000, overshooting the island's carrying capacity. This led to a population crash, when the herd size plummeted to only 8 reindeer by 1950. **Question:** Why do you think the sizes of some populations level off while others such as the reindeer in this example exceed their carrying capacities and crash?

tion. Other factors include the presence or absence of predators and an abundance or scarcity of competitors.

RESEARCH FRONTIER

Calculating more exactly the carrying capacities for various habitats and determining what factors can change those capacities; see **www.cengage.com/login**.

Species Have Different Reproductive Patterns

Species use different reproductive patterns to help ensure their long-term survival. Some species have many, usually small, offspring and give them little or no parental care or protection. These species overcome typically massive losses of offspring by producing so many offspring that a few will likely survive to reproduce many more offspring themselves, and to keep this reproductive pattern going. Examples include algae, bacteria, and most insects.

At the other extreme are species that tend to reproduce later in life and have a small number of offspring with fairly long life spans. Typically, the offspring of mammals with this reproductive strategy develop inside their mothers (where they are safe), and are born fairly large. After birth, they mature slowly and are cared for and protected by one or both parents, and in some cases by living in herds or groups, until they reach reproductive age and begin the cycle again.

Most large mammals (such as elephants, whales, and humans) and birds of prey follow this reproductive pattern. Many of these species—especially those with long times between generations and with low reproductive rates like elephants, rhinoceroses, and sharks—are vulnerable to extinction. Most organisms have reproductive patterns between these two extremes. **Explore More:** See **www.cengage.com/login** to learn about how genetic diversity can affect the sizes of small populations.

Under Some Circumstances Population Density Affects Population Size

Population density is the number of individuals in a population found in a particular area or volume. Figure 5-11, for example, shows a high-density population of snow geese. Some factors that limit population growth have a greater effect as a population's density increases. Examples of such *density-dependent population controls* include parasitism, infectious disease, and competition for resources.

Higher population density may help sexually reproducing individuals to find mates, but it can also lead to increased competition for mates, food, living space, water, sunlight, and other resources. High population density can help to shield some members from predators, but it can also make large groups such as schools of fish vulnerable to human harvesting methods. In addition, close contact among individuals in dense populations can increase the transmission of parasites and infectious diseases. When population density decreases, the opposite effects occur. Density-dependent factors tend to regulate a population, keeping it at a fairly constant size, often near the carrying capacity of its environment.

Some factors that can kill members of a population are *density independent*. In other words, their effect is not dependent on the density of the population. For example, a severe freeze in late spring can kill many individuals in a plant population or in a population of butterflies, regardless of their density. Other such factors include floods, hurricanes, fire, pollution, and habitat destruction, such as clearing a forest of its trees or filling in a wetland.

Several Different Types of Population Change Occur in Nature

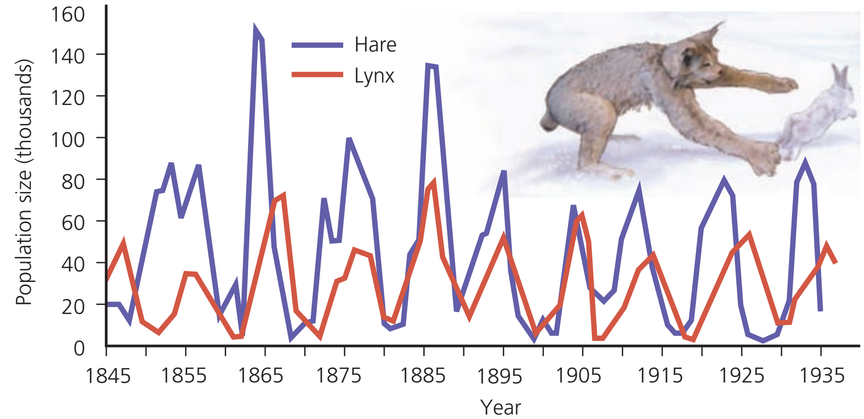
In nature, we find four general patterns of variation in population size: *stable*, *irruptive*, *cyclic*, and *irregular*. A species whose population size fluctuates slightly above and below its carrying capacity is said to have a fairly *stable* population size (Figure 5-15). Such stability is characteristic of many species found in undisturbed tropical rain forests, where average temperature and rainfall vary little from year to year.

For some species, population growth may occasionally surge, or *irrupt*, to a high peak and then crash to a more stable lower level or, in some cases, to a very low, unstable level. Short-lived, rapidly reproducing species such as algae and many insects have irruptive population cycles that are linked to seasonal changes in weather or nutrient availability. For example, in temperate climates, insect populations grow rapidly during the spring and summer and then crash during the hard frosts of winter.

A third type of fluctuation consists of regular *cyclic fluctuations*, or *boom-and-bust cycles*, of population size over a time period. Examples are lemmings, whose populations rise and fall every 3–4 years, and lynx and snowshoe hare, whose populations generally rise and fall in 10-year cycles (Figure 5-18, p. 118). Ecologists distinguish between *top-down population regulation*, through predation, and *bottom-up population regulation*, in which the size of predator and prey populations is controlled by the scarcity of one or more resources.

Finally, some populations appear to have *irregular* changes in population size, with no recurring pattern. Some scientists attribute this irregularity to chaos in such systems. Other scientists contend that it may represent fluctuations in response to catastrophic population crashes resulting from occasionally severe winter weather.

Figure 5-18 This graph represents the population cycles for the snowshoe hare and the Canadian lynx. At one time, scientists believed these curves provided evidence that these predator and prey populations regulated one another. More recent research suggests that the periodic swings in the hare population are caused by a combination of *top-down population control*—through predation by lynx and other predators—and *bottom-up population control*, in which changes in the availability of the food supply for hares help to determine their population size, which in turn helps to determine the lynx population size. (Data from D. A. MacLulich)



Humans Are Not Exempt from Nature's Population Controls

Humans are not exempt from population crashes. Ireland experienced such a crash after a fungus destroyed its potato crop in 1845. About 1 million people died from hunger or diseases related to malnutrition, and 3 million people migrated to other countries, especially the United States.

During the 14th century, the *bubonic plague* spread through densely populated European cities and killed at least 25 million people. The bacterium causing this disease normally lives in rodents. It was transferred to humans by fleas that fed on infected rodents and then bit humans. The disease spread like wildfire through crowded cities, where sanitary conditions were poor and rats were abundant. Today, several antibiotics, not available until recently, can be used to treat bubonic plague. But without treatment, about half of any group of individuals infected with this disease die within 3 to 7 days.

Currently, the world is experiencing a global epidemic of AIDS, caused by infection with the human immunodeficiency virus (HIV). Between 1981 and 2008, AIDS killed more than 27 million people and continues to claim another 2 million lives each year—an average of four deaths per minute.

So far, technological, social, and other cultural changes have expanded the earth's carrying capacity for the human species. We have increased food production and used large amounts of energy and matter resources to occupy formerly uninhabitable areas, to expand agriculture, and to control the populations of other species that compete with us for resources.

Some say we can keep expanding our ecological footprint (see Figure 7, p. S38, in Supplement 8) indefinitely, mostly because of our technological ingenuity. Others say that sooner or later, we will reach the limits that nature always imposes on all populations.

HOW WOULD YOU VOTE?

Can we continue to expand the earth's carrying capacity for humans? Cast your vote online at **www.cengage.com/login**.

5-3 How Do Communities and Ecosystems Respond to Changing Environmental Conditions?

▶ **CONCEPT 5-3 The structure and species composition of communities and ecosystems change in response to changing environmental conditions through a process called ecological succession.**

Communities and Ecosystems Change over Time: Ecological Succession

The types and numbers of species in biological communities and ecosystems change in response to changing environmental conditions such as a fires, volcanic eruptions, climate change, and the clearing of forests to plant crops. The normally gradual change in species composition in a given area is called **ecological succession** (Concept 5-3).

Ecologists recognize two main types of ecological succession, depending on the conditions present at the

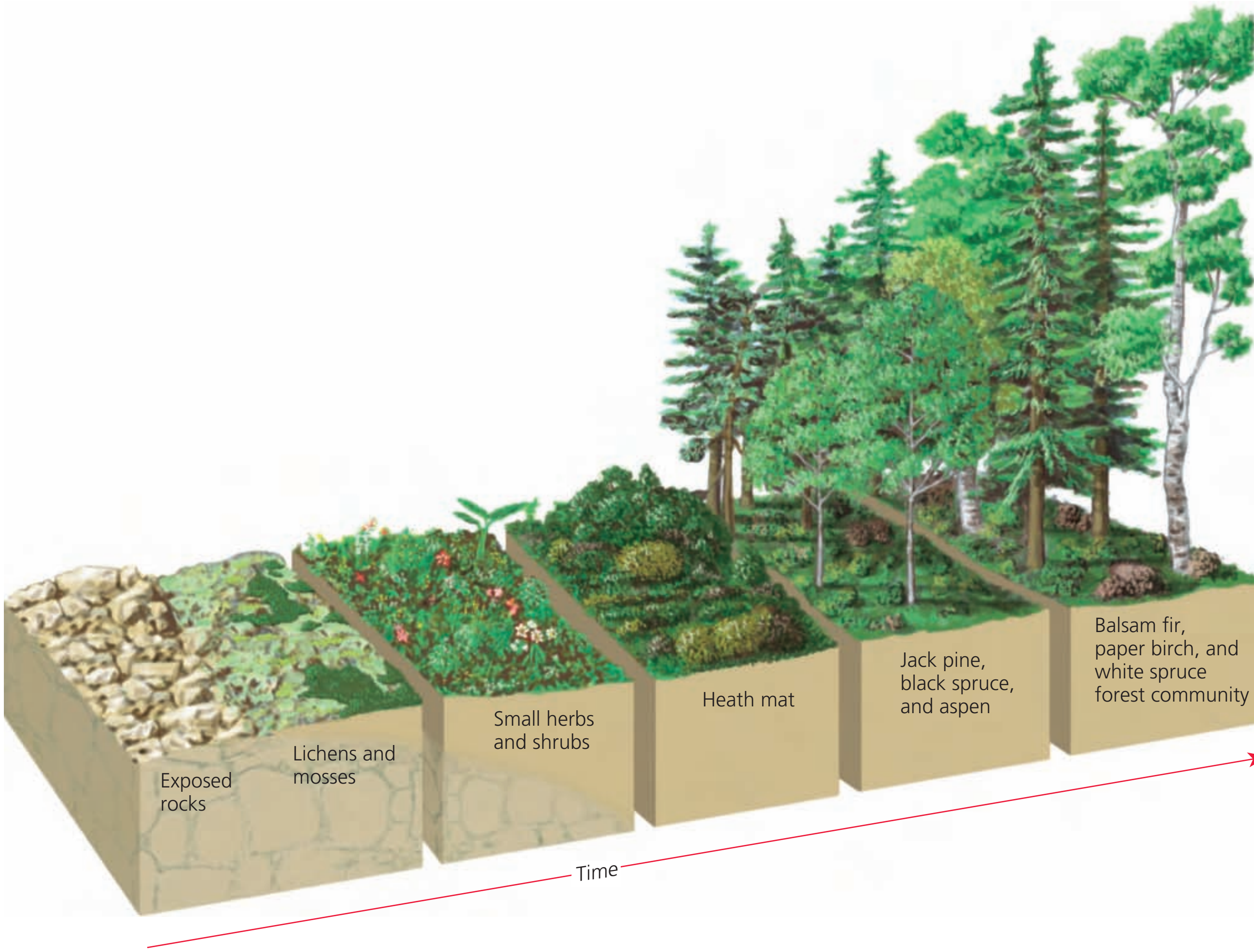


Figure 5-19 *Primary ecological succession:* Over almost a thousand years, these plant communities developed, starting on bare rock exposed by a retreating glacier on Isle Royal, Michigan (USA) in northern Lake Superior. The details of this process vary from one site to another. **Question:** What are two ways in which lichens, mosses, and plants might get started growing on bare rock?

beginning of the process. **Primary ecological succession** involves the gradual establishment of biotic communities in lifeless areas where there is no soil in a terrestrial ecosystem or no bottom sediment in an aquatic ecosystem. Examples include bare rock exposed by a retreating glacier (Figure 5-19), newly cooled lava, an abandoned highway or parking lot, and a newly created shallow pond or reservoir. Primary succession usually takes hundreds to thousands of years because of the need to build up fertile soil or aquatic sediments to provide the nutrients needed to establish a plant community.

The other, more common type of ecological succession is called **secondary ecological succession**, in which a series of communities or ecosystems with different species develop in places containing soil or bottom sediment. This type of succession begins in an area where an ecosystem has been disturbed, removed, or destroyed, but some soil or bottom sediment remains. Candidates for secondary succession include abandoned farmland (Figure 5-20, p. 120), burned or cut forests (Figure 5-21, p. 120), heavily polluted streams, and land that has been flooded. Because some soil or sediment is present, new vegetation can begin to germinate, usually within a few weeks. It begins with seeds already in the soil and seeds imported by wind or in the droppings of birds and other animals.

Primary and secondary ecological succession are important natural services that tend to increase biodiversity, and thus the sustainability of communities and ecosystems, by increasing species richness and interactions among species. Such interactions in turn enhance sustainability by promoting population control and by increasing the complexity of food webs. This then enhances the energy flow and nutrient cycling, which are functional components of biodiversity (see Figure 4-2, p. 82). As part of the earth's natural capital, both types of succession are examples of *natural ecological restoration*. Ecologists have been conducting research to find out more about the factors involved in ecological succession (Science Focus, p. 121).

CENGAGENOW™ **Active Figure 5-20** *Natural ecological restoration of disturbed land:* This diagram shows the undisturbed secondary ecological succession of plant communities on an abandoned farm field in the U.S. state of North Carolina. It took 150–200 years after the farmland was abandoned for the area to become covered with a mature oak and hickory forest. A new disturbance such as deforestation or fire would create conditions favoring pioneer species such as annual weeds. In the absence of new disturbances, secondary succession would recur over time, but not necessarily in the same sequence shown here. *See an animation based on this figure at* CengageNOW. **Questions:** Do you think the annual weeds (left) would continue to thrive in the mature forest (right)? Why or why not?

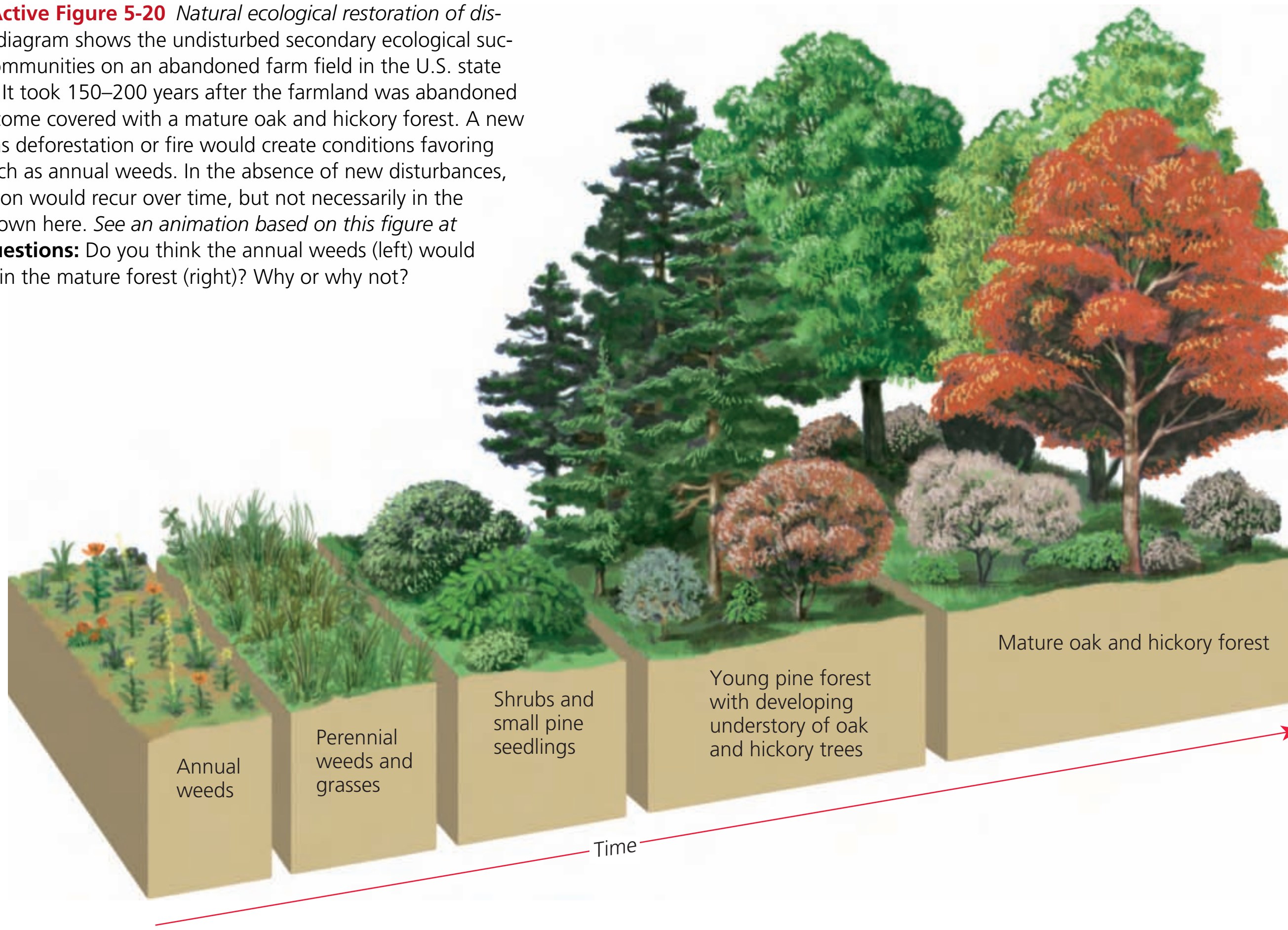


Figure 5-21 These young lodgepole pines growing around standing dead trees after a 1998 forest fire in Yellowstone National Park are an example of secondary ecological succession.

SCIENCE FOCUS

How Do Species Replace One Another in Ecological Succession?

Ecologists have identified three factors that affect how and at what rate succession occurs. One is *facilitation*, in which one set of species makes an area suitable for species with different niche requirements, but less suitable for itself. For example, as lichens and mosses gradually build up soil on a rock in primary succession, herbs and grasses can colonize the site and crowd out the original, or *pioneer*, community of lichens and mosses.

A second factor is *inhibition*, in which some early species hinder the establishment and growth of other species. Inhibition often occurs when plants such as butternut and black walnut trees release toxic chemicals that reduce competition from other plants. Succession then can proceed only when a fire, bulldozer, or other human or natural disturbance removes most of the inhibiting species.

A third factor is *tolerance*, in which plants in the late stages of succession are largely unaffected by plants that came in during earlier stages because the later plants are not in direct competition with the earlier ones for key resources. For example, shade-tolerant trees and other plants can thrive beneath the older, larger trees of a mature forest (Figure 5-19) because they do not need to compete with the taller species for access to sunlight.

Critical Thinking

Explain how tolerance can increase biodiversity by increasing species diversity and functional diversity (energy flow and chemical cycling) in an ecosystem.

CENGAGENOW™ Explore the difference between primary and secondary succession at CengageNOW.

During primary or secondary succession, environmental disturbances such as fires (Figure 15-21), hurricanes, clear-cutting of forests, plowing of grasslands, and invasions by nonnative species can interrupt a particular stage of succession, setting succession back to an earlier stage.

Succession Does Not Follow a Predictable Path

According to the traditional view, succession proceeds in an orderly sequence along an expected path until a certain stable type of *climax community* occupies an area. Such a community is dominated by a few long-lived plant species and is in balance with its environment. This equilibrium model of succession is what ecologists once meant when they talked about the *balance of nature*.

Over the last several decades, many ecologists have changed their views about balance and equilibrium in nature. Under the balance-of-nature view, a large terrestrial community or ecosystem undergoing succession eventually became covered with an expected type of climax vegetation such as a mature forest (Figures 5-19 and 5-20). There is a general tendency for succession to lead to more complex, diverse, and presumably stable ecosystems. But a close look at almost any terrestrial community or ecosystem reveals that it consists of an ever-changing mosaic of patches of vegetation in different stages of succession.

The current view is that we cannot predict a given course of succession or view it as inevitable progress toward an ideally adapted climax plant community or ecosystem. Rather, succession reflects the ongoing struggle by different species for enough light, water, nutrients, food, and space. Most ecologists now recognize that mature, late-successional ecosystems are not in a state of permanent equilibrium. Rather, they are in a state of continual disturbance and change.

Living Systems Are Sustained through Constant Change

All living systems, from a cell to the biosphere, are constantly changing in response to changing environmental conditions. Continents move, climates change, and disturbances and succession change the composition of communities and ecosystems.

GOOD NEWS

Living systems contain complex networks of positive and negative feedback loops (see Figures 2-18, p. 49, and 2-19, p. 50) that interact to provide some degree of stability, or sustainability, over each system's expected life span. This *stability*, or capacity to withstand external stress and disturbance, is maintained only by constant change in response to changing environmental conditions. For example, in a mature tropical rain forest, some trees die and others take their places. However, unless the forest is cut, burned, or otherwise destroyed, you would still recognize it as a tropical rain forest 50 or 100 years from now.

It is useful to distinguish between two aspects of stability in living systems. One is **inertia**, or **persistence**: the ability of a living system such as a grassland or a forest to survive moderate disturbances. A second factor is **resilience**: the ability of a living system to be restored through secondary succession after a more severe disturbance.

Evidence suggests that some ecosystems have one of these properties but not the other. For example, tropical rain forests have high species richness and high inertia and thus are resistant to significant change or damage. But once a large tract of tropical rain forest is cleared or severely damaged, the resilience of the resulting degraded forest ecosystem may be so low that it reaches an ecological tipping point after which it may not be restored by secondary ecological succession. One reason for this is that most of the nutrients in a typical rain forest are stored in its vegetation, not in the topsoil, as in most other terrestrial ecosystems. Once the nutrient-rich vegetation is gone, daily rains can remove most of the other nutients left in the topsoil and thus prevent a tropical rain forest from regrowing on a large cleared area.

By contrast, grasslands are much less diverse than most forests, and consequently they have low inertia and can burn easily. However, because most of their plant matter is stored in underground roots, these ecosystems have high resilience and can recover quickly after a fire, as their root systems produce new grasses. Grassland can be destroyed only if its roots are plowed up and something else is planted in its place, or if it is severely overgrazed by livestock or other herbivores.

This variation among species in resilience and inertia is yet another example of how biodiversity has helped life on earth to sustain itself for billions of years. Thus, it illustrates one aspect of the biodiversity **principle of sustainability** (see back cover).

Here are this chapter's *three big ideas*:

- Certain interactions among species affect their use of resources and their population sizes.
- There are always limits to population growth in nature.
- Changes in environmental conditions cause communities and ecosystems to gradually alter their species composition and population sizes (ecological succession).

REVISITING Southern Sea Otters and Sustainability

CORE CASE STUDY

Before the arrival of European settlers on the western coast of North America, the sea otter population was part of a complex ecosystem made up of kelp, bottom-dwelling creatures, otters, whales, and other species depending on one another for survival. Giant kelp forests served as food and shelter for sea urchins. Sea otters ate the sea urchins and other kelp eaters. Some species of whales and sharks ate the otters. And detritus from all these species helped to maintain the giant kelp forests. Each of these interacting populations was kept in check by—and helped to sustain—all the others.

When European settlers arrived and began hunting the otters for their pelts, they probably didn't know much about the intricate web of life beneath the ocean surface. But with the effects of overhunting, people realized they had done more than simply take sea otters. They had torn the web, disrupted an entire ecosystem, and triggered a loss of valuable natural resources and services, including biodiversity.

Populations of most plants and animals depend, directly or indirectly, on solar energy and all populations play roles in the cycling of nutrients in the ecosystems where they live. In addition, the biodiversity found in the variety of species in different terrestrial and aquatic ecosystems provides alternative paths for energy flow and nutrient cycling, and better opportunities for natural selection as environmental conditions change. When we disrupt these paths, we violate all three **principles of sustainability**. In this chapter, we looked more closely at two effects of one of those principles: first, *biodiversity promotes sustainability*, and second, *there are always limits to population growth in nature*, mostly because of biodiversity and diverse species interactions.

We cannot command nature except by obeying her.

SIR FRANCIS BACON

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 105. Explain how southern sea otters act as a keystone species in their environment. Explain why we should care about protecting this species from premature extinction that could result mostly from human activities.

2. Define **interspecific competition**, **predation**, **parasitism**, **mutalism**, and **commensalism** and give an example of each. Explain how each of these species interactions can affect the population sizes of species in ecosystems. Describe and give an example of **resource partitioning** and explain how it can increase species diversity.

3. Distinguish between a **predator** and a **prey** species and give an example of each. What is a **predator–prey relationship**? Explain why we should help to preserve kelp forests. Describe three ways in which prey species can avoid their predators and three ways in which predators can increase their chances of feeding on their prey.

4. Define and give an example of **coevolution**.

5. Define **population**, describe four variables that govern changes in population size, and write an equation showing how they interact. What is a population's **age structure** and what are the three major age groups called? Define **range of tolerance**. Define **limiting factor** and give an example. State the **limiting factor principle**.

6. Distinguish between the **environmental resistance** and the **carrying capacity** of an environment, and use these concepts to explain why there are always limits to population growth in nature. Why are southern sea otters making a slow comeback and what factors can threaten this recovery?

7. Define and give an example of a **population crash**. Explain why humans are not exempt from nature's population controls. Describe the exploding white-tailed deer population problem in the United States and discuss options for dealing with it. Describe two different reproductive strategies that can enhance the long-term survival of a species. Define **population density** and explain how it can affect the size of some but not all populations.

8. What is **ecological succession**? Distinguish between **primary ecological succession** and **secondary ecological succession** and give an example of each. Explain why succession does not follow a predictable path.

9. Explain how living systems achieve some degree of sustainability by undergoing constant change in response to changing environmental conditions. In terms of stability, distinguish between **inertia (persistence)** and **resilience** and give an example of each.

10. What are this chapter's *three big ideas*? Explain how changes in the nature and size of populations are related to the three **principles of sustainability**.

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. What difference would it make if the southern sea otter (**Core Case Study**) became extinct mostly because of human activities? What are three things we could do to help prevent the extinction of this species?

2. Use the second law of thermodynamics (see Chapter 2, p. 47) to help explain why predators are generally less abundant than their prey.

3. Explain why most species with a high capacity for population growth (such as bacteria, flies, and cockroaches) tend to have small individuals, while those with a low capacity for population growth (such as humans, elephants, and whales) tend to have large individuals.

4. Which reproductive strategy do most insect pest species and harmful bacteria use? Why does this make it difficult for us to control their populations?

5. List three factors that have limited human population growth in the past that we have overcome. Describe how we overcame each of these factors. List two factors that may limit human population growth in the future. Do you think that we are close to reaching those limits? Explain.

6. If the human species suffered a population crash, name three species that might move in to occupy part of our ecological niche.

7. How would you reply to someone who argues that we should not worry about our effects on natural systems because natural succession will heal the wounds of human activities and restore the balance of nature?

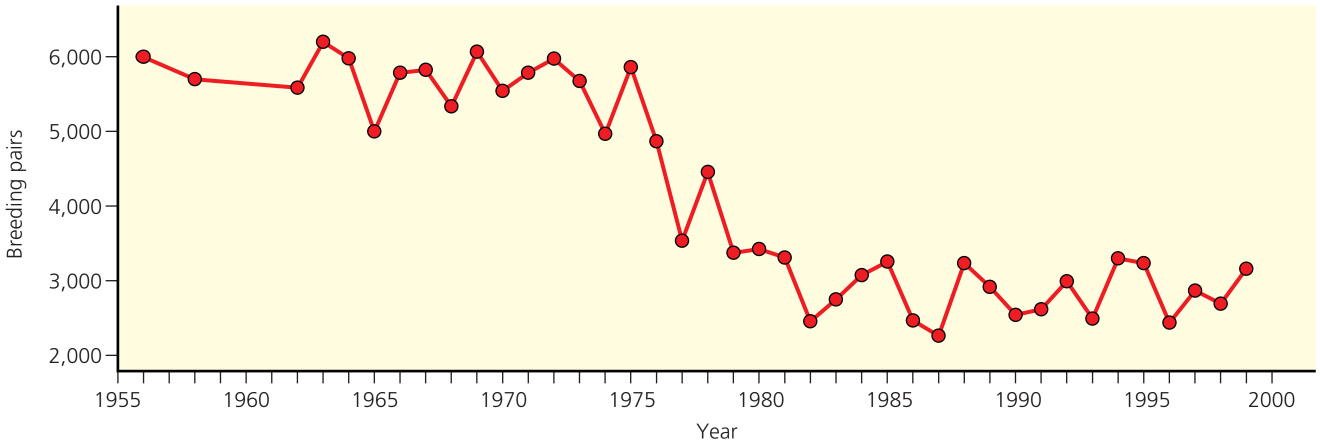
8. How would you reply to someone who contends that efforts to preserve natural systems are not worthwhile because nature is largely unpredictable?

9. In your own words, restate this chapter's closing quotation by Sir Francis Bacon. Do you agree with this notion? Why or why not?

10. List two questions that you would like to have answered as a result of reading this chapter.

DATA ANALYSIS

The graph below shows changes in the size of an emperor penguin population in terms of breeding pairs on the island of Terre Adelie in the Antarctic. Use the graph to answer the questions below.



Source: Data from *Nature*, May 10, 2001.

1. What was the approximate carrying capacity of the island for the penguin population from 1960 to 1975? What was the approximate carrying capacity of the island for the penguin population from 1980 to 2000? (Hint: see Figure 5-14.)

2. What is the percentage decline in the penguin population from 1975 to 2000?

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengagebrain.com/shop/ISBN/0538735341** and choose Chapter 5 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

For students with access to premium online resources, log on to **www.cengage.com/login**.

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The Human Population and Its Impact

6

Slowing Population Growth in China: A Success Story

CORE CASE STUDY

What is the world's most populous country? Answer: China, with 1.3 billion people (Figure 6-1). United Nations projections indicate that if China's current population trends continue, its population will increase to almost 1.5 billion by 2025 and then begin a slow decline to about 1.4 billion by 2050.

Since the 1960s, which country has done the most to reduce its population growth: China or the United States? Answer: China. In the 1960s, China's large population was growing so rapidly that there was a serious threat of mass starvation. To avoid this, government officials decided to establish the world's most extensive, intrusive, and strict family planning and birth control program.

China's goal has been to sharply reduce population growth by promoting one-child families. The government provides contraceptives, sterilizations, and abortions for married couples. In addition, married couples pledging to have no more than one child receive a number of benefits including better housing, more food, free health care, salary bonuses, and preferential job opportunities for their child. Couples who break their pledge lose such benefits.

Since this government-controlled program began, China has made impressive efforts to feed its people and bring its population growth under control. Between 1972 and 2010, the country cut its birth rate in half and trimmed the average number of children born to its women from 5.7 to 1.5, compared to 2.1 children per woman in the United States. As a result, the U.S. population is growing faster than China's population.

Since 1980, China has undergone rapid industrialization and economic growth. This has helped at least 100 million Chinese—a number equal to about one-third of the U.S. population—to work their way out of poverty and become middle-class consumers. Over time, China's rapidly growing middle class will consume more resources per person, increasing China's ecological footprint (see Figure 1-13, p. 16) within its own borders and in other parts of the world that provide it with resources. This will put a strain on the earth's natural capital unless China steers a course toward more sustainable economic development.

So why should we care about population growth in China, India, the United States, or anywhere else in the world? There are two major reasons. *First*, each of us depends on the earth's life-support systems to meet our basic needs for air, water, food, land, shelter, and energy as well as a number of other natural resources that we use to produce an incredible variety of manufactured goods. As our population grows and incomes rise, we use more of the earth's natural resources to satisfy our growing wants, and this increases our ecological footprints (see Figure 1-13, p. 16) and degrades the natural capital (see Figure 1-4, p. 9) that keeps us alive and supports our lifestyles. *Second*, we are not meeting the basic needs of 1.4 billion people—one of every five people on the planet.

This raises a very important question: If we are now failing to meet the basic needs for 1.4 billion people—4.5 times the entire U.S. population and more than the number of people currently living in China—and if we continue to degrade our life-support system, what will happen in 2050 when there are expected to be 2.7 billion more of us?

L. Young/UNEP/Peter Arnold, Inc.

Figure 6-1 Hundreds of people crowd a street in China. Almost one of every five persons on the planet lives in China, and the country's resource use per person is projected to grow rapidly as China becomes more modernized and wealthy.

Key Questions and Concepts

6-1 How many people can the earth support?

CONCEPT 6-1 We do not know how long we can continue increasing the earth's carrying capacity for humans without seriously degrading the life-support system that keeps us and many other species alive.

6-2 What factors influence the size of the human population?

CONCEPT 6-2A Population size increases through births and immigration, and decreases through deaths and emigration.

CONCEPT 6-2B The average number of children born to women in a population (*total fertility rate*) is the key factor that determines population size.

6-3 How does a population's age structure affect its growth or decline?

CONCEPT 6-3 The numbers of males and females in young, middle, and older age groups determine how fast a population grows or declines.

6-4 How can we slow human population growth?

CONCEPT 6-4 We can slow human population growth by reducing poverty, elevating the status of women, and encouraging family planning.

Note: Supplements 2 (p. S3), 8 (p. S30), and 9 (p. S57) can be used with this chapter.

The problems to be faced are vast and complex, but come down to this: 6.9 billion people are breeding exponentially. The process of fulfilling their wants and needs is stripping earth of its biotic capacity to support life; a climactic burst of consumption by a single species is overwhelming the skies, earth, waters, and fauna.

PAUL HAWKEN

6-1 How Many People Can the Earth Support?

▶ **CONCEPT 6-1 We do not know how long we can continue increasing the earth's carrying capacity for humans without seriously degrading the life-support system that keeps us and many other species alive.**

Human Population Growth Continues but Is Unevenly Distributed

For most of history, the human population grew slowly (see Figure 1-18, p. 21, left part of curve). But for the past 200 years, the human population has grown rapidly, resulting in the characteristic J-curve of exponential growth (see Figure 1-18, p. 21, right part of curve).

Three major factors account for this population increase. *First*, humans developed the ability to expand into almost all of the planet's climate zones and habitats. *Second*, the emergence of early and modern agriculture allowed us to grow more food for each unit of land area farmed. *Third*, death rates dropped sharply because of improved sanitation and health care and development of antibiotics and vaccines to help control infectious diseases. Thus, *most of the increase in the world's population during the last 100 years took place because of a sharp drop in death rates—not a sharp rise in birth rates*.

About 10,000 years ago, when agriculture began, there were roughly 5 million humans on the planet; now there are about 6.9 billion of us. It took from the time we arrived on the earth until about 1927 to add the first 2 billion people to the planet; less than 50 years to add the next 2 billion (by 1974); and just 25 years to add the next 2 billion (by 1999). This is an illustration of the awesome power of exponential growth (see Chapter 1, p. 20). **Explore More:** Go to a Case Study at **www.cengage.com/login** to learn more about what it means to be living in our current exponential age. By 2012 we will be trying to support 7 billion people and perhaps 9.5 billion by 2050. (See Figure 3, p. S58, in Supplement 9 for a timeline of key events related to human population growth.)

The rate of population growth has slowed (Figure 6-2), but the world's population is still growing exponentially at a rate of about 1.21% a year. This means that about 83 million people were added to the world's population during 2010—an average of more than 227,000 people each day, or 2 more people every time your heart beats. This is roughly equal to adding

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. GOOD NEWS refers to good news about the environmental challenges we face.

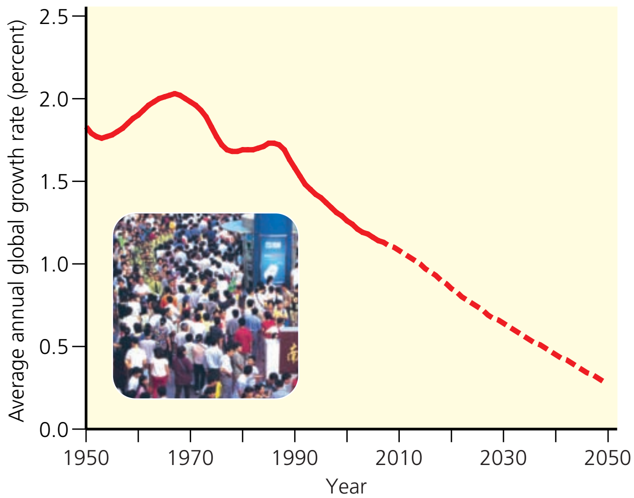


Figure 6-2 This graph tracks the annual growth rate of world population, 1950–2010, with projections to 2050. (Data from United Nations Population Division and U.S. Census Bureau)

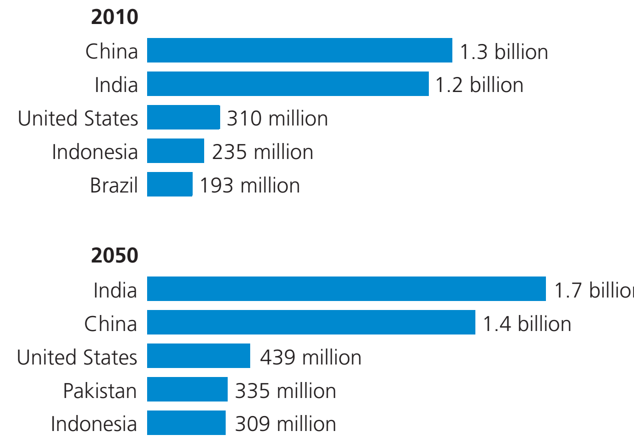


Figure 6-4 This chart shows the populations of the world's five most populous countries in 2010 and 2050 (projected). In 2010, more than one of every three persons on the earth lived in China (with 19% of the world's population) or India (with 17%). (Data from United Nations Population Division)

the equivalent of all of the people in the U.S. states of California, Texas, New York, and Iowa to the world's population every year.

Geographically, this growth is unevenly distributed and this pattern is expected to continue (Figure 6-3). About 1% of the 83 million new arrivals on the planet in 2010 were added to the world's more-developed countries, which are growing at 0.17% a year. The other 99% were added to the world's middle- and low-income, less-developed countries, which are growing 9 times faster at 1.4% a year, on average. And at least 95% of the 2.7 billion people likely to be added to world's population by 2050 will be born into less-developed countries. Figure 6-4 shows what the world's five most populous countries will be in 2010 and in 2050 (projected).

Estimates of how many of us are likely to be here in 2050 range from 7.8–10.8 billion people, with a medium projection of 9.6 billion people. These varying estimates depend mostly on projections about the average number of babies women are likely to have. But experts who make these projections, called *demographers*, also have to make assumptions about a number of other variables. If their assumptions are wrong, their population forecasts can be way off the mark (Science Focus, p. 128).

There is little, if any, chance for stabilizing the size of the human population in the near future, barring global nuclear war or some other major catastrophe. However, during this century, the human population may level off as it moves from a J-shaped curve of exponential

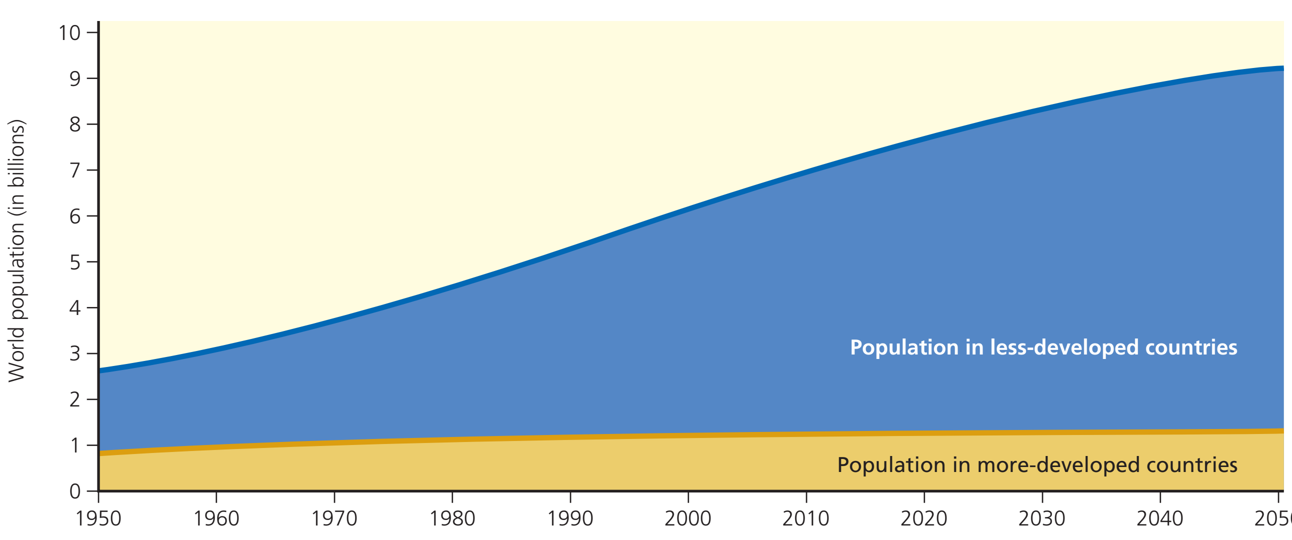


Figure 6-3 Most of the world's population growth between 1950 and 2010 took place in the world's less-developed countries. This gap is projected to increase between 2010 and 2050. (Data from United Nations Population Division, *The 2008 Revision* and Population Reference Bureau, *2010 World Population Data Sheet*)

SCIENCE FOCUS

Projecting Population Change

Recall that estimates of the human population size in 2050 range from 7.8–10.8 billion people—a difference of 3 billion. Why this wide range of estimates? The answer is that there are countless factors that demographers, or population experts, have to consider when making projections for any country or region of the world.

First, they have to determine the reliability of current population estimates. Many of the more-developed countries such as the United States have fairly good estimates. But many countries have poor knowledge of their population size. Some countries even deliberately inflate or deflate the numbers for economic or political purposes.

Second, demographers make assumptions about trends in fertility—that is, whether women in a country will on average have fewer babies in the future or more babies. The demographers might assume that fertility is declining by a certain percentage per year. But because population has momentum, it changes gradually, just as a large ship in motion travels some distance before it can change direction. If the estimate of the rate of declining fertility is off by a few percentage points, the resulting percentage increase in population can be magnified over a number of years, and be quite different from the projected population size increase.

An example of this process happened in Kenya. UN demographers assumed that Kenya's fertility rate would decline, and based on that, in 2002, they projected that Kenya's total population would be 44 million by 2050. In reality, the fertility rate rose from 4.7 to 4.8 children per woman. The population momentum was therefore more powerful than expected, and in 2008, the UN revised its projection for Kenya's population in 2050 to 65 million, much higher than its earlier projection.

Third, population projections are made by a variety of organizations employing demographers. UN projections tend to be cited most often. But the U.S. Census Bureau also makes world population projections, as does the International Institute for Applied Systems Analysis (IIASA). The World Bank has also made projections in the past and maintains a database. All of these organizations use differing sets of data and differing methods, and their projections vary (Figure 6-A). (See *The Habitable Planet*, Video 5, at **www.learner.org/resources/series209.html** for a discussion of how demographers measure population size and growth.).

Critical Thinking

If you were in charge of the world and making decisions about resource use based on population projections, which of the projections in Figure 6-A would you rely on? Explain.

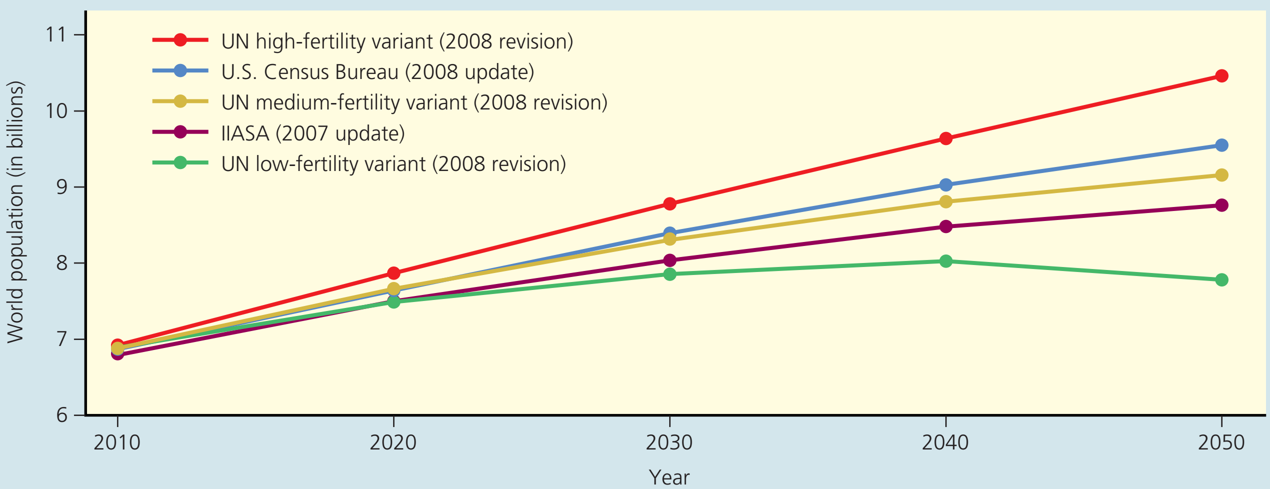


Figure 6-A This graph shows world population projections to 2050 from three different organizations: the UN, the U.S. Census Bureau, and IIASA. Note that the upper-most, middle, and lower-most curves of these five projections are all from the UN, each assuming a different level of fertility.

growth to an S-shaped curve of logistic growth (see Figure 5-14, p. 115, and Figure 6-A). This could happen because of various factors that can limit human population growth or because governments or individuals might act to reduce population growth.

HOW WOULD YOU VOTE?

Should the population of the country where you live be stabilized as soon as possible? Cast your vote online at **www.cengage.com/login**.

This raises a question: How many people can the earth support indefinitely? Some analysts believe this is the wrong question. Instead, they believe we should ask, what is the planet's **cultural carrying capacity**? This would be the maximum number of people who could live in reasonable freedom and comfort indefinitely, without decreasing the ability of the earth to sustain future generations. (See the Guest Essay by Garrett Hardin on this topic at CengageNOW™.) This issue has long been a topic of scientific debate (Science Focus, at right).

RESEARCH FRONTIER

Estimating the cultural carrying capacity of the earth and of its various regions; see **www.cengage.com/login**.

How Long Can the Human Population Keep Growing?

To survive and provide resources for growing numbers of people, humans have modified, cultivated, built on, and degraded a large and increasing portion of the earth's natural systems. Our activities have directly affected, to some degree, about 83% of the earth's land surface, excluding Antarctica (see Figure 7, p. S38, in Supplement 8), as our ecological footprints have spread across the globe (see Figure 1-13, p. 16).

Scientific studies of the populations of other species tell us that *no population can continue growing indefinitely*. How long can we continue to avoid the reality of the earth's carrying capacity for our species by sidestepping many of the factors that sooner or later limit the growth of any population?

The debate over this important question has been going on since 1798 when Thomas Malthus, a British economist, hypothesized that the human population tends to increase exponentially, while food supplies tend to increase more slowly at a linear rate. So far, Malthus has been proven wrong. Food production has grown at an exponential rate instead of at a linear rate because of genetic and other technological advances in industrialized food production.

Environmental scientists are re-examining arguments such as those of Malthus about possible limits to the growth of human populations and economies. One view is that the planet has too many people collectively degrading its life-support system. To some scientists and other analysts, the key problem is *overpopulation* because of the sheer number of people in less-developed countries (see Figure 1-14, top, p. 17), which have 82% of the world's population. To others, the key factor is *overconsumption* in affluent, more-developed countries because of their high rates of resource use per person (see Figure 1-14, bottom, p. 17).

Excessive and wasteful resource consumption per person has grown in more-developed countries and to an increasing extent in rapidly growing less-developed countries such as China (**Core Case Study**) and India. Such resource consumption increases the environmental impact, or ecological footprint, of each person (see Figure 1-13, top right, p. 16). For example, ecological footprint analysts have estimated that the average ecological footprint of each American is 4.5 times larger than that of the average Chinese person and about 9.5 times as large as the footprint of the average Indian.

At today's level of consumption, scientists estimate that we would need the equivalent of 1.3 planet Earths to sustain our per capita use of renewable resources indefinitely (see Figure 1-13, bottom, p. 16). By 2050, with the projected population increase, we will likely need almost 2 planet Earths to meet such resource needs and 5 Earths if everyone reaches the current U.S. level of renewable resource consumption per person. People who hold the general view that overpopulation is contributing to major environmental problems argue that slowing human population growth is a very important priority.

Another view of population growth is that technological advances have allowed us to overcome the environmental resistance that all populations face (see Figure 5-14, p. 115) and that this has the effect of increasing the earth's carrying capacity for our species. Some analysts believe that because of our technological ingenuity, there are few, if any, limits to human population growth and resource use per person.

To these analysts, adding more people means having more workers and consumers to support ever-increasing economic growth. They believe that we can avoid serious damage to our life-support systems through technological advances in areas such as food production and medicine, and by finding replacements for resources that we are depleting. As a result, they see no need to slow the world's population growth.

No matter which side people take in this important debate, most agree that we have used technology to alter natural systems to meet our growing needs and wants. Scientists cite eight major ways in which this has occurred (Figure 6-B).

No one knows how close we are to the environmental limits that will control the size of the human population. But it is a vital scientific, political, economic, and ethical issue that we must confront.

Critical Thinking

How close do you think we are to the environmental limits of human population growth—pretty close, moderately close, or far away? Explain.

CENGAGENOW™ **Active Figure 6-B** This list describes eight major ways in which we humans have altered natural systems to meet our growing population's resource needs and wants (**Concept 6-1**). *See an animation based on this figure at* CengageNOW. **Questions:** Which three of these impacts do you believe have been the most harmful? Explain. How does your lifestyle contribute directly or indirectly to each of these harmful impacts?

6-2 What Factors Influence the Size of the Human Population?

▶ **CONCEPT 6-2A Population size increases through births and immigration, and decreases through deaths and emigration.**

▶ **CONCEPT 6-2B The average number of children born to women in a population (*total fertility rate*) is the key factor that determines population size.**

The Human Population Can Grow, Decline, or Remain Fairly Stable

The basics of global population change are quite simple. If there are more births than deaths during a given period of time, the earth's population increases, and when the reverse is true, it decreases. When the number of births equals the number of deaths during a particular time period, the global population size does not change.

Instead of using the total numbers of births and deaths per year, demographers use the *birth rate*, or **crude birth rate** (the number of live births per 1,000 people in a population in a given year), and the *death rate*, or **crude death rate** (the number of deaths per 1,000 people in a population in a given year).

Human populations grow or decline in particular countries, cities, or other areas through the interplay of three factors: *births (fertility)*, *deaths (mortality)*, and *migration*. We can calculate the **population change** of an area by subtracting the number of people leaving a population (through death and emigration) from the number entering it (through birth and immigration) during a specified period of time (usually one year) (**Concept 6-2A**).

Population change = (Births + Immigration) − (Deaths + Emigration)

When births plus immigration exceed deaths plus emigration, a population increases; when the reverse is true, a population declines. (Figure 11, p. S43, in Supplement 8 is a map showing percentage rates of population change in the world's countries in 2010.)

Women Are Having Fewer Babies but Not Few Enough to Stabilize the World's Population

Another measurement used in population studies is the **fertility rate**, the number of children born to a woman during her lifetime. Two types of fertility rates affect a country's population size and growth rate. The first type, called the **replacement-level fertility rate**, is the average number of children that couples in a population must bear to replace themselves. It is slightly higher than two children per couple (2.1 in more-developed countries and as high as 2.5 in some less-developed countries), mostly because some children die before reaching their reproductive years.

Does reaching replacement-level fertility bring an immediate halt to population growth? No, because so many *future* parents are alive. If each of today's couples had an average of 2.1 children, they would not be contributing to population growth. But if all of today's girl children grow up to have an average of 2.1 children as well, the world's population would continue to grow for 50 years or more (assuming death rates do not rise) because there are so many girls under age 15 who will be moving into their reproductive years.

The second type of fertility rate, the **total fertility rate** (**TFR**), is the average number of children born to women in a population during their reproductive years. This factor plays a key role in determining population size (**Concept 6-2B**). Between 1955 and 2010, the average TFR dropped from 2.8 to 1.7 children per woman in more-developed countries and from 6.2 to 2.7 in less-developed countries. The average TFR for less-developed countries is projected to continue dropping (Figure 6-5), while that for more-developed countries is likely to rise slightly. (See Figure 12, p. S44, in Supplement 8 for a map of how TFRs vary globally.)

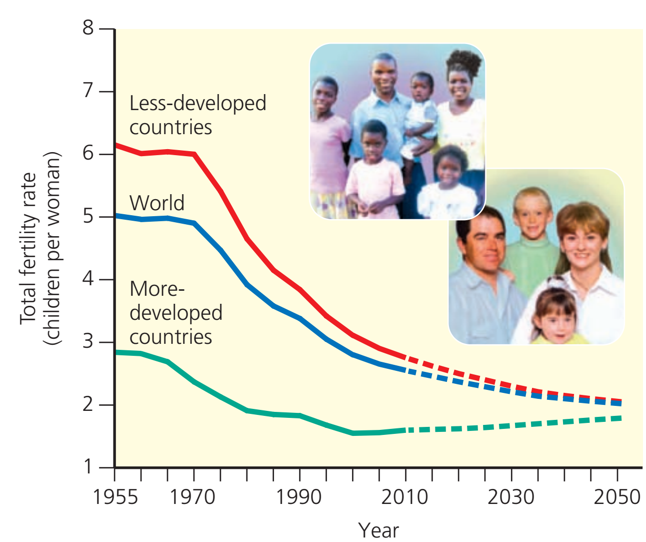


Figure 6-5 This graph tracks the total fertility rate for both the more-developed and less-developed regions of the world, 1955–2010, with projections to 2050 (based on medium population projections). Although the world's average TFR has dropped to 2.5, it will have to drop to around 2.1 to eventually halt the world's population growth. (Data from United Nations Population Division)

CONNECTIONS

Population Growth and Fertility Rates in China CORE CASE STUDY

Because of China's strict one-child population policy, the country's total fertility rate dropped from 5.7 to 1.5 between 1972 and 2010. Some have criticized China for having such a strict population control policy. But government officials say that the alternative was mass starvation. They estimate that China's one-child policy has reduced its population size by 300–400 million people, a figure probably larger than the current U.S. population, and well below what China's population would have been without the policy.

CASE STUDY

The U.S. Population Is Growing Rapidly

The population of the United States grew from 76 million in 1900 to 310 million in 2010, despite oscillations in the country's TFR and birth rates (Figure 6-6). It took the country 139 years to add its first 100 million people, 52 years to add another 100 million by 1967, and only 39 years to add the third 100 million by 2006. During the period of high birth rates between 1946 and 1964, known as the *baby boom*, 79 million people were added to the U.S. population. At the peak of the baby boom in 1957, the average TFR was 3.7 children per woman. In 2010, and in most years since 1972, it has been at or below 2.1 children per woman, compared to 1.5 in China in 2010.

The drop in the TFR has slowed the rate of population growth in the United States. But the country's population is still growing faster than those of all other more-developed countries as well as that of China, and it is not close to leveling off. According to the U.S. Census Bureau, about 2.7 million people were added to the U.S. population in 2010. About 1.8 million (two-thirds of the total) were added because there were that many more births than deaths, and almost 900,000 (a third of the total) were legal immigrants.

In addition to the fourfold increase in population growth since 1900, some amazing changes in lifestyles took place in the United States during the 20th century (Figure 6-7, p. 132), which led to dramatic increases in per capita resource use and a much larger U.S. ecological footprint (see Figure 1-13, top, p. 16).

Here are a few more changes that occurred during the last century. In 1907, the three leading causes of death in the United States were pneumonia, tuberculosis, and diarrhea (ailments that are seldom life-threatening now); 90% of U.S. doctors had no college education; one of five adults could not read or write; only 6% of Americans graduated from high school; the average U.S. worker earned a few hundred to a few thousand dollars per year; there were only 9,000 cars in the country and only 232 kilometers (144 miles) of paved roads; a 3-minute phone call from Denver, Colorado, to New York city cost $11; only 30 people lived in Las Vegas, Nevada; marijuana, heroin, and morphine

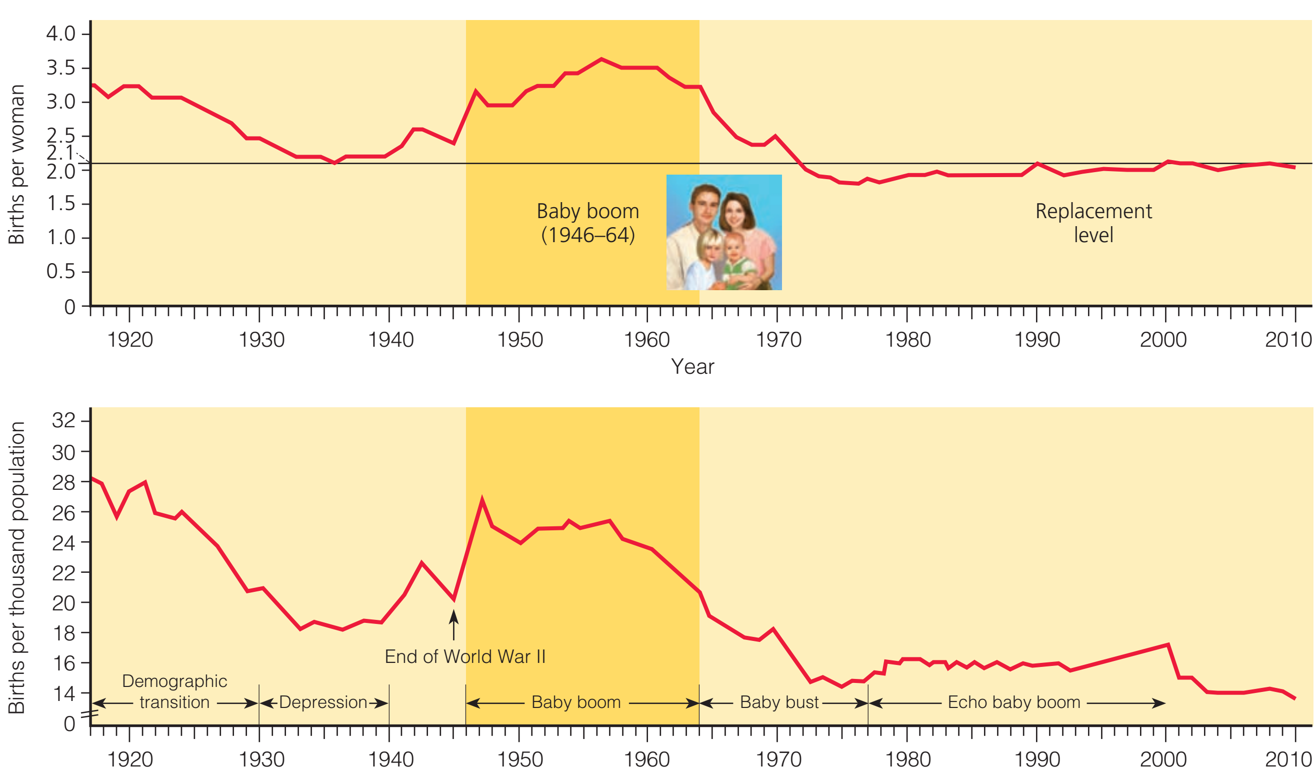
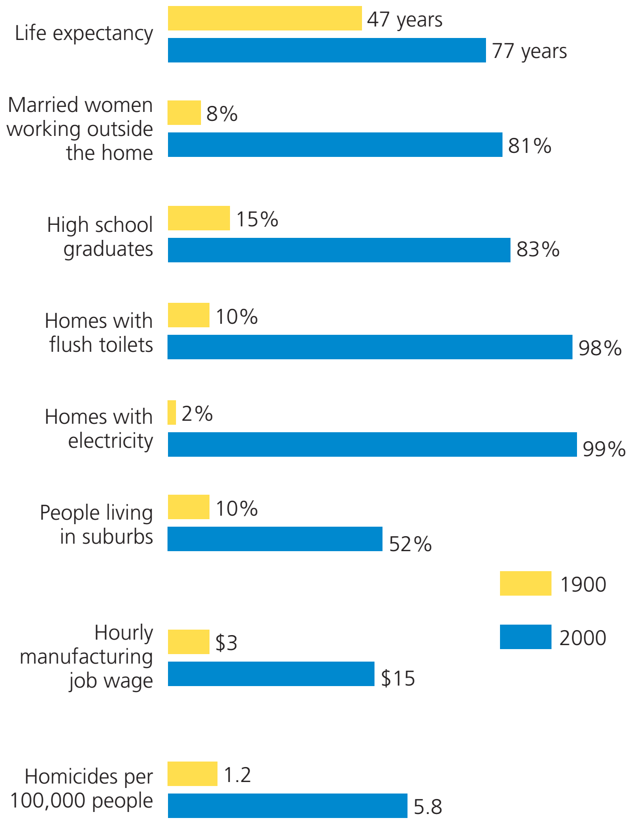


Figure 6-6 The top graph shows the total fertility rates for the United States between 1917 and 2010 and the bottom graph shows the country's birth rate between 1917 and 2010. **Question:** The U.S. fertility rate has declined and remained at or below replacement levels since 1972. So why is the population of the United States still increasing? (Data from Population Reference Bureau and U.S. Census Bureau)

Figure 6-7 This chart lists some major changes that took place in the United States between 1900 and 2000. **Question:** Which two of these changes do you think were the most important? (Data from U.S. Census Bureau and Department of Commerce)



were available over the counter at local drugstores; and there were only 230 reported murders in the entire country.

The U.S. Census Bureau projects that the U.S. population is likely to increase from 310 million in 2010 to 423 million by 2050. In contrast, since 1950, population growth has slowed in other major more-developed countries, most of which are expected to have declining populations in the near future.

Because of a high per capita rate of resource use and the resulting waste and pollution, each addition to the U.S. population has an enormous environmental impact (see Figure 1-14, top, p. 17, and the map in Figure 9, p. S41, in Supplement 8). In terms of environmental impact per person, many analysts consider the United States to be by far the world's most overpopulated country, mostly because of its high rate of resource use per person and its fairly high population growth rate compared to most other more-developed countries and to China. If U.S. Census Bureau projections are correct, between 2010 and 2050, there will be about 113 million more Americans.

Several Factors Affect Birth Rates and Fertility Rates

Many factors affect a country's average birth rate and TFR. One is the *importance of children as a part of the labor force*, especially in less-developed countries. This is a major reason for why it makes sense for many poor couples in those countries to have a large number of children. They need help with hauling daily drinking water (Figure 6-8), gathering wood for heating and cooking, and tending crops and livestock.

Another economic factor is the *cost of raising and educating children*. Birth and fertility rates tend to be lower in more-developed countries, where raising children is much more costly because they do not enter the labor force until they are in their late teens or twenties. (In the United States, for example, it costs more than $220,000 to raise a middle-class child from birth to age 18.) By contrast, many children in poor countries receive little education and instead have to work to help their families survive (Figure 6-9).

The *availability of, or lack of, private and public pension systems* can influence the decision of some couples on how many children to have, especially the poor in less-developed countries. Pensions reduce a couple's need to have many children to help support them in old age.

There are more *infant deaths* in poorer countries, so having several children might insure survival of at least a few—somewhat like having an insurance policy.

Urbanization plays a role. People living in urban areas usually have better access to family planning services and tend to have fewer children than do those living in rural areas. This is especially true in less-developed countries where children are often needed to help raise crops and carry daily water and fuelwood supplies.

Another important factor is the *educational and employment opportunities available for women*. Total fertility rates tend to be low when women have access to education and paid employment outside the home. In less-developed countries, a woman with little or no formal

A. Ishokon-UNEP/Peter Arnold, Inc.

Figure 6-8 This girl is carrying well water across parched earth that has dried out and cracked during a severe drought in India.

Mark Edwards/Peter Arnold, Inc.

Figure 6-9 These young girls are child laborers in the state of Rajasthan in India. They are weaving wool on looms to make carpets for export, and receive very little money for their work.

education typically has two more children than does a woman with a high school education. In nearly all societies, better-educated women tend to marry later and have fewer children.

Average age at marriage (or, more precisely, the average age at which a woman has her first child) also plays a role. Women normally have fewer children when their average age at marriage is 25 or older.

Birth rates and TFRs are also affected by the *availability of legal abortions*. Each year, about 190 million women become pregnant. The United Nations and the Alan Guttmacher Institute estimate that at least 40 million of these women get abortions—about 20 million of them legal and the other 20 million illegal (and often unsafe). Also, the *availability of reliable birth control methods* allows women to control the number and spacing of the children they have.

Religious beliefs, traditions, and cultural norms also play a role (Connections, below). In some countries, these factors favor large families as many people there strongly oppose abortion and some forms of birth control.

CONNECTIONS

China, Male Children, and the Bride Shortage

CORE CASE STUDY

In China, there is a strong preference for male children, because unlike sons, daughters are likely to marry and leave their parents. And traditionally the families of brides are obligated to provide expensive dowries. Some pregnant Chinese women use ultrasound to determine the gender of their fetuses, and some get an abortion if it is female. This has led to some worrisome problems. For one thing, thieves are stealing baby boys and are selling them to families that want a boy. Also, the government estimates that by 2030, there may be approximately 30 million Chinese men who will not be able to find wives. Because of this rapidly growing "bride shortage," young girls in some parts of rural China are being kidnapped and sold as brides for single men in other parts of the country.

Several Factors Affect Death Rates

The rapid growth of the world's population over the past 100 years is not primarily the result of a rise in the birth rate. Instead, it has been caused largely by a decline in death rates, especially in less-developed countries. More people in these countries started living longer and fewer infants died. This happened because of increased food supplies and distribution, better nutrition, medical advances such as immunizations and antibiotics, improved sanitation, and safer water supplies (which curtailed the spread of many infectious diseases).

Two useful indicators of the overall health of people in a country or region are **life expectancy** (the average number of years a newborn infant can be expected to live) and the **infant mortality rate** (the number of babies out of every 1,000 born who die before their first birthday). (See a map of infant mortality by country in Figure 13, p. S45, of Supplement 8.) Between 1955 and 2010, the global life expectancy increased from 48 years to 69 years (77 years in more-developed countries and 67 years in less-developed countries) and is projected to reach 74 by 2050. In 2010, Japan had the world's longest life expectancy of 83 years. Between 1900 and 2009, life expectancy in the United States increased from 47 to 78 years and, by 2050, is projected to reach 83 years. In the world's poorest countries, however, life expectancy is 57 years or less and may fall further in some countries because of more deaths from AIDS and internal strife.

GOOD NEWS

Infant mortality is viewed as one of the best measures of a society's quality of life because it reflects a country's general level of nutrition and health care. A high infant mortality rate usually indicates insufficient food (undernutrition), poor nutrition (malnutrition), and a high incidence of infectious disease (usually from drinking contaminated water and having weakened

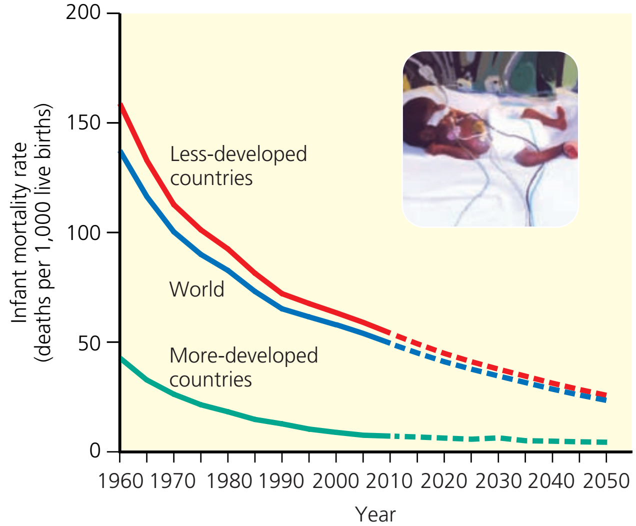


Figure 6-10 This graph tracks the infant mortality rates for the world's more-developed countries and less-developed countries, 1950–2010, with projections to 2050 based on medium population projections. (Data from United Nations Population Division)

disease resistance due to undernutrition and malnutrition). Infant mortality also affects the TFR. In areas with low infant mortality rates, women tend to have fewer children because fewer children die at an early age.

Infant mortality rates in more-developed and less-developed countries have declined dramatically since 1965, as shown in Figure 6-10. But despite this sharp drop, more than 4 million infants (most in less-developed countries) die each year of preventable causes during their first year of life—an average of nearly 11,000 mostly unnecessary infant deaths per day. This is equivalent to 55 jet airliners, each loaded with 200 infants younger than age 1, crashing *every day* with no survivors!

The U.S. infant mortality rate declined from 165 in 1900 to 6.4 in 2010. This sharp decline was a major factor in the marked increase in U.S. average life expectancy during this period. Although the United States ranks number one in terms of health care spending, the country ranks 54th in the world in terms of infant mortality rates.

Three factors helped to keep the U.S. infant mortality rate higher than it could be. First was generally inadequate health care for poor women during pregnancy and for their babies after birth. A second factor was drug addiction among pregnant women. Third, there was a high birth rate among teenagers. The rate of teenage pregnancies dropped by about one-third between 1991 and 2005. However, that trend was reversed in 2006 and 2007 when the rate of teenage pregnancies rose by almost 5%. The United States now has the world's highest teenage pregnancy rate.

Scientists also measure *child mortality rates*—the annual number of deaths among children under age 5 per 1,000 live births. According to the United Nations, the world's child mortality rate dropped 20% between 1960 and 2008. This amounted to a drop in the total number of such deaths from 20 million to 8.8 million between 1960 and 2008.

GOOD NEWS

Child mortality varies greatly from region to region. The most common cause of child mortality in many less-developed regions is the use of contaminated water for drinking and washing, resulting in diarrheal diseases and other illnesses that are not as prevalent in more-developed countries.

Migration Affects an Area's Population Size

The third factor in population change is **migration**: the movement of people into (*immigration)* and out of *(emigration*) specific geographic areas. In 2009, more than 190 million people migrated from one country to another—more than 60 million of them from less-developed countries to more-developed countries.

Most people migrating from one area or country to another seek jobs and economic improvement. But religious persecution, ethnic conflicts, political oppression, wars, and certain types of environmental degradation such as soil erosion and water and food shortages drive some to migrate. According to a UN study and another study by environmental scientist Norman Myers, in 2008 there were at least 40 million *environmental refugees*—people who had to leave their homes because of water or food shortages, drought, flooding, or other environmental crises. An estimated 1 million more are added to this number every year.

CONNECTIONS

Climate Change and Environmental Refugees

Environmental scientist Norman Myers warns that, as the world experiences climate change in this century as projected by most climate scientists, conditions that create environmental crises such as drought and flooding will worsen. With more such crises, the number of environmental refugees could soar to 250 million or more before the end of this century. (See more on this in the Guest Essay by Norman Myers at CengageNOW.)

CASE STUDY

The United States: A Nation of Immigrants

Since 1820, the United States has admitted almost twice as many immigrants and refugees as all other countries combined. The number of legal immigrants (including refugees) has varied during different periods because of changes in immigration laws and rates of economic growth (Figure 6-11). Currently, legal and illegal immigration account for about 36% of the country's annual population growth.

Between 1820 and 1960, most legal immigrants to the United States came from Europe. Since 1960, most

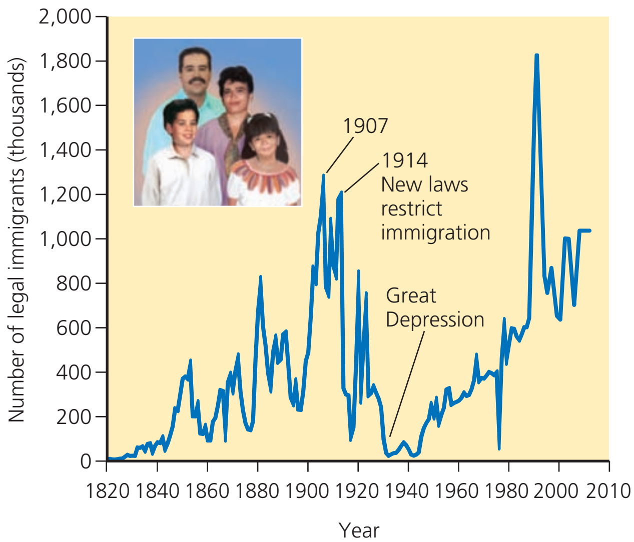


Figure 6-11 This graph shows legal immigration to the United States, 1820–2006 (the last year for which data are available). The large increase in immigration since 1989 resulted mostly from the Immigration Reform and Control Act of 1986, which granted legal status to certain illegal immigrants who could show they had been living in the country prior to January 1, 1982. (Data from U.S. Immigration and Naturalization Service and the Pew Hispanic Center)

have come from Latin America (53%) and Asia (25%), followed by Europe (14%). In 2009, legal Hispanic immigrants (2 out of 3 from Mexico) made up 15% of the U.S. population, and by 2050, are projected to make up 30% of the population.

There is controversy over whether to reduce legal immigration to the United States. Some legislators recommend accepting new entrants only if they can support themselves, arguing that providing legal immigrants with public services makes the United States a magnet for the world's poor. Proponents of reducing legal immigration argue that it would allow the United States to stabilize its population sooner and help to reduce the country's enormous environmental impact from its large ecological footprint.

Polls show that almost 60% of the American public strongly supports reducing legal immigration. There is also intense political controversy over what to do about illegal immigration. In 2009, there were an estimated 11 million illegal immigrants in the United States.

Those opposed to reducing current levels of legal immigration argue that it would diminish the historical role of the United States as a place of opportunity for the world's poor and oppressed. They also argue that it would take away from the cultural diversity and innovative spirit that has been a hallmark of American culture since the country's beginnings.

In addition, according to several studies, including a 2006 study by the Pew Hispanic Center, most immigrants and their descendants pay taxes. They also start new businesses, create jobs, add cultural vitality, and help the United States to succeed in the global economy. Also, many immigrants take menial and low-paying jobs that most other Americans shun. In fact, if the baby-boom generation is to receive social security benefits at the levels that retirees have come to expect, the U.S. workforce will have to grow, and immigrants will help to solve that problem.

HOW WOULD YOU VOTE?

Should legal immigration into the United States be reduced? Cast your vote online at **www.cengage.com/login**.

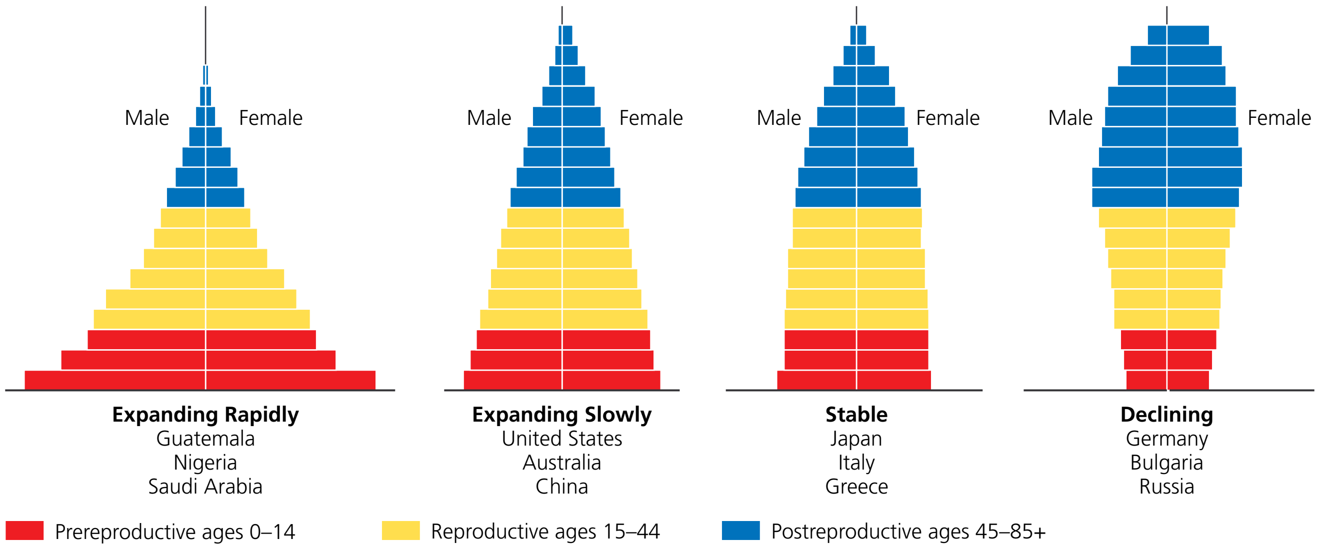
6-3 How Does a Population's Age Structure Affect Its Growth or Decline?

▶ **CONCEPT 6-3 The numbers of males and females in young, middle, and older age groups determine how fast a population grows or declines.**

A Population's Age Structure Helps Us to Make Projections

As mentioned earlier, even if the global replacement-level fertility rate of 2.1 children per woman were magically achieved tomorrow, the world's population would keep growing for at least another 50 years (assuming no large increase in the death rate). This continued growth results mostly from a population's **age structure**: the numbers or percentages of males and females in young, middle, and older age groups in that population (**Concept 6-3**).

Population experts construct a population *age-structure diagram* by plotting a given population's percentages of males and females in each of three age categories: *prereproductive* (ages 0–14), consisting of individuals normally too young to have children; *reproductive* (ages 15–44), consisting of those normally able to have children; and *postreproductive* (ages 45 and older), with individuals normally too old to have children.



CENGAGENOW™ **Active Figure 6-12** This chart represents the generalized population age-structure diagrams for countries with rapid (1.5–3%), slow (0.3–1.4%), zero (0–0.2%), and negative (declining) population growth rates. A population with a large proportion of its people in the prereproductive age group (far left) has a significant potential for rapid population growth. *See an animation based on this figure at* CengageNOW. **Question:** Which of these diagrams best represents the country where you live? (Data from Population Reference Bureau)

Figure 6-12 presents generalized age-structure diagrams for countries with rapid, slow, zero, and negative population growth rates.

A country with a large percentage of its people younger than age 15 (represented by a wide base in Figure 6-12, far left) will experience rapid population growth unless death rates rise sharply. Because of this *demographic momentum,* the number of births will rise for several decades even if women have an average of only one or two children, due to the large number of girls entering their prime reproductive years.

In 2010, about 27% of the world's population—30% in the less-developed countries and 16% in more-developed countries—was under age 15. Over the next 14 years, these 1.8 billion young people—amounting to about 1 of every 4 persons on the planet—are poised to move into their prime reproductive years. The dramatic differences in population age structure between less- and more-developed countries (Figure 6-13) show why most future human population growth will take place in less-developed countries.

However, the fastest growing age group is seniors—people who are 65 and older, according to a 2009 report from the U.S. Census Bureau. The global population of seniors is projected to triple by 2050, when one of every six people will be a senior. This graying of the world's

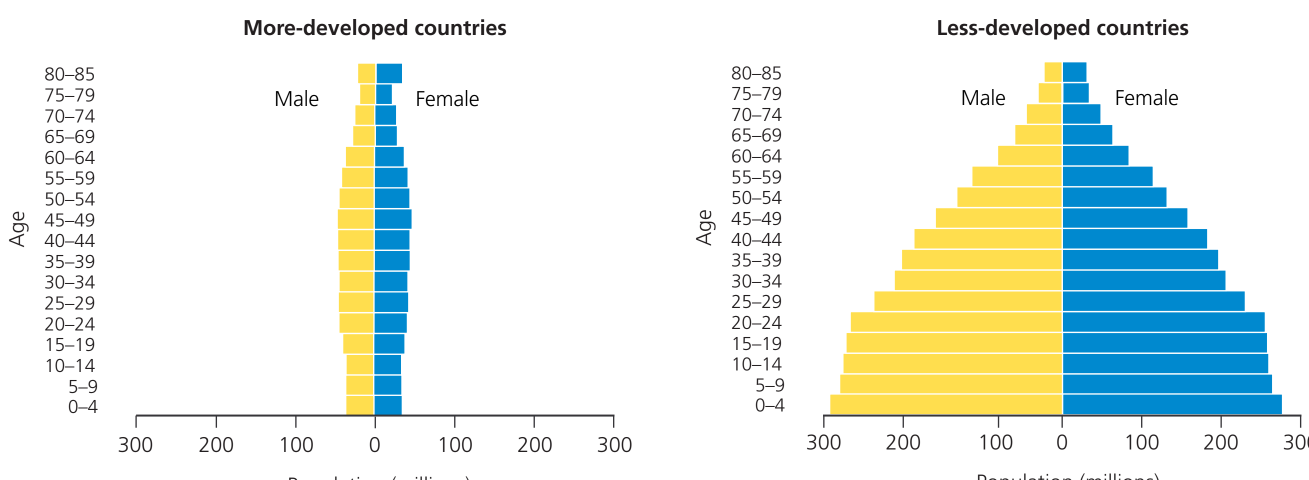


Figure 6-13 *Global outlook:* These charts illustrate population structure by age and sex in less-developed countries and more-developed countries for 2010. **Question:** If all girls under 15 were to have only one child during their lifetimes, how do you think these structures would change over time? (Data from United Nations Population Division and Population Reference Bureau)

population is due largely to declining birth rates and medical advances that have extended our lifespans.

Some analysts worry about how societies will support this growing group of elderly people. For example, China (**Core Case Study**) currently has 16 seniors per 100 workers. By 2025, it will have roughly 30 seniors per 100 workers, and by 2050, this ratio will be 61 to 100.

CORE CASE STUDY

■ CASE STUDY
The American Baby Boom

Changes in the distribution of a country's age groups have long-lasting economic and social impacts. For example, consider the American baby boom, which added 79 million people to the U.S. population. For decades, members of the baby-boom generation have strongly influenced the U.S. economy because they make up about 36% of all adult Americans. Over time, this group looks like a bulge moving up through the country's age structure, as shown in Figure 6-14.

In addition to dominating the population's demand for goods and services, the baby-boom generation plays an increasingly important role in deciding who gets elected to public office and what laws are passed. Baby boomers created the youth market in their teens and twenties and are now creating the late-middle-age and senior markets.

In the economic downturn that began in 2007, many of these people have lost their jobs and much of their savings. How this large portion of the American population will deal with these losses as they advance into later life could provide major challenges for them and for younger generations of U.S. workers. A 2010 study by the Pew Research Center projected that Americans in the millennial generation (those who were born since about 1980) will probably face higher unemployment (37% in 2009), and higher taxes. This will make it harder for them to raise families and support baby boomers.

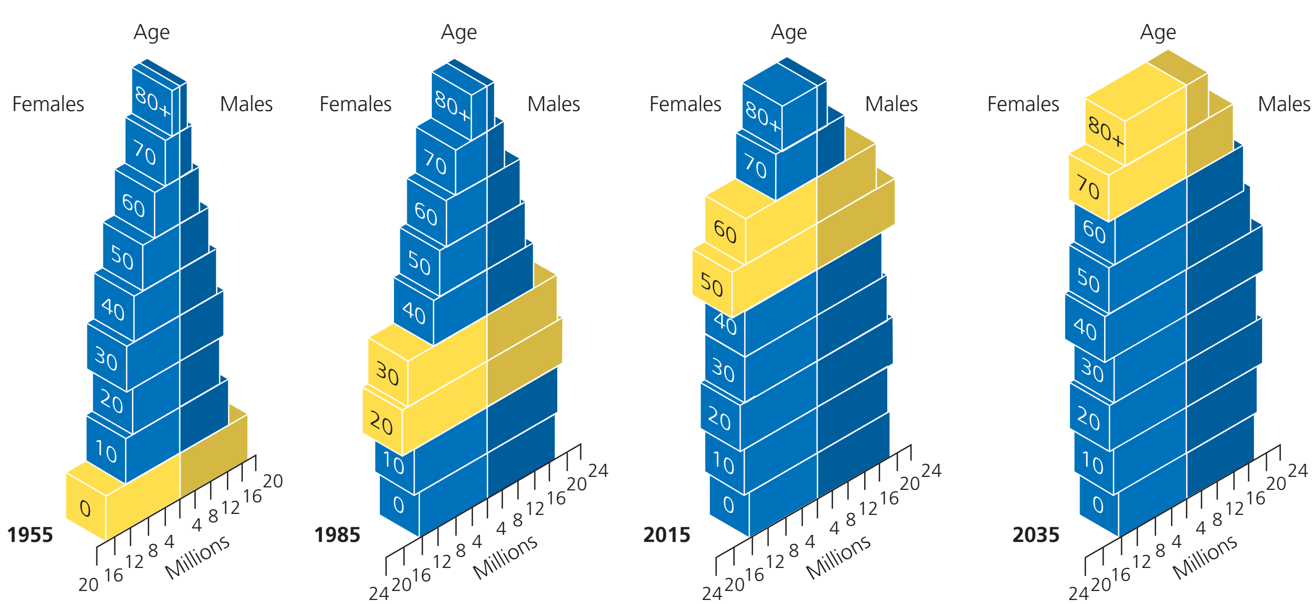
In 1960, one in 11 Americans were older than 65. After 2011, when the first baby boomers begin turning 65, the number of Americans older than age 65 will grow sharply through 2030 when they will be one of every five people in the country. This process has been called the *graying of America*.

CONNECTIONS

Baby Boomers, the U.S. Work Force, and Immigration

According to the U.S. Census Bureau, after 2020, much higher immigration levels will be needed to supply enough workers as baby boomers retire. According to a recent study by the UN Population Division, if the United States wants to maintain its current ratio of workers to retirees, it will need to absorb an average of 10.8 million immigrants each year—more than 10 times the current immigration level—through 2050. At that point, the U.S. population could total 1.1 billion people, and 73% of them would be immigrants or their descendants. Housing this influx of almost 11 million immigrants per year would require building the equivalent of another New York City every 10 months.

CENGAGENOW™ Examine how the baby boom affects the U.S. age structure over several decades at CengageNOW.



CENGAGENOW™ **Active Figure 6-14** These charts track the baby-boom generation in the United States, showing the U.S. population by age and sex for 1955, 1985, 2015 (projected), and 2035 (projected). *See an animation based on this figure at* CengageNOW. (Data from U.S. Census Bureau)

Populations Made Up Mostly of Older People Can Decline Rapidly

As the age structure of the world's population changes and the percentage of people age 60 and older increases, more countries will begin experiencing population declines. If population decline is gradual, its harmful effects usually can be managed.

Japan has the world's highest percentage of elderly people and the world's lowest percentage of young people. Its population of 127 million in 2010 is projected to shrink to around 95 million by 2050. At that time, about 40% of Japan's population will be 65 or over.

In China, because there are fewer children as a result of the one-child policy (**Core Case Study**), the average age of China's population is increasing rapidly. While China's population is not yet declining, the UN estimates that by 2020, 31% of the Chinese population will be over 60 years old, compared to 8% in 2010. This graying of the Chinese population could lead to a declining work force, limited funds for supporting continued economic development, and fewer children and grandchildren to care for the growing number of elderly people. These concerns and other factors may slow economic growth and lead to some relaxation of China's one-child population control policy in the future.

Rapid population decline can lead to severe economic and social problems. A country that experiences a fairly rapid "baby bust" or a "birth dearth," when its TFR falls below 1.5 children per couple for a prolonged period, sees a sharp rise in the proportion of older people. This puts severe strains on government budgets because these individuals consume an increasingly larger share of medical care, pension funds, and other costly public services, which are funded by a decreasing number of working taxpayers.

Such countries can also face labor shortages unless they rely more heavily on automation or massive immigration of foreign workers. For example, in the next two to three decades, countries such as the United States and many European nations with rapidly aging populations will face shortages of health-care workers.

Figure 6-15 lists some of the problems associated with rapid population decline.

Countries that will soon have rapidly declining populations include Japan, Russia, Germany, Bulgaria, Hungary, Ukraine, Serbia, Greece, Portugal, and Italy.

Populations Can Decline Due to a Rising Death Rate: The AIDS Tragedy

A large number of deaths from AIDS can disrupt a country's social and economic structure by removing significant numbers of young adults from its population. According to the World Health Organization, between 1981 and 2009, AIDS killed more than 27 million people and it takes about 2 million more lives each year (including 22,000 in the United States, 39,000 in China, 140,000 in Zimbabwe, and 350,000 in South Africa).

Unlike hunger and malnutrition, which kill mostly infants and children, AIDS kills many young adults and leaves many children orphaned. This change in the young-adult age structure of a country has a number of harmful effects. One is a sharp drop in average life expectancy, especially in several African countries where 15–26% of the adult population is infected with HIV.

Another effect of the AIDS pandemic is the loss of productive young adult workers and trained personnel such as scientists, farmers, engineers, and teachers, as well as government, business, and health-care workers. The essential services they could provide are therefore lacking, and thus there are fewer workers available to support the very young and the elderly. Within a decade, African countries such as Botswana, Swaziland, Lesotho, and South Africa could each lose more

Some Problems with Rapid Population Decline

Can threaten economic growth

Labor shortages

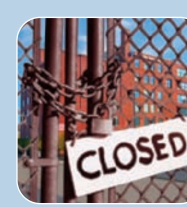
Less government revenues with fewer workers

Less entrepreneurship and new business formation

Less likelihood for new technology development

Increasing public deficits to fund higher pension and health-care costs

Pensions may be cut and retirement age increased



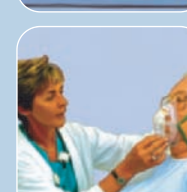


Figure 6-15 Rapid population decline can cause several problems. **Question:** Which three of these problems do you think are the most important?

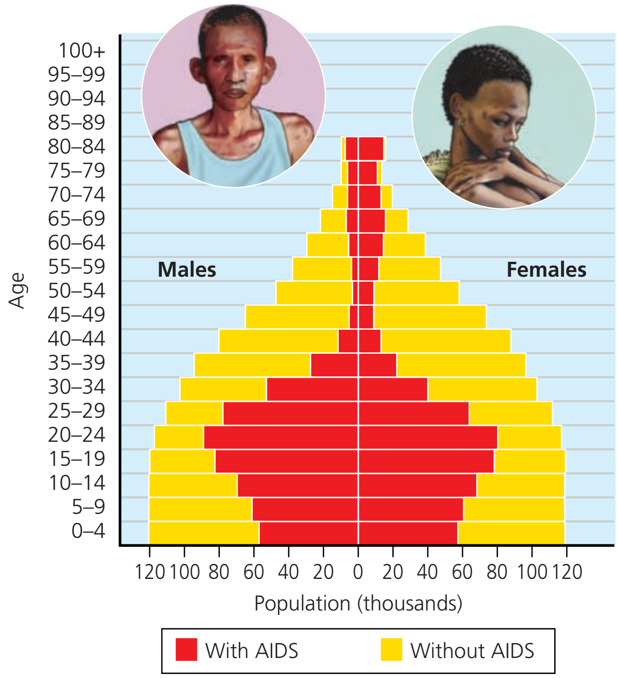


Figure 6-16 *Global outlook:* Worldwide, AIDS is the leading cause of death for people ages 15–49. This loss of productive working adults can affect the age structure of a population. In Botswana, more than 24% of this age group was infected with HIV in 2008 and about 148,000 people died. This figure shows two projected age structures for Botswana's population in 2020—one including the possible effects of the AIDS epidemic (red bars), and the other not including those effects (yellow bars). See the Data Analysis Exercise at the end of this chapter for further analysis of this problem. (Data from the U.S. Census Bureau) **Question:** How might this affect Botswana's economic development?

than a fifth of their adult population. Such death rates drastically alter a country's age structure (Figure 6-16) and result in large numbers of orphans, many of them infected with HIV.

Population and health experts call for the international community to create and fund a massive program to help countries ravaged by AIDS. The program would reduce the spread of HIV by providing financial assistance for improving education and health care. It would also provide funding for volunteer teachers, as well as health-care and social workers to try to compensate for the missing young-adult generation.

6-4 How Can We Slow Human Population Growth?

▶ **CONCEPT 6-4 We can slow human population growth by reducing poverty, elevating the status of women, and encouraging family planning.**

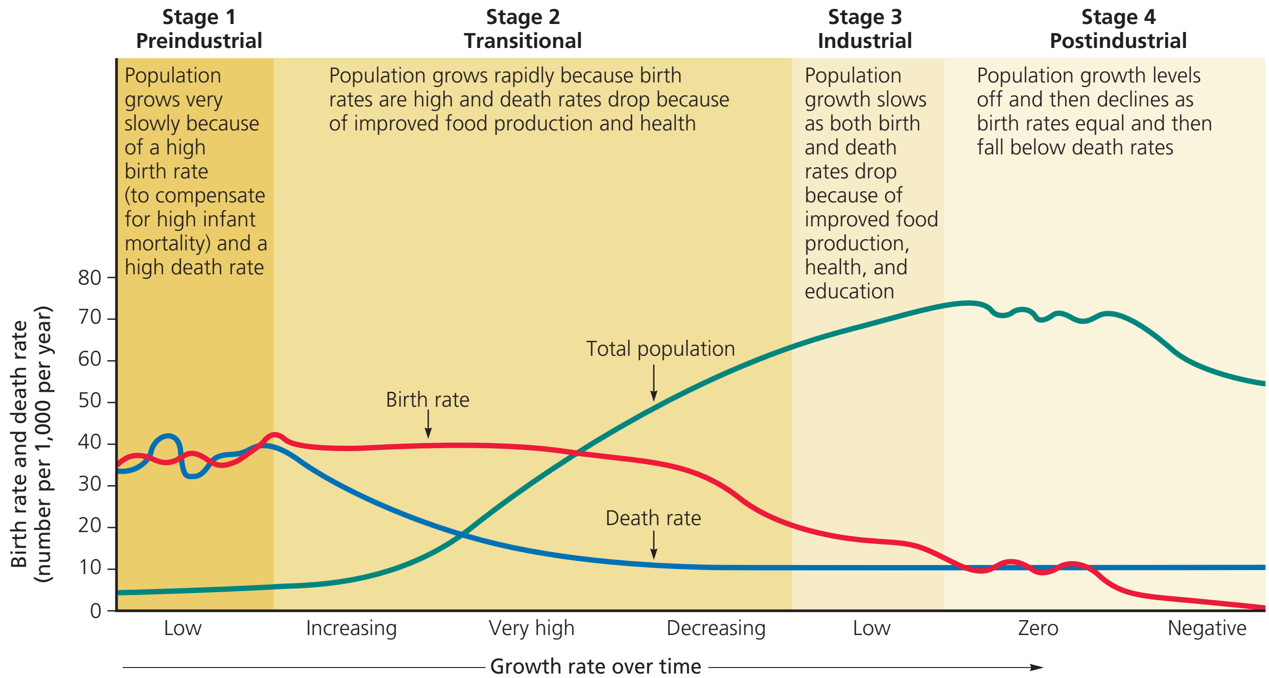
The First Step Is to Promote Economic Development

Earlier in this chapter, we discussed the long-running debate over whether there are limits to the growth of the human population on our planetary home (Science Focus, p. 129). Assuming that our population will eventually exceed the ability of the earth's resources to support us, even though no one knows when that would be, many scientists argue for adopting a precautionary approach by taking steps to slow or stop population growth. Scientific studies and experience have shown that the three most important steps to take toward that goal are **(1)** to reduce poverty primarily through economic development and universal primary education, **(2)** to elevate the status of women, and **(3)** to encourage family planning and reproductive health care (**Concept 6-4**).

Demographers, examining birth and death rates of western European countries that became industrialized during the 19th century, developed a hypothesis of population change known as the **demographic transition**: As countries become industrialized and economically developed, first their death rates decline and then their birth rates decline. According to the hypothesis based on such data, this transition takes place in four distinct stages (Figure 6-17, p. 140).

Figure 6-18 (p. 140) shows the progress of two countries—the United States and Bangladesh—in making a demographic transition in terms of the average number of births per woman (TFR). The United States is in the early phase of stage 4 and Bangladesh is approaching the early phase of stage 4.

Some analysts believe that most of the world's less-developed countries will make a demographic transition over the next few decades, mostly because modern technology can raise per capita incomes by bringing economic development and family planning to such countries. But other analysts fear that rapid population



CENGAGE**NOW**™ **Active Figure 6-17** The *demographic transition*, which a country can experience as it becomes industrialized and more economically developed, can take place in four stages. *See an animation based on this figure at* CengageNOW. **Question:** At what stage is the country where you live?

growth, extreme poverty, and increasing environmental degradation in some low-income, less-developed countries—especially in Africa—could leave these countries stuck in stage 2 of the demographic transition.

Many of such countries are classified as *failing states* (see Figure 17, p. S64, in Supplement 9). They are countries where the national governments can no longer ensure the personal security of most of their people, mostly because they have lost control over all or most of their country's territory. In such countries, governments can no longer provide their people with basic services such as food security, health care, and education. Such states often end up with civil war, when the rule of law and order breaks down and opposing groups fight for power. Some failing states can also become training grounds for international terrorist groups that often draw recruits from large groups of impoverished and unemployed young adults.

Seventeen of the 20 top failing states in 2008 had rapid rates of population growth, high total fertility rates, and a large percentage of their population under age 15. One example of this kind of nation, caught in a demographic trap, is Somalia—rated as the world's most failed state. In 2010, its population was growing rapidly at 3% a year, its women on average had 6.5 children, and 45% of its people were under age 15.

Other factors that could hinder the demographic transition in some less-developed countries are short-

Figure 6-18 This graph tracks demographic transition in terms of the average lifetime number of births per woman (TFR) in Bangladesh and in the United States, 1800–2010. **Question:** What role do you think economic development has played in the different paths that these two countries have taken toward making a demographic transition? (Data from Population Reference Bureau, *World Population Data Sheet 2009* and *2010*; Bangladesh: United Nations Demographic and Heath Surveys; United States: Ansley Coale and Melvin Zeinik and National Center for Health Statistics)

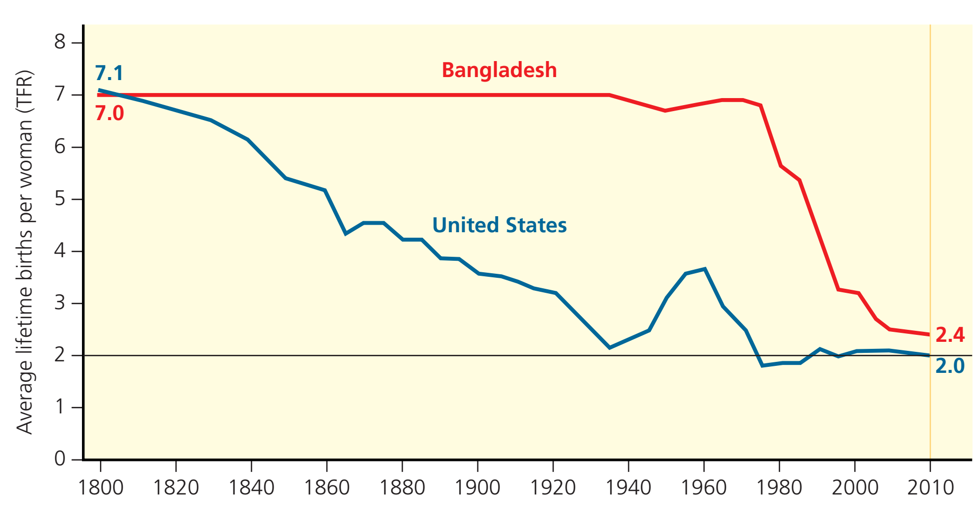


Figure 6-19 More than 200,000 people are packed into this huge slum in India. Residents tend to have a large number of children as a survival mechanism. Economic development that provides jobs and more economic security would help to reduce the average number of children per woman and slow population growth.

ages of scientists, engineers, and skilled workers, insufficient financial capital, large foreign debt to more-developed countries, and a drop in economic assistance from more-developed countries since 1985. This could leave large numbers of people trapped in poverty (Figure 6-19). Such is the danger in Haiti, another failed state swamped by foreign debt and lacking skilled workers. In 2010, Haiti suffered a devastating earthquake, making its demographic transition far more difficult.

CENGAGE**NOW**™ Explore the effects of economic development on birth and death rates, and population growth at CengageNOW.

Empowering Women Helps to Slow Population Growth

A number of studies show that women tend to have fewer children if they are educated, have the ability to control their own fertility, earn an income of their own, and live in societies that do not suppress their rights. Although women make up roughly half of the world's population, in most societies they have fewer rights and educational and economic opportunities than men have. For example, in 2008 the government of Afghanistan passed a law that allows a man to withhold food from his wife if she refuses to have sex with him; it also forbids any woman from going out of her home without her husband's permission.

Women do almost all of the world's domestic work and child care for little or no pay and provide more unpaid health care (within their families) than do all of the world's organized health care services combined. They also do 60–80% of the work associated with growing food, gathering and hauling wood (Figure 6-20) and animal dung for use as fuel, and hauling water in rural areas of Africa, Latin America, and Asia. As one Brazilian woman observed, "For poor women, the only holiday is when you are asleep."

Globally, women account for two-thirds of all hours worked but receive only 10% of the world's income, and they own less than 2% of the world's land. Women also make up 70% of the world's poor and 64% of its 800 million illiterate adults.

Figure 6-20 These women from a village in the West African country of Burkina Faso are bringing home fuelwood. Typically, they spend two hours a day, two or three times a week, searching for and hauling fuelwood.

Because sons are more valued than daughters in many societies, girls are often kept at home to work instead of being sent to school. Globally, the number of school-age girls who do not attend elementary school is more than 900 million—almost three times the entire U.S. population. Teaching women to read has a major impact on fertility rates and population growth. Poor women who cannot read often have an average of five to seven children, compared to two or fewer children in societies where almost all women can read.

According to Thorya Obaid, executive director of the UN Population Fund, "Many women in the developing world are trapped in poverty by illiteracy, poor health, and unwanted high fertility. All of these contribute to environmental degradation and tighten the grip of poverty."

GOOD NEWS

An increasing number of women in less-developed countries are taking charge of their lives and reproductive behavior. As it expands, such bottom-up change by individual women will play an important role in stabilizing populations, reducing poverty and environmental degradation, and allowing more access to basic human rights.

Promote Family Planning

Family planning provides educational and clinical services that help couples choose how many children to have and when to have them. Such programs vary from culture to culture, but most provide information on birth spacing, birth control, and health care for pregnant women and infants.

GOOD NEWS

Family planning has been a major factor in reducing the number of births throughout most of the world. It has also reduced the number of abortions performed each year and has decreased the numbers of mothers and fetuses dying during pregnancy.

Studies by the UN Population Division and other population agencies indicate that family planning is responsible for a drop of at least 55% in total fertility rates (TFRs) in less-developed countries, from 6.0 in 1960 to 2.7 in 2010. For example, family planning, coupled with economic development, played a major role in the sharp drop in average number of children per woman (TFR) in Bangladesh from around 6.8 to 2.4 by 2010 (Figure 6-19). Between 1971 and 2010, Thailand also used family planning to cut its annual population growth rate from 3.2% to 0.6%, and to reduce its TFR from 6.4 to 1.8 children per family. According to the UN, had there not been the sharp drop in TFRs since the 1970s, with all else being equal, the world's population today would be about 8.5 billion instead of 6.9 billion.

Family planning also has financial benefits. Studies have shown that each dollar spent on family planning in countries such as Thailand, Egypt, and Bangladesh saves $10–$16 in health, education, and social service costs by preventing unwanted births.

Despite such successes, two problems remain. *First*, according to the UN Population Fund, 42% of all pregnancies in less-developed countries are unplanned and 26% end with abortion. In addition, a 2007 study by the Guttmacher Institute found that almost half of the annual pregnancies in the United States are unintended and result in 1.4 million unplanned births and 1.3 million abortions.

Second, an estimated 201 million couples in less-developed countries want to limit their number of children and determine their spacing, but they lack access to family planning services. According to a recent study by the UN Population Fund and the Alan Guttmacher Institute, meeting women's current unmet needs for family planning and contraception could *each year* prevent 52 million unwanted pregnancies, 22 million induced abortions, 1.4 million infant deaths, and 142,000 pregnancy-related deaths. This could reduce the global population size projected for 2050 by more than 1 billion people, at an average cost of $20 per couple per year.

Some analysts call for expanding family planning programs to include teenagers and sexually active unmarried women, who are excluded from many existing programs. Another suggestion is to develop programs that educate men about the importance of having fewer children and taking more responsibility for raising them. Proponents also call for greatly increased research on developing more effective and more acceptable birth control methods for men.

The experiences of countries such as Japan, Thailand, Bangladesh, South Korea, Taiwan, Iran, and China (**Core Case Study**) show that a country can achieve or come close to replacement-level fertility within a decade or two. Such experiences also suggest that the best ways to slow and stabilize population growth are through *promoting economic development, elevating the social and economic status of women, and encouraging family planning* (**Concept 6-4**).

CORE CASE STUDY

CONNECTIONS

Family Planning and the Demographic Transition

Environmental analyst Lester Brown has noted that when a country moves quickly to having smaller families, which can be accomplished through intensive family planning, they get a boost on the demographic transition curve (Figures 6-17 and 6-18). The number of working adults increases relative to the smaller numbers of children. Then productivity surges, people save and invest more money, and economic growth results. Brown notes that, except for a few oil-rich countries, no less-developed country has succeeded in becoming modernized without slowing population growth.

CASE STUDY

Slowing Population Growth in India

For more than five decades, India has tried to control its population growth with only modest success. The world's first national family planning program began in India in 1952, when its population was nearly 400 million. In 2010, after 58 years of population control efforts, India had 1.2 billion people—the world's second largest population.

In 1952, India added 5 million people to its population. In 2010, it added 18 million—more than any other country. Also, 32% of India's population is under age 15 compared to 18% in China (**Core Case Study**), CORE CASE STUDY which sets India up for further rapid population growth. The United Nations projects that by 2015, India will be the world's most populous country, and by 2050, it will have a population of 1.74 billion.

India has the world's fourth largest economy and a thriving and rapidly growing middle class of more than 50 million people. But the country faces a number of serious poverty, malnutrition, and environmental problems that could worsen as its population continues to grow rapidly. About one of every four of India's urban population live in slums (Figure 6-19), and prosperity and progress have not touched many of the nearly 650,000 rural villages where more than two-thirds of India's population lives. Nearly half of the country's labor force is unemployed or underemployed, and about three-fourths of its people struggle to live on the equivalent of less than $2.25 a day (Figure 6-21). While China also has serious environmental problems, its poverty rate is only about half that of India.

For decades, the Indian government has provided family planning services throughout the country and has strongly promoted a smaller average family size; even so, Indian women have an average of 2.6 children. Two factors help account for larger families in India. First, most poor couples believe they need several children to work and care for them in old age. Second, as in China (**Core Case Study**), CORE CASE STUDY the strong cultural preference in India for male children means that some couples keep having children until they produce one or more boys. The result: even though 9 of every 10 Indian couples have access to at least one modern birth control method, only 48% actually use one (compared to 86% in China).

Like China, India also faces critical resource and environmental problems. With 17% of the world's people, India has just 2.3% of the world's land resources and 2% of its forests. About half the country's cropland is degraded as a result of soil erosion and overgrazing. In addition, more than two-thirds of its water is seriously polluted, sanitation services often are inadequate, and many of its major cities suffer from serious air pollution.

India is undergoing rapid economic growth, which is expected to accelerate. As members of its growing middle class increase their resource use per person, India's ecological footprint will expand and increase the pressure on the country's and the earth's natural capital. On the other hand, economic growth may help India to slow its population growth by accelerating its demographic transition.

THINKING ABOUT

China, India, the United States, and Overpopulation CORE CASE STUDY

Based on population size and resource use per person (see Figure 1-14, p. 17) is the United States more overpopulated than China? Explain. Answer the same question for the United States vs. India.

Here are this chapter's *three big ideas*:

- The human population is increasing rapidly and may soon bump up against environmental limits.
- Even if population growth were not a serious problem, the increasing use of resources per person is expanding the overall human ecological footprint and putting a strain on the earth's resources.
- We can slow human population growth by reducing poverty through economic development, elevating the status of women, and encouraging family planning.

ullstein-Leber/Peter Arnold, Inc.

Figure 6-21 About three of every four (76%) of the people in India, like this homeless mother and her child, struggle to live on the equivalent of less than $2.25 per day. In China, the percentage of the population living in extreme poverty is about 36% of the population.

REVISITING Population Growth in China and Sustainability

This chapter began by considering the case of China's growing population (**Core Case Study**). It serves as a good application for the concepts that organize this chapter. China's population problems raise questions about carrying capacity. China's story shows how population growth can be affected by a key factor such as its strict national policy to promote one-child families. China's age structure tells us about challenges the country will soon face, as well as those it is currently facing. The example of China is a unique story about how a society can attempt to slow its population growth and about what unexpected consequences might occur as a result.

In the first five chapters of this book, you have learned how ecosystems and species have been sustained throughout history as a result of three **principles of sustainability**—relying on solar energy, nutrient recycling, and biodiversity (see back cover). This included a look at how populations of species interact, grow, and decline according to limits placed on them by nature. In this chapter, we sought to apply some of these lessons to the human population—to see how it has grown and ask questions concerning how that growth might be limited in the future.

Many have asked whether there are too many humans on the planet. As we have seen, some experts say this is the wrong question to be asking, and they suggest that instead, we ought to ask, "What is the optimal level of human population that the planet can support *sustainably now and in the future*?" We can apply the **principles of sustainability** to try to answer this question by defining a *cultural carrying capacity*. Some scientists envision a world in which we depend much more on direct and indirect forms of solar energy, we reuse and recycle at least 80% of all materials that we are accustomed to throwing away, and we preserve the biodiversity of species and ecosystems that help to keep us alive and support our economies.

Our numbers expand but Earth's natural systems do not.

LESTER R. BROWN

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 126. Summarize the story of population growth in China and the Chinese government's efforts to regulate it (**Core Case Study**).
2. List three factors that account for the rapid increase in the world's human population over the past 200 years. About how many people are added to the world's population each year? Explain how this growth is unevenly distributed. What five countries had the largest numbers of people in 2010? How many of us are likely to be on the planet in 2050? What are demographers? Give three reasons why it is difficult for them to project population changes.
3. What is **cultural carrying capacity**? Describe the debate over whether and how long the human population can keep growing. Describe eight ways in which we have used technology to alter nature to meet our growing needs and wants.
4. Distinguish between **crude birth rate** and **crude death rate**. List four variables that affect the **population change** of an area and write an equation showing how they are related.
5. What is **fertility rate**? Distinguish between **replacement-level fertility rate** and **total fertility rate (TFR)**. Explain why reaching the replacement level fertility rate will not stop global population growth until about 50 years have passed (assuming that death rates do not rise). Describe what has happened since 1950 to total fertility rates in the world, in China, and in the United States.
6. Describe population growth in the United States and explain why it is high compared to population growth in most other more-developed countries and in China (**Core Case Study**). Is the United States overpopulated? Explain.
7. List ten factors that can affect the birth rate and fertility rate of a country. Explain why there is a bride shortage in China. Define **life expectancy** and **infant mortality rate** and explain how they affect the population size of a country. Why does the United States have a lower life expectancy and higher infant mortality rate than a number of other countries? What is **migration**? Describe immigration into the United States and the issues it raises.
8. What is the **age structure** of a population. Explain how it affects population growth and economic growth. Describe the American baby boom and some of the effects it has had on American culture. What are some problems related to rapid population decline due to an aging population? How has the AIDS epidemic affected the age structure of some countries in Africa?

9. What is the **demographic transition** and what are its four stages? What factors could hinder some less-deveoped countries from making this transition? What is **family planning**? Describe the roles of reducing poverty, elevating the status of women, and family planning in slowing population growth. Describe India's efforts to control its population growth.

10. What are this chapter's *three big ideas*? Describe the relationship between human population growth, as exemplified in China, and the three **principles of sustainability**.

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. Do you think that the problems resulting from China's one-child policy (**Core Case Study**) outweigh the problems of overpopulation that likely would have resulted without some sort of population growth regulation? Can you think of other ways in which China could try to regulate its population growth? Explain.

2. If you could greet a new person every second without taking a break, how many people could you greet in one day? How many in a year? How many in a lifetime of 80 years? How long would you have to live to greet **(a)** all 6.9 billion people on earth at a rate of one every second working around the clock and **(b)** the 83 million people added to the world's population this year?

3. Which of the three major environmental worldviews summarized on pp. 24–25 do you believe underlie the two major positions on whether the world is overpopulated (Science Focus, p. 129)?

4. Identify a major local, national, or global environmental problem, and describe the role of population growth in this problem.

5. Is it rational for a poor couple in a less-developed country such as India to have four or five children? Explain.

6. Do you believe that the population is too high in **(a)** China (**Core Case Study**), **(b)** the world, **(c)** your own country, and **(d)** the area where you live? Explain.

7. Should everyone have the right to have as many children as they want? Explain. Is your belief on this issue consistent with your environmental worldview?

8. Some people believe the most important environmental goal is to sharply reduce the rate of population growth in less-developed countries, where at least 92% of the world's population growth is expected to occur. Others argue that the most serious environmental problems stem from high levels of resource consumption per person in more-developed countries, which use 88% of the world's resources and have much larger ecological footprints per person than the less-developed countries do. What is your view on this issue? Explain.

9. Congratulations! You are in charge of the world. Write a summary of your population policy. In the summary, consider the following: will you enact a program to regulate population growth? If not, explain your reasoning. If so, describe the program and how you will enact and fund it.

10. List two questions that you would like to have answered as a result of reading this chapter.

ECOLOGICAL FOOTPRINT ANALYSIS

The chart below shows selected population data for two different countries, A and B.

Study the data and then answer the questions that follow on page 146.

	Country A	Country B
Population (millions)	144	82
Crude birth rate	43	8
Crude death rate	18	10
Infant mortality rate	100	3.8
Total fertility rate	5.9	1.3
% of population under 15 years old	45	14
% of population older than 65 years	3.0	19
Average life expectancy at birth	47	79
% urban	44	75

(Data from Population Reference Bureau 2010. *World Population Data Sheet*)

1. Calculate the rates of natural increase (due to births and deaths, not counting immigration) for the populations of country A and country B. Based on these calculations and the data in the table, suggest whether A and B are more-developed or less-developed countries and explain the reasons for your answers.
2. Describe where each of the two countries may be in terms of their stage in the demographic transition (Figure 6-17). Discuss factors that could hinder country A from progressing to later stages in the demographic transition.
3. Explain how the percentages of people under 15 years of age in country A and country B could affect the per capita and total ecological footprints of each country.

LEARNING ONLINE

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Climate and Biodiversity

7

CORE CASE STUDY

Different Climates Support Different Life Forms

The earth has a great diversity of species and *habitats*, or places where these species can live. Some species live on land, or *terrestrial*, habitats such as deserts, grasslands, and forests. Others live in water-covered, or *aquatic*, habitats such as rivers, lakes, and oceans. In this chapter, we look at key terrestrial habitats, and in the next chapter, we look at major aquatic habitats.

Why is one area of the earth's land surface a desert, another a grassland, and another a forest? The answers lie largely in differences in *climate*, the average atmospheric or weather conditions in a given region during a time frame of several decades to thousands of years.

Differences in climate result mostly from long-term differences in average annual precipitation and temperature. This leads to three major types of climate—*tropical* (areas near the equator, receiving the most intense sunlight), *polar* (areas near the earth's poles, receiving the least intense sunlight), and *temperate* (areas between the equatorial region and the earth's two poles). In these areas, we find different types of vegetation (Figure 7-1) and animals, adapted to the planet's different climate conditions, as discussed in this chapter.

In other words, *climate matters* because it determines where humans and other species can live and thrive. When the climate changes, as current climate models project is likely to happen during this century, there is usually a shift in location of areas where food can be found or grown and where species can live.

The world's three major types of terrestrial ecosystems—forests, grasslands, and deserts—largely determined by their climates, are called *biomes*. They cover the planet's entire land surface except for ice-covered areas. Each year, these ecosystems and the rich diversity of species they contain provide trillions of dollars worth of ecological and economic benefits for us. In this chapter, we examine the key role that climate plays in the formation and locations of these deserts, grasslands, and forests that make up an important part of the earth's terrestrial biodiversity.

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Figure 7-1 Earth has three major climate zones: *tropical*, where the climate is generally warm throughout the year (top); *temperate*, where the climate is not extreme and typically changes in four different annual seasons (middle); and *polar*, where it is generally cold during both winter and summer seasons (bottom). These differences lead to different types of vegetation such as those found in a hot and wet tropical rain forest in Australia (top), a temperate deciduous forest in the autumn near Hamburg, Germany (middle), and the arctic tundra found in the U.S. state of Alaska during summer (bottom).

Key Questions and Concepts

7-1 What factors influence climate?

CONCEPT 7-1 Key factors that determine an area's climate are incoming solar energy, the earth's rotation, global patterns of air and water movement, gases in the atmosphere, and the earth's surface features.

7-2 How does climate affect the nature and location of biomes?

CONCEPT 7-2 Differences in long-term average annual precipitation and temperature lead to the formation of tropical, temperate, and cold deserts, grasslands, and forests, and largely determine their locations.

7-3 How have we affected the world's terrestrial ecosystems?

CONCEPT 7-3 In many areas, human activities are impairing ecological and economic services provided by the earth's deserts, grasslands, forests, and mountains.

Note: Supplements 2 (p. S3), 6 (p. S20), 7 (p. S26), 8 (p. S30), and 9 (p. S57) can be used with this chapter.

To do science is to search for repeated patterns, not simply to accumulate facts, and to do the science of geographical ecology is to search for patterns of plant and animal life that can be put on a map.

ROBERT H. MACARTHUR

7-1 What Factors Influence Climate?

▶ **CONCEPT 7-1 Key factors that determine an area's climate are incoming solar energy, the earth's rotation, global patterns of air and water movement, gases in the atmosphere, and the earth's surface features.**

The Earth Has Many Different Climates

The first step in understanding issues related to climate, such as how climate affects terrestrial biodiversity (**Core Case Study**), is to be sure that we understand the difference between weather and climate. **Weather** is a set of physical conditions of the lower atmosphere such as temperature, precipitation, humidity, wind speed, cloud cover, and other factors in a given area over a period of hours or days. (Supplement 7, p. S26, introduces you to weather basics.) Go outside and you experience the current *weather*—the short-term atmospheric conditions that often change from hour to hour and day to day.

CORE CASE STUDY

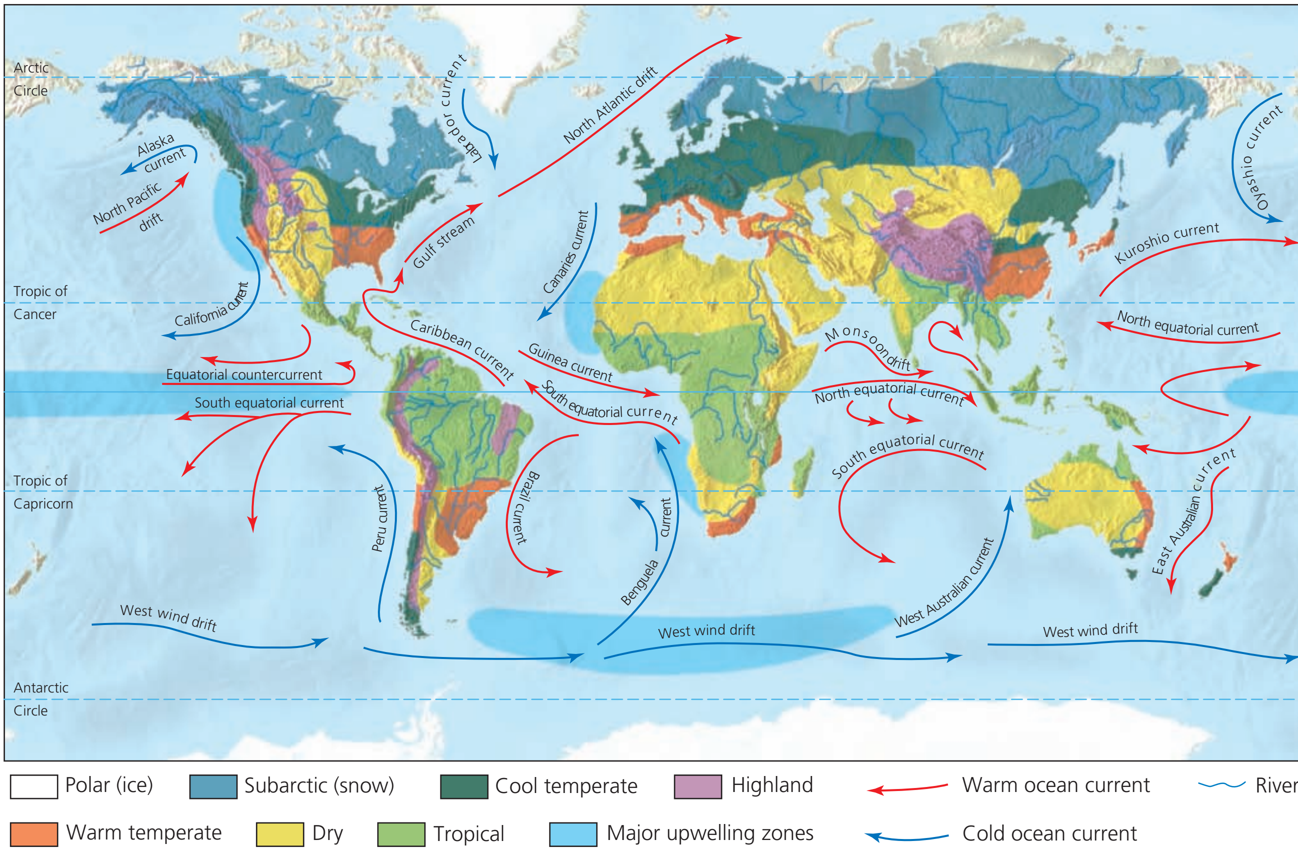
Weather differs from **climate**, which is an area's general pattern of atmospheric conditions over periods of at least three decades and up to thousands of years. In other words, climate is weather, averaged over a long time. As American writer and humorist Mark Twain once said, "Climate is what we expect, weather is what we get."

We know a lot about the daily weather where we live but most of us have a poor or fuzzy understanding of the climate where we live and how it has changed over the past 50 to 100 years. To determine the climate of the area where you live and how it has changed, you would first have to find out and plot the average temperature and average precipitation of your area from year to year over at least the last three decades. Then you would have to note whether these numbers have generally gone up, stayed the same, or gone down. Figure 7-2 depicts the earth's current major climate zones and ocean currents, which are key components of the earth's natural capital (see Figure 1-4, p. 9).

Climate varies in different parts of the earth mostly because, over long periods of time, patterns of global air circulation and ocean currents distribute heat and precipitation unevenly between the tropics and other parts of the world (Figure 7-3). Three major factors determine how air circulates in the lower atmosphere:

1. *Uneven heating of the earth's surface by the sun.* Air is heated much more at the equator, where the sun's rays strike directly, than at the poles, where sunlight strikes at an angle and spreads out over a much greater area (Figure 7-3, right). These differences in the input of solar energy help explain why tropical regions near the equator are hot, why polar regions

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. GOOD NEWS refers to good news about the environmental challenges we face.



CENGAGENOW™ **Active Figure 7-2** **Natural capital:** This generalized map of the earth's current climate zones shows the major ocean currents and upwelling areas (where currents bring nutrients from the ocean bottom to the surface). *See an animation based on this figure at* CengageNOW. **Question:** Based on this map, what is the general type of climate where you live?

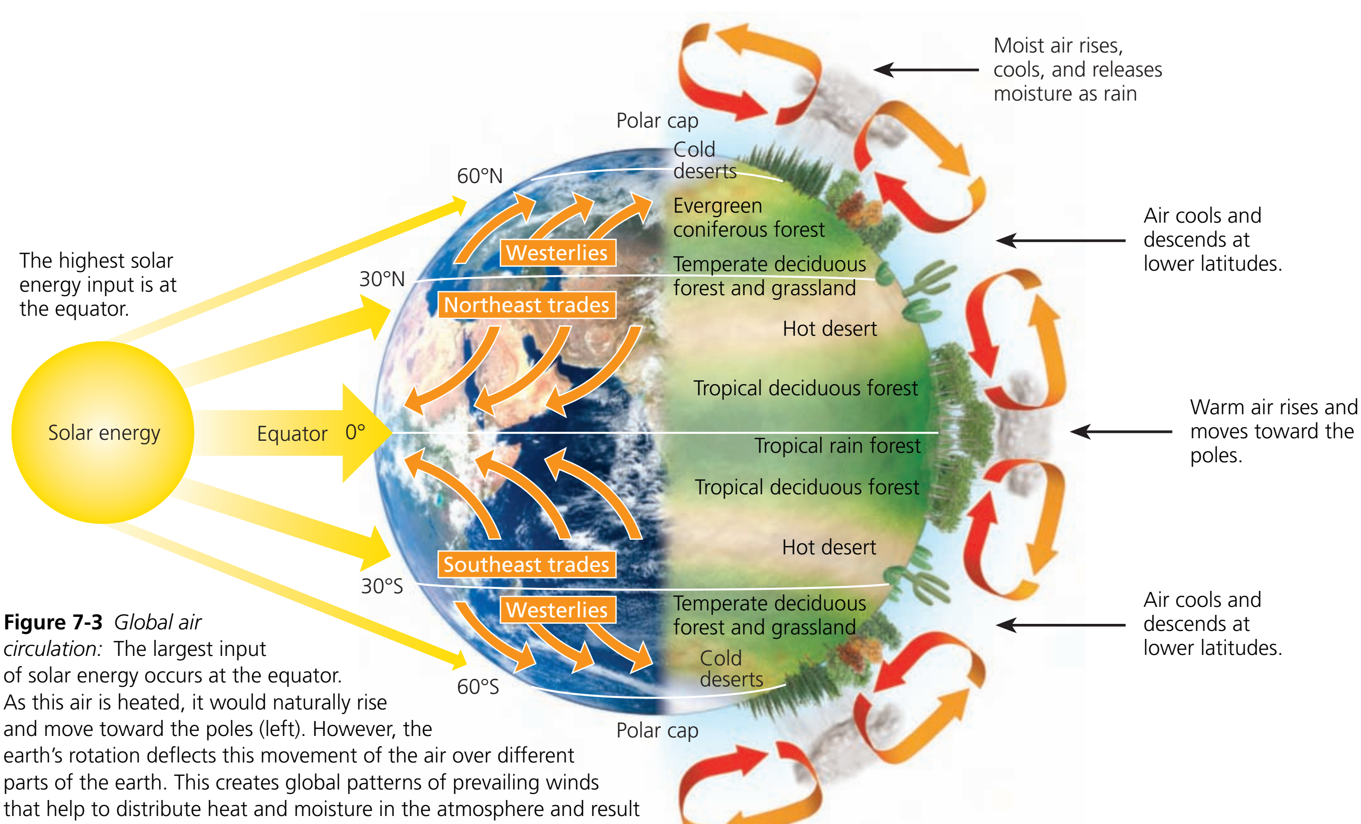


Figure 7-3 *Global air circulation:* The largest input of solar energy occurs at the equator. As this air is heated, it would naturally rise and move toward the poles (left). However, the earth's rotation deflects this movement of the air over different parts of the earth. This creates global patterns of prevailing winds that help to distribute heat and moisture in the atmosphere and result in the earth's variety of forests, grasslands, and deserts (right).

are cold, and why temperate regions in between generally have warm and cool temperatures (Figure 7-2). The intense input of solar radiation in tropical regions leads to greatly increased evaporation of moisture from forests, grasslands, and bodies of water. As a result, tropical regions normally receive more precipitation than do other areas of the earth.

2. *Rotation of the earth on its axis*. As the earth rotates around its axis, the equator spins faster than regions to its north and south. As a result, heated air masses, rising above the equator and moving north and south to cooler areas, are deflected to the west or east over different parts of the planet's surface (Figure 7-3, right). The atmosphere over these different areas is divided into huge regions called *cells*, distinguished by the direction of air movement. The differing directions of air movement are called *prevailing winds* (Figure 7-3, left)—major surface winds that blow almost continuously and help to distribute heat and moisture over the earth's surface and to drive ocean currents.

3. *Properties of air, water, and land*. Heat from the sun evaporates ocean water and transfers heat from the oceans to the atmosphere, especially near the hot equator. This evaporation of water creates giant cyclical convection cells that circulate air, heat, and moisture both vertically and from place to place in the atmosphere, as shown in Figure 7-4.

Prevailing winds blowing over the oceans produce mass movements of surface water called **ocean currents**. Driven by prevailing winds and the earth's rotation, the earth's major ocean currents (Figure 7-2) help redistribute heat from the sun, thereby influencing climate and vegetation, especially near coastal areas. This heat and differences in water *density* (mass per unit volume) create warm and cold ocean currents. Prevailing winds and irregularly shaped continents interrupt these currents and cause them to flow in roughly circular patterns between the continents, clockwise in the northern hemisphere and counterclockwise in the southern hemisphere.

Water also moves vertically in the oceans as denser water sinks while less dense water rises. This creates a connected loop of deep and shallow ocean currents (which are separate from those shown in Figure 7-2). This loop acts somewhat like a giant conveyer belt that moves heat to and from the deep sea and transfers warm and cold water between the tropics and the poles (Figure 7-5).

The ocean and the atmosphere are strongly linked in two ways: ocean currents are affected by winds in the atmosphere, and heat from the ocean affects atmospheric circulation. One example of the interactions between the ocean and the atmosphere is the *El Niño–Southern Oscillation*, or *ENSO*. (See Figure 4, p. S27, in Supplement 7 and *The Habitable Planet*, Video 3, at **www.learner.org/resources/series209.html**.) This large-scale weather phenomenon occurs every few years

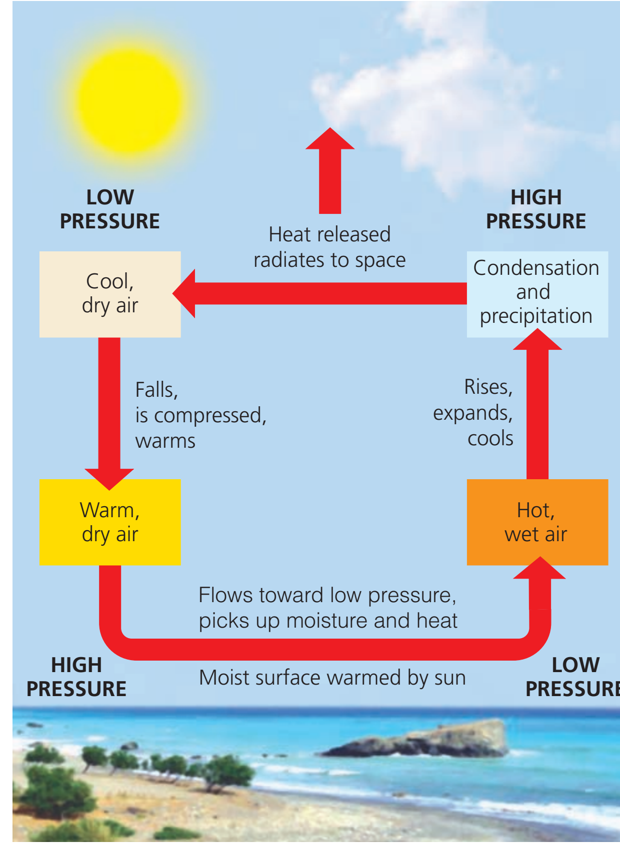


Figure 7-4 This diagram illustrates energy transfer by convection in the atmosphere. *Convection* occurs when warm, wet air rises, then cools and releases heat and moisture as precipitation (right side and top, center). Then the cooler, denser, and drier air sinks, warms up, and absorbs moisture as it flows across the earth's surface (bottom) to begin the cycle again.

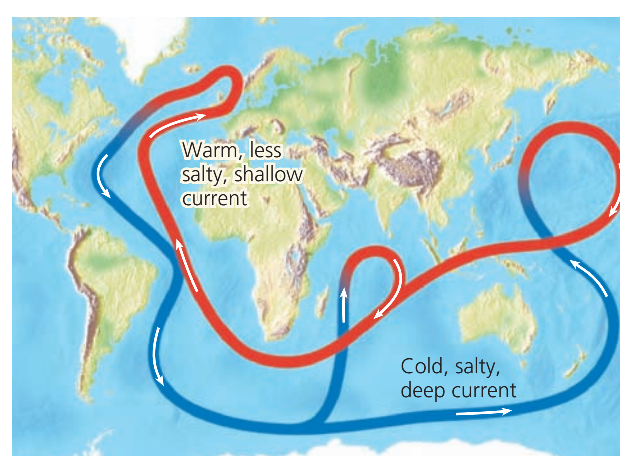


Figure 7-5 *Connected deep and shallow ocean currents:* A connected loop of shallow and deep ocean currents transports warm and cool water to various parts of the earth. This loop, which rises in some areas and falls in others, results when ocean water in the North Atlantic near Iceland is dense enough (because of its salt content and cold temperature) to sink to the ocean bottom, flow southward, and then move eastward to well up in the warmer Pacific. A shallower return current, aided by winds, then brings warmer, less salty, and thus less dense water to the Atlantic. This water then cools and sinks to begin this extremely slow cycle again. **Question:** How do you think this loop affects the climates of the coastal areas around it?

when prevailing winds in the tropical Pacific Ocean weaken and change direction. The resulting above-average warming of Pacific waters alters the weather over at least two-thirds of the earth for 1 or 2 years (see Figure 5, p. S28, in Supplement 7).

CENGAGENOW™ Learn more about how oceans affect air movements where you live and all over the world at CengageNOW.

The earth's air circulation patterns, prevailing winds, and configuration of continents and oceans are all factors in the formation of six giant convection cells (like the one shown in Figure 7-3, right), three of them south of the equator and three north of the equator. These cells lead to an irregular distribution of climates and the resulting deserts, grasslands, and forests, as shown in Figure 7-3, right (**Concept 7-1** and **Core Case Study**). CORE CASE STUDY

CENGAGENOW™ Watch the formation of six giant convection cells and learn more about how they affect climates at CengageNOW.

Greenhouse Gases Warm the Lower Atmosphere

Figure 3-4 (p. 57) shows how energy flows to and from the earth. Small amounts of several gases in the atmosphere, including water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), absorb and release heat that warms the atmosphere, thus playing a role in determining the earth's average temperatures and its climates. These **greenhouse gases** allow mostly visible light and some infrared radiation and ultraviolet (UV) radiation (see Figure 2-11, p. 45) from the sun to pass through the atmosphere. The earth's surface absorbs much of this solar energy and transforms it to longer-wavelength infrared radiation (heat), which then rises into the lower atmosphere.

Some of this heat escapes into space, but some is absorbed by molecules of greenhouse gases and emitted into the lower atmosphere as even longer-wavelength infrared radiation. Some of this released energy radiates into space, and some warms the lower atmosphere and the earth's surface. This natural warming effect of the troposphere is called the **natural greenhouse effect** (see Figure 3-4, p. 57, and *The Habitable Planet*, Video 2, at **www.learner.org/resources/series209.html**). Without this natural heating effect, the earth would be a very cold and mostly lifeless planet.

Human activities such as burning fossil fuels (see Figure 2-14, p. 46), clearing forests (see Figure 3-1, p. 54), and growing crops (see Figure 1-6, p. 10) release carbon dioxide, methane, and nitrous oxide into the atmosphere. A large and growing body of scientific evidence, combined with climate model projections, indicate that it is likely that the large inputs of greenhouse gases into the atmosphere from human activities will significantly enhance the earth's natural greenhouse effect and change the earth's climate during this century.

In other words, human activities, especially the burning of carbon-containing fossil fuels, have added carbon dioxide to the atmosphere faster than it is removed by the carbon cycle (see Figure 3-19, p. 70). According to current climate models, this rapid human-enhanced warming of the atmosphere during this century is likely to cause climate changes in various places on the earth that could last for centuries to thousands of years. If this projected warming intensifies, climate models project that it is likely to alter precipitation patterns, raise average sea levels, and shift areas where we can grow crops and where some types of plants and animals (including humans) can live, as discussed more fully in Chapter 19.

CENGAGENOW™ Witness the natural greenhouse effect and see how human activity has affected it at at CengageNOW.

Earth's Surface Features Affect Local Climates

Heat is absorbed and released more slowly by water than by land. This difference creates land and sea breezes. As a result, the world's oceans and large lakes moderate the weather and climates of nearby lands.

Various other topographic features of the earth's surface can create local and regional climatic conditions that differ from the general climate of some regions. For example, mountains interrupt the flow of prevailing surface winds and the movement of storms. When moist air blowing inland from an ocean reaches a mountain range, it is forced upward. As it rises, it cools and expands and then loses most of its moisture as rain and snow that fall on the windward slope of the mountain (the side facing the area from which the wind is blowing).

As the drier air mass passes over the mountaintops, it flows down the leeward slopes (facing away from the wind), and warms up. This increases its ability to hold moisture, but the air releases little moisture and instead tends to dry out plants and soil below. Over many decades, the resulting semiarid or arid conditions on the leeward side of a high mountain create what is called the **rain shadow effect** (Figure 7-6, p. 152). Sometimes this leads to the formation of deserts such as Death Valley, a part of the Mojave Desert found in parts of the U.S. states of California, Nevada, Utah, and Arizona. Death Valley lies in the rain shadow of Mount Whitney, the highest mountain in the Sierra Nevada range.

Cities also create distinct microclimates. Bricks, concrete, asphalt, and other building materials absorb and hold heat, and buildings block wind flow. Motor vehicles and the heating and cooling systems of buildings release large quantities of heat and pollutants. As a result, on average, cities tend to have more haze and smog, higher temperatures, and lower wind speeds than the surrounding countryside.

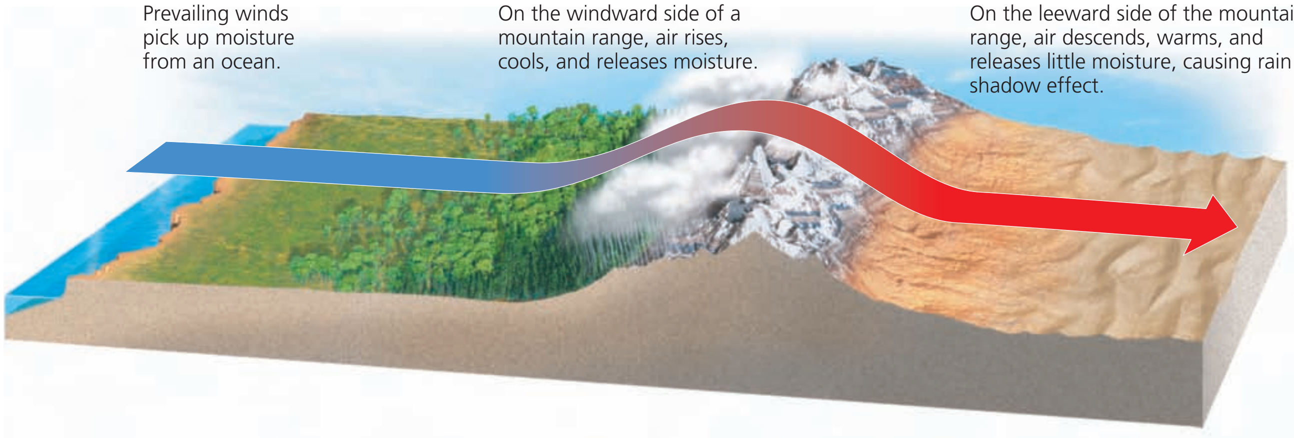


Figure 7-6 The *rain shadow effect* is a reduction of rainfall and loss of moisture from the landscape on the side of mountains facing away from prevailing surface winds. Warm, moist air in onshore winds loses most of its moisture as rain and snow that fall on the windward slopes of a mountain range. This leads to semiarid and arid conditions on the leeward side of the mountain range and the land beyond. The Mojave Desert in the U.S. state of California and Asia's Gobi Desert were both created by this effect.

7-2 How Does Climate Affect the Nature and Location of Biomes?

CONCEPT 7-2 Differences in long-term average annual precipitation and temperature lead to the formation of tropical, temperate, and cold deserts, grasslands, and forests, and largely determine their locations.

Climate Helps to Determine Where Organisms Can Live

Differences in climate (Figure 7-2) explain why one area of the earth's land surface is a desert, another a grassland, and another a forest. They can also explain why global air circulation patterns (Figure 7-3) account for different types of deserts, grasslands, and forests (**Core Case Study**).

CORE CASE STUDY

Figure 7-7 shows how scientists have divided the world into several major **biomes**—large terrestrial regions, each characterized by certain types of climate and dominant plant life (**Concept 7-2**). The variety of terrestrial biomes and aquatic systems is one of the four components of the earth's biodiversity (see Figure 4-2, p. 82)—a vital part of the earth's natural capital.

By comparing Figure 7-7 with Figure 7-2, you can see how the world's major biomes vary with climate. Figure 4-5 (p. 85) shows how major biomes along the 39th parallel in the United States are related to its different climates.

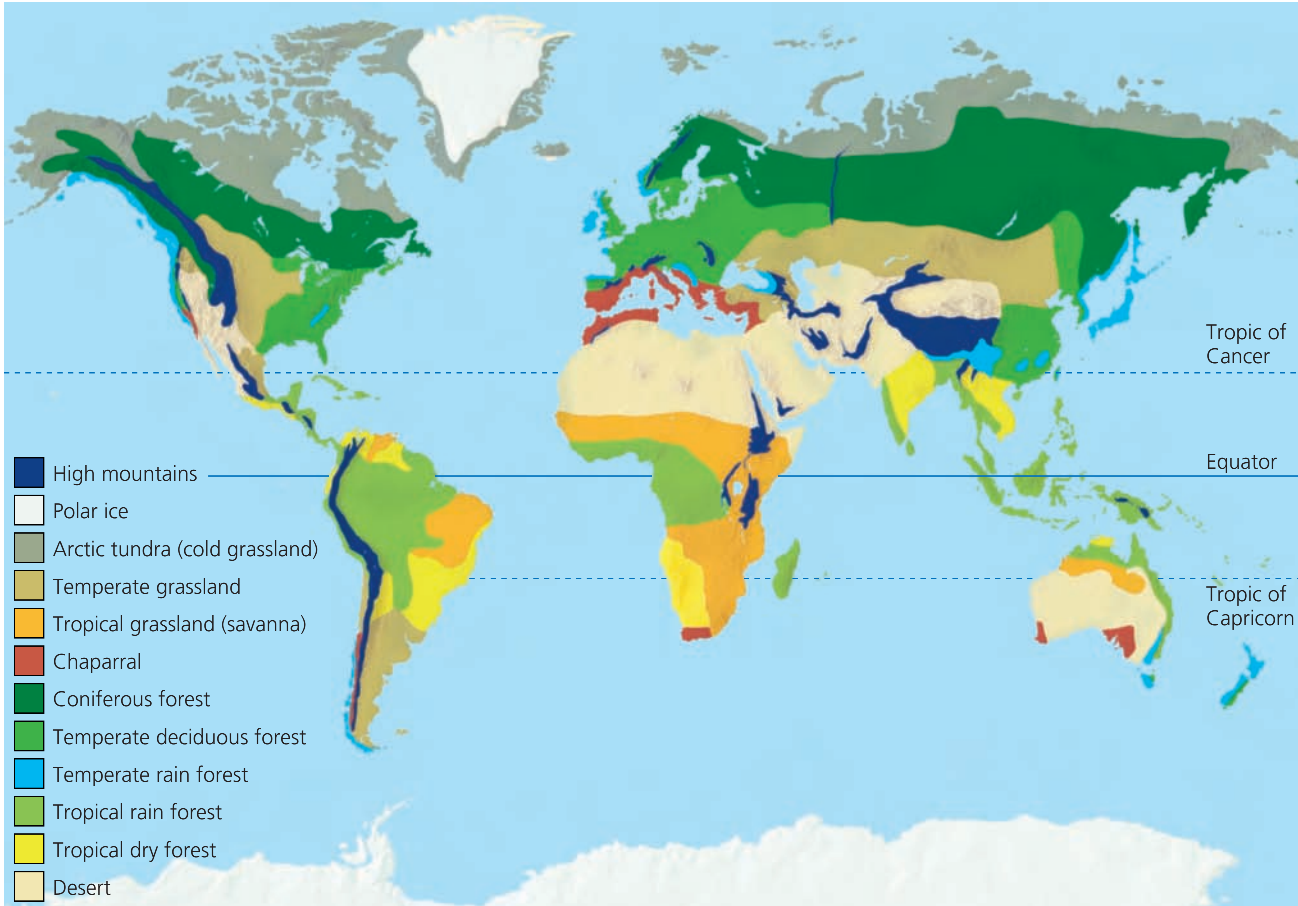
On maps such as the one in Figure 7-7, biomes are shown with sharp boundaries, and each biome is covered with one general type of vegetation. In reality, *biomes are not uniform*. They consist of a *mosaic of patches*, each with somewhat different biological communities but with similarities typical of the biome. These patches occur mostly because of the irregular distribution of the resources needed by plants and animals and because human activities have removed or altered the natural vegetation in many areas.

Figure 7-8 shows how climate and vegetation vary with both *latitude* and *elevation*. If you climb a tall mountain, from its base to its summit, you can observe changes in plant life similar to those you would encounter in traveling from the equator to the earth's northern polar region. For example, if you hike up a tall Andes mountain in Ecuador, your trek will begin in a tropical rain forest and end up on a glacier at the summit.

CONNECTIONS

Biomes, Climate, and Human Activities

Use Figure 7-2 to determine the general type of climate where you live and Figure 7-7 to determine the general type of biome that should exist where you live. Then use Figure 7, p. S38, and Figure 9, p. S41, in Supplement 8 to determine how human ecological footprints have affected the biome where you live.



CENGAGENOW™ **Active Figure 7-7** **Natural capital:** The earth's major *biomes*—each characterized by a certain combination of climate and dominant vegetation—result primarily from differences in climate (**Core Case Study**). Each biome contains many ecosystems whose communities have adapted to differences in climate, soil, and other environmental factors. People have removed or altered much of the natural vegetation in some areas for farming, livestock grazing, obtaining timber and fuelwood, mining, and construction of towns and cities. (Figure 3, p. S33, in Supplement 8 shows the major biomes of North America.) *See an animation based on this figure at* CengageNOW. **Question:** If you take away human influences such as farming and urban development, what kind of biome do you live in?

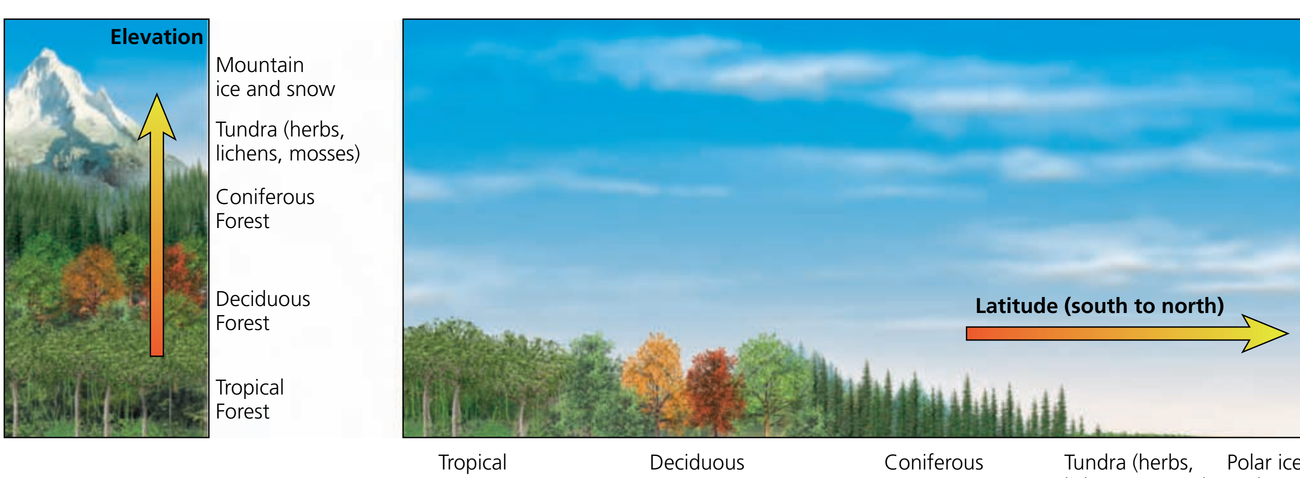


Figure 7-8 This diagram shows the generalized effects of elevation (left) and latitude (right) on climate and biomes (**Core Case Study**). Parallel changes in vegetation type occur when we travel from the equator toward the north pole and from lowlands to mountaintops. **Question:** How might the components of the left diagram change as the earth warms during this century? Explain.

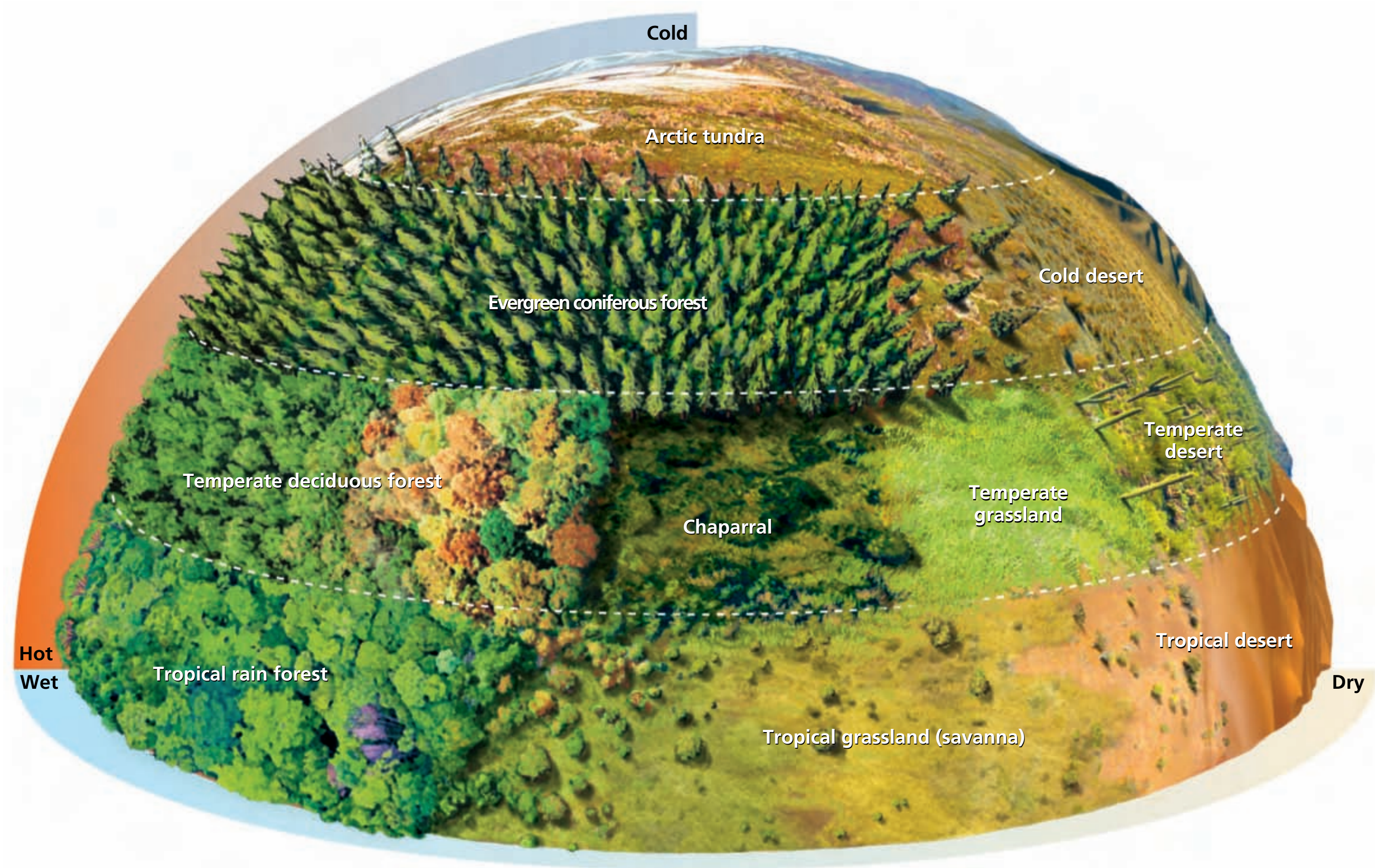


Figure 7-9 **Natural capital:** This diagram demonstrates that average precipitation and average temperature, acting together as limiting factors over a long time, help to determine the type of desert, grassland, or forest in a particular area, and thus the types of plants, animals, and decomposers found in that area (assuming it has not been disturbed by human activities).

Differences in climate, mostly in average annual precipitation and temperature, lead to the formation of tropical (hot), temperate (moderate), and polar (cold) deserts, grasslands, and forests (**Concept 7-2**) (Figure 7-9 and **Core Case Study**). CORE CASE STUDY

There Are Three Major Types of Deserts

In a *desert*, annual precipitation is low and often scattered unevenly throughout the year. During the day, the baking sun warms the ground and evaporates water from plant leaves and the soil. But at night, most of the heat stored in the ground radiates quickly into the atmosphere. Desert soils have little vegetation and moisture to help store the heat and the skies above deserts are usually clear. This explains why in a desert you may roast during the day but shiver at night.

The lack of vegetation, especially in tropical and polar deserts, makes them vulnerable to sandstorms driven by winds that can spread sand from one area to another. Desert surfaces are also vulnerable to disruption from vehicles such as SUVs (Figure 7-10, top photo).

A combination of low rainfall and varying average temperatures creates tropical, temperate, and cold deserts (**Core Case Study**) (Figures 7-9 and 7-10 and **Concept 7-2**). CORE CASE STUDY

Tropical deserts (Figure 7-10, top photo) such as the Sahara and the Namib of Africa are hot and dry most of the year (Figure 7-10, top graph). They have few plants and a hard, windblown surface strewn with rocks and some sand. They are the deserts we often see in the movies.

In *temperate deserts* (Figure 7-10, center photo) such as the Sonoran Desert in southeastern California, southwestern Arizona, and northwestern Mexico, daytime temperatures are high in summer and low in winter and there is more precipitation than in tropical deserts (Figure 7-10, center graph). The sparse vegetation consists mostly of widely dispersed, drought-resistant shrubs and cacti or other succulents adapted to the lack of water and temperature variations.

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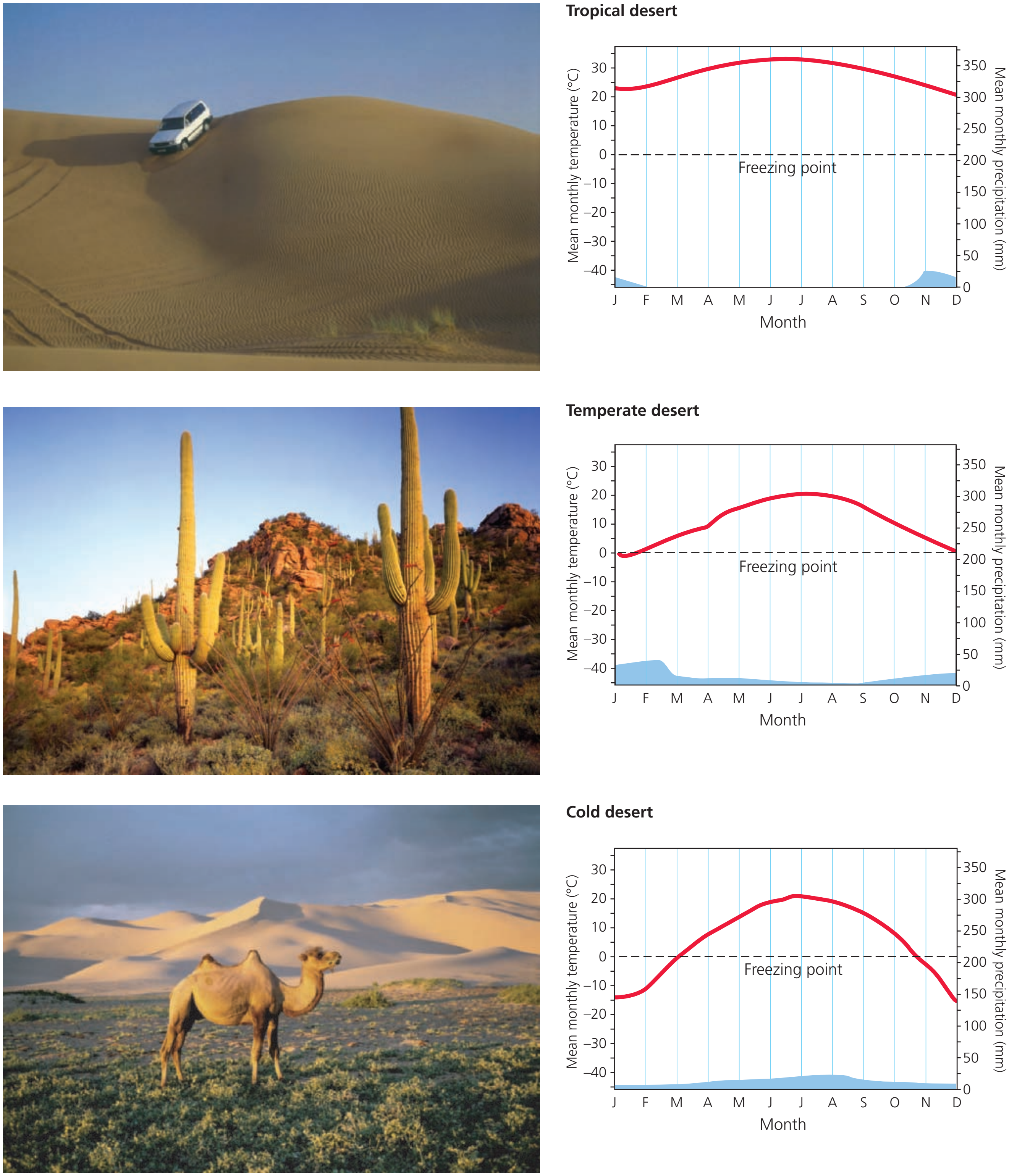

Figure 7-10 These climate graphs track the typical variations in annual temperature (red) and precipitation (blue) in tropical, temperate, and cold deserts. Top photo: a *tropical desert* in the United Arab Emirates, in which a sport utility vehicle (SUV) participates in a popular but environmentally destructive SUV rodeo. Center photo: a *temperate desert* in southeastern California, with saguaro cactus, a prominent species in this ecosystem. Bottom photo: a *cold desert*, Mongolia's Gobi Desert, where Bactrian camels live. **Question:** What month of the year has the highest temperature and the lowest rainfall for each of the three types of deserts?

SCIENCE FOCUS

Staying Alive in the Desert

Adaptations for survival in the desert have two themes: *beat the heat* and *every drop of water counts*.

Desert plants have evolved a number of strategies based on such adaptations. During long hot and dry spells, plants such as mesquite and creosote drop their leaves to survive in a dormant state. *Succulent* (fleshy) *plants* such as the saguaro ("sah-WAH-ro") cactus (Figure 7-A and Figure 7-10, middle photo) have three adaptations: they have no leaves, which can lose water to the atmosphere through *transpiration*; they store water and synthesize food in their expandable, fleshy tissue; and they reduce water loss by opening their pores only at night to take up carbon dioxide (CO_2). The spines of these and many other desert plants guard them from being eaten by herbivores seeking the precious water they hold.

Some desert plants use deep roots to tap into groundwater. Others such as prickly pear and saguaro cacti use widely spread shallow roots to collect water after brief showers and store it in their spongy tissues.

Some plants found in deserts conserve water by having wax-coated leaves that reduce water loss. Others such as annual wildflowers and grasses store much of their biomass in seeds that remain inactive, sometimes for years, until they receive enough water to germinate. Shortly after a rain, these seeds germinate, grow, and carpet some deserts with dazzling arrays of colorful flowers (Figure 7-A) that last for up to a few weeks.

Anton Foltin/Shutterstock

Figure 7-A After a brief rain, these wildflowers bloomed in this temperate desert in Picacho Peak State Park in the U.S. state of Arizona.

Most desert animals are small. Some beat the heat by hiding in cool burrows or rocky crevices by day and coming out at night or in the early morning. Others become dormant during periods of extreme heat or drought. Some larger animals such as camels can drink massive quantities of water when it is available and store it in their fat for use as needed. Also, the camel's thick fur actually helps it to keep cool because the air spaces in the fur insulate the camel's skin against the outside heat. And camels do not sweat, which reduces their water loss through evaporation. Kangaroo rats never drink water. They get the water they need by breaking down fats in seeds that they consume.

Insects and reptiles such as rattlesnakes have thick outer coverings to minimize water loss through evaporation, and their wastes are dry feces and a dried concentrate of urine. Many spiders and insects get their water from dew or from the food they eat.

Critical Thinking

What are three steps you would take to survive in the open desert if you had to?

In *cold deserts* such as the Gobi Desert in Mongolia, vegetation is sparse (Figure 7-10, bottom photo). Winters are cold, summers are warm or hot, and precipitation is low (Figure 7-10, bottom graph). Desert plants and animals have adaptations that help them to stay cool and to get enough water to survive (Science Focus, above).

Desert ecosystems are fragile. Their soils take from decades to hundreds of years to recover from disturbances such as off-road vehicle traffic (Figure 7-10, top photo). This is because deserts have slow plant growth, low species diversity, slow nutrient cycling (due to low bacterial activity in the soils), and very little water. Also, off-road vehicle traffic in deserts can destroy the habitats for a variety of animals that live underground in this biome.

There Are Three Major Types of Grasslands

Grasslands occur mostly in the interiors of continents in areas that are too moist for deserts to form and too dry for forests to grow (Figure 7-7). Grasslands persist because of a combination of seasonal drought, grazing by large herbivores, and occasional fires—all of which keep shrubs and trees from growing in large numbers.

The three main types of grassland—tropical, temperate, and cold (arctic tundra)—result from combinations of low average precipitation and varying average temperatures (Figures 7-9 and 7-11 and **Concept 7-2**). Note the locations in Figure 7-7 of large areas of tropical grasslands in South America and Africa, temperate

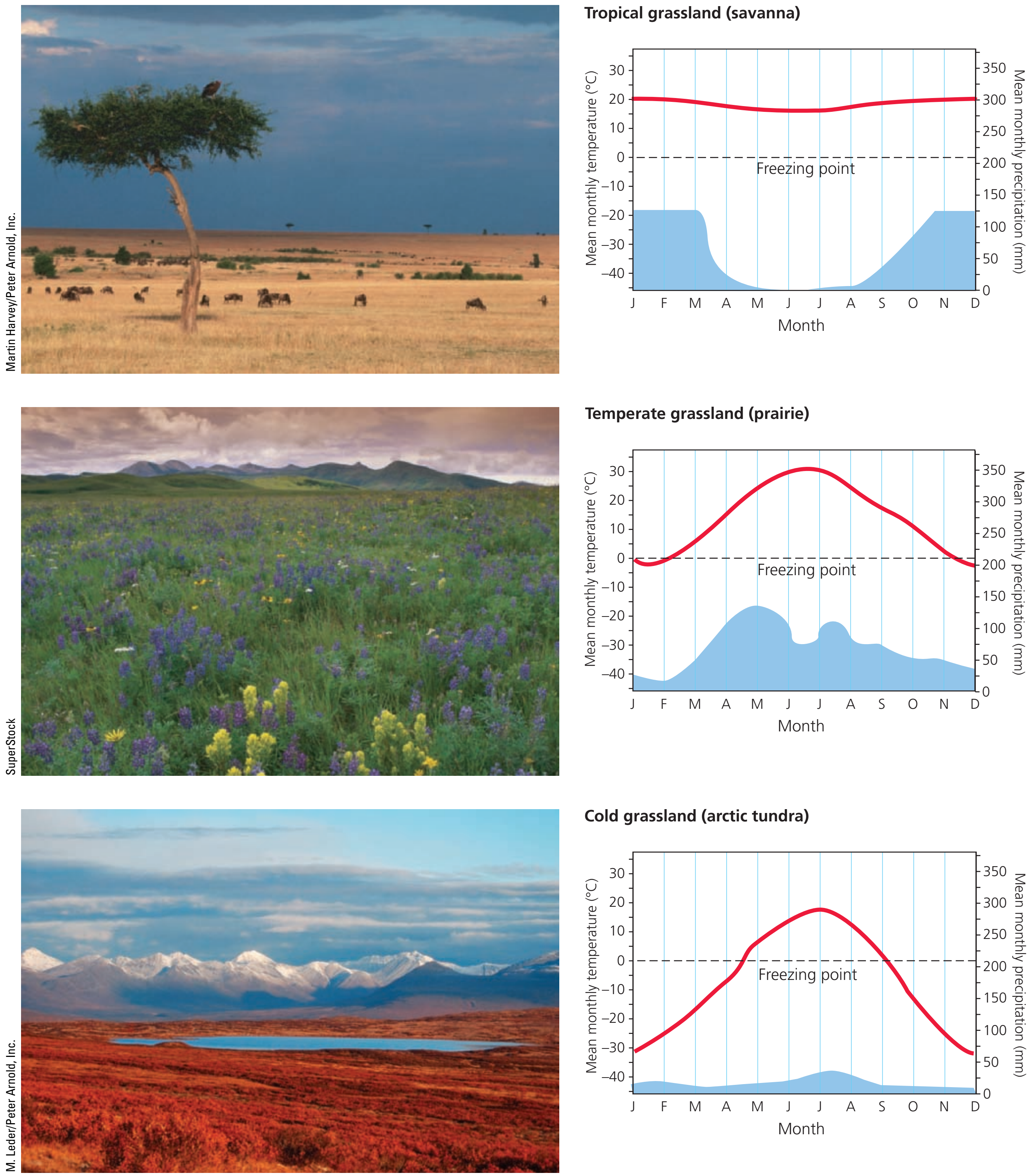

Figure 7-11 These climate graphs track the typical variations in annual temperature (red) and precipitation (blue) in tropical, temperate, and cold (arctic tundra) grasslands. Top photo: *savanna* (*tropical grassland*) in Maasai Mara National Park in Kenya, Africa, with wildebeests grazing. Center photo: *prairie* (*temperate grassland*) near East Glacier Park in the U.S. state of Montana, with wildflowers in bloom. Bottom photo: *arctic tundra* (*cold grassland*) in autumn in the U.S. state of Alaska (see also Figure 7-1, bottom). **Question:** What month of the year has the highest temperature and the lowest rainfall for each of the three types of grassland?

grasslands in North America and Asia, and cold grasslands (arctic tundra) in far northern areas.

One type of tropical grassland, called a *savanna,* contains widely scattered clumps of trees such as acacia (Figure 7-11, top photo), which are covered with thorns that keep some herbivores away. This biome usually has warm temperatures year-round and alternating dry and wet seasons (Figure 7-11, top graph).

Tropical savannas in East Africa are home to *grazing* (mostly grass-eating) and *browsing* (twig- and leaf-nibbling) hoofed animals, including wildebeests (Figure 7-11, top photo), gazelles, zebras, giraffes, and antelopes, as well as their predators such as lions, hyenas, and humans. Herds of these grazing and browsing animals migrate to find water and food in response to seasonal and year-to-year variations in rainfall (Figure 7-11, blue region in top graph) and food availability. Savanna plants, like those in deserts, are adapted to survive drought and extreme heat; many have deep roots that can tap into groundwater.

CONNECTIONS

Grassland Niches and Feeding Habits

As an example of differing niches, some large herbivores have evolved specialized eating habits that minimize competition among species for the vegetation found on the savanna. For example, giraffes eat leaves and shoots from the tops of trees, elephants eat leaves and branches farther down, wildebeests prefer short grasses, and zebras graze on longer grasses and stems.

In a *temperate grassland,* winters can be bitterly cold, summers are hot and dry, and annual precipitation is fairly sparse and falls unevenly throughout the year (Figure 7-11, center graph). Because the aboveground parts of most of the grasses die and decompose each year, organic matter accumulates to produce a deep, fertile topsoil. This topsoil is held in place by a thick network of the drought-tolerant grasses' intertwined roots (unless the topsoil is plowed up, which exposes it to being blown away by high winds found in these biomes). The natural grasses are also adapted to fires that burn the plant parts above the ground but do not harm the roots, from which new grass can grow.

Two types of temperate grasslands are the *short-grass prairies* (Figure 7-11, center photo) and the *tall-grass prairies* of the mid-western and western areas of the United States and Canada (which get more rain). Figure 2, p. S21 in Supplement 6 shows some components and food-web interactions in a temperate tall-grass prairie ecosystem in North America.

In all prairies, winds blow almost continuously and evaporation is rapid, often leading to fires in the summer and fall. This combination of winds and fires helps maintain such grasslands by hindering tree growth and adding ash to the soil.

Many of the world's natural temperate grasslands have been converted to farmland, because their fertile soils are useful for growing crops (Figure 7-12) and grazing cattle.

Cold grasslands, or *arctic tundra* (Russian for "marshy plain"), lie south of the arctic polar ice cap (Figure 7-7). During most of the year, these treeless plains are bitterly cold (Figure 7-11, bottom graph), swept by frigid winds, and covered with ice and snow. Winters are long with short days, and scant precipitation falls mostly as snow.

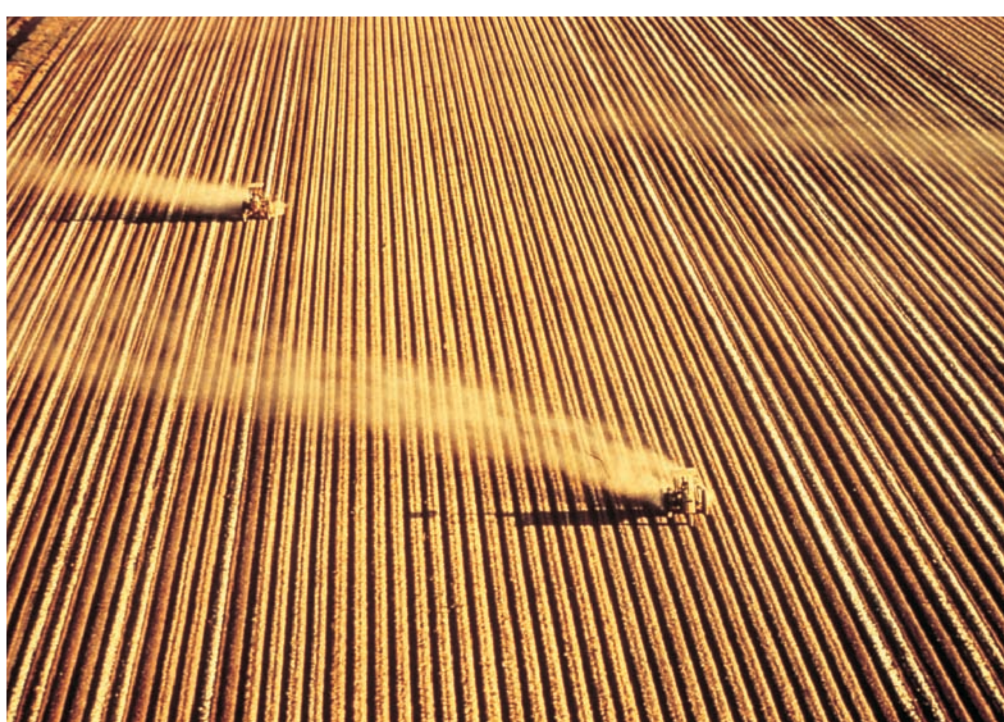

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Figure 7-12 Natural capital degradation: This intensively cultivated cropland is an example of the replacement of a biologically diverse temperate grassland with a monoculture crop in the U.S. state of California. When humans remove the tangled root network of natural grasses, the fertile topsoil becomes subject to severe wind erosion unless it is covered with some type of vegetation.

Under the snow, this biome is carpeted with a thick, spongy mat of low-growing plants, primarily grasses, mosses, lichens, and dwarf shrubs (Figure 7-11, bottom photo). Trees or tall plants cannot survive in the cold and windy tundra because they would lose too much of their heat. Most of the annual growth of the tundra's plants occurs during the 7- to 8-week summer, when the sun shines almost around the clock.

One outcome of the extreme cold is the formation of **permafrost**, underground soil in which captured water stays frozen for more than 2 consecutive years. During the brief summer, the permafrost layer keeps melted snow and ice from draining into the ground. As a consequence, many shallow lakes, marshes, bogs, ponds, and other seasonal wetlands form when snow and frozen surface soil melt on the waterlogged tundra (Figure 7-1, bottom photo). Hordes of mosquitoes, black flies, and other insects thrive in these shallow surface pools. They serve as food for large colonies of migratory birds (especially waterfowl) that return from the south to nest and breed in the bogs and ponds.

Animals in this biome survive the intense winter cold through adaptations such as thick coats of fur (arctic wolf, arctic fox, and musk oxen) and feathers (snowy owl) and living underground (arctic lemming). In the summer, caribou migrate to the tundra to graze on its vegetation.

Tundra is a fragile biome. Most tundra soils formed about 17,000 years ago when glaciers began retreating after the last Ice Age (see Figure 4-9, p. 89). These soils usually are nutrient poor and have little detritus. Because of the short growing season, tundra soil and vegetation recover very slowly from damage or disturbance. Human activities in the arctic tundra—mostly on and around oil drilling sites, pipelines, mines, and military bases—leave scars that persist for centuries.

Another type of tundra, called *alpine tundra*, occurs above the limit of tree growth but below the permanent snow line on high mountains (Figure 7-8, left). The vegetation is similar to that found in arctic tundra, but it receives more sunlight than arctic vegetation gets. During the brief summer, alpine tundra can be covered with an array of beautiful wildflowers.

In some areas, especially in coastal regions that border on deserts, we find fairly small patches of a biome known as *temperate shrubland* or *chaparral* (Figure 7-7). It consists mostly of dense growths of low-growing evergreen shrubs and occasional small trees with leathery leaves that reduce evaporation. This biome is found along coastal areas of southern California in the United States, the Mediterranean Sea, central Chile, southern Australia, and southwestern Africa.

People like living in this biome because of its moderate, sunny climate with mild, wet winters and long, warm, and dry summers. As a result, many people live in such areas and have modified this biome significantly.

However, during the summer season, its vegetation becomes very dry and highly flammable; in the late summer and fall, fires started by lightning or human activities can spread with incredible swiftness. The fires are often followed by mudslides during rainy seasons.

There Are Three Major Types of Forests

Forests are lands dominated by trees. The three main types of forest—*tropical*, *temperate*, and *cold* (northern coniferous, or boreal)—result from combinations of varying precipitation levels and varying average temperatures (Figures 7-9 and 7-13, p. 160, and **Concept 7-2**).

CORE CASE STUDY

Tropical rain forests (Figure 7-13, top photo and Figure 7-1, top photo) are found near the equator (Figure 7-7), where hot, moisture-laden air rises and dumps its moisture (Figure 7-3). These lush forests have year-round, uniformly warm temperatures, high humidity, and almost daily heavy rainfall (Figure 7-13, top graph). This fairly constant warm and wet climate is ideal for a wide variety of plants and animals. These forests are often called *jungle*, but that word refers to the thickest and most dense parts of a tropical rain forest.

Figure 7-14 (p. 161) shows some of the components and food web interactions in these extremely diverse ecosystems. Tropical rain forests are dominated by *broadleaf evergreen plants*, which keep most of their leaves year-round. The tops of the trees form a dense canopy (Figure 7-13, top photo) that blocks most light from reaching the forest floor. For this reason, there is little vegetation on the forest floor. Many of the plants that do live at the ground level have enormous leaves to capture what little sunlight filters through to the dimly lit forest floor.

Some trees are draped with vines (called lianas) that reach for the treetops to gain access to sunlight. Once up into the canopy, the vines grow from one tree to another, providing walkways for many species living there. When a large tree is cut down, its network of lianas can pull down other trees.

Tropical rain forests have a very high net primary productivity (see Figure 3-14, p. 65). They are teeming with life and possess incredible biological diversity. Although tropical rain forests cover only about 2% of the earth's land surface, ecologists estimate that they contain at least half of the earth's known terrestrial plant and animal species. For example, a single tree in these forests may support several thousand different insect species. Plants from tropical rain forests are a source of chemicals used as blueprints for making most of the world's prescription drugs.

Rain forest species occupy a variety of specialized niches in distinct layers, which help to enable these forests' great biodiversity (high species richness). For example, vegetation layers are structured, for the most part,

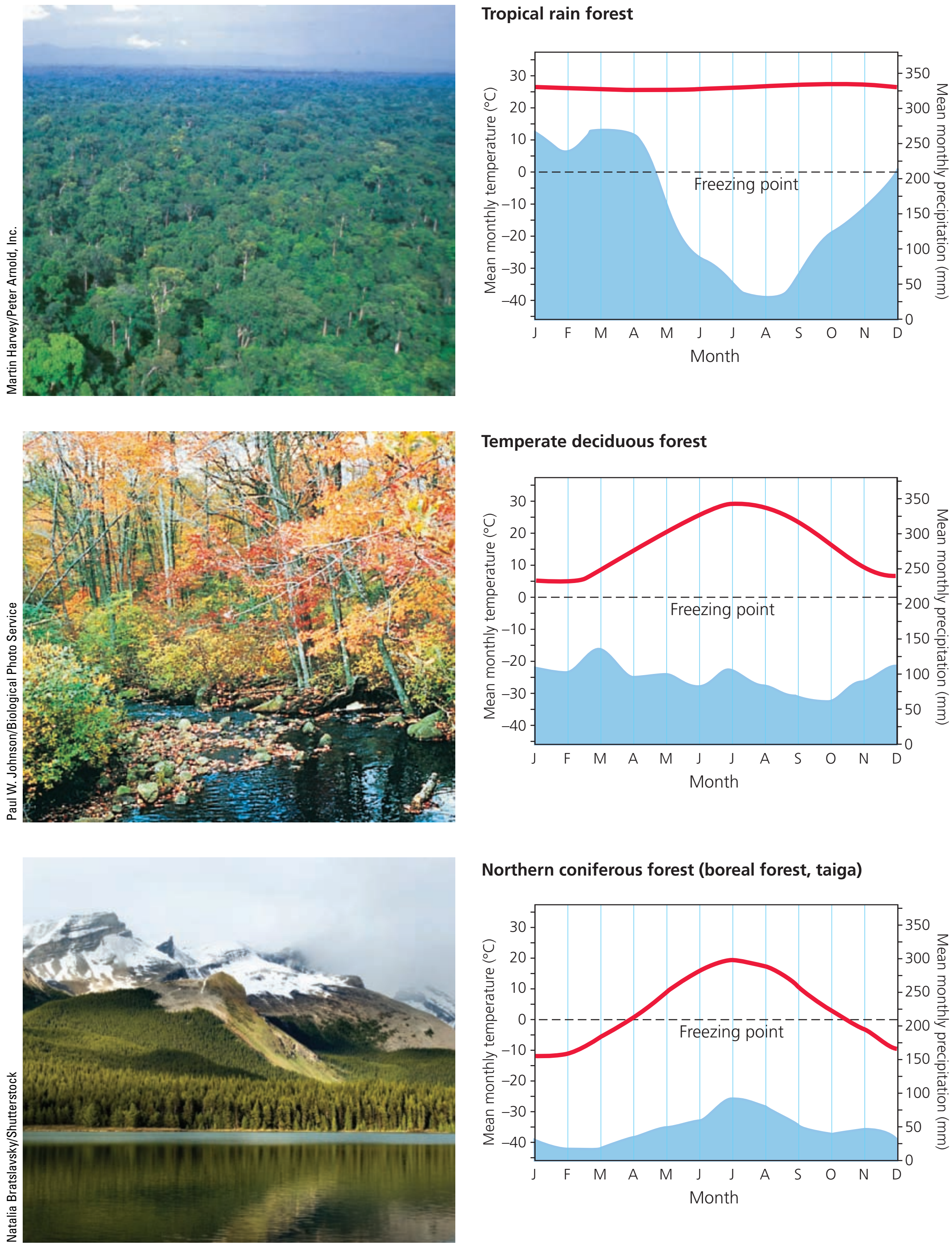


Figure 7-13 These climate graphs track the typical variations in annual temperature (red) and precipitation (blue) in tropical, temperate, and cold (northern coniferous, or boreal) forests. Top photo: the closed canopy of a *tropical rain forest* in the western Congo Basin of Gabon, Africa. Middle photo: a *temperate deciduous forest* in the U.S. state of Rhode Island during the fall. (Photo 1 in the Detailed Contents shows this same area of forest during winter when its trees have lost their leaves.) Bottom photo: a *northern coniferous forest* in Canada's Jasper National Park. **Question:** What month of the year has the highest temperature and the lowest rainfall for each of the three types of forest?

CENGAGENOW™ **Active Figure 7-14** This diagram shows some of the components and interactions in a *tropical rain forest ecosystem*. When these organisms die, decomposers break down their organic matter into minerals that plants use. Colored arrows indicate transfers of matter and energy between producers; primary consumers (herbivores); secondary, or higher-level, consumers (carnivores); and decomposers. Organisms are not drawn to scale. *See an animation based on this figure at* CengageNOW.

according to the plants' needs for sunlight, as shown in Figure 7-15 (p. 162). Much of the animal life, particularly insects, bats, and birds, lives in the sunny *canopy* layer, with its abundant shelter and supplies of leaves, flowers, and fruits. To study life in the canopy, ecologists climb trees, and build platforms and boardwalks in the upper canopy. (See *The Habitable Planet*, Videos 4 and 9, at **www.learner.org/resources/series209.html** for information on how scientists gather information about tropical rain forests and the effects of human activities on such forests.)

CENGAGENOW™ Learn more about how plants and animals in a rain forest are connected in a food web at CengageNOW.

Dropped leaves, fallen trees, and dead animals decompose quickly in tropical rain forests because of the warm, moist conditions and the hordes of decomposers. This rapid recycling of scarce soil nutrients explains why there is so little plant litter on the ground. Nutrients that do reach the ground are soon leached from the thin topsoil by the almost daily rainfall. Instead of being stored in the soil, about 90% of plant nutrients released by decomposition are quickly taken up and stored by trees, vines, and other plants. The resulting lack of fertile soil helps to explain why rain forests are not good places to clear and grow crops or graze cattle on a sustainable basis.

So far, at least half of these forests have been destroyed or disturbed by human activities such as farming and raising cattle, and the pace of this destruction and degradation is increasing (see Chapter 3 Core Case Study, p. 54). Ecologists warn that without strong protective measures, most of these forests, along with their rich biodiversity and other very valuable ecological services, will probably be gone within your lifetime. This will reduce the earth's biodiversity and could help accelerate atmospheric warming and the projected climate change that could follow by eliminating large areas of trees that remove carbon dioxide from the atmosphere (see *The Habitable Planet*, Video 9, at **www.learner.org/resources/series209.html**.)

THINKING ABOUT

Tropical Rain Forest Destruction

What harmful effects might the loss of most of the world's remaining tropical rain forests have on your lifestyle and that of any child or grandchild that you might have? What are two things you could do to help reduce this loss?

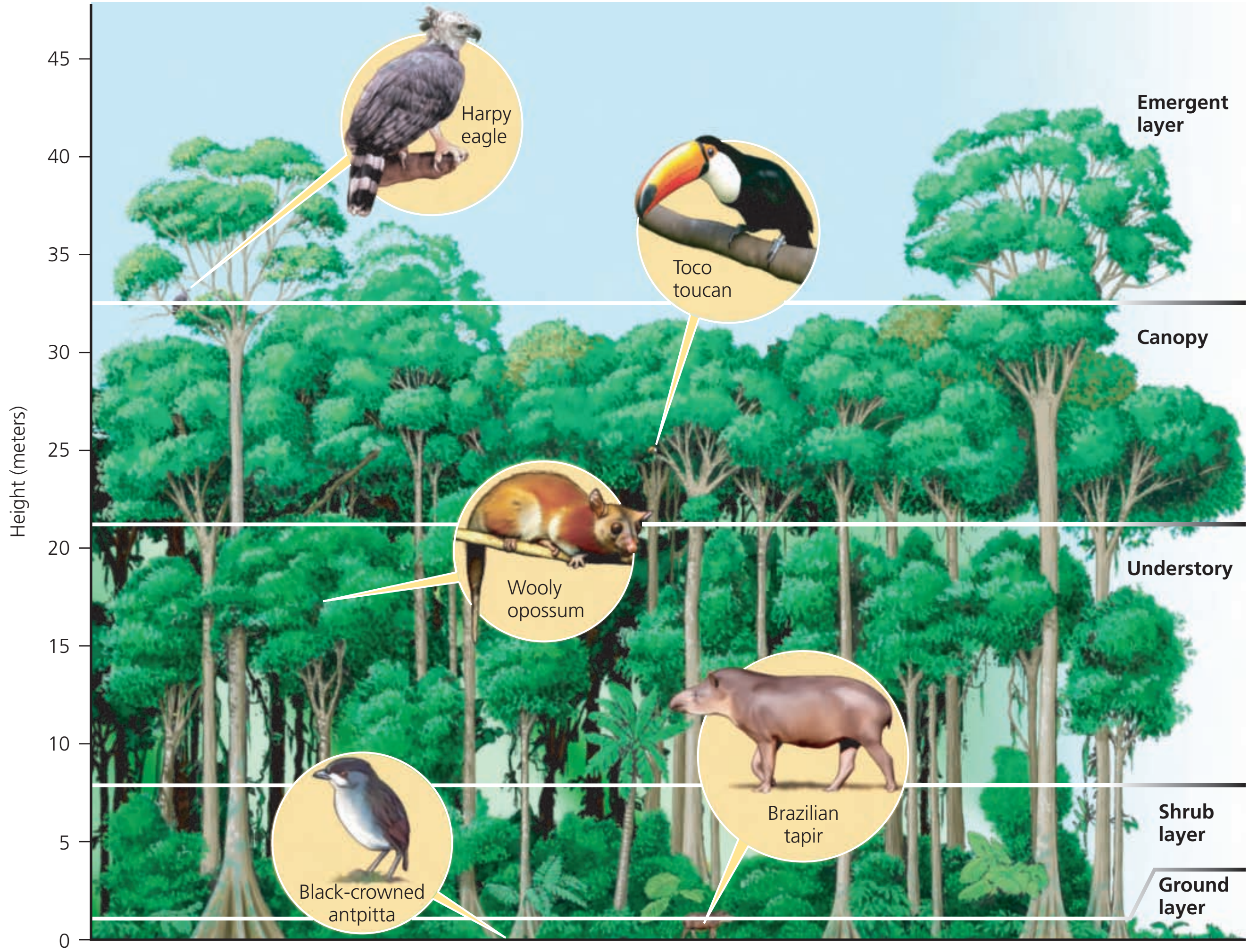


Figure 7-15 This diagram illustrates the stratification of specialized plant and animal niches in a *tropical rain forest*. Filling such specialized niches enables species to avoid or minimize competition for resources and results in the coexistence of a great variety of species.

Temperate deciduous forests such as the one shown in Figure 7-13, center photo, grow in areas with moderate average temperatures that change significantly with the seasons. These areas have long, warm summers, cold but not too severe winters, and abundant precipitation, often spread fairly evenly throughout the year (Figure 7-13, center graph).

This biome is dominated by a few species of *broadleaf deciduous trees* such as oak, hickory, maple, poplar, and beech. They survive cold winters by dropping their leaves in the fall and becoming dormant through the winter (see Photo 1 in the Detailed Contents). Each spring, they grow new leaves whose colors change in the fall into an array of reds and golds before the leaves drop, as shown in Figure 7-1, middle (**Core Case Study**). CORE CASE STUDY

Because they have cooler temperatures and fewer decomposers, these forests have a slower rate of decomposition than tropical forests have. As a result, they accumulate a thick layer of slowly decaying leaf litter, which becomes a storehouse of nutrients. On a global basis, this biome has been disturbed by human activity more than any other terrestrial biome. However, within 100–200 years, areas cleared of their trees can return to a deciduous forest through secondary ecological succession (see Figure 5-20 p. 120).

Evergreen coniferous forests (Figure 7-13, bottom photo) are also called *boreal forests* and *taigas* ("TIE-guhs"). These cold forests are found just south of the arctic tundra in northern regions across North America, Asia, and Europe (Figure 7-7) and above certain altitudes in the Sierra Nevada and Rocky Mountain ranges of the United States. In this subarctic climate, winters are long, dry, and extremely cold; in the northernmost taigas, winter sunlight is available only 6–8 hours per day. Summers are short, with cool to warm temperatures (Figure 7-13, bottom graph), and the sun shines up to 19 hours a day.

Most boreal forests are dominated by a few species of *coniferous* (cone-bearing) *evergreen trees* such as spruce, fir, cedar, hemlock, and pine that keep most of their leaves year-round. Most of these species have small, needle-shaped, wax-coated leaves that can withstand the intense cold and drought of winter, when snow blankets the ground. Such trees are ready to take advantage of the brief summers because they need not take time to grow new needles. Plant diversity is low because few species can survive the winters when soil moisture is frozen.

Beneath the stands of trees is a deep layer of partially decomposed conifer needles. Decomposition is slow because of low temperatures, the waxy coating on the needles, and high soil acidity. The decomposing conifer needles make the thin, nutrient-poor topsoil acidic and prevent most other plants (except certain shrubs) from growing on the forest floor.

This biome contains a variety of wildlife. Year-round residents include bears, wolves, moose, lynx, and many burrowing rodent species. Caribou spend the winter in taiga and the summer in arctic tundra (Figure 7-11, bottom). During the brief summer, warblers and other insect-eating birds feed on hordes of flies, mosquitoes, and caterpillars. Figure 5, p. S24, in Supplement 6 shows some components and food web interactions in an evergreen coniferous forest ecosystem.

Coastal coniferous forests or *temperate rain forests* (Figure 7-16) are found in scattered coastal temperate areas with ample rainfall or moisture from dense ocean fogs. Dense stands of these forests with large conifers such as Sitka spruce, Douglas fir, and redwoods once dominated undisturbed areas of these biomes along the coast of North America, from Canada to northern California in the United States.

R. Erl/Peter Arnold, Inc.

Figure 7-16 Temperate rain forest in Olympic National Park in the U.S. state of Washington.

Mountains Play Important Ecological Roles

Some of the world's most spectacular environments are high on *mountains* (Figure 7-17), steep or high lands which cover about one-fourth of the earth's land surface (Figure 7-7). Mountains are places where dramatic changes in altitude, slope, climate, soil, and vegetation take place over a very short distance (Figure 7-8, left).

About 1.2 billion people (17% of the world's population) live in mountain ranges or in their foothills, and 4 billion people (58% of the world's population) depend on mountain systems for all or some of their water. Because of the steep slopes, mountain soils are easily eroded when the vegetation holding them in place is removed by natural disturbances such as landslides and avalanches, or by human activities such as timber cutting and agriculture. Many mountains are *islands of biodiversity* surrounded by a sea of lower-elevation landscapes transformed by human activities.

Mark Hamblin/WWI/Peter Arnold, Inc.

Figure 7-17 Mountains such as this one in the U.S. state of Washington play important ecological roles.

Mountains play important ecological roles. They contain the majority of the world's forests, which are habitats for much of the planet's terrestrial biodiversity. They often are habitats for *endemic species* found nowhere else on earth. They also serve as sanctuaries for animal species that are capable of migrating to higher altitudes and surviving in such environments if they are driven from lowland areas by human activities or by a warming climate.

CONNECTIONS

Mountains and Climate

Mountains help to regulate the earth's climate. Mountaintops covered with glacial ice and snow that reflect some solar radiation back into space, which helps to cool the earth and offset atmospheric warming. However, many of the world's mountain glaciers are melting, mostly because of atmospheric warming. While glaciers reflect solar energy, the darker rocks exposed by melting glaciers absorb that energy. This helps to increase atmospheric warming, which melts more ice and warms the atmosphere more—in an escalating positive feedback loop (see Figure 2-18, p. 49).

Finally, mountains play a critical role in the hydrologic cycle (see Figure 3-16, p. 67) by serving as major storehouses of water. During winter, precipitation is stored as ice and snow. In the warmer weather of spring and summer, much of this snow and ice melts and is released to streams for use by wildlife and by humans for drinking and irrigating crops. With atmospheric warming, mountaintop snow packs and glaciers are melting earlier in the spring each year. This can lower food production in certain areas, because much of the water needed during the summer to irrigate crops has already been released.

Measurements and climate models indicate that an increasing number of the world's mountaintop glaciers may disappear during this century if the atmosphere gets warmer as projected. This could cause many people to have to move in search of new water supplies and places to grow their crops. Despite the ecological, economic, and cultural importance of mountain ecosystems, protecting them has not been a high priority for governments or for many environmental organizations.

7-3 How Have We Affected the World's Terrestrial Ecosystems?

CONCEPT 7-3 In many areas, human activities are impairing ecological and economic services provided by the earth's deserts, grasslands, forests, and mountains.

Humans Have Disturbed Most of the Earth's Land

According to the 2005 Millennium Ecosystem Assessment, about 62% of the world's major terrestrial ecosystems are being degraded or used unsustainably, as the human ecological footprint gets bigger and spreads across the globe (see Figure 7, p. S38, in Supplement 8). Figure 7-18 summarizes some of the human impacts on the world's deserts, grasslands, forests, and mountains (**Concept 7-3**).

How long can we keep eating away at these terrestrial forms of natural capital without threatening our economies and the long-term survival of our own and many other species? No one knows. But there are increasing signs that we need to come to grips with this vital issue.

An important concern is that if we increase the stresses on some of these biomes, such as by clearing tropical forests, they could be replaced by grasslands in many areas. This would represent a massive loss of biodiversity. It would also reduce the vegetation needed to remove some of the excess carbon dioxide that we add to the atmosphere, mostly be burning fossil fuels. This would lead to higher levels of carbon dioxide in the atmosphere, which would accelerate projected climate change.

To help preserve biodiversity and to slow projected climate change, many environmental scientists call for a global effort to protect the world's remaining wild areas from development. In addition, they call for us to restore many of the land areas that we have degraded. However, such efforts are highly controversial because of timber, mineral, fossil fuel, and other resources found on or under many of the earth's remaining wild land areas. These issues are discussed in Chapter 10.

RESEARCH FRONTIER

Better understanding of the effects of human activities on terrestrial biomes and how we can reduce these impacts; see **www.cengage.com/login**.

Here are this chapter's *three big ideas*:

- Differences in climate, based mostly on long-term differences in average temperature and precipitation, largely determine the types and locations of the earth's deserts, grasslands, and forests.
- The earth's terrestrial systems provide important ecological and economic services.
- Human activities are degrading and disrupting many of the ecological and economic services provided by the earth's terrestrial ecosystems.

Figure 7-18 This diagram illustrates the major human impacts on the world's deserts, grasslands, forests, and mountains (**Concept 7-3**). **Question:** For each of these biomes, which two of the impacts listed do you think are the most harmful?

REVISITING Climate, Biodiversity, and Sustainability

CORE CASE STUDY

SUSTAINABILITY

This chapter's opening **Core Case Study** describes the influence of climate on terrestrial biodiversity in the formation of deserts, grasslands, and forests. These forms of the earth's biodiversity resulted mostly from the interaction of climate with the earth's life forms over billions of years, in keeping with the three **principles of sustainability** (see back cover). The earth's dynamic climate system helps to distribute solar energy and to recycle the earth's nutrients. In turn, this helps to generate and support the terrestrial biodiversity found in the earth's biomes. Through these global processes, life has sustained itself for at least 3.5 billion years.

Scientists have made a good start in understanding the ecology of the world's terrestrial systems and how the vital ecological and economic services they provide are being degraded and disrupted. One of the major lessons from their research is: *in nature, everything is connected*. According to these scientists, we urgently need more research on the components and workings of the world's biomes, on how they are interconnected, and on which connections are the strongest and which are in the greatest danger of being disrupted by human activities. With such vital information, we will have a clearer picture of how our activities affect the earth's natural capital and what we can do to help sustain it and thus ourselves and other species.

When we try to pick out anything by itself, we find it hitched to everything else in the universe.

JOHN MUIR

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 148. Describe how differences in climate lead to formation of tropical, temperate, and polar deserts, grasslands, and forests.
2. Distinguish between **weather** and **climate**. Describe three major factors that determine how air circulates in the lower atmosphere. Describe how the properties of air, water, and land affect global air circulation. Define **ocean currents** and explain how they, along with global air circulation, support the formation of forests, grasslands, and deserts.
3. Define and give four examples of a **greenhouse gas**. What is the **natural greenhouse effect** and why is it important to the earth's life and climate?
4. What is the **rain shadow effect** and how can it lead to the formation of deserts? Why do cities tend to have more haze and smog, higher temperatures, and lower wind speeds than the surrounding countryside?
5. What is a **biome**? Explain why there are three major types of each of the major biomes (deserts, grasslands, and forests). Describe how climate and vegetation vary with latitude and elevation.
6. Describe how the three major types of deserts differ in their climate and vegetation. How do desert plants and animals survive?
7. Describe how the three major types of grasslands differ in their climate and vegetation. What is a savanna? Why have many of the world's temperate grasslands disappeared? What is **permafrost**? Distinguish between arctic tundra and alpine tundra.
8. What are the three major types of forests? Describe how these three types of forests differ in their climate and vegetation. Why is biodiversity so high in tropical rain forests? Why do most soils in tropical rain forests hold few plant nutrients? Describe what happens in temperate deciduous forests in the winter and fall. What are coastal coniferous or temperate rain forests? What important ecological roles do mountains play?
9. Describe how human activities have affected the world's deserts, grasslands, forests, and mountains.
10. What are this chapter's *three big ideas*? Describe the connections between the climates, terrestrial systems, and the three **principles of sustainability** (see back cover).

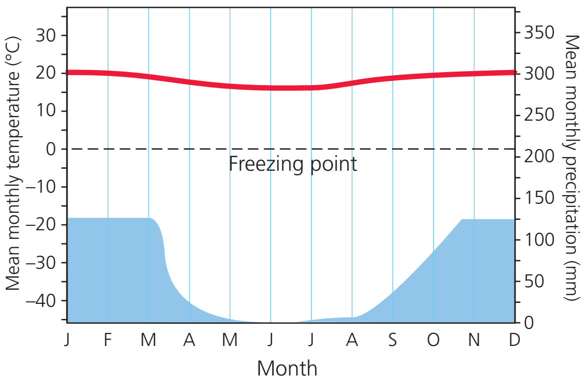
Note: Key terms are in **bold** type.

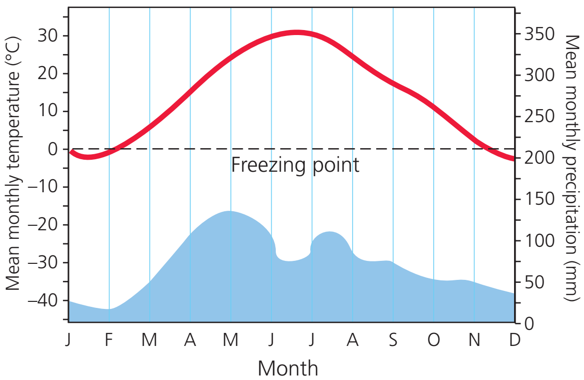
CRITICAL THINKING

1. What would be likely to happen to the earth's climate **(a)** if most of the world's oceans disappeared and **(b)** if most of the world's land disappeared?
2. Describe the roles of temperature and precipitation in determining what parts of the earth's land are covered with: **(a)** desert, **(b)** arctic tundra, **(c)** temperate grassland, **(d)** tropical rain forest, and **(e)** temperate deciduous forest.
3. Why do deserts and arctic tundra support a much smaller biomass of animals than do tropical forests? Why do most animals in a tropical rain forest live in its trees?
4. How might the distribution of the world's forests, grasslands, and deserts shown in Figure 7-7 differ if the prevailing winds shown in Figure 7-3 did not exist?
5. Which biomes are best suited for **(a)** raising crops and **(b)** grazing livestock? Use the three **principles of sustainability** to come up with three guidelines for growing food and grazing livestock in these biomes on a more sustainable basis.
6. What do you think would happen if all or most of the world's mountain glaciers melted? Write a brief scenario describing the resulting problems and ways in which you think mountainous nations would deal with the problems.
7. What type of biome do you live in? (If you live in a developed area, what type of biome was the area before it was developed?) List three ways in which your lifestyle could be contributing to the degradation of this biome?
8. You are a defense attorney arguing in court for sparing a tropical rain forest from being cut. Give your three best arguments for the defense of this ecosystem.
9. Congratulations! You are in charge of the world. What are the three most important features of your plan for helping to sustain the earth's terrestrial biodiversity and the ecosystems services it provides?
10. List two questions that you would like to have answered as a result of reading this chapter.

DATA ANALYSIS

In this chapter, you learned how long-term variations in average temperatures and average precipitation play a major role in determining the types of deserts, forests, and grasslands found in different parts of the world. Below are typical annual climate graphs for a tropical grassland (savanna) in Africa and a temperate grassland in the mid-western United States.





1. In what month (or months) does the most precipitation fall in each of these areas?
2. What are the driest months in each of these areas?
3. What is the coldest month in the tropical grassland?
4. What is the warmest month in the temperate grassland?

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengagebrain.com/shop/ISBN/0538735341** and choose Chapter 7 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

For students with access to premium online resources, log on to **www.cengage.com/login**.

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8 Aquatic Biodiversity

CORE CASE STUDY

Why Should We Care about Coral Reefs?

Coral reefs form in clear, warm coastal waters of the tropics and subtropics (Figure 8-1, left). These stunningly beautiful natural wonders are among the world's oldest, most diverse, and most productive ecosystems. In terms of biodiversity, they are the marine equivalents of tropical rain forests.

Coral reefs are formed by massive colonies of tiny animals called *polyps* (close relatives of jellyfish). They slowly build reefs by secreting a protective crust of limestone (calcium carbonate) around their soft bodies. When the polyps die, their empty crusts remain behind as a platform for more reef growth. The resulting elaborate network of crevices, ledges, and holes serves as calcium carbonate "condominiums" for a variety of marine animals.

Coral reefs are the result of a mutually beneficial relationship between the polyps and tiny single-celled algae called *zooxanthellae* ("zoh-ZAN-thel-ee") that live in the tissues of the polyps. In this example of mutualism (see Chapter 5, p. 110), the algae provide the polyps with food and oxygen through photosynthesis, and help produce calcium carbonate, which forms the coral's skeleton. Algae also give the reefs their stunning coloration. The polyps, in turn, provide the algae with a well-protected home and some of their nutrients.

Although coral reefs occupy only about 0.2% of the ocean floor, they provide important ecological and economic services. For example, they act as natural barriers that help to protect 15% of the world's coastlines from erosion caused by battering waves and storms. Further, they provide habitats for one-quarter of all marine organisms.

Economically, coral reefs produce about one-tenth of the global fish catch—one-fourth of the catch in less-developed countries—and they provide fishing and ecotourism jobs for some of the world's poorest countries. These biological treasures give us an underwater world to study and enjoy. Each year, more than 1 million scuba divers and snorkelers visit coral reefs to experience these wonders of aquatic biodiversity.

In a 2008 report by the Global Coral Reef Monitoring Network, scientists estimated that 19% of the world's coral reefs had been destroyed. Other studies indicated that another 20% of all coral reef ecosystems had been degraded by coastal development, pollution, overfishing, warmer ocean temperatures, increasing ocean acidity, and other stresses. And another 25–33% of all reefs could be lost within 20–40 years.

Coral reefs are vulnerable to damage because they grow slowly and are disrupted easily. They thrive only in clear and fairly shallow water of constant high salinity, and runoff of soil and other materials from the land can cloud the water and block sunlight needed by the reefs' producer organisms. Also, the water in which they live must have a temperature of 18–30°C (64–86°F). This explains why the biggest long-term threat to coral reefs may be projected climate change, which could raise the water temperature above this limit in most reef areas. One resulting problem is *coral bleaching* (Figure 8-1, upper right). It occurs when stresses such as increased temperature cause the algae, upon which corals depend for food, to die off. Without food, the coral polyps then die, leaving behind a white skeleton of calcium carbonate.

Another threat is the increasing acidity of ocean water as it absorbs some of the carbon dioxide (CO_2) produced mostly by the burning of carbon-containing fossils fuels. The CO_2 reacts with ocean water to form a weak acid, which can slowly dissolve the calcium carbonate that makes up the corals.

The decline and degradation of these colorful oceanic sentinels should serve as a warning about threats to the health of ocean ecoystems, which provide us with crucial ecological and economic services.

Rich Carey/Shutterstock

Rich Carey/Shutterstock

Figure 8-1 A healthy coral reef in the Red Sea is covered by colorful algae (left), while a bleached coral reef (right) has lost most of its algae because of changes in the environment (such as cloudy water or high water temperatures). With the algae gone, the white limestone of the coral skeleton becomes visible. If the environmental stress is not removed and no other algae fill the abandoned niche, the corals die. These diverse and productive ecosystems are being damaged and destroyed at an alarming rate.

Key Questions and Concepts

8-1 What is the general nature of aquatic systems?

CONCEPT 8-1A Saltwater and freshwater aquatic life zones cover almost three-fourths of the earth's surface, with oceans dominating the planet.

CONCEPT 8-1B The key factors determining biodiversity in aquatic systems are temperature, dissolved oxygen content, availability of food, and availability of light and nutrients necessary for photosynthesis.

8-2 Why are marine aquatic systems important?

CONCEPT 8-2 Saltwater ecosystems are irreplaceable reservoirs of biodiversity and provide major ecological and economic services.

8-3 How have human activities affected marine ecosystems?

CONCEPT 8-3 Human activities threaten aquatic biodiversity and disrupt ecological and economic services provided by saltwater systems.

8-4 Why are freshwater ecosystems important?

CONCEPT 8-4 Freshwater ecosystems provide major ecological and economic services, and are irreplaceable reservoirs of biodiversity.

8-5 How have human activities affected freshwater ecosystems?

CONCEPT 8-5 Human activities threaten biodiversity and disrupt ecological and economic services provided by freshwater lakes, rivers, and wetlands.

Note: Supplements 2 (p. S3) and 8 (p. S30) can be used with this chapter.

If there is magic on this planet, it is contained in water.

LOREN EISLEY

8-1 What Is the General Nature of Aquatic Systems?

▶ **CONCEPT 8-1A Saltwater and freshwater aquatic life zones cover almost three-fourths of the earth's surface, with oceans dominating the planet.**

▶ **CONCEPT 8-1B The key factors determining biodiversity in aquatic systems are temperature, dissolved oxygen content, availability of food, and availability of light and nutrients necessary for photosynthesis.**

Most of the Earth Is Covered with Water

When viewed from a certain point in outer space, the earth appears to be almost completely covered with water (Figure 8-2). Saltwater covers about 71% of the earth's surface, and freshwater occupies roughly another 2.2%. Yet, in proportion to the entire planet, it all amounts to a thin and precious film of water.

Although the *global ocean* is a single and continuous body of water, geographers divide it into four large areas—the Atlantic, Pacific, Arctic, and Indian Oceans—separated by the continents. The largest ocean is the Pacific, which contains more than half of the earth's water and covers one-third of the earth's surface.

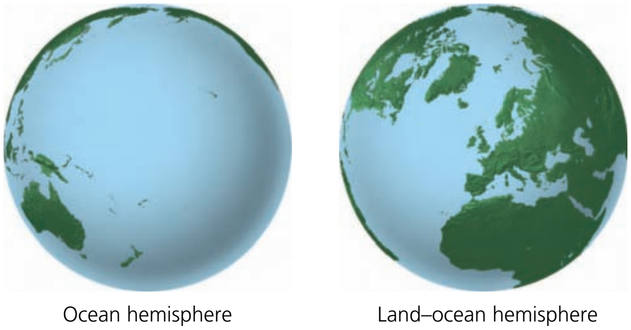


Figure 8-2 *The ocean planet:* The salty oceans cover 71% of the earth's surface and contain 97% of the earth's water. Almost all of the earth's water is in the interconnected oceans, which cover 90% of the planet's ocean hemisphere (left) and nearly half of its land-ocean hemisphere (right). Freshwater systems cover less than 2.2% of the earth's surface (**Concept 8-1A**).

(a)

(b)

(c)

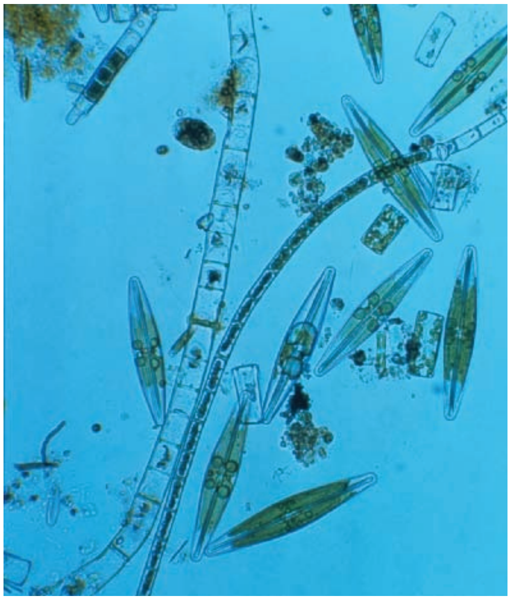
(d)

Figure 8-3 Aquatic systems include **(a)** saltwater oceans and **(b)** bays, such as Trunk Bay at St. John in the U.S. Virgin Islands, **(c)** freshwater lakes such as Peyto Lake in Canada's Banff National Park, and **(d)** wild freshwater mountain streams.

The aquatic equivalents of biomes are called **aquatic life zones**—saltwater and freshwater portions of the biosphere that can support life. The distribution of many aquatic organisms is determined largely by the water's *salinity*—the amounts of various salts such as sodium chloride (NaCl) dissolved in a given volume of water. As a result, aquatic life zones are classified into two major types (Figure 8-3): **saltwater** or **marine life zones** (oceans and their bays, estuaries, coastal wetlands, shorelines, coral reefs, and mangrove forests) and **freshwater life zones** (lakes, rivers, streams, and inland wetlands). Although some systems such as estuaries are a mix of saltwater and freshwater, we classify them as marine systems for purposes of discussion.

Most Aquatic Species Live in Top, Middle, or Bottom Layers of Water

Saltwater and freshwater life zones contain several major types of organisms. One such type consists of weakly swimming, free-floating **plankton**, which can be divided into three groups. The first group is *phytoplankton* ("FY-toe-plank-ton," Greek for "drifting plants"; Figure 8-4a), which includes many types of algae. Phytoplankton and various rooted plants near shorelines are the primary producers that support most aquatic food webs. (See *The Habitable Planet*, Videos 2 and 3 at **www.learner.org/resources/series209.html**.)



(a)

(b)

Figure 8-4 We can divide aquatic life forms into several major types: plankton, which include **(a)** phytoplankton, tiny drifting plants, and **(b)** zooplankton, drifting animals that feed on each other and on phytoplankton; one example is this jellyfish, which uses long tentacles with stinging cells to stun or kill its prey. Other major types of aquatic life are **(c)** nekton, or strongly swimming aquatic animals such as this right whale, and **(d)** benthos, or bottom dwellers such as this sea star attached to coral in the Red Sea.

(c)

(d)

The second group is *zooplankton* ("ZOH-uh-plank-ton," Greek for "drifting animals"). It consists of primary consumers (herbivores), which feed on phytoplankton, and secondary consumers, which feed on other zooplankton. The members of this group range from single-celled protozoa to large invertebrates such as jellyfish (Figure 8-4b).

A third group consists of huge populations of much smaller plankton called *ultraplankton*. These tiny photosynthetic bacteria may be responsible for 70% of the primary productivity near the ocean surface.

A second major type of organisms is **nekton,** strongly swimming consumers such as fish, turtles (see photo on title page), and whales (Figure 8-4c). The third type, **benthos,** consists of bottom-dwellers such as: oysters and sea stars (Figure 8-4d), which anchor themselves to ocean bottom structures; clams and worms, which burrow into the sand or mud; and lobsters and crabs, which walk about on the sea floor. A fourth major type is **decomposers** (mostly bacteria), which break down organic compounds in the dead bodies and wastes of aquatic organisms into nutrients that aquatic primary producers can use.

In most aquatic systems, the key factors determining the types and numbers of organisms found in these layers are *temperature, dissolved oxygen content, availability of food,* and *availability of light and nutrients required for photosynthesis*, such as carbon (as dissolved CO_2 gas), nitrogen (as NO_3^-), and phosphorus (mostly as PO_4^{3-}) (**Concept 8-1B**).

In deep aquatic systems, photosynthesis is largely confined to the upper layer—the *euphotic* or *photic* zone, through which sunlight can penetrate. The depth of the euphotic zone in oceans and deep lakes is reduced when the water is clouded by excessive algal growths (or *algal blooms* resulting from nutrient overloads). This cloudiness, called **turbidity**, can occur naturally, such as from algal growth, or can result from disturbances such as clearing of land, which when it rains, causes silt to flow into bodies of water. This is one of the problems plaguing coral reefs (**Core Case Study**), as excessive turbidity due to silt runoff prevents photosynthesis and causes the corals to die.

In shallow systems such as small open streams, lake edges, and ocean shorelines, ample supplies of nutrients for primary producers are usually available. By contrast, in most areas of the open ocean, nitrates, phosphates, iron, and other nutrients are often in short supply, and this limits net primary productivity (NPP) (see Figure 3-15, p. 66).

8-2 Why Are Marine Aquatic Systems Important?

CONCEPT 8-2 Saltwater ecosystems are irreplaceable reservoirs of biodiversity and provide major ecological and economic services.

Oceans Provide Vital Ecological and Economic Services

Oceans provide enormously valuable ecological and economic services (Figure 8-5). One estimate of the combined value of these goods and services from all marine coastal ecosystems is over $12 trillion per year, nearly equal to the annual U.S. gross domestic product.

Figure 8-5 Marine systems provide a number of important ecological and economic services (**Concept 8-2**). **Questions:** Which two ecological services and which two economic services do you think are the most important? Why?

As land dwellers, we have a distorted and limited view of the blue aquatic wilderness that covers most of the earth's surface. We know more about the surface of the moon than we know about the oceans. According to aquatic scientists, the scientific investigation of poorly understood marine and freshwater aquatic systems could yield immense ecological and economic benefits.

RESEARCH FRONTIER

Discovering, cataloging, and studying the huge number of unknown aquatic species and their interactions; see **www.cengage.com/login**.

Marine aquatic systems are enormous reservoirs of biodiversity. They include many different ecosystems, which host a great variety of species, genes, and biological and chemical processes, thus helping to sustain the four major components of the earth's biodiversity (see Figure 4-2, p. 82). Marine life is found in three major *life zones*: the coastal zone, the open sea, and the ocean bottom (Figure 8-6).

The **coastal zone** is the warm, nutrient-rich, shallow water that extends from the high-tide mark on land to the gently sloping, shallow edge of the *continental shelf* (the submerged part of the continents). It makes up less than 10% of the world's ocean area, but it contains 90% of all marine species and is the site of most large commercial marine fisheries.

Most coastal zone aquatic systems such as estuaries, coastal marshes, mangrove forests, and coral reefs have a high net primary productivity (see Figure 3-15, p. 66). This is the result of the zone's ample supplies of sunlight and plant nutrients that flow from land and are distributed by wind and ocean currents. Here, we look at some of these systems in more detail.

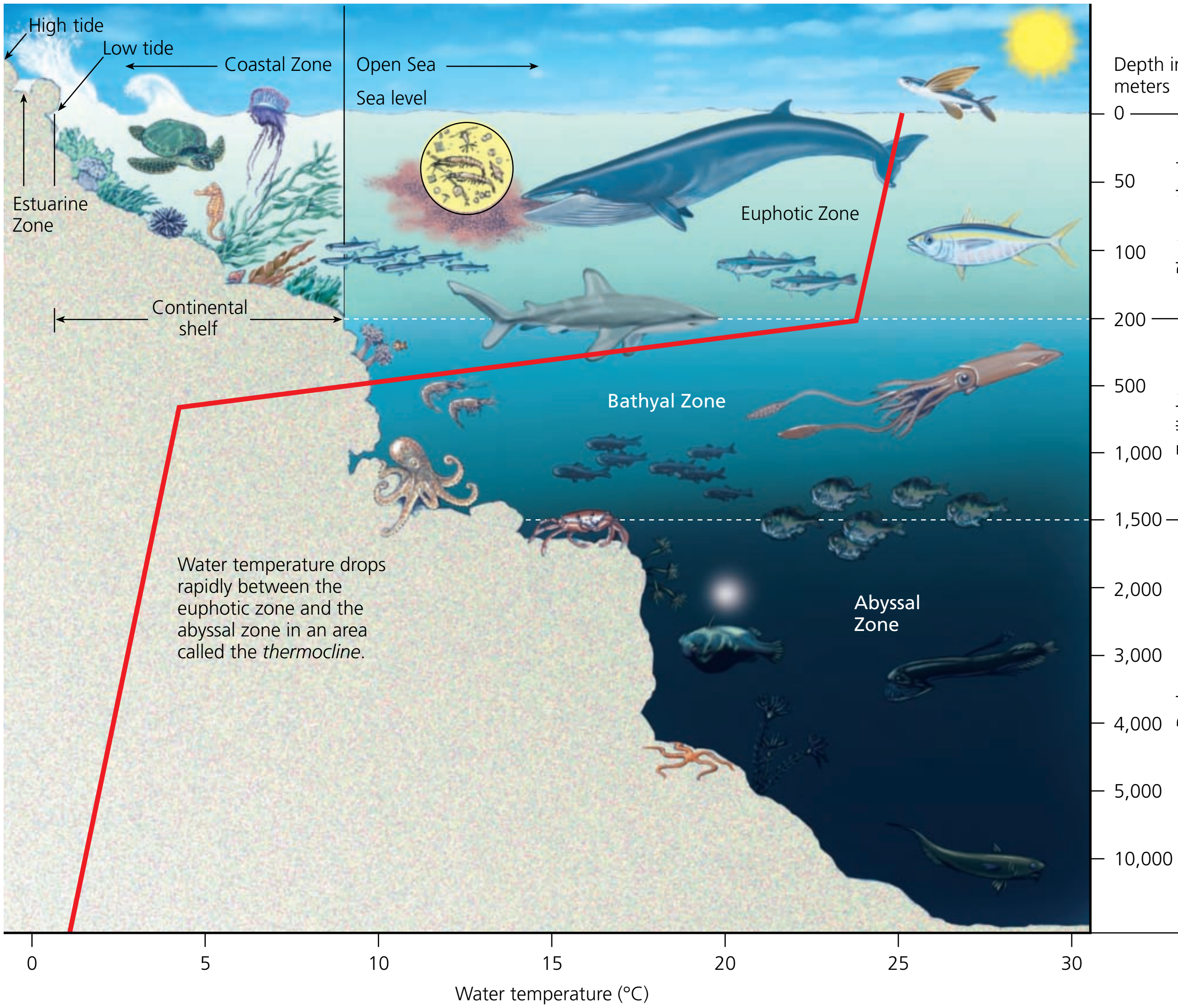
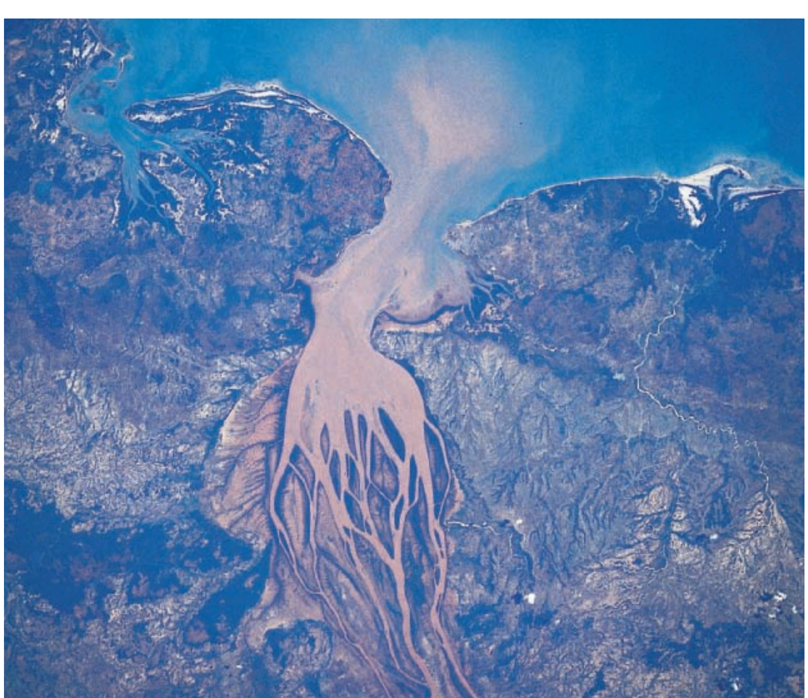


Figure 8-6 This diagram illustrates the major life zones and vertical zones (not drawn to scale) in an ocean. Actual depths of zones may vary. Available light determines the euphotic, bathyal, and abyssal zones. Temperature zones also vary with depth, shown here by the red line. **Question:** How is an ocean like a rain forest? (Hint: see Figure 7-15, p. 162.)



NASA

Figure 8-7 This satellite photo shows a view of an *estuary* taken from space. A sediment plume (turbidity caused by runoff) forms at the mouth of Madagascar's Betsiboka River as it flows through the estuary and into the Mozambique Channel. Because of its topography, heavy rainfall, and the clearing of its forests for agriculture, Madagascar is the world's most eroded country.

Estuaries and Coastal Wetlands Are Highly Productive

Estuaries are where rivers meet the sea (Figure 8-7). They are partially enclosed bodies of water where seawater mixes with freshwater as well as nutrients and pollutants from streams, rivers, and runoff from the land.

Figure 8-8 This diagram shows some of the components and interactions in a *coastal marsh ecosystem*. When these organisms die, decomposers break down their organic matter into minerals used by plants. Colored arrows indicate transfers of matter and energy between consumers (herbivores), secondary or higher-level consumers (carnivores), and decomposers. Organisms are not drawn to scale. The photo above shows a coastal marsh in Peru.

Estuaries and their associated **coastal wetlands**—coastal land areas covered with water all or part of the year—include river mouths, inlets, bays, sounds, coastal marshes (called *salt marshes* in temperate zones, Figure 8-8), and mangrove forests. They are some of the earth's most productive ecosystems because of high nutrient inputs from rivers and nearby land, rapid circulation of nutrients by tidal flows, and ample sunlight penetrating the shallow waters.

Sea grass beds are another component of coastal marine biodiversity (Figure 8-9). They consist of at least 60 species of plants that grow underwater in shallow marine and estuarine areas along most continental coastlines. These highly productive and physically complex systems support a variety of marine species. They also help to stabilize shorelines and reduce wave impacts.

Life in these coastal ecosystems is harsh. It must adapt to significant daily and seasonal changes in tidal and river flows, water temperatures and salinity, and

Figure 8-9 Sea grass beds support a variety of marine species. Since 1980, about 29% of the world's sea grass beds have been lost to pollution and other disturbances.

runoff of eroded soil sediment and other pollutants from the land. Because of these stresses, despite their productivity, some coastal ecosystems have low plant diversity composed of a few species that can withstand the daily and seasonal variations.

Mangrove forests are found along some 70% of gently sloping sandy coastlines in tropical and subtropical regions, especially Australia and Southeast Asia. The dominant organisms in these nutrient-rich coastal forests are mangroves—69 different tree species that can grow in salt water. They have extensive root systems that often extend above the water, where they can obtain oxygen and support the trees during periods of changing water levels (Figure 8-10).

These coastal aquatic systems provide important ecological and economic services. They help to maintain water quality in tropical coastal zones by filtering toxic pollutants, excess plant nutrients, and sediments, and by absorbing other pollutants. They provide food, habitats, and nursery sites for a variety of aquatic and terrestrial species. They also reduce storm damage and coastal erosion by absorbing waves and storing excess water produced by storms and tsunamis. Historically, they have sustainably supplied timber and fuelwood to coastal communities. Loss of mangroves can lead to polluted drinking water, caused by inland intrusion of saltwater into aquifers that are used to supply clean, freshwater.

Despite their ecological and economic importance, in 2008, the UN Food and Agriculture Organization estimated that between 1980 and 2005, at least one-fifth of the world's mangrove forests were lost mostly because of human coastal development.

Rocky and Sandy Shores Host Different Types of Organisms

The gravitational pull of the moon and sun causes *tides* to rise and fall about every 6 hours in most coastal areas. The area of shoreline between low and high tides is called the **intertidal zone**. Organisms living in this zone must be able to avoid being swept away or crushed by waves, and must deal with being immersed during high tides and left high and dry (and much hotter) at low tides. They must also survive changing levels of salinity when heavy rains dilute saltwater. To deal with such stresses, most intertidal organisms hold on to something, dig in, or hide in protective shells.

On some coasts, steep *rocky shores* are pounded by waves. The numerous pools and other habitats in these intertidal zones contain a great variety of species that occupy different niches in response to daily and seasonal changes in environmental conditions such as temperature, water flows, and salinity (Figure 8-11, p. 176, top).

Other coasts have gently sloping *barrier beaches,* or *sandy shores,* that support other types of marine organisms (Figure 8-11, bottom), most of which keep hidden from view and survive by burrowing, digging, and

Theo Allofs/Visuals Unlimited

Figure 8-10 This mangrove forest is in Daintree National Park in Queensland, Australia. The tangled roots and dense vegetation in these coastal forests act like shock absorbers to reduce damage from storms and tsunamis. They also provide highly complex habitat for a diversity of invertebrates and fishes.

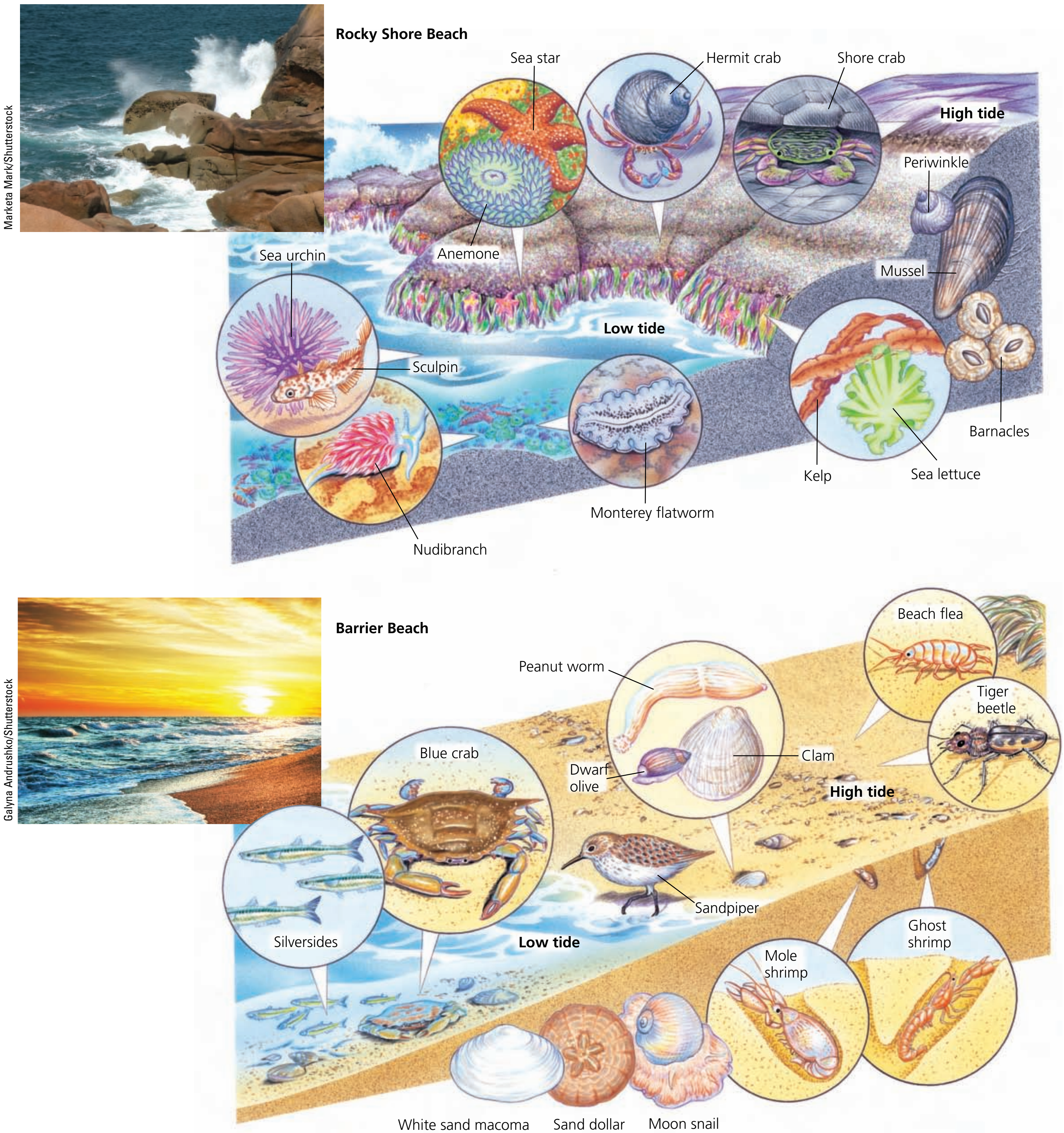


Figure 8-11 *Living between the tides:* Some organisms with specialized niches are found in various zones on rocky shore beaches (top) and barrier or sandy beaches (bottom). Organisms are not drawn to scale.

tunneling in the sand. These sandy beaches and their adjoining coastal wetlands are also home to a variety of shorebirds that have evolved in specialized niches to feed on crustaceans, insects, and other organisms (see Figure 4-14, p. 96). Many of these same species also live on *barrier islands*—low, narrow, sandy islands that form offshore, parallel to nearby coastlines.

Undisturbed barrier beaches generally have one or more rows of natural sand dunes in which the sand is held in place by the roots of plants, usually grasses. These dunes are the first line of defense against the ravages of the sea. Such real estate is so scarce and valuable that coastal developers frequently remove the protective dunes or build behind the first set of dunes, and cover them with buildings and roads. Large storms can then flood and even sweep away seaside construction and severely erode the sandy beaches. Some people incorrectly call these human-influenced events "natural disasters."

Coral Reefs Are Amazing Centers of Biodiversity

As we noted in the **Core Case Study**, coral reefs are among the world's oldest, most diverse, and productive ecosystems (Figure 8-1 and Figure 4-12, left, p. 93). These amazing centers of aquatic biodiversity are the marine equivalents of tropical rain forests, with complex interactions among their diverse populations of species (Figure 8-12). Coral reefs provide homes for one-fourth of all marine species.

CORE CASE STUDY

Open Sea and the Ocean Floor Host a Variety of Species

The sharp increase in water depth at the edge of the continental shelf separates the coastal zone from the vast volume of the ocean called the **open sea**. Primarily

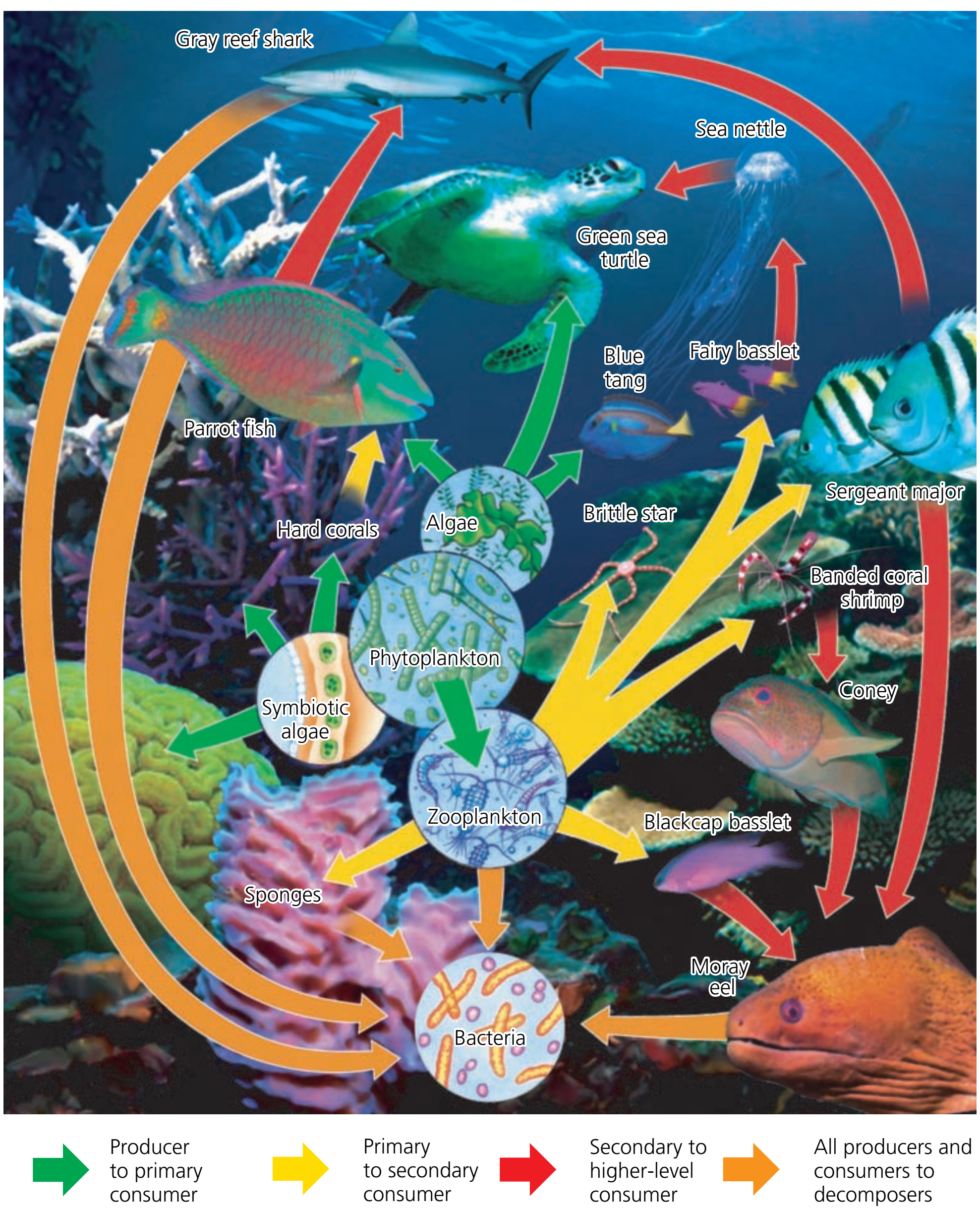


Figure 8-12 Natural capital: This diagram illustrates some of the components and interactions in a *coral reef ecosystem*. When these organisms die, decomposers break down their organic matter into minerals used by plants. Colored arrows indicate transfers of matter and energy between producers, primary consumers (herbivores), secondary or higher-level consumers (carnivores), and decomposers. Organisms are not drawn to scale.

on the basis of the penetration of sunlight, this deep blue sea is divided into three *vertical zones* (see Figure 8-6). But temperatures also change with depth and we can use them to define zones that help to determine species diversity in these layers (Figure 8-6, red line).

The *euphotic zone* is the brightly lit upper zone, where drifting phytoplankton carry out about 40% of the world's photosynthetic activity (see *The Habitable Planet*, Video 3, at **www.learner.org/resources/series209.html**). Nutrient levels are low and levels of dissolved oxygen are high in the euphotic zone. There is one exception to this, however. In areas called *upwelling zones*, ocean currents driven by differences in temperature or by coastal winds bring water up from the abyssal zone (see Figure 7-2, p. 149, and Figure 8-6). Upwellings carry nutrients from the ocean bottom to the surface for use by producers, and thus these zones contain high levels of nutrients. Large, fast-swimming predatory fishes such as swordfish, sharks, and bluefin tuna populate the euphotic zone. They feed on secondary and higher-level consumers, which are supported directly or indirectly by producers.

The *bathyal zone* is the dimly lit middle zone, which receives little sunlight and therefore does not contain photosynthesizing producers. Zooplankton and smaller fishes, many of which migrate to feed on the surface at night, populate this zone.

The lowest zone, called the *abyssal zone*, is dark and very cold. There is no sunlight to support photosynthesis, and this zone has little dissolved oxygen. Nevertheless, the deep ocean floor is teeming with life—so much that it is considered a major life zone—because it contains enough nutrients to support a large number of species. Most organisms of the deep waters and ocean floor get their food from showers of dead and decaying organisms—called *marine snow*—drifting down from upper, lighted levels of the ocean.

Some abyssal-zone organisms, including many types of worms, are *deposit feeders,* which take mud into their guts and extract nutrients from it. Others such as oysters, clams, and sponges are *filter feeders,* which pass water through or over their bodies and extract nutrients from it.

Net primary productivity (NPP) is quite low in the open sea, except in upwelling areas. However, because the open sea covers so much of the earth's surface, it makes the largest contribution to the earth's overall NPP.

In 2007, a team of scientists led by J. Craig Venter released a report that dramatically challenged scientists' assumptions about biodiversity in the open sea. After sailing around the world and spending 2 years collecting data, they found that the open sea contains many more bacteria, viruses, and other microbes than scientists had previously assumed.

CENGAGE**NOW**™ Learn about ocean zones, where all ocean life exists at CengageNOW.

8-3 How Have Human Activities Affected Marine Ecosystems?

▶ **CONCEPT 8-3 Human activities threaten aquatic biodiversity and disrupt ecological and economic services provided by saltwater systems.**

Human Activities Are Disrupting and Degrading Marine Ecosystems

Human activities are disrupting and degrading some ecological and economic services provided by marine aquatic systems, especially coastal marshes, shorelines, mangrove forests, and coral reefs (see **Concept 8-3** and *The Habitable Planet*, Video 9 at **www.learner.org/resources/series209.html**).

In 2008, the U. S. National Center for Ecological Analysis and Synthesis (NCEAS) used computer models to analyze and provide the first-ever comprehensive map of the effects of 17 different types of human activities on the world's oceans. In this 4-year study, an international team of scientists found that human activity has heavily affected 41% of the world's ocean area. No area of the oceans has been left completely untouched, according to the report.

In their desire to live near a coast, some people are unwittingly destroying or degrading the aquatic biodiversity and the ecological and economic services (Figure 8-5) that make coastal areas so enjoyable and valuable. In 2010, about 45% of the world's population and more than half of the U.S. population lived along or near coasts and these percentages are increasing rapidly.

Major threats to marine systems from human activities include:

- Coastal development, which destroys and pollutes coastal habitats (see *The Habitable Planet*, Video 5, at **www.learner.org/resources/series209.html**).
- Runoff of nonpoint sources of pollutants such as silt, fertilizers, pesticides, and livestock wastes

(see *The Habitable Planet*, Videos 7 and 8, at **www.learner.org/resources/series209.html**).

- Point-source pollution such as sewage from cruise ships and spills from oil tankers.
- Pollution and degradation of coastal wetlands and estuaries (Case Study, below).
- Overfishing, which depletes populations of commercial fish species.
- Use of fishing trawlers, which drag weighted nets across the ocean bottom, degrading and destroying its habitats.
- Invasive species, introduced by humans, that can deplete populations of native aquatic species and cause economic damage.
- Climate change, enhanced by human activities, which is warming the oceans and making them more acidic; this could cause a rise in sea levels during this century that would destroy coral reefs and flood coastal marshes and coastal cities (see *The Habitable Planet*, Videos 7 and 8, at **www.learner.org/resources/series209.html**).

Figure 8-13 shows some of the effects of these human impacts on marine systems (left) and coral reefs (right) (**Core Case Study**). According to a 2007 study by Ove Hoegh-Guldberg and 16 other scientists, unless we take action soon to significantly reduce carbon dioxide emissions, the oceans may be too acidic and too warm for most of the world's coral reefs to survive this century, and the important ecological and economic services they provide will be lost. We examine some of these impacts more closely in Chapters 11 and 19.

Figure 8-13 This diagram shows the major threats to marine ecosystems (left) and particularly coral reefs (right) (**Core Case Study**) resulting from human activities (**Concept 8-3**). **Questions:** Which two of the threats to marine ecosystems do you think are the most serious? Why? Which two of the threats to coral reefs do you think are the most serious? Why?

THINKING ABOUT
Coral Reef Destruction

How might the loss of most of the world's remaining tropical coral reefs affect your life and the lives of any children or grandchildren you might have? What are two things you could do to help reduce this loss?

RESEARCH FRONTIER

Learning more about the harmful human impacts on marine ecosystems and how to reduce these impacts; see **www.cengage.com/login**.

CASE STUDY
The Chesapeake Bay—An Estuary in Trouble

Since 1960, the Chesapeake Bay (Figure 8-14, p. 180)—the largest estuary in the United States—has been in serious trouble from water pollution, mostly because of human activities. One problem is population growth. Between 1940 and 2007, the number of people living in the Chesapeake Bay area grew from 3.7 million to 16.8 million, and could reach 18 million by 2020, according to 2009 estimates by the Chesapeake Bay Program.

The estuary receives wastes from point and nonpoint sources scattered throughout a huge drainage basin in parts of six states and the District of Columbia (Figure 8-14). The bay has become a huge pollution sink because only 1% of the waste entering it is flushed into the Atlantic Ocean. It is also so shallow that people can wade through much of it.

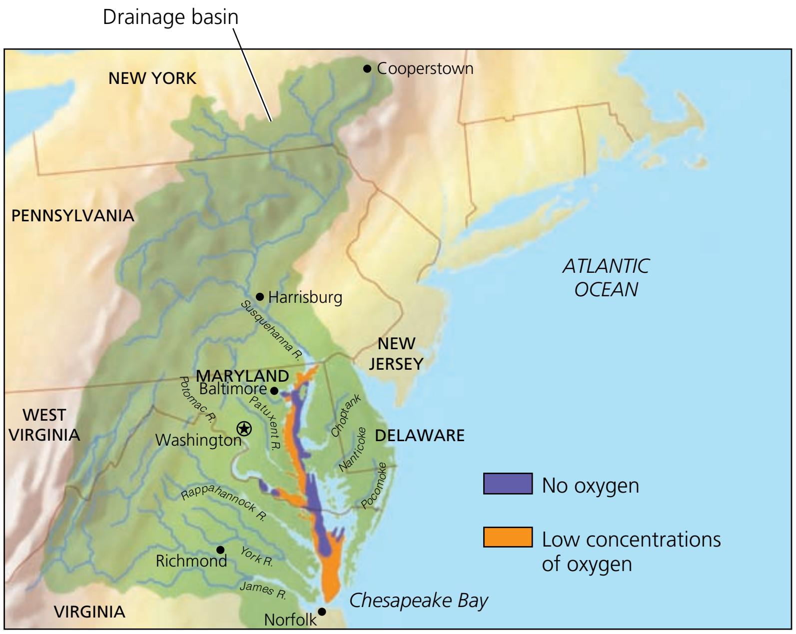


Figure 8-14 The *Chesapeake Bay* is the largest estuary in the United States. However, the bay is severely degraded as a result of water pollution from point and nonpoint sources in six states and the District of Columbia, and from the atmospheric deposition of air pollutants.

Phosphate and nitrate levels have risen sharply in many parts of the bay, causing algal blooms and oxygen depletion. Commercial harvests of the bay's once-abundant oysters and crabs, as well as several important fish species, have fallen sharply since 1960 because of a combination of pollution, overfishing, and disease.

Point sources, primarily sewage treatment plants and industrial plants (often in violation of their discharge permits), account for 60% by weight of the phosphates. Nonpoint sources—mostly runoff of fertilizer, animal wastes from urban, suburban, and agricultural land, and deposition of pollutants from the atmosphere—account for 60% by weight of the nitrates. In addition, runoff of sediment, mostly from soil erosion, harms the submerged grasses needed by crabs and young fish. Runoff also increases when trees near the bay are cut down for development.

A century ago, oysters were so abundant that they filtered and cleaned the Chesapeake's entire volume of water every 3 days. This important form of natural capital provided by these *keystone species* (see Chapter 4, p. 99) helped remove or reduce excess nutrients and algal blooms, both of which lead to decreased levels of dissolved oxygen. Now the oyster population has been reduced to the point where this filtration process takes a year and the keystone role of this species has been severely weakened.

GOOD NEWS

In 2009, researchers at the Virginia Institute of Marine Science and at the College of William and Mary reported that several protected experimental reefs created in 2004 are now home to a significant population of oysters. This research suggests that creating thousands of such reefs as oyster sanctuaries would help to raise the overall oyster population. This could also help to clean the water and provide more habitat for crabs, fish, and other forms of marine life.

CONNECTIONS

Asian Oysters and the Chesapeake Bay

Officials in the states of Maryland and Virginia are evaluating whether to help rebuild the Chesapeake's oyster population by introducing an Asian oyster that appears resistant to two parasites that have killed off many of the bay's native oysters. The Asian oysters grow bigger and faster and taste as good as native oysters. But introducing nonnative species anywhere is unpredictable and usually irreversible. And some researchers warn that this nonnative Asian oyster may not be able to help clean the water because it needs to have clean water before it can flourish.

In 1983, the United States implemented the Chesapeake Bay Program. In this ambitious attempt at *integrated coastal management,* citizens' groups, communities, state legislatures, and the federal government worked together to reduce pollution inputs into the bay. One strategy of the program was to establish land-use regulations to reduce agricultural and urban runoff in the six states that form the bay's drainage area. Other strategies included banning phosphate detergents, upgrading sewage treatment plants, and monitoring industrial discharges more closely. In addition, some adjoining wetlands were restored and large areas of the bay were replanted with sea grasses to help filter out excessive nutrients and other pollutants.

However, by 2008, despite 25 years of effort costing almost $6 billion, the program had failed to meet its goals. This was because of increased population and development, a drop in state and federal funding, and lack of cooperation and enforcement among local, state, and federal officials. In 2008, the Chesapeake Bay Foundation reported that the bay's water quality was "very poor" and only 21% of the established goals had been met.

GOOD NEWS

There are some signs of hope for the Chesapeake Bay. In 2009, President Barack Obama signed an executive order directing the Environmental Protection Agency (EPA) to take charge of a new federal effort to revitalize the Chesapeake and to use its full authority under the Clean Water Act to help clean it up. The order also called for reducing inputs from agriculture and for development of a strategy to deal with threats from projected climate change during this century. However, this is a tall order and will require considerable funding from federal and state governments.

THINKING ABOUT

The Chesapeake Bay

SUSTAINABILITY

What are three ways in which Chesapeake Bay-area residents could apply the three **principles of sustainability** (see back cover) to try to improve the environmental quality of the bay?

8-4 Why Are Freshwater Ecosystems Important?

▶ **CONCEPT 8-4 Freshwater ecosystems provide major ecological and economic services, and are irreplaceable reservoirs of biodiversity.**

Water Stands in Some Freshwater Systems and Flows in Others

Freshwater life zones include *standing* (lentic) bodies of freshwater such as lakes (Figure 8-3c), ponds, and inland wetlands, and *flowing* (lotic) systems such as streams (Figure 8-3d) and rivers. Although these freshwater systems cover less than 2.2% of the earth's surface, they provide a number of important ecological and economic services (Figure 8-15).

Lakes are large natural bodies of standing freshwater formed when precipitation, runoff, streams, rivers, and groundwater seepage fill depressions in the earth's surface (Figure 8-3c). Causes of such depressions include glaciation (Lake Louise in Alberta, Canada), displacement of the earth's crust (Lake Nyasa in East Africa), and volcanic activity (Crater Lake in the U.S. state of Oregon). Drainage areas on surrounding land supply lakes with water from rainfall, melting snow, and streams.

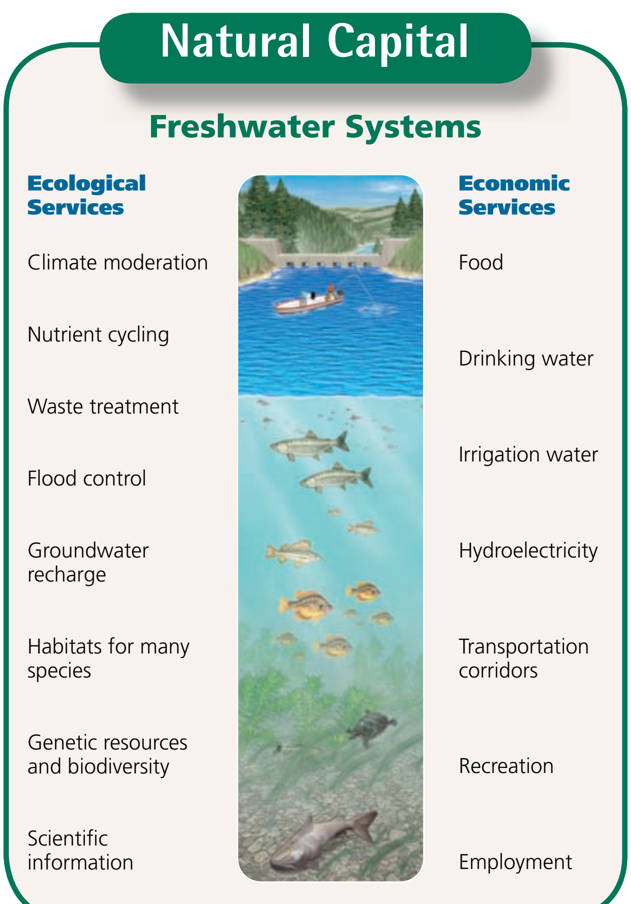


Figure 8-15 Freshwater systems provide many important ecological and economic services (**Concept 8-4**). **Questions:** Which two ecological services and which two economic services do you think are the most important? Why?

Freshwater lakes vary tremendously in size, depth, and nutrient content. Deep lakes normally consist of four distinct zones that are defined by their depth and distance from shore (Figure 8-16, p. 182). The top layer, called the *littoral* ("LIT-tore-el") *zone,* is near the shore and consists of the shallow sunlit waters to the depth at which rooted plants stop growing. It has a high biological diversity because of ample sunlight and inputs of nutrients from the surrounding land. Species living in the littoral zone include many rooted plants, animals such as turtles, frogs, and crayfish, and fish such as bass, perch, and carp.

The next layer is the *limnetic* ("lim-NET-ic") *zone*, the open, sunlit surface layer away from the shore that extends to the depth penetrated by sunlight. The main photosynthetic zone of the lake, this layer produces the food and oxygen that support most of the lake's consumers. Its most abundant organisms are microscopic phytoplankton and zooplankton. Some large species of fish spend most of their time in this zone, with occasional visits to the littoral zone to feed and reproduce.

Next comes the *profundal* ("pro-FUN-dahl") *zone*, a layer of deep, open water where it is too dark for photosynthesis. Without sunlight and plants, oxygen levels are often low here. Fishes adapted to the lake's cooler and darker water are found in this zone.

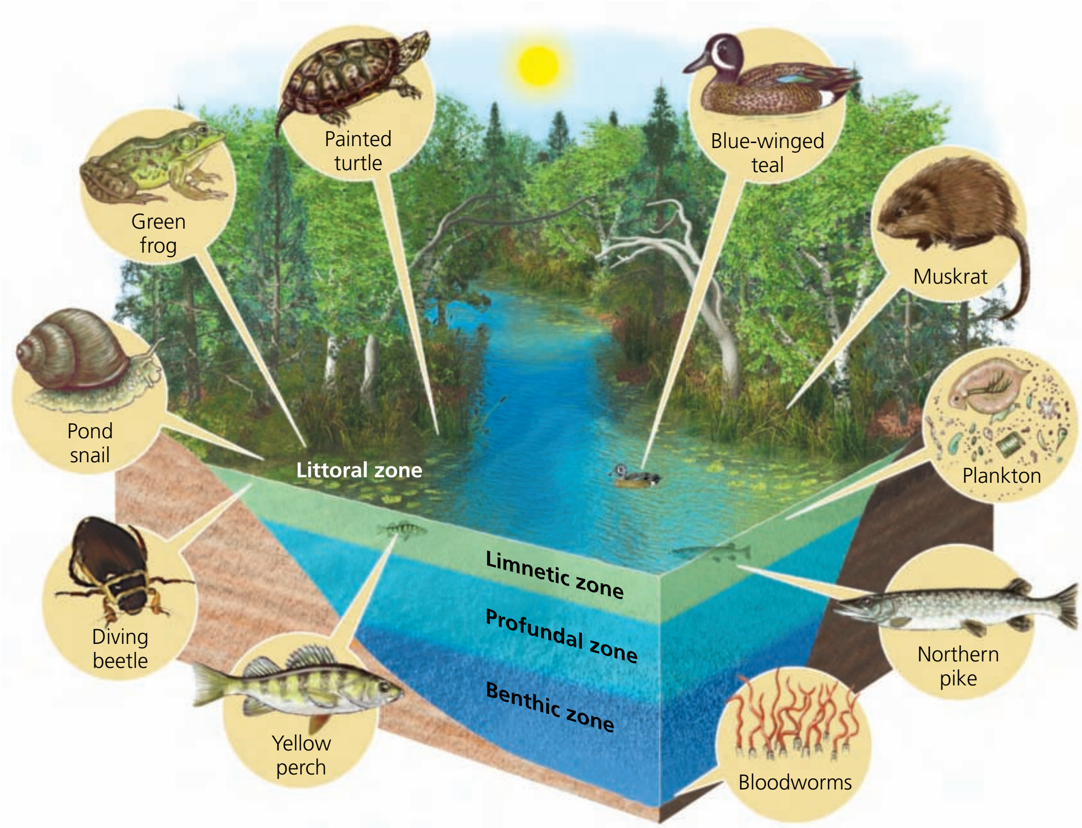
The bottom layer of the lake is called the *benthic* ("BEN-thic") *zone*, inhabited mostly by decomposers, detritus feeders, and some species of fish (benthos). The benthic zone is nourished mainly by dead matter that falls from the littoral and limnetic zones and by sediment washing into the lake.

Some Lakes Have More Nutrients Than Others

Ecologists classify lakes according to their nutrient content and primary productivity. Lakes that have a small supply of plant nutrients are called **oligotrophic** (poorly nourished) **lakes** (Figure 8-17, p. 182, left). This type of lake is often deep and has steep banks.

Glaciers and mountain streams supply water to many such lakes, bringing little in the way of sediment or microscopic life to cloud the water. These lakes usually have crystal-clear water and small populations of phytoplankton and fish species (such as smallmouth

CENGAGENOW™ **Active Figure 8-16** This diagram illustrates the distinct zones of life in a fairly deep temperate-zone lake. *See an animation based on this figure at* CengageNOW. **Question:** How are deep lakes like tropical rain forests? (Hint: See Figure 7-15, p. 162)



bass and trout). Because of their low levels of nutrients, these lakes have a low net primary productivity.

Over time, sediment, organic material, and inorganic nutrients wash into most oligotrophic lakes, and plants grow and decompose to form bottom sediments. A lake with a large supply of nutrients needed by producers is called a **eutrophic** (well-nourished) **lake** (Figure 8-17, right). Such lakes typically are shallow and have murky brown or green water with high turbidity. Because of their high levels of nutrients, these lakes have a high net primary productivity.

Human inputs of nutrients from the atmosphere and from nearby urban and agricultural areas can accelerate the eutrophication of lakes, a process called **cul-**

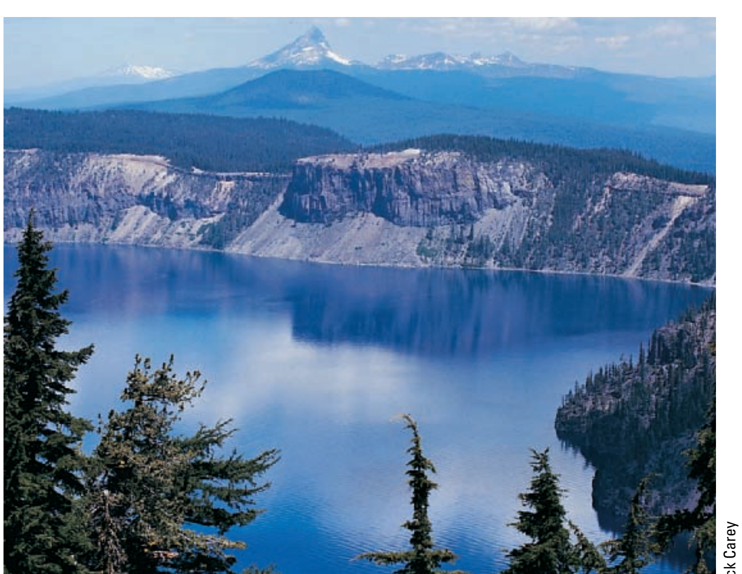


Figure 8-17 These photos show the effect of nutrient enrichment on a lake. Crater Lake in the U.S. state of Oregon (left) is an example of an *oligotrophic lake*, which is low in nutrients. Because of the low density of plankton, its water is quite clear. The lake on the right, found in western New York State, is a *eutrophic lake*. Because of an excess of plant nutrients, its surface is covered with mats of algae.

tural eutrophication. This process often puts excessive nutrients into lakes. Many lakes fall somewhere between the two extremes of nutrient enrichment. They are called **mesotrophic lakes**.

Freshwater Streams and Rivers Carry Water from the Mountains to the Oceans

Precipitation that does not sink into the ground or evaporate is **surface water**. It becomes **runoff** when it flows into streams. A **watershed**, or **drainage basin**, is the land area that delivers runoff, sediment, and dissolved substances to a stream. Small streams (Figure 8-3d) join to form rivers, and rivers flow downhill to the ocean (Figure 8-18).

In many areas, streams begin in mountainous or hilly areas, which collect and release water falling to the earth's surface as rain or as snow that melts during warm seasons. The downward flow of surface water and groundwater from mountain highlands to the sea typically takes place in three aquatic life zones characterized by different environmental conditions: the *source zone*, the *transition zone*, and the *floodplain zone* (Figure 8-18). Rivers and streams can differ somewhat from this generalized model.

In the first, narrow *source zone* (Figure 8-18, top), headwaters, or highland streams are usually shallow, cold, clear, and swiftly flowing (Figure 8-3d). As this turbulent water flows and tumbles downward over obstacles like rocks, waterfalls, and rapids, it dissolves large amounts of oxygen from the air. Most of these streams are not very productive because of a lack of nutrients and primary producers. Their nutrients come primarily from organic matter (mostly leaves, branches, and the bodies of living and dead insects) that falls into the stream from nearby land.

The source zone is populated by cold-water fish species (such as trout in some areas), which need lots of dissolved oxygen. Many fishes and other animals in fast-flowing headwater streams have compact and flattened bodies that allow them to live under stones. Others have streamlined and muscular bodies that allow them to swim in the rapid, strong currents. Most of the plants in this zone are algae and mosses attached to rocks and other surfaces under water.

In the *transition zone* (Figure 8-18, middle), headwater streams merge to form wider, deeper, and warmer streams that flow down gentler slopes with fewer obstacles. They can be more turbid (from suspended sediment), slower flowing, and can have less dissolved oxygen than headwater streams. The warmer water and other conditions in this zone support more producers as well as cool-water and warm-water fish species (such as black bass) with slightly lower oxygen requirements.

As streams flow downhill, they shape the land through which they pass. Over millions of years, the friction of moving water has leveled mountains and cut deep canyons, and rocks and soil removed by the water have been deposited as sediment in low-lying areas. In

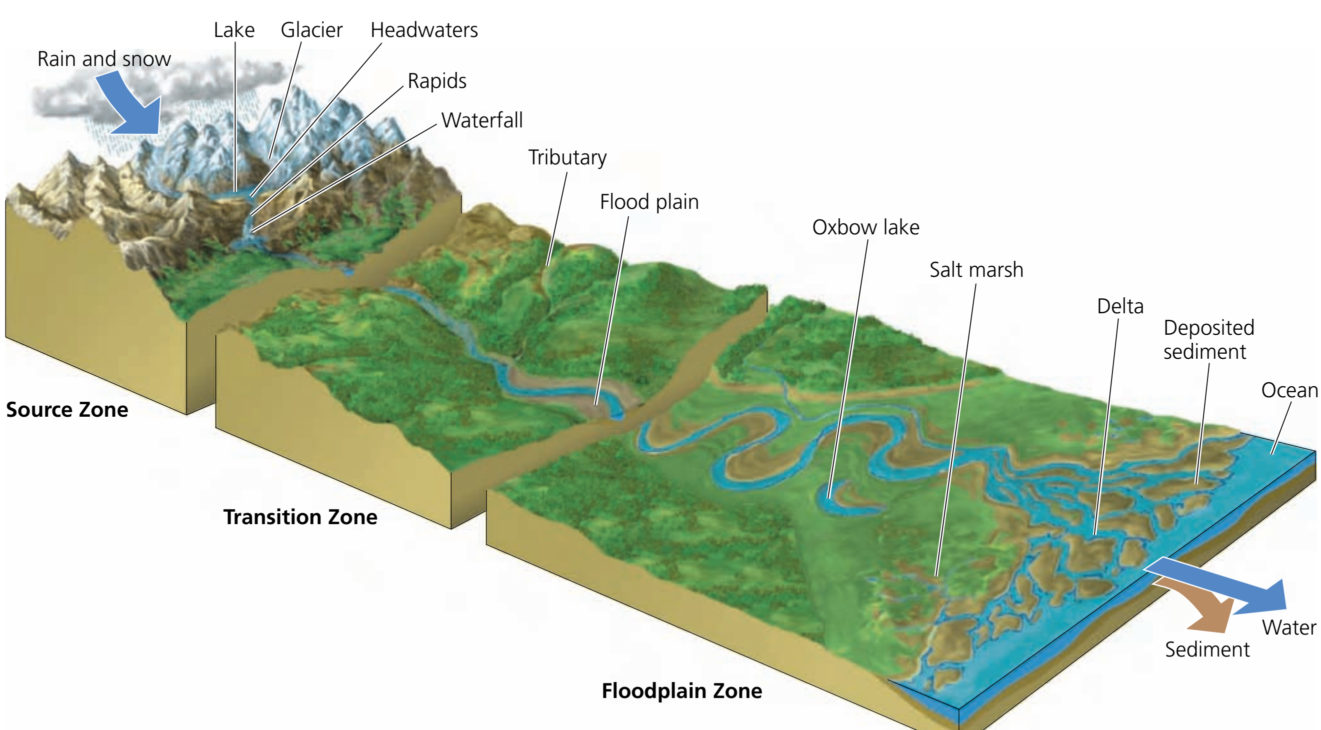


Figure 8-18 There are three zones in the downhill flow of water: the *source zone*, which contains mountain (headwater) streams; the *transition zone*, which contains wider, lower-elevation streams; and the *floodplain zone*, which contains rivers that empty into larger rivers or into the ocean.

these *floodplain zones* (Figure 8-18, bottom), streams join into wider and deeper rivers that flow across broad, flat valleys. Water in this zone usually has higher temperatures and less dissolved oxygen than water in the two higher zones. These slow-moving rivers sometimes support fairly large populations of producers such as algae and cyanobacteria as well as rooted aquatic plants along the shores.

Because of increased erosion and runoff over a larger area, water in the floodplain zone often is muddy and contains high concentrations of suspended particulate matter (silt). The main channels of these slow-moving, wide, and murky rivers support distinctive varieties of fishes (such as carp and catfish), whereas their backwaters support species similar to those present in lakes. At its mouth, a river may divide into many channels as it flows through its *delta*—an area at the mouth of a river that was built up by deposited sediment and contains coastal wetlands and estuaries (Figure 8-7).

Coastal deltas and wetlands as well as inland wetlands and floodplains are important parts of the earth's natural capital (see Figure 1-4, p. 9). They absorb and slow the velocity of floodwaters from coastal storms, hurricanes (see the Case Study that follows), and tsunamis.

CONNECTIONS

Streams and Bordering Land

Streams receive many of their nutrients from bordering land ecosystems. Such nutrients come from falling leaves, animal feces, insects, and other forms of biomass washed into streams during heavy rainstorms or by melting snow. Thus, the levels and types of nutrients in a stream depend on what is happening in the stream's watershed.

■ CASE STUDY

Dams, Deltas, Wetlands, Hurricanes, and New Orleans

Coastal deltas, mangrove forests, and coastal wetlands provide considerable natural protection against flood and wave damage from coastal storms, hurricanes, typhoons, and tsunamis.

When we remove or degrade these natural speed bumps and sponges, any damage from a natural disaster such as a hurricane or typhoon is intensified. As a result, flooding in places like New Orleans, Louisiana (USA), the U.S. Gulf Coast, and Venice, Italy, are largely self-inflicted unnatural disasters. For example, the U.S. state of Louisiana, which contains about 40% of all coastal wetlands in the lower 48 states, has lost more than a fifth of such wetlands since 1950 to oil and gas wells and other forms of coastal development.

Humans have built dams and levees along most of the world's rivers to control water flows and provide electricity (from hydroelectric power plants). This helps to reduce flooding along rivers, but it also reduces flood protection provided by the coastal deltas and wetlands. Because the dams retain river sediments, the river deltas do not get their normal inputs of sediment to build them back up as they naturally sink into the sea.

As a result, 24 of the world's 33 major river deltas are sinking rather than rising and their protective coastal wetlands are flooding, according to a 2009 study by geologist James Syvitski and his colleagues. The study found that 85% of the world' sinking deltas have experienced severe flooding in recent years, and that global delta flooding is likely to increase 50% by the end of this century. This is because of dams and other human activities that reduce the flow of silt and because of the projected rise in sea levels resulting from climate change. It poses a serious threat to the roughly 500 million people in the world who live on river deltas.

For example, the Mississippi River once delivered huge amounts of sediments to its delta each year. But the multiple dams, levees, and canals built in this river system funnel much of this sediment load through the wetlands and out into the Gulf of Mexico. Instead of building up delta lands, this causes them to subside. Other human processes that are increasing such subsidence include extraction of groundwater, oil, and natural gas. As freshwater wetlands are lost, saltwater from the Gulf has intruded and killed many plants that depended on river water, further degrading this coastal aquatic system.

This helps to explain why the U.S. city of New Orleans, Louisiana (Figure 8-19), has long been 3 meters (10 feet) below sea level. Dams and levees were built to help protect the city from flooding. However, the powerful winds and waves from Hurricane Katrina overwhelmed these defenses. They are being rebuilt, but the geologic processes described here will probably put New Orleans 6 meters (20 feet) below sea level in the not-too-distant future. Add to this the reduced protection of coastal and inland wetlands and barrier islands, and you have a recipe for a major and much more damaging unnatural disaster if the area is struck by another major hurricane.

To make matters worse, global sea levels have risen almost 0.3 meters (1 foot) since 1900 and are projected to rise 0.3–0.9 meter (1–3 feet) by the end of this century. Figure 8-20 shows a projection of how such a rise in sea level would put New Orleans and other areas of Louisiana's present-day coast under water. Most of this projected rise would be due to the expansion of the oceans' water and the added volume of water from melting glaciers and other land-based ice caused by the projected warming of the atmosphere.

The good news is that we now understand some of the connections between dams, deltas, wetlands, barrier islands, sea-level rise, and hurricanes. The question is whether we will use such ecological and geological wisdom to change our ways or suffer the increasingly severe ecological and economic consequences of our own actions.

Figure 8-19 Much of the U. S. city of New Orleans, Louisiana, was flooded by the storm surge that accompanied Hurricane Katrina, which made landfall just east of the city on August 29, 2005. When the surging water rushed through the Mississippi River Gulf Outlet, a dredged waterway on the edge of the city, it breached a floodwall, and parts of New Orleans were flooded with 2 meters (6.5 feet) of water within a few minutes. Within a day, floodwaters reached a depth of 6 meters (nearly 20 feet) in some places; 80% of the city was under water at one point. The hurricane killed more than 1,800 people, and caused more than $100 billion in damages, making it the costliest and deadliest hurricane in U.S. history. In addition, a variety of toxic chemicals from flooded industrial and hazardous waste sites, as well as oil and gasoline from more than 350,000 ruined cars and other vehicles, were released into the stagnant floodwaters. After the waters receded, parts of New Orleans were covered with a thick oily sludge.

Freshwater Inland Wetlands Are Vital Sponges

Inland wetlands are lands located away from coastal areas that are covered with freshwater all or part of the time—excluding lakes, reservoirs, and streams. They include *marshes*, *swamps*, and *prairie potholes* (which are depressions carved out by ancient glaciers). Other examples of inland wetlands are *floodplains*, which receive excess water during heavy rains and floods, and the wet *arctic tundra* in summer (Figure 7-1, bottom, p. 147). Some wetlands are huge while others are quite small.

Some wetlands are covered with water year-round. Others, called *seasonal wetlands*, remain under water or are soggy for only a short time each year. The latter include prairie potholes, floodplain wetlands, and bottomland hardwood swamps. Some can stay dry for years before water covers them again. In such cases, scientists must use the composition of the soil or the presence of certain plants (such as cattails, bulrushes, or red maples) to determine that a particular area is a wetland. Wetland plants are highly productive because of an abundance of nutrients. Many of these wetlands are important habitats for game fishes, muskrats, otters, beavers (which as foundation species build dams to create wetlands for their use; see Figure 4-19, p. 100), migratory waterfowl, and many other bird species.

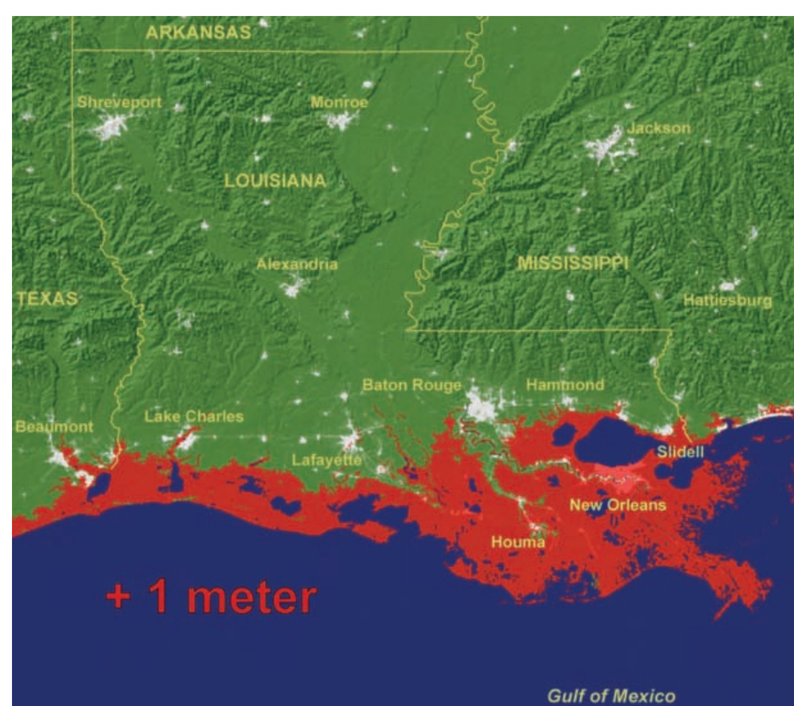


Figure 8-20 This map represents a projection of how a 0.9-meter (3-foot) rise in sea level due to projected climate change by the end of this century would put New Orleans and much of Louisiana's current coast under water. (Used by permission from Jonathan Overpeck and Jeremy Weiss, University of Arizona)

Inland wetlands provide a number of free ecological and economic services, which include:

- filtering and degrading toxic wastes and pollutants.
- reducing flooding and erosion by absorbing storm water and releasing it slowly, and by absorbing overflows from streams and lakes.
- helping to replenish stream flows during dry periods.
- helping to recharge groundwater aquifers.
- helping to maintain biodiversity by providing habitats for a variety of species.
- supplying valuable products such as fishes and shellfish, blueberries, cranberries, wild rice, and timber.
- providing recreation for birdwatchers, nature photographers, boaters, anglers, and waterfowl hunters.

THINKING ABOUT
Inland Wetlands

Which two ecological services and which two economic services provided by inland wetlands do you believe are the most important? Why? List two ways in which your lifestyle directly or indirectly degrades inland wetlands.

8-5 How Have Human Activities Affected Freshwater Ecosystems?

CONCEPT 8-5 Human activities threaten biodiversity and disrupt ecological and economic services provided by freshwater lakes, rivers, and wetlands.

Human Activities Are Disrupting and Degrading Freshwater Systems

Human activities are disrupting and degrading many of the ecological and economic services provided by freshwater rivers, lakes, and wetlands (**Concept 8-5**) in four major ways. *First*, dams and canals fragment about 40% of the world's 237 largest rivers. They alter and destroy terrestrial and aquatic wildlife habitats along these rivers and in their coastal deltas and estuaries by reducing water flow and increasing damage from coastal storms (Case Study, p. 184).

Second, flood control levees and dikes built along rivers disconnect the rivers from their floodplains, destroy aquatic habitats, and alter or reduce the functions of nearby wetlands. **Explore More:** See a Science Focus Study at **www.cengage.com/login** on the effects of dams and levees on the Missouri River.

A *third* major human impact on freshwater systems comes from cities and farms, which add pollutants and excess plant nutrients to nearby streams, rivers, and lakes. For example, runoff of nutrients into a lake (cultural eutrophication, Figure 8-17, right) causes explosions in the populations of algae and cyanobacteria, which deplete the lake's dissolved oxygen. When these organisms die and sink to the lake bottom, decomposers go to work and further deplete the oxygen in deeper waters. Fishes and other species may then die off, which causes a major loss in biodiversity.

Fourth, many inland wetlands have been drained or filled to grow crops or have been covered with concrete, asphalt, and buildings. More than half of the inland wetlands estimated to have existed in the continental United States during the 1600s no longer exist. About 80% of lost wetlands were destroyed to grow crops. The rest were lost to mining, logging, oil and gas extraction, highway construction, and urban development. The heavily farmed U.S. state of Iowa has lost about 99% of its original inland wetlands.

This loss of natural capital has been an important factor in increased flood damage in the United States, which are examples of unnatural disasters. Many other countries have suffered similar losses. For example, 80% of all inland wetlands in Germany and France have been destroyed.

RESEARCH FRONTIER

Learning more about harmful human impacts on freshwater aquatic biodiversity and how to reduce these impacts; see **www.cengage.com/login**.

When we look further into human impacts on aquatic systems in Chapter 11, we will also explore possible solutions to environmental problems that result from these impacts, as well as ways to help sustain aquatic biodiversity.

Here are this chapter's *three big ideas*:

- Saltwater and freshwater aquatic life zones cover almost three-fourths of the earth's surface, and oceans dominate the planet.
- The earth's aquatic systems provide important ecological and economic services.
- Human activities threaten biodiversity and disrupt ecological and economic services provided by aquatic systems.

REVISITING Coral Reefs and Sustainability

This chapter's **Core Case Study** pointed out the ecological and economic importance of the world's incredibly diverse coral reefs. They are living examples of the three **principles of sustainability** (see back cover) in action. They thrive on solar energy, participate in the cycling of carbon and other chemicals, and are a prime example of aquatic biodiversity. In this chapter, we have seen that coral reefs and other aquatic systems are being severely stressed by a variety of human activities. Research shows when such harmful human activities are reduced, some coral reefs and other endangered aquatic systems can recover fairly quickly.

As with terrestrial systems, scientists have made a good start in understanding the ecology of the world's aquatic systems and how humans are degrading and disrupting the vital ecological and economic services they provide. In studying these systems, they have again found that *in nature, everything is connected.* These scientists argue that we urgently need more research on the components and workings of the world's aquatic life zones, on how they are interconnected, and on which systems are in the greatest danger of being disrupted by human activities. With such vital information, we will have a clearer picture of how our activities affect the earth's natural aquatic capital and what we can do to help sustain it.

We can take the lessons on how life in aquatic ecosystems has sustained itself for billions of years and use them to help sustain our own systems as well as the ecosystems on which we depend. By relying more on solar energy and less on oil and other fossil fuels, we could drastically cut pollution of the oceans and other aquatic systems. By reusing and recycling more of the materials and chemicals we use, we could further reduce pollution of aquatic systems and disruption of the chemical cycling within those systems. And by respecting aquatic biodiversity and educating people about its importance, we could go a long way toward preserving it and retaining its valuable ecological services for our own use and for the benefit of all other life forms.

. . . the sea, once it casts its spell, holds one in its net of wonders forever.

JACQUES-YVES COUSTEAU

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 169. What are **coral reefs** and why should we care about them? What is coral bleaching?
2. What percentage of the earth's surface is covered with water? What is an **aquatic life zone**? Distinguish between a **saltwater (marine) life zone** and a **freshwater life zone**, and give two examples of each. What major types of organisms live in the top, middle, and bottom layers of aquatic life zones? Define **plankton** and describe three types of plankton. Distinguish among **nekton**, **benthos**, and **decomposers** and give an example of each. List five factors that determine the types and numbers of organisms found in the three layers of aquatic life zones. What is **turbidity** and how does it occur? Describe one of its harmful impacts.
3. What major ecological and economic services are provided by marine systems? What are the three major life zones in an ocean? Distinguish between the **coastal zone** and the **open sea**. Distinguish between an **estuary** and a **coastal wetland** and explain why they each have high net primary productivity. Describe some of the interactions among species in a coastal marsh ecosystem. Explain the importance of sea grass beds. What is a **mangrove forest** and what is its ecological and economic importance? What is the **intertidal zone**? Distinguish between rocky and sandy shores and describe some of the organisms often found on each type of shoreline.
4. Explain the importance of coral reefs and some of the interactions among the species in such systems. Describe the three major zones in the open sea. Why does the open sea have a low net primary productivity? List five human activities that pose major threats to marine systems and nine human activities that threaten coral reefs.
5. Explain why the Chesapeake Bay is an estuary in trouble. What is being done about some of its problems?
6. What major ecological and economic services do freshwater systems provide? What is a **lake**? What four zones are found in deep lakes? Distinguish among **oligotrophic**, **eutrophic**, and **mesotrophic lakes**. What is **cultural eutrophication**?
7. Define **surface water**, **runoff**, and **watershed (drainage basin)**. Describe the three zones that a river passes through as it flows from mountains to the sea. Describe the relationships between dams, deltas, wetlands, hurricanes, and flooding in New Orleans, Louisiana (USA).
8. Give three examples of **inland wetlands** and describe the ecological and economic importance of such wetlands.

9. What are four ways in which human activities are disrupting and degrading freshwater systems? Describe losses of inland wetlands in the United States in terms of the area of wetlands lost and the resulting loss of ecological and economic services.

10. What are this chapter's *three big ideas*? What is the relationship between coral reefs and the three **principles of sustainability**?

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. What are three things governments and industries could do to protect the world's remaining coral reefs (**Core Case Study**)? What are three ways in which individuals can help to protect those reefs?

2. You are a defense attorney arguing in court for protecting a coral reef (**Core Case Study**) from harmful human activities. Give your three most important arguments for the defense of this ecosystem.

3. Why do aquatic plants such as phytoplankton tend to be very small, whereas most terrestrial plants such as trees tend to be larger and have more specialized structures for growth such as stems and leaves?

4. Why are some aquatic animals, especially marine mammals such as whales, extremely large compared with terrestrial animals?

5. How would you respond to someone who proposes that we use the deep portions of the world's oceans to deposit our radioactive and other hazardous wastes because the deep oceans are vast and are located far away from human habitats? Give reasons for your response.

6. Suppose a developer builds a housing complex overlooking a coastal marsh and the result is pollution and degradation of the marsh. Describe the effects of such a development on the wildlife in the marsh, assuming at least one species is eliminated as a result (see Figure 8-8).

7. How might a levee built on a river affect species such as deer and hawks living in a forest overlooking the river?

8. Suppose you have a friend who owns property that includes a freshwater wetland and the friend tells you she is planning to fill the wetland to make more room for her lawn and garden. What would you say to this friend?

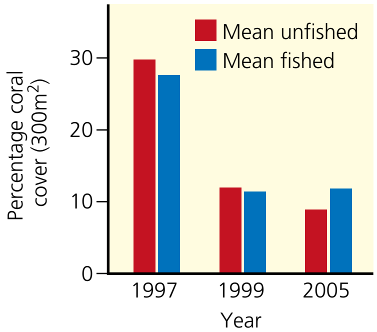
9. Congratulations! You are in charge of the world. What are the three most important features of your plan to help sustain the earth's aquatic biodiversity?

10. List two questions that you would like to have answered as a result of reading this chapter.

DATA ANALYSIS

At least 25% of the world's coral reefs have been severely damaged. A number of factors have played a role in this serious loss of aquatic biodiversity (Figure 8-13), including ocean warming, sediment from coastal soil erosion, excessive algae growth from fertilizer runoff, coral bleaching, rising sea levels, overfishing, and damage from hurricanes.

In 2005, scientists Nadia Bood, Melanie McField, and Rich Aronson conducted research to evaluate the recovery of coral reefs in Belize from the combined effects of mass bleaching and Hurricane Mitch in 1998. Some of these reefs are in protected waters where no fishing is allowed. The researchers speculated that reefs in waters where no fishing is allowed should recover faster than reefs in water where fishing is allowed. The graph to the right shows some of the data they collected from three highly protected (unfished) sites and three unprotected (fished) sites to evaluate their hypothesis. Study this graph and answer the questions on page 189.



This graph tracks the effects of restricting fishing on the recovery of unfished and fished coral reefs damaged by the combined effects of mass bleaching and Hurricane Mitch in 1998. (Data from Melanie McField, et al., *Status of Caribbean Coral Reefs After Bleaching and Hurricanes in 2005*, NOAA, 2008. (Report available at **www.coris.noaa.gov/activities/caribbean_rpt/**)

1. By about what percentage did the mean coral cover drop in the protected (unfished) reefs between 1997 and 1999?
2. By about what percentage did the mean coral cover drop in the protected (unfished) reefs between 1997 and 2005?
3. By about what percentage did the coral cover drop in the unprotected (fished) reefs between 1997 and 1999?
4. By about what percentage did the coral cover change in the unprotected (fished) reefs between 1997 and 2005?
5. Do these data support the hypothesis that coral reef recovery should occur faster in areas where fishing is prohibited? Explain.

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengagebrain.com/shop/ISBN/0538735341** and choose Chapter 8 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

For students with access to premium online resources, log on to **www.cengage.com/login**.

Find the latest news and research, (including videos and podcasts), at the GLOBAL ENVIRONMENT WATCH. Visit **www.CengageBrain.com** for more information.

9 Sustaining Biodiversity: The Species Approach

CORE CASE STUDY Polar Bears and Climate Change

The world's 20,000–25,000 polar bears are found in 19 populations scattered across the frozen Arctic. About 60% of them are in Canada, and the rest live in arctic areas of Denmark, Norway, Russia, and the U.S. state of Alaska.

Throughout the winter, polar bears hunt for seals on floating sea ice (Figure 9-1) that expands southward each winter and contracts as the temperature rises during summer. By eating the seals, the bears build up their body fat. In the summer and fall, they live off this fat until hunting resumes when the ice expands again during winter.

Measurements reveal that the earth's atmosphere is getting warmer and that this warming is occurring twice as fast in the Arctic as in the rest of the world. Hence, arctic ice is melting faster and the average annual area of floating sea ice in the Arctic during the summer is decreasing. The floating winter ice is also breaking up earlier each year, shortening the polar bears' hunting season.

These changes mean that polar bears have less time to feed and store fat. As a result, they must fast longer, which weakens them. As females become weaker, their ability to reproduce and keep their young cubs alive declines. Polar bears are strong swimmers, but ice shrinkage has forced them to swim longer distances to find enough food and to spend more time during winter hunting on land, where it is nearly impossible for them to find enough prey. As the bears grow hungrier, they are more likely to go to human settlements looking for food.

In 2008, the U.S. Fish and Wildlife Service placed the Alaskan polar bear on its list of threatened species. Alaska state government officials are trying to have this decision repealed because they say it will hurt economic growth in their state. Oil and coal industry leaders also want the listing decision overturned because they fear it might be used as a way to regulate carbon dioxide, the climate-changing gas that is released into the atmosphere when oil and coal are burned.

According to a 2006 study by the International Union for the Conservation of Nature, the world's total polar bear population is likely to decline by 30–35% by 2050. At the end of this century, polar bears might be found only in zoos.

Scientists project that during this century, human activities, especially those that cause habitat loss and contribute to climate change, are likely to lead to the extinction of one-fourth to one-half of the world's plant and animal species, possibly including the polar bear. Many biologists consider the current rapid loss of the earth's vital biodiversity—largely resulting from human activities—to be the most serious and long-lasting environmental problem that the world faces. In this chapter, we discuss the causes of the rising rate of species extinction and possible ways to slow it down.

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Figure 9-1 On floating ice in Svalbard, Norway, a polar bear feeds on its seal prey. Polar bears in the Arctic could become extinct sometime during this century if projected atmospheric warming melts much of the floating sea ice on which they hunt seals. **Question:** What do you think about the possibility that the polar bear might become extinct mostly because of human activities? Explain.

Key Questions and Concepts

9-1 **What role do humans play in the extinction of species?**

CONCEPT 9-1 Species are becoming extinct 100 to 1,000 times faster than they were before modern humans arrived on earth, and by the end of this century, the extinction rate is expected to be 10,000 times higher than that background rate.

9-2 **Why should we care about the rising rate of species extinction?**

CONCEPT 9-2 We should avoid speeding up the extinction of wild species because of the ecological and economic services they provide, and because many people believe that wild species have a right to exist regardless of their usefulness to us.

9-3 **How do humans accelerate species extinction?**

CONCEPT 9-3 The greatest threats to any species are (in order) loss or degradation of habitat, harmful invasive species, human population growth, pollution, climate change, and overexploitation.

9-4 **How can we protect wild species from extinction?**

CONCEPT 9-4 We can reduce the rising rate of species extinction and help to protect overall biodiversity by establishing and enforcing national environmental laws and international treaties, creating a variety of protected wildlife sanctuaries, and taking precautionary measures to prevent such harm.

Note: Supplements 2 (p. S3), 3 (p. S6), 5 (p. S18), and 8 (p. S30) can be used with this chapter.

The last word in ignorance is the person who says of an animal or plant: "What good is it?" . . . If the land mechanism as a whole is good, then every part of it is good, whether we understand it or not. Harmony with land is like harmony with a friend; you cannot cherish his right hand and chop off his left.

ALDO LEOPOLD

9-1 What Role Do Humans Play in the Extinction of Species?

▶ **CONCEPT 9-1** **Species are becoming extinct 100 to 1,000 times faster than they were before modern humans arrived on earth, and by the end of this century, the extinction rate is expected to be 10,000 times higher than that background rate.**

Extinctions Are Natural but Sometimes They Increase Sharply

When a species can no longer be found anywhere on the earth, it has suffered **biological extinction**. Biological extinction is forever and represents an irreversible loss of natural capital. The disappearance of any species, and especially those that play keystone roles (see Chapter 4, p. 99), can weaken or break some of the connections in the ecosystem where they once existed and thus can threaten ecosystem services. This can lead to *secondary extinctions* of species with strong connections to species that have already gone extinct.

According to biological and fossil evidence, all species eventually become extinct. During most of the 3.5 billion years that life has existed on the earth, there has been a natural, low rate of species extinction known as the **background extinction rate**.

An **extinction rate** is expressed as a percentage or number of species that go extinct within a certain time period such as a year. For example, one extinction per million species per year would be 1/1,000,000 = 0.000001 species per year. Expressed as a percentage, this is 0.000001 × 100, or 0.0001%—the estimated background extinction rate that existed before the human species arrived and spread over the globe.

The balance between formation of new species and extinction of existing species determines the earth's biodiversity. The extinction of many species in a relatively short period of geologic time is called a **mass extinction**. Geological and other records indicate that the earth has experienced three and perhaps five mass extinctions, when 50–95% of the world's species appear to have become extinct. After each mass extinction, biodiversity eventually returned to equal or higher levels, but each recovery required millions of years.

The causes of past mass extinctions are poorly understood but probably involved global changes in environmental conditions. Examples are major climate change or large-scale catastrophes such as volcanic eruptions. One hypothesis is that the last mass extinction, which took place about 65 million years ago, occurred after a large asteroid hit the planet and spewed huge amounts of dust and debris into the atmosphere. This could have reduced the input of solar energy and cooled the planet long enough to wipe out the dinosaurs and many other forms of earth's life at that time.

Some Human Activities Are Causing Extinctions

Extinction is a natural process. But a growing body of scientific evidence indicates that it has accelerated as human populations have spread over most of the globe, consuming huge quantities of resources and creating large and growing ecological footprints (see Figure 1-13, p. 16, and Figure 7, p. S38, in Supplement 8). According to biodiversity expert Edward O. Wilson (see Individuals Matter, p. 85), "The natural world is everywhere disappearing before our eyes—cut to pieces, mowed down, plowed under, gobbled up, replaced by human artifacts."

According to the 2005 Millennium Ecosystem Assessment and other studies, humans have taken over and disturbed at least half of, and more likely, about 80% of, the earth's land surface (see Figure 7, p. S38, in Supplement 8). Most of these disturbances involve filling in wetlands or converting grasslands and forests to crop fields and urban areas. Human activities have also polluted and disturbed almost half of the surface waters that cover about 71% of the earth's surface. According to the International Union for the Conservation of Nature (IUCN), the world's largest and oldest global environmental network, this has greatly increased the rate at which species are disappearing or are being threatened with extinction.

Extinction Rates Are Rising Rapidly

Using the methods described in the Science Focus box below, scientists from around the world who conducted the 2005 Millennium Ecosystem Assessment estimated that the current annual rate of species extinction is up to 1,000 times the historical background rate of about 0.0001%.

Biodiversity researchers project that during this century, the extinction rate caused by habitat loss, climate change due mostly to atmospheric warming, and other environmentally harmful effects related to human activities will rise to 10,000 times the background rate (**Concept 9-1**). If this estimate is correct, the annual extinction rate would rise to about 1% per year. This would amount to an extinction rate of 10,000 species per year for every 1 million wild species living on the earth.

So why is this a big deal? A 1% per year species extinction rate might not seem like much. But according to biodiversity researchers Edward O. Wilson and Stuart Pimm, at a 1% extinction rate, at least one-fourth and as many as half of the world's current animal and plant species could vanish by the end of this century. In the chilling words of biodiversity expert Norman Myers, "Within just a few human generations, we shall—in the absence of greatly expanded conservation efforts—impoverish the biosphere to an extent that will persist

SCIENCE FOCUS

Estimating Extinction Rates

Scientists who trying to catalog extinctions, estimate past extinction rates, and project future rates face three problems. *First*, because the natural extinction of a species typically takes a very long time, it is not easy to document. *Second*, we have identified only about 1.9 million of the world's estimated 8 million to 100 million species. *Third*, scientists know little about the nature and ecological roles of most of the species that have been identified.

One approach to estimating future extinction rates is to study records documenting the rates at which mammals and birds (the easiest to observe) have become extinct since humans began dominating the planet about 10,000 years ago. This information can be compared with fossil records of extinctions that occurred before that time.

Another approach is to observe how reductions in habitat size affect extinction rates. The *species–area relationship* suggests that, on average, a 90% loss of habitat in a given area causes the extinction of about 50% of the species living in that area. This is based on the *theory of island biogeography* (see Chapter 4, Science Focus, p. 94). Scientists use this model to estimate the number of current and future extinctions in patches or "islands" of shrinking habitat that are surrounded by degraded habitats or by rapidly growing human developments.

Scientists also use mathematical models to estimate the risk of a particular species becoming endangered or extinct within a certain period of time. These *population viability analysis* (PVA) models include factors such as trends in population size, changes in habitat availability, interactions with other species, and genetic factors.

Researchers know that their estimates of extinction rates are based on incomplete data and sampling, and on incomplete models. Thus, they are continually striving to get more and better data and to improve the models they use to estimate extinction rates.

At the same time, they point to clear evidence that human activities have accelerated the rate of species extinction and that this rate is increasing. According to these biologists, arguing over the numbers and waiting to get better data and models should not delay our acting now to help prevent the extinctions of species that result mostly from human activities.

Critical Thinking

Does the fact that extinction rates can only be estimated (not proven absolutely) make them unreliable? Why or why not?

for at least 200,000 human generations or twenty times longer than the period since humans emerged as a species." If such estimates are only half correct, we can see why many biologists warn that such a massive loss of biodiversity within the span of a single human lifetime is the most important and long-lasting environmental problem that humanity faces.

> **THINKING ABOUT**
> **Extinction**
>
> How might your lifestyle and that of any child or grandchild you might have change if human activities contribute to the extinction of up to half of the world's species during this century? List two aspects of your lifestyle that contribute to this threat to the earth's natural capital.

In fact, most extinction experts consider a projected extinction rate of 1% a year to be on the low side, for several reasons. *First*, both the rate of species loss and the extent of biodiversity losses are likely to increase sharply during the next 50–100 years because of the projected growth of the human population and its growing use of resources per person, and because of the projected human influence on climate change (as we discuss in Chapter 19).

Second, current and projected extinction rates are much higher than the global average in parts of the world that are already highly endangered centers of biodiversity. Norman Myers and other biodiversity researchers urge us to focus our efforts on slowing the much higher rates of extinction in such *biodiversity hotspots*; they see this emergency action as the best and quickest way to protect much of the earth's biodiversity from being lost during this century. (We discuss this further in Chapter 10.)

Third, we are eliminating, degrading, fragmenting, and simplifying many biologically diverse environments—such as tropical forests, tropical coral reefs, wetlands, and estuaries—that serve as potential colonization sites for the emergence of new species. Thus, in addition to increasing the rate of extinction, we may be limiting the long-term recovery of biodiversity by reducing the rate of speciation for some species. In other words, we are also creating a *speciation crisis*. (See the Guest Essay by Normal Myers on this topic at CengageNOW™.) Based on what we know about the recovery of biodiversity after past mass extinctions, it will take 5 million to 10 million years for the earth's processes to replace the projected number of species that are likely to become extinct during this century.

In addition, Philip Levin, Donald Levin, and other biologists argue that, while our activities are likely to reduce the speciation rates for some species, they might help to increase the speciation rates for other rapidly reproducing opportunist species such as weeds and rodents, as well as cockroaches and other insects. This could further accelerate the extinction of other species that are likely to be crowded out of their habitats by these expanding generalist species.

Endangered and Threatened Species Are Ecological Smoke Alarms

Biologists classify species that are heading toward biological extinction as either *endangered* or *threatened*. An **endangered species** has so few individual survivors that the species could soon become extinct. A **threatened species** (also known as a *vulnerable species*) still has enough remaining individuals to survive in the short term, but because of declining numbers, it is likely to become endangered in the near future.

An example of a threatened species is the polar bear (**Core Case Study**). Figure 9-2 shows four of the most endangered of the more than 17,300

CORE CASE STUDY

(a) Sumatran tiger: less than 60 in Sumatra, Indonesia

(b) Mexican gray wolf: about 60 in the forests of Arizona and New Mexico

(c) California condor: 172 in the southwestern United States

(d) Whooping crane: 210 in North America

Figure 9-2 *Endangered natural capital:* These four critically endangered species are threatened with extinction, largely because of human activities. More than 17,300 of the world's species, including 1,318 species in the United States, were officially listed in 2009 as endangered or threatened species. The number below each photo indicates the estimated total number of individuals of that species remaining in the wild. These and thousands of other species may disappear forever during your lifetime. According to most biologists, the actual number of species at risk is much larger. **Question:** What kinds of human activities to you think are putting these four animals in danger?

species listed in 2009 by the IUCN as threatened and of the more than 1,370 species listed in 2010 as endangered or threatened under the U.S. Endangered Species Act. (The real number is likely much higher because only about 48,000 of the 1.9 million known species have been evaluated.)

Some species have characteristics that increase their chances of becoming extinct (Figure 9-3). As biodiversity expert Edward O. Wilson puts it, "The first animal species to go are the big, the slow, the tasty, and those with valuable parts such as tusks and skins."

Some species also have *behavioral characteristics* that make them prone to extinction. The passenger pigeon (see the Case Study that follows) and the Carolina parakeet, both extinct, nested in large flocks that made them easy to kill. Some types of species are more threatened with extinction resulting from human activities than others are (Figure 9-4).

RESEARCH FRONTIER

Identifying and cataloguing the millions of unknown species and improving models for estimating extinction rates; see **www.cengage.com/login**.

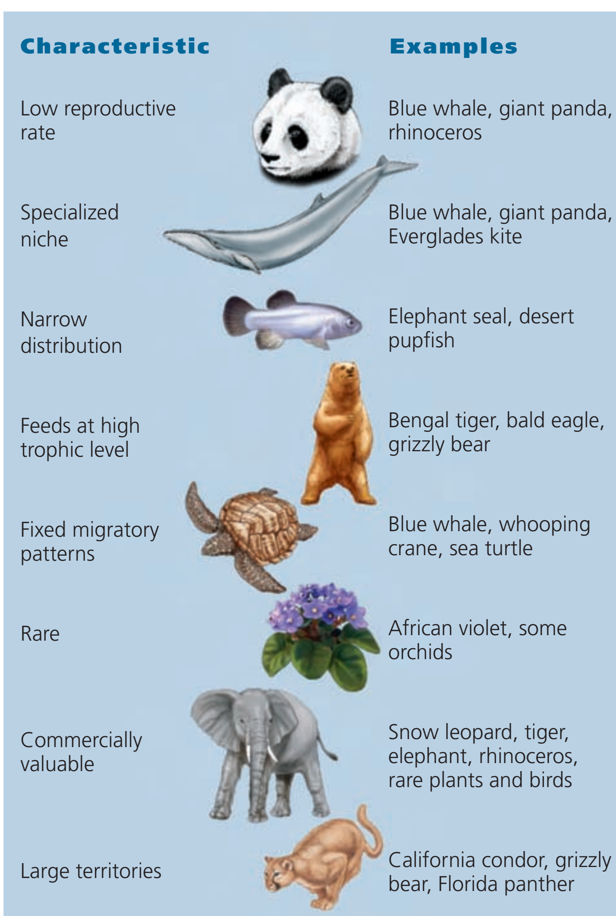


Figure 9-3 This diagram shows the characteristics of species that can put them in greater danger of becoming extinct. **Question:** Which of these characteristics might possibly contribute to the extinction of the polar bear (**Core Case Study**) during this century?

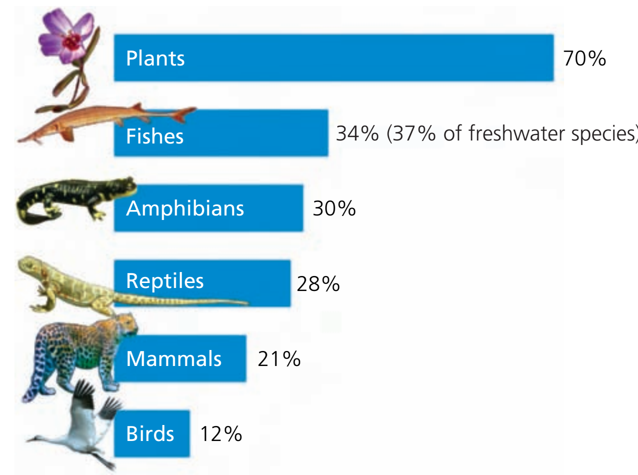


Figure 9-4 **Endangered natural capital:** This graph shows the estimated percentages of various types of known species that are threatened with extinction because of human activities (**Concept 9-1**). **Question:** Why do you think plants (see Photo 4 in the Detailed Contents) and fish species top this list? (Data from International Union for Conservation of Nature, Conservation 2009)

CASE STUDY

The Passenger Pigeon: Gone Forever

At one time, the North American passenger pigeon (Figure 9-5) was one of world's most abundant bird species. In 1813, bird expert John James Audubon watched a flock of these passenger pigeons that was so huge it darkened the sky and took three days to fly over his location.

By 1900, North America's passenger pigeon had disappeared from the wild because of three factors: habitat loss as forests were cleared to make room for farms

Michael Sewell/Peter Arnold, Inc.

Figure 9-5 Because of human activities, the North American passenger pigeon became extinct in the wild in 1900. In 1914, the world's last known passenger pigeon died in a zoo in the U.S. city of Cincinnati, Ohio.

and cities, uncontrolled commercial hunting, and the fact that they were easy to kill. These birds were good to eat, their feathers made good pillows, and their bones were widely used for fertilizer. They were easy targets because they flew in gigantic flocks and nested in long, narrow, densely packed colonies.

Beginning in 1858, passenger pigeon hunting became a big business. Shotguns, traps, artillery, and even dynamite were used. Hunters burned grass or sulfur below the pigeons' roosts to suffocate the birds. Shooting galleries used live birds as targets. In 1878, a professional pigeon trapper made $60,000 by killing 3 million birds at their nesting grounds near Petoskey, Michigan.

By the early 1880s, only a few thousand birds remained. At that point, recovery of the species was doomed. On March 24, 1900, a young boy in the U.S. state of Ohio shot the last known wild passenger pigeon.

9-2 Why Should We Care about the Rising Rate of Species Extinction?

▶ **CONCEPT 9-2 We should avoid speeding up the extinction of wild species because of the ecological and economic services they provide, and because many people believe that wild species have a right to exist regardless of their usefulness to us.**

Species Are a Vital Part of the Earth's Natural Capital

If all species eventually become extinct, why should we worry about the rate of extinction? Does it matter that the passenger pigeon became extinct because of human activities, or that the remaining polar bears (**Core Case Study**), orangutans (Figure 9-6), or some unknown plant or insect in a tropical forest might suffer the same fate?

CORE CASE STUDY

Speciation results in new species eventually evolving to take the places of those species lost through mass extinctions. So why should we care if we speed up the extinction rate over the next 50–100 years? According to biologists, there are four major reasons why we should work to prevent our activities from causing the extinction of other species.

First, the world's species are a vital part of the earth's life support system. They provide natural resources and natural services (see Figure 1-4, p. 9) that keep us and

SuperStock

Figure 9-6 Natural capital degradation: These endangered orangutans are shown in their rapidly disappearing tropical forest habitat. In 1900, there were over 315,000 wild orangutans, which are found only in the tropical forests of Indonesia and Malaysia. According to the WWF, today there are fewer than 56,000 left in the wild (90% of them in Indonesia). These highly intelligent animals are disappearing at a rate of more than 1,000–2,000 per year because of illegal smuggling and the clearing of their tropical forest habitat to make way for plantations that supply palm oil used in cosmetics, cooking, and the production of biodiesel fuel. An illegally smuggled, live orangutan sells for a street price of up to $10,000. Without urgent protective action, the endangered orangutan may be the first great ape species to become extinct, primarily because of human activities. **Question:** What difference will it make if human activities cause the extinction of the orangutan?

other species alive. For example, we depend on some insects for pollination of food crops and on some birds for natural pest control. Each species also has ecological value, because it plays a role in the key ecosystem functions of energy flow and chemical cycling (see Figure 3-11, p. 62), in keeping with one of the three **principles of sustainability**. Thus, by eliminating species, especially those that play keystone roles (see Chapter 4, p. 99), we can upset ecosystems and speed up the extinction of other species that depend on those systems. Eventually such degradation of the earth's natural capital can threaten human health and lifestyles. Thus, by protecting species from extinction caused by human activities, and by protecting their vital habitats from environmental degradation (as we discuss in the next chapter), we are helping to sustain our own health and well-being.

A *second* reason for preventing extinctions resulting from human activities is that most species contribute to *economic services*—those services that support our economies (**Concept 9-2**). For example, various plant species provide economic value as food crops, fuelwood and lumber, paper, and medicine (Figure 9-7). *Bioprospectors* search tropical forests and other ecosystems to find plants and animals that scientists can use to make medicinal drugs. According to a 2005 United Nations University report, 62% of all cancer drugs were derived from the discoveries of bioprospectors. Despite their economic and medicinal potential, less than 0.5% of the world's known plant species have been examined for their medicinal properties. **GREEN CAREER:** Bioprospecting

GOOD NEWS

Species diversity also provides economic benefits from wildlife tourism, or *ecotourism*, which generates more than $1 million per minute in tourist expenditures. Conservation biologist Michael Soulé estimates that a male lion living to age 7 generates about $515,000 in tourist dollars in Kenya, but only about $1,000 if killed for its skin. Similarly, over a lifetime of 60 years, a Kenyan elephant is worth about $1 million in ecotourism revenue. This is much more than what could be gained from the illegal sale of ivory obtained by killing an elephant and removing its tusks. Ecotourism is thriving because people enjoy wildlife (Figure 9-8). **GREEN CAREER:** Ecotourism guide

GOOD NEWS

A *third* reason for preventing extinctions caused by human activities is that analysis of past mass extinctions indicates it will take 5 million to 10 million years—25 to 50 times longer than the amount of time that our species has been around—for natural speciation to rebuild the biodiversity that is likely to be lost during this century. As a result, any grandchildren that you might have along with hundreds of future generations are unlikely to be able to depend on the life-sustaining biodiversity that we now enjoy.

Fourth, many people believe that each wild species has a right to exist, regardless its usefulness to us (**Concept 9-2**). According to this view, we have an ethical responsibility to protect species from becoming extinct as a result of human activities and to prevent the deg-

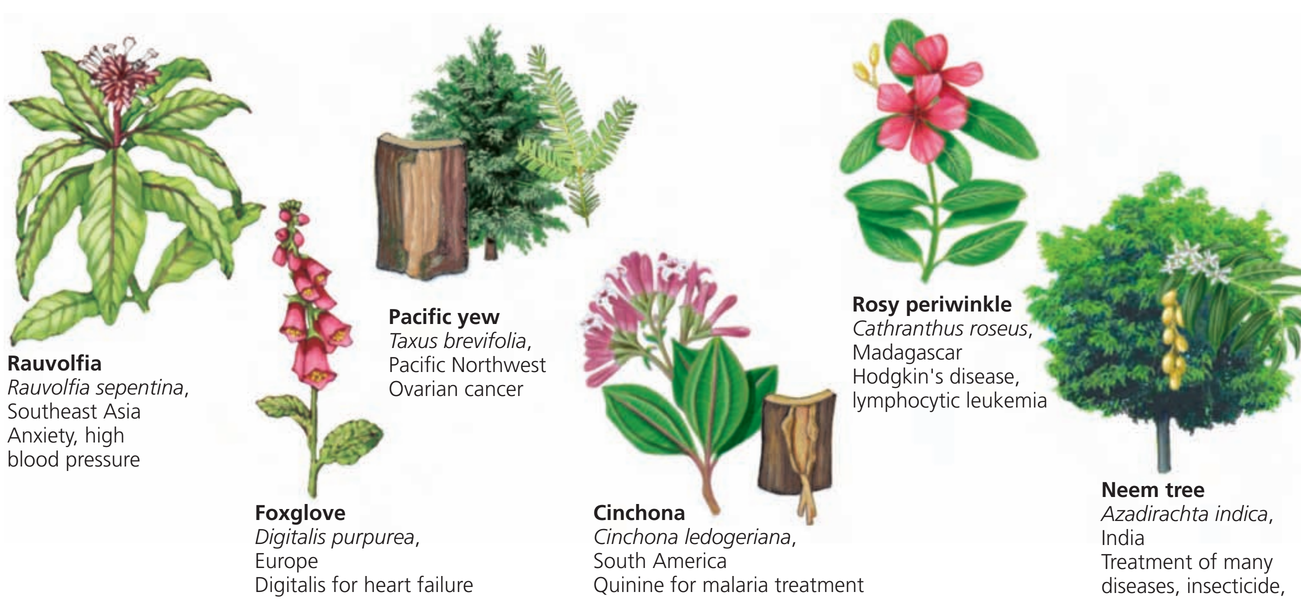


Figure 9-7 **Natural capital:** These plant species are examples of *nature's pharmacy.* Their scientific names (see Supplement 5, p. S18–S19) and some of their medicinal uses are shown as well. Parts of these plants as well as a number of other plant and animal species (many of them found in tropical forests) are used to treat a variety of human ailments and diseases. Once the active ingredients in the plants have been identified, scientists can usually produce them synthetically. The active ingredients in nine of the ten leading prescription drugs originally came from wild organisms. Many of the world's tropical plant species are likely to become extinct before we can even study them. **Question:** Which of these species, if any, might have helped you or people you know to deal with health problems?

Christian Musat/Shutterstock

Figure 9-8 Many species of wildlife such as this endangered hyacinth macaw are sources of beauty and pleasure. This species of parrot is found in fairly open woodlands and swamps in several areas of Brazil, Bolivia, and Paraguay. This and other colorful species of parrots have become endangered because many birds have been removed from the wild and sold (sometimes illegally) as pets.

radation of the world's ecosystems and their overall biodiversity.

This ethical viewpoint raises a number of challenging questions. Since we can't save all species from the harmful consequences of our actions, we have to make choices about which ones to protect. Should we protect more animal species than plant species and, if so, which ones should we protect? Some people support protecting well-known and appealing species such as elephants, whales, polar bears (**Core Case Study**), tigers, and orangutans (Figure 9-6). But they care much less about protecting plants that serve as the base of the food supply for all species.

CORE CASE STUDY

Other people distinguish among various types of species. For example, they might think little about getting rid of species that they fear or hate, such as mosquitoes, cockroaches, disease-causing bacteria, snakes, and bats. **Explore More:** Go to **www.cengage.com/login** to learn more about the important ecological roles that bats play and why we need to avoid causing their extinction.

Some scientists argue that the current extinction crisis is tragic, partly because we do not even know what we are losing. No one has ever seen or studied many of the species that are rapidly becoming extinct. To biologist Edward O. Wilson, carelessly and rapidly eliminating species that make up an essential part of the world's biodiversity is like burning all the copies of millions of books that we have never read.

9-3 How Do Humans Accelerate Species Extinction?

CONCEPT 9-3 The greatest threats to any species are (in order) loss or degradation of habitat, harmful invasive species, human population growth, pollution, climate change, and overexploitation.

Loss of Habitat Is the Single Greatest Threat to Species: Remember HIPPCO

Figure 9-9 (p. 198) shows the *underlying* and *direct* causes of the endangerment and extinction of wild species. Biodiversity researchers summarize the most important direct causes of extinction resulting from human activities using the acronym **HIPPCO: H**abitat destruction, degradation, and fragmentation; **I**nvasive (nonnative) species; **P**opulation growth and increasing use of resources; **P**ollution; **C**limate change; and **O**verexploitation (**Concept 9-3**).

According to biodiversity researchers, the greatest threat to wild species is habitat loss (Figure 9-10, p. 199), degradation, and fragmentation. A stunning example of this is the loss of habitat for polar bears (**Core Case Study**). Because the atmosphere above the Arctic has been getting warmer during the past several decades, the floating sea ice that is a vital part of the bears' habitat is melting away beneath their feet, which is causing a decline in their numbers.

CORE CASE STUDY

Deforestation in tropical areas (see Figure 3-1, p. 54) is the greatest eliminator of species, followed by the destruction and degradation of coral reefs (see Figure 8-13, right, p. 179) and coastal wetlands, the plowing of grasslands (see Figure 7-12, right, p. 158), and the pollution of streams, lakes, and oceans.

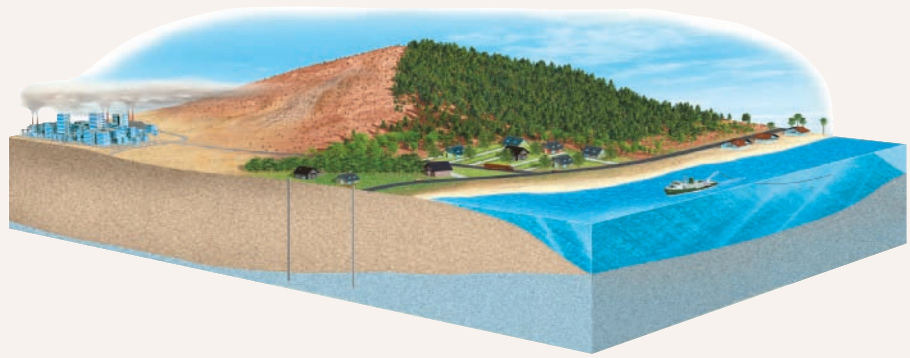
Island species—many of them found nowhere else on earth—are especially vulnerable to extinction when their habitats are destroyed, degraded, or fragmented and they have nowhere else to go. This is why the collection of islands that make up the U.S. state of Hawaii is America's "extinction capital"—with 63% of its species at risk.

Natural Capital Degradation

Causes of Depletion and Extinction of Wild Species

Underlying Causes

- Population growth
- Rising resource use
- Undervaluing natural capital
- Poverty



Direct Causes

- Habitat loss
- Habitat degradation and fragmentation
- Introduction of nonnative species
- Pollution
- Climate change
- Overfishing
- Commercial hunting and poaching
- Sale of exotic pets and decorative plants
- Predator and pest control

Figure 9-9 This figure illustrates both the underlying and direct causes of depletion and extinction of wild species resulting from human activities (**Concept 9-3**) (see Figure 1-9, p. 13). The biggest cause is habitat loss, degradation, and fragmentation. This is followed by the deliberate or accidental introduction of harmful invasive (nonnative) species into ecosystems. **Question:** What are two direct causes that are specifically related to each of the underlying causes?

Habitat fragmentation occurs when a large, intact area of habitat such as a forest or natural grassland is divided, typically by roads, logging operations, crop fields, and urban development, into smaller, isolated patches or "habitat islands" (see Figure 3-1, p. 54). This process can decrease tree cover in forests (see *The Habitable Planet*, Video 9, at **www.learner.org/resources/series209.html**), and block animal migration routes. It can also divide populations of a species into smaller, increasingly isolated groups that are more vulnerable to predators, competitor species, disease, and catastrophic events such as storms and fires. In addition, habitat fragmentation creates barriers that limit the abilities of some species to disperse and colonize new areas, to locate adequate food supplies, and to find mates.

Most national parks and other nature reserves are habitat islands, many of them surrounded by potentially damaging logging and mining operations, industrial activities, coal-burning power plants, and human settlements. Freshwater lakes are also habitat islands that are especially vulnerable to the introduction of nonnative species and pollution from human activities.

Scientists use the theory of island biogeography (see Chapter 4, Science Focus, p. 94) to help them understand the role of fragmentation in species extinction and to develop ways to help prevent such extinction.

CENGAGENOW™ See how serious the habitat fragmentation problem is for elephants, tigers, and rhinos at CengageNOW.

Some Deliberately Introduced Species Can Disrupt Ecosystems

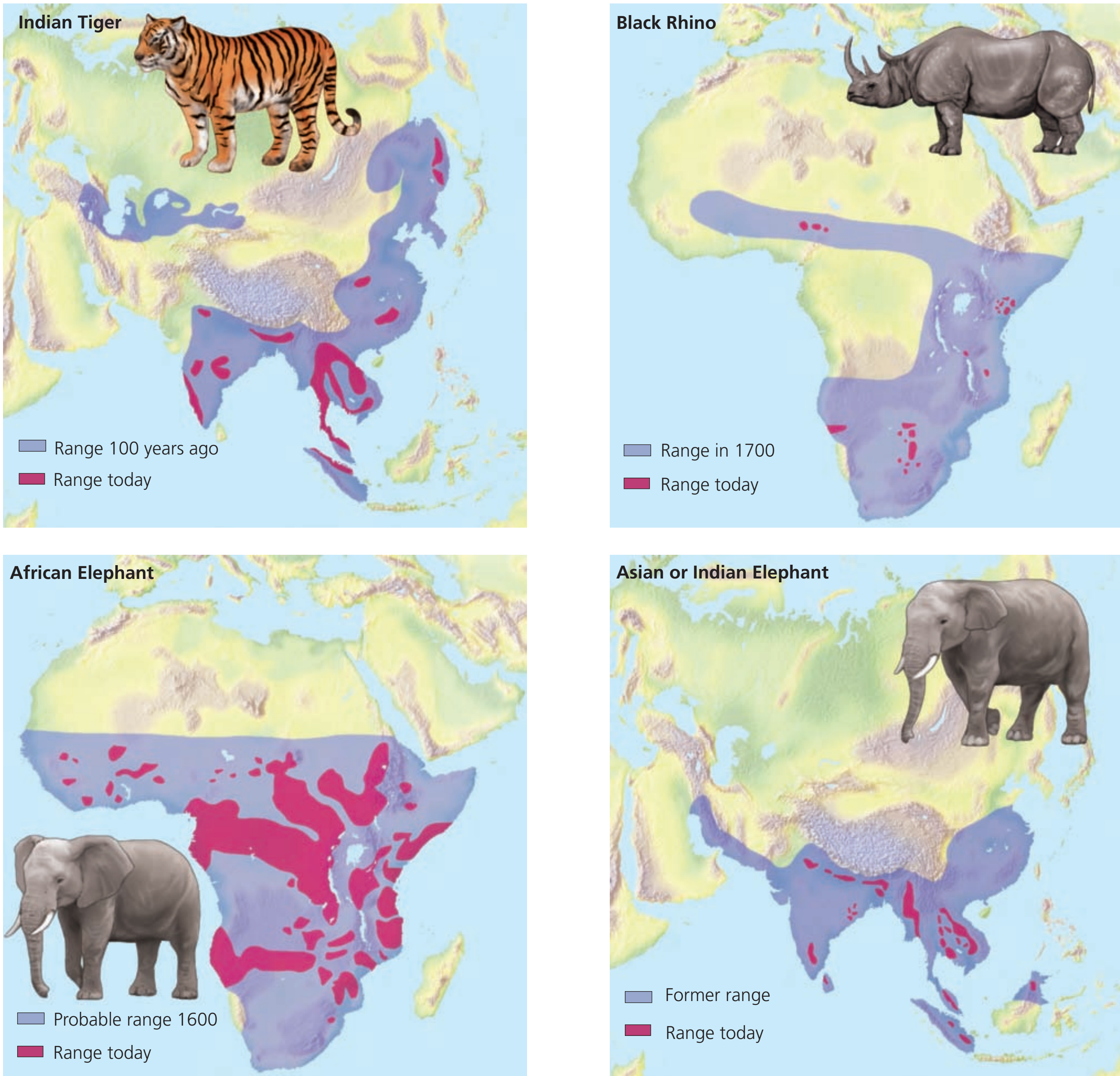
After habitat loss and degradation, the biggest cause of animal and plant extinctions is the deliberate or accidental introduction of harmful invasive species into ecosystems (**Concept 9-3**).

GOOD NEWS

Most species introductions are beneficial to us. According to a study by ecologist David Pimentel, introduced species such as corn, wheat, rice, and other food crops, as well as species of cattle, poultry, and other livestock provide more than 98% of the U.S. food supply. Similarly, nonnative tree species are grown in about 85% of the world's tree plantations. Some deliberately introduced species have helped to control pests.

The problem is that, in their new habitats, some introduced species face no natural predators, competitors, parasites, or pathogens that would help to control their numbers in their original habitats. Such nonnative species can thus crowd out populations of many native species, trigger ecological disruptions, cause human health problems, and lead to economic losses.

In 1988, for example, a giant African land snail was imported into Brazil as a cheap substitute for conventional escargot (snails) used as a source of food. It grows to the size of a human fist and can weigh 1 kilogram (2.2 pounds) or more. When export prices for escargot fell, breeders dumped the imported snails into the wilds. Now it has spread to 23 of Brazil's states and devours



CENGAGENOW™ **Active Figure 9-10 Natural capital degradation:** These maps reveal the reductions in the ranges of four wildlife species, mostly as the result of severe habitat loss and fragmentation and illegal hunting for some of their valuable body parts. What will happen to these and millions of other species during the next few decades when the human population grows by at least 2 billion—the equivalent of more than 6 times the current U.S. population and almost twice the current population of China—as is projected by scientists? *See an animation based on this figure at* CengageNOW. **Question:** Would you support expanding these ranges even though this would reduce the land available for human habitation and farming? Explain. (Data from International Union for the Conservation of Nature and World Wildlife Fund)

many native plants and food crops such as lettuce. It also can carry rat lungworm, a parasite that burrows into the human brain and causes meningitis (a potentially lethal swelling of the membranes that cover the brain and spinal cord), and it carries another parasite that can rupture human intestines. Authorities eventually banned the snail, but it was too late. So far, the snail has been unstoppable.

Figure 9-11 (p. 200) shows some of the estimated 7,100 invasive species that, after being deliberately or accidentally introduced into the United States, have caused ecological and economic harm. According to the U.S. Fish and Wildlife Service, about 40% of the species listed as endangered in the United States and 95% of those in the U.S. state of Hawaii are on the list because of threats from invasive species.

In 2009, Achim Steiner, head of the UN Environment Program (UNEP), and environmental scientist David Pimentel estimated that invader species are causing economic and ecological damages that average at least $162,000 an hour, worldwide. And the damages are rising rapidly.

Figure 9-11 These are some of the more than 7,100 harmful invasive (nonnative) species that have been deliberately or accidentally introduced into the United States.

Some deliberately introduced species, such as *kudzu* (see the following Case Study) and *European wild boars* have caused significant ecological and economic damage. Biologists estimate that there are now about 4 million European wild boars in Florida, Texas, and 22 other U.S. states. These deliberately introduced species eat almost anything, compete for food with endangered animals, use their noses to root up farm fields, and cause traffic accidents when they wander onto roads. Their tusks make them dangerous to people who encounter them. Game and wildlife officials have failed to control their numbers through hunting and trapping, and some say there is no way to stop them.

■ **CASE STUDY**

The Kudzu Vine

An example of a deliberately introduced plant species is the *kudzu* ("CUD-zoo") *vine*, which grows rampant in the southeastern United States. In the 1930s, this vine was imported from Japan and planted in the southeastern United States in an attempt to control soil erosion.

Kudzu does control erosion. But it is grows so rapidly and is so difficult to kill that it engulfs hillsides, gardens, trees, stream banks, and anything else in its path (Figure 9-12). This plant—sometimes called "the vine that ate the South"—has spread throughout much of the southeastern United States. It could spread to the north if the climate gets warmer as scientist project.

Kudzu is considered a menace in the United States, but Asians use a powdered kudzu starch in beverages, gourmet confections, and herbal remedies for a range of diseases. A Japanese firm has built a large kudzu farm and processing plant in the U.S. state of Alabama and ships the extracted starch to Japan. Almost every part of the kudzu plant is edible. Its deep-fried leaves are delicious and contain high levels of vitamins A and C. Stuffed kudzu leaves, anyone?

GOOD NEWS

Although kudzu can engulf and kill trees, it might eventually also help to save some of them. Researchers at the Georgia Institute of Technology have found that kudzu could be used in place of trees as a source of fiber for making paper. Also, ingesting small amounts of kudzu powder can lessen one's desire for alcohol, and thus it could be used to reduce alcoholism and binge drinking.

Some Accidentally Introduced Species Can Disrupt Ecosystems

Many unwanted nonnative invaders arrive from other continents as stowaways on aircraft, in the ballast water of tankers and cargo ships, and as hitchhikers on imported products such as wooden packing crates. Cars and trucks can also spread the seeds of nonnative plant species embedded in their tire treads. Many tourists return home with living plants that can multiply and become invasive. Some of these plants might also contain insects that can escape, multiply rapidly, and threaten crops.

In the 1930s, the extremely aggressive Argentina fire ant (Figure 9-11) was accidentally introduced into the United States in Mobile, Alabama. The ants may have arrived on shiploads of lumber or coffee imported from South America. Without natural predators, fire ants have spread rapidly by land and water (they can

Chuck Pratt/Bruce Coleman, Inc.

Figure 9-12 Kudzu has taken over this abandoned house in the U.S. state of Mississippi. The vine, which can grow 5 centimeters (2 inches) per hour, was deliberately introduced into the United States for erosion control. Digging it up and burning it do not halt its spread. Grazing goats and repeated doses of herbicides can destroy it, but goats and herbicides also destroy other plants, and herbicides can contaminate water supplies. Scientists have found a common fungus that can kill kudzu within a few hours, apparently without harming other plants, but they need to investigate any harmful side effects it may have.

float) over much of the southern United States and are also found in Puerto Rico, New Mexico, and California. Now the insect has stowed away on imported goods and shipping containers and has invaded other countries, including China, Taiwan, Malaysia, and Australia.

When these ants invade an area, they can wipe out as much as 90% of native ant populations. Mounds containing fire ant colonies cover many fields and invade yards in the southeastern United States. Walk on one of these mounds, and as many as 100,000 ants may swarm out of their nest to attack you with painful and burning stings. They have killed deer fawns, birds, livestock, pets, and at least 80 people who were allergic to their venom.

Widespread pesticide spraying in the 1950s and 1960s temporarily reduced fire ant populations. But this chemical warfare actually hastened the advance of the rapidly multiplying fire ants by reducing populations of many native ant species. Even worse, it promoted development of genetic resistance to pesticides in the fire ants through natural selection (Figure 4-7, p. 87). In other words, we helped wipe out their competitors and made them more genetically resistant to pesticides.

In 2009, pest management scientist Scott Ludwig reported some success in using tiny parasitic flies to reduce fire ant populations. The flies dive-bomb the fire ants and lay eggs inside them. Maggots then hatch and eat away the brains of the ants. After about two weeks, the ants become staggering zombies, and after about a month, their heads fall off. Then the parasitic fly emerges looking for more fire ants to attack and kill. The researchers say that the flies do not attack native ant species. But more research is needed to see how well this approach works.

GOOD NEWS

Burmese and African pythons and several species of boa constrictors have accidentally ended up in Everglades in the U.S. state of Florida. About 2 million of these snakes, imported from Africa and Asia, have been sold as pets. After learning that these reptiles do not make good pets, some owners have dumped them into the wetlands in and around the Florida Everglades.

Some of these snakes can live 25–30 years, reach 6 meters (20 feet) in length, weigh more than 90 kilograms (200 pounds), and be as big around as a telephone pole. They are hard to find and kill, and they reproduce rapidly. They seize their prey with their sharp teeth, wrap themselves around the prey, and squeeze them to death before feeding on them. They have huge appetites, devouring a variety of birds, raccoons, pet cats and dogs, and full-grown deer. Pythons have been known to eat American alligators—a keystone species in the Everglades ecosystem (see Case Study, p. 99, in Chapter 4) and the only predator in the Everglades capable of killing these snakes (Figure 9-13). According to wildlife officials, tens of thousands of these snakes now live in the Everglades and their numbers are increasing rapidly. It is feared that they will spread to other swampy wetlands in the southern half of the United States by the end of this century.

Shutterstock

Figure 9-13 This huge python and an American alligator were in a life-or-death struggle in the Florida Everglades. After a 10-hour battle the alligator killed the snake by taking it underwater and drowning it. However, in some struggles, these snakes kill and eat the alligators—their only natural predator in the Everglades.

Prevention Is the Best Way to Reduce Threats from Invasive Species

Once a harmful nonnative species becomes established in an ecosystem, its removal is almost impossible—somewhat like trying to collect smoke after it has come out of a chimney. Clearly, the best way to limit the harmful impacts of nonnative species is to prevent them from being introduced and becoming established.

Scientists suggest several ways to do this:

- Fund a massive research program to identify the major characteristics that enable some species to become successful invaders; the types of ecosystems that are vulnerable to invaders; and the natural predators, parasites, bacteria, and viruses that could be used to control populations of established invaders.
- Greatly increase ground surveys and satellite observations to track invasive plant and animal species, and develop better models for predicting how they will spread and what harmful effects they might have.
- Identify major harmful invader species and establish international treaties banning their transfer from one country to another, as is now done for endangered species, while stepping up inspection of imported goods to enforce such bans.
- Require cargo ships to discharge their ballast water and replace it with saltwater at sea before entering ports, or require them to sterilize such water or to pump nitrogen into the water to displace dissolved oxygen and kill most invader organisms.
- Educate the public about the effects of releasing exotic plants and pets into the environment near where they live.

What Can You Do?

Controlling Invasive Species

- Do not capture or buy wild plants and animals.
- Do not remove wild plants from their natural areas.
- Do not release wild pets back into nature.
- Do not dump the contents of an aquarium into waterways, wetlands, or storm drains.
- When camping, use wood found near your campsite instead of bringing firewood from somewhere else.
- Do not dump unused bait into waterways.
- After dogs visit woods or the water, brush them before taking them home.
- After each use, clean your mountain bike, canoe, boat, motor, and trailer, all fishing tackle, hiking boots, and other gear before heading for home.

Figure 9-14 **Individuals matter:** Here is a list of some ways to prevent or slow the spread of harmful invasive species. **Questions:** Which two of these actions do you think are the most important? Why? Which of these actions do you plan to take?

RESEARCH FRONTIER

Learning more about harmful invasive species, why they thrive, and how to control them; see **www.cengage.com/login**.

Figure 9-14 shows some of the things you can do to help prevent or slow the spread of harmful invasive species.

Population Growth, Overconsumption, Pollution, and Climate Change Can Cause Species Extinctions

Past and projected *human population growth* (see Figure 6-3, p. 127) and excessive and wasteful consumption of resources have greatly expanded the human ecological footprint, which has eliminated, degraded, and fragmented vast areas of wildlife habitat (Figure 9-10). Acting together, these two factors have caused the extinction of many species (**Concept 9-3**). (See *The Habitable Planet*, Video 13, at **www.learner.org/resources/series209.html**.)

Pollution also threatens some species with extinction (**Concept 9-3**), as has been shown by the unintended effects of certain pesticides. According to the U.S. Fish and Wildlife Service, each year, pesticides kill about one-fifth of the honeybee colonies that pollinate almost a third of U.S. food crops (see Case Study, p. 204). They also kill more than 67 million birds and 6–14 million fish each year, and they threaten about one-fifth of the country's endangered and threatened species.

During the 1950s and 1960s, populations of fish-eating birds such as ospreys, brown pelicans, and bald eagles plummeted. A chemical derived from the pesticide DDT, when biologically magnified in food webs (Figure 9-15), made the birds' eggshells so fragile they could not reproduce successfully. Also hard hit were such predatory birds as the prairie falcon, sparrow hawk, and peregrine falcon, which help to control populations of rabbits, ground squirrels, and other crop eaters.

Since the U.S. ban on DDT in 1972, most of these bird species have made a comeback. For example, the American bald eagle has rebounded from only 487 breeding pairs in the lower 48 states in 1963 to almost 10,000 breeding pairs in 2007, enough to have it removed from the endangered species list. (The eagle was also aided by crackdowns on poaching of the bird and on destruction of its habitat.) The comeback of this species from the brink of extinction is one of the greatest wildlife protection success stories in U.S. history. However, success can also lead to unintended consequences (Connections, p. 204).

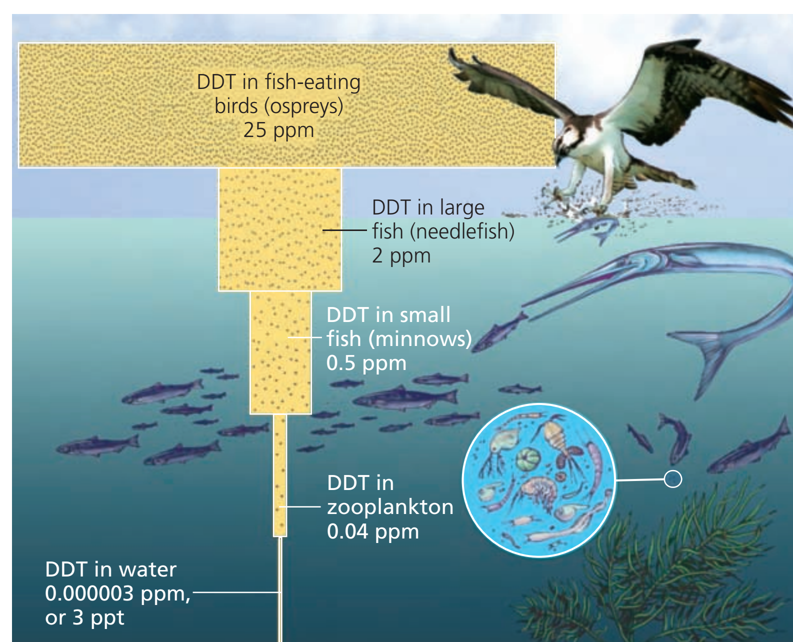


Figure 9-15 *Bioaccumulation and biomagnification:* DDT is a fat-soluble chemical that can accumulate in the fatty tissues of animals. In a food chain or web, the accumulated DDT is biologically magnified in the bodies of animals at each higher trophic level. (Dots in this figure represent DDT.) The concentration of DDT in the fatty tissues of organisms was biomagnified about 10 million times in this food chain in an estuary near Long Island Sound in the U.S. state of New York. If each phytoplankton organism takes up and retains one unit of DDT, a small fish eating thousands of zooplankton (which feed on the phytoplankton) will store thousands of units of DDT in its fatty tissue. Each large fish that eats ten of the smaller fish will ingest and store tens of thousands of units, and each bird (or human) that eats several large fish will ingest hundreds of thousands of units. **Question:** How does this story demonstrate the value of pollution prevention?

CONNECTIONS

Saving Eagles, Overfishing, and Losing Rare Great Cormorants

Whenever we do anything in nature, it always affects something else. For example, thanks to conservation efforts, the *American bald eagle* has made a great comeback. But in the waters off the coast of Maine, some 500 pairs of bald eagles are facing a shortage of fish—the main staple of their diet—mostly because of human overfishing. But eagles are opportunistic feeders and will eat whatever is easiest to catch. So off the coast of Maine, in the country's only known nesting colonies of rare *great cormorants*, eagles have been devouring large numbers of easy-to-catch cormorant chicks. Eagles are also driving the cormorant adults from their nests, which leaves their eggs exposed to other predators. As a result, between 1992 and 2008, the number of breeding pairs of cormorants dropped from 250 to 80. Because every species has to eat or decompose something, everything is connected to something else in nature.

According to a 2004 study by Conservation International, projected *climate change* could help to drive a quarter to half of all land animals and plants to extinction by the end of this century. Scientific studies indicate that polar bears (**Core Case Study**) and 10 of the world's 17 penguin species are already threatened because of higher temperatures and melting sea ice in their polar habitats.

CORE CASE STUDY

THINKING ABOUT

Polar Bears

CORE CASE STUDY

What difference would it make if most or all of the world's polar bears (**Core Case Study**) disappeared? List two things you would do to help protect the world's remaining polar bears from extinction.

CASE STUDY

Where Have All the Honeybees Gone?

Adult honeybees live on honey they make from the nectar they collect from flowering plants (see Figure 4-16, p. 97). They also feed their young with protein-rich pollen from the flowers. Besides converting nectar into sweet honey and producing wax that we can use for candles, honeybees provides us with one of nature's most important free ecological services: the pollination of flowering plants.

Globally, about one-third of the human food supply comes from insect-pollinated plants, and honeybees are responsible for 80% of that pollination, according to the U.S. Department of Agriculture (USDA). In the United States, the industrious European honeybee pollinates most flower species and nearly 100 commercially grown crops that are vital to U.S. agriculture, including up to one-third of U.S. fruit, nut, and vegetable crops.

In 2006, the U.S. National Academy of Sciences reported a 30% drop in U.S. honeybee populations since the 1980s. No single culprit has been found. But possible causes of this decline include pesticide exposure. Bees pick up pesticides during pollination and the wax in beehives absorbs these and other toxins. Causes could also include attacks by certain parasitic mites that can wipe out a colony in hours, invasion by Africanized honeybees (killer bees, Figure 4-16, p. 97), and a newly discovered virus from Israel. Another factor contributing to their decline is poor nutrition because of a decrease in the natural diversity of flowers and other plants on which bees feed.

In 2008 in the United States, a record 36% of commercial honeybee colonies (each with 30,000 to 100,000 individual bees) were lost. Almost one-third of the deaths were due to *colony collapse disorder* (CCD) in which most or all of the adult worker bees mysteriously disappeared from their hives. Suspected causes of CCD include parasites, a fungus, viruses, bacteria, pesticides, and poor nutrition resulting in stress caused when commercial bee colonies are fed an artificial diet while being trucked around the country and rented out for pollination.

Another possibility might be microwave radiation from cell phones and cell towers that could be disrupting the navigation systems of the worker bees that gather nectar and pollen. The radiation might be disorienting the bees and preventing them from returning to their hives; or, it may be decreasing their ability to fly by damaging their nervous systems. In an experiment performed to test these hypotheses, cell phones were placed near bee hives, and the hives collapsed within 5 to 10 days after the worker bees failed to return from their foraging.

CONNECTIONS

Pesticides, Honeybees, and Food Prices

China, where some scientists warn that pesticides are overused, gives us a glimpse of a future without enough honeybees. Individual trees in pear orchards in China's Sichuan province are now largely pollinated by hand at great cost. Without honeybees, many fruits, vegetables, and nuts that depend on bees for pollination could become too expensive for most people worldwide. Prices of meat and dairy products would also rise, because honeybees pollinate forage crops such as alfalfa and clover hay that are fed to farm animals. This shows what can happen when we severely impair one of nature's free ecological services such as pollination.

So what can we do to reduce threats to honeybees? Many beekeepers are having some success in reducing CCD by practicing stringent hygiene, improving the diets of the bees, and trying to reduce viral infections. But everyone can help. The USDA suggests that we cut back on our use of pesticides, especially at midday when honeybees are most likely to be searching for nectar. We can also make our yards and gardens into buffets for bees by planting native plants that they like, such as bee balm, foxglove, red clover, and joe-pye weed. Bees also need places to live, so some homeowners are purchasing bee houses from their local garden centers.

THINKING ABOUT
Honeybees

What difference would it make to you if most of the honeybees disappeared? What are two things you could do to help reduce the loss of honeybees?

Illegally Killing, Capturing, and Selling of Wild Species Threatens Biodiversity

Some protected species are illegally killed (poached) for their valuable parts or are sold live to collectors. Globally, this illegal trade in wildlife brings in an average of at least $600,000 an hour. Organized crime has moved into illegal wildlife smuggling because of the huge profits involved—surpassed only by the illegal international trade in drugs and weapons. Few of the smugglers are caught or punished and at least two-thirds of all live animals smuggled around the world die in transit.

To poachers, a highly endangered, live mountain gorilla (Figure 9-16) is worth $150,000; a pelt of a critically endangered giant panda (less than 1,600 left in the wild in China) $100,000; a live chimpanzee $50,000; and a live Komodo dragon lizard from Indonesia $30,000. A poached rhinoceros horn (Figure 9-17) can be worth as much as $55,500 per kilogram ($25,000 per pound). Rhinoceros are killed for no reason other than to harvest their horns, which are used to make dagger handles in the Middle East and as a fever reducer and alleged aphrodisiac in China and other parts of Asia.

Martin Harvey/Peter Arnold, Inc

Figure 9-17 This white rhinoceros was killed by a poacher in South Africa solely for its horns. **Question:** What would you say if you could talk to the person who killed this animal?

Jiri Haureljuk/ Shutterstock

Figure 9-16 This male mountain gorilla inhabits the bush of the African country of Rwanda. Mountain gorillas feed mostly on the leaves, shoots, and stems of a variety of plants. Only about 700 individuals of this critically endangered species remain in the wild.

Elephants continue to lose habitat in Africa and Asia (Figure 9-10). In addition, each year about 25,000 African elephants are killed illegally for their valuable ivory tusks, despite an international ban on the sale of poached ivory since 1989. **Explore More:** See a Science Focus at **www.cengage.com/login** to learn about how scientists are using DNA samples to help reduce the illegal killing of elephants for their ivory.

In 1900, an estimated 100,000 tigers roamed free in the world. Despite international protection, only about 3,400 to 5,100 adult tigers remain in the wild, in a rapidly shrinking range, according to a 2009 study by the IUCN. Today, all six tiger subspecies are endangered in the wild and roam across only about 7% of their former natural range.

For example, the Indian or Bengal tiger (Figure 9-10, top left) is at risk because a coat made from its fur can sell for as much as $100,000 in Tokyo. With the body parts of a single tiger worth as much as $70,000—and because few of its poachers are caught or punished—it is not surprising that the illegal hunting of tigers has skyrocketed or that they have become highly endangered species (Figure 9-2a). According to tiger experts, without emergency action to curtail poaching and preserve their habitat, it is likely that few if any tigers will be left in the wild within 20 years.

THINKING ABOUT
Tigers

What do you think would happen to their ecosystems if all the world's tigers disappeared? What are two steps that could be taken to help protect the world's remaining tigers from extinction?

Across the globe, the legal and illegal trade in wild species for use as pets is also a huge and very profitable business. Many owners of wild pets do not know that, for every live animal captured and sold in the pet market, many others are killed or die in transit. More than 60 bird species, mostly parrots (Figure 9-8), are endangered or threatened because of the wild bird trade.

CONNECTIONS
The Pet Trade and Infectious Diseases

Most people are unaware that some imported exotic animals carry diseases such as hantavirus, Ebola virus, Asian bird flu, herpes B virus (carried by most adult macaques), and salmonella (from pets such as hamsters, turtles, and iguanas). These are diseases that can spread quite easily from pets to their owners and then to other people.

Other wild species whose populations are depleted because of the pet trade include many amphibians, various reptiles, some mammals, and tropical fishes (taken mostly from the coral reefs of Indonesia and the Philippines). Divers catch tropical fish by using plastic squeeze bottles of poisonous cyanide to stun them. For each fish caught alive, many more die. In addition, the cyanide solution kills the coral animals (polyps) that create the reef.

Some exotic plants, especially orchids and cacti (see Figure 7-10, center, p. 155), are endangered because they are gathered (often illegally) and sold to collectors to decorate houses, offices, and landscapes. A collector might pay $5,000 for a single rare orchid. A mature crested saguaro cactus can earn cactus rustlers as much as $15,000.

Wild species in their natural habitats have ecological value because of the roles they play in their ecosystems. They can also have great economic value if left in the wild. According to the U.S. Fish and Wildlife Service, collectors of exotic birds may pay $10,000 for an endangered hyacinth macaw parrot (Figure 9-8) smuggled out of Brazil. But during its lifetime, a single hyacinth macaw left in the wild might account for as much as $165,000 in tourist revenues. Some scientists are using this sort of information in their efforts to preserve biodiversity (Individuals Matter, below).

INDIVIDUALS MATTER

GOOD NEWS

A Scientist Who Confronted Poachers

In Thailand, biologist Pilai Poonswad (Figure 9-A) decided to do something about poachers taking rhinoceros hornbills (Figure 9-B) from a rain forest. This bird species is one of the world's largest hornbills and its large beak amplifies its peculiar and loud squawking.

Dr. Poonswad visited the poachers in their villages and showed them why the birds are worth more alive than dead. Today, some former poachers earn money by taking ecotourists into the forest to see these magnificent birds. Because of their vested financial interest in preserving the hornbills, these former poachers now help to protect the birds from further poaching.

The rhinoceros hornbill's population in this area of Thailand was in steady decline, but partly because of Dr. Poonswad's work, it is now gradually recovering. It is considered to be an indicator species in some of its tropical rain forest habitats.

©Rolex Awards/Tomas Bertelsen

Figure 9-A Professor Pilai Poonswad, a biologist at Mahidol University in Thailand, decided to confront poachers who were a threat to the rare rhinoceros hornbill.

Karen McGougan/Bruce Coleman USA

Figure 9-B The rare Rhinoceros hornbill is found in tropical and subtropical forest habitats in parts of Asia. It emits a loud honking squawk and uses its long bill to defend itself from predators such as snakes and monkeys. Its habitat is threatened by agricultural development and logging, and in some areas, the hornbill is threatened by local tribesmen who kill it for food and for its feathers. It is also captured and sold live as part of the illegal wildlife trade.

THINKING ABOUT
Collecting Wild Species

Some people believe it is unethical to collect wild animals and plants for display and personal pleasure. They believe we should leave most exotic wild species in the wild. Explain why you agree or disagree with this view.

CONNECTIONS
Bush Meat Hunting and Overfishing

A 2004 study showed that people living in coastal areas of West Africa have stepped up bush-meat hunting because local fish harvests have declined due to overfishing by heavily subsidized European Union fishing fleets.

Rising Demand for Bush Meat Threatens Some African Species

Indigenous people in much of West and Central Africa have for centuries sustainably hunted wildlife for *bush meat* as a source of food. But in the last 2 decades, bush-meat hunting in some areas has skyrocketed as hunters try to provide food for rapidly growing populations or to make a living by supplying restaurants with exotic meats (Figure 9-18). Logging roads have enabled miners, ranchers, and settlers to move into once-inaccessible forests, which has made it easier to hunt animals for bush meat.

Figure 9-18 *Bush meat* such as this severed head of an endangered lowland gorilla in the Congo is consumed as a source of protein by local people in parts of West and Central Africa and is sold in national and international marketplaces. You can find bush meat on the menu in Cameroon and the Democratic Republic of the Congo in West Africa as well as in Paris, London, Toronto, New York, and Washington, DC. Poachers are often the suppliers of bush meat. Wealthy patrons of some restaurants regard gorilla meat as a source of status and power. **Question:** How, if at all, is this different from killing a cow for food?

So what is the big deal? After all, people have to eat. For most of our existence, humans have survived by hunting and gathering wild species.

One problem today is that bush-meat hunting has led to the local extinction of many wild animals in parts of West and Central Africa. It has driven at least one species—Miss Waldron's red colobus monkey—to complete extinction. It is also a factor in reducing orangutan (Figure 9-6), gorilla (Figure 9-16), chimpanzee, elephant, and hippopotamus populations. According to the IUCN, almost half (48%) of the world's primates (including orangutans, chimpanzees, and lemurs) were in danger of extinction in 2008 (compared to 39% in 2003), mostly as a result of habitat loss and bush-meat hunting. Another problem is that butchering and eating some forms of bush meat has helped to spread fatal diseases such as HIV/AIDS and the Ebola virus from animals to humans.

The U.S. Agency for International Development (USAID) is trying to reduce unsustainable hunting for bush meat in some areas of Africa by introducing alternative sources of food such as farmed fish. They are also showing villagers how to breed large rodents such as cane rats as a source of food.

CASE STUDY

A Disturbing Message from the Birds

Approximately 70% of the world's nearly 10,000 known bird species are declining in numbers, and much of this decline is clearly related to human activities, summarized by HIPPCO.

First, roughly one of every eight (12%) of all bird species is threatened with extinction mostly by habitat loss, degradation, and fragmentation (the H in HIPPCO), according to the 2009 *Red List of Endangered Species* published by the International Union for Conservation of Nature (IUCN). About three-fourths of the threatened bird species live in forests, many of which are being cleared at a rapid rate, especially in the tropical areas of Asia and Latin America.

In 2009, the U.S. Fish and Wildlife Service and the U.S Geological Survey, in cooperation with conservation groups and volunteer birdwatchers (see **www.stateofthebirds.org**) published the *State of the Birds* report. According to this exhaustive scientific study, nearly one-third of the more than 800 bird species in the United States are endangered or threatened, mostly because of habitat loss and degradation, invasive species, and climate change. Most of these declining bird species live in forests and grasslands, as well as in arid habitats where bird populations have declined as much as 40% since 1968.

The greatest declines have occurred among long-distance migrant songbird species such as tanagers, orioles, thrushes, vireos, and warblers. These birds nest deep in North American woods in the summer and spend their winters in Central or South America or on the Caribbean Islands.

The primary causes of these population declines appear to be habitat loss and fragmentation of the birds' breeding habitats. In North America, road construction and housing developments result in the breaking up or clearing of woodlands. In Central and South America, tropical forest habitats, mangroves, and wetland forests are suffering the same fate. In addition, the populations of 40% of the world's water birds are in decline because of the global loss of wetlands.

After habitat loss, the intentional or accidental introduction of nonnative species such as bird-eating rats is the second greatest danger, affecting about 28% of the world's threatened birds. Other such invasive species (the I in HIPPCO) are snakes, mongooses, and both domestic and feral cats, which kill hundreds of millions of birds each year.

Millions of migrating birds are killed each year when they collide with power lines, communications towers, and skyscrapers that have been erected within their migration routes. As many as 1 billion birds in the United States die each year when they fly into glass windows, especially those in tall city buildings that are lit up at night. This is the number one cause of U.S. bird mortality.

The second P in HIPPCO is for pollution, another major threat to birds. Countless birds are exposed to oil spills, pesticides, and herbicides that destroy their habitats. And birds sometimes eat lead shotgun pellets that fall into wetlands and lead sinkers left by anglers. Lead poisoning is a severe threat to many birds, especially waterfowl.

The greatest new threat to birds is climate change. A 2006 review of more than 200 scientific articles, done for the WWF, found that climate change is causing declines of some bird populations in every part of the globe. And this is expected to increase sharply during this century.

Finally, overexploitation of birds and other species is a major threat to bird populations. Fifty-two of the world's 388 parrot species (Figure 9-8) are threatened partly because so many parrots are captured (often illegally) for the pet trade. They are taken from tropical areas and sold, usually to buyers in Europe and the United States.

Industrialized fishing fleets also pose a threat. At least 23 species of seabirds, including albatrosses (Figure 9-19), face extinction. Many of these diving birds drown after becoming hooked on baited lines or trapped in huge nets that are set out by fishing boats.

Figure 9-19 The IUCN reports that 82% of albatrosses are threatened. The black-browed albatross shown here is endangered because of a drastic reduction in its population, due largely to long-line and trawler fishing fleets whose hooks and nets ensnare and drown these birds when they dive into the water for food.

Biodiversity scientists view this decline of bird species with alarm. One reason is that birds are excellent *environmental indicators* because they live in every climate and biome, respond quickly to environmental changes in their habitats, and are relatively easy to track and count.

Furthermore, birds perform critically important ecological and economic services in ecosystems throughout the world. For example, many birds play specialized roles in pollination and seed dispersal, especially in tropical areas. Extinctions of these species might lead to extinctions of plants that depend on the birds for pollination. Then some specialized animals that feed on these plants may also become extinct. This cascade of extinctions, in turn, can affect our own food supplies and well-being. Protecting birds and their habitats is not only a conservation issue; it is an important issue for human health as well (Science Focus, p. 209).

Biodiversity scientists urge us to listen more carefully to what birds are telling us about the state of the environment, for their sake, as well as for ours.

THINKING ABOUT
Bird Extinctions

How does your lifestyle directly or indirectly contribute to the extinction of some bird species? What are two things that you think should be done to reduce the extinction of birds?

RESEARCH FRONTIER

Learning more about why birds are declining, what it implies for the biosphere, and what can be done about it; see **www.cengage.com/login**.

SCIENCE FOCUS

Vultures, Wild Dogs, and Rabies: Some Unexpected Scientific Connections

In 2004, the World Conservation Union placed three species of vultures found in India and South Asia on the critically endangered list. During the early 1990s, there were more than 40 million of these carcass-eating vultures. But within a few years their populations had fallen by more than 97%.

This is an interesting scientific mystery, but should anyone care if various vulture species disappear? The answer is yes.

Scientists were puzzled, but they eventually discovered that the vultures were being poisoned by *diclofenac*. This anti-inflammatory drug was given to cows to help increase their milk production by reducing inflammation in their bodies. But it caused kidney failure in vultures that fed on the carcasses of such cows.

As the vultures died off, huge numbers of cow carcasses, normally a source of food for the vultures, were now consumed by wild dogs and rats whose populations the vultures had helped to control by reducing their food supply. As wild dog populations exploded due to a greatly increased food supply, the number of dogs with rabies also increased. This increased the risks to people bitten by rabid dogs. In 1997 alone, more than 30,000 people in India died of rabies—more than half the world's total number of rabies deaths that year.

Thus, protecting vulture species from extinction can result in the protection of millions of people from a life-threatening disease. Discovering often-unexpected ecological connections in nature is not only fascinating but also vital to our own lives and health.

Some critics of efforts to protect species and ecosystems from harmful human activities frame the issue as one of choosing between protecting people and protecting wildlife. Most conservation biologists reject this as a misleading conclusion, arguing that it is important to protect both wildlife and people because their fates and well-being are interconnected.

Critical Thinking

What would happen to your life and lifestyle if most of the world's vultures disappeared?

9-4 How Can We Protect Wild Species from Extinction?

CONCEPT 9-4 We can reduce the rising rate of species extinction and help to protect overall biodiversity by establishing and enforcing national environmental laws and international treaties, creating a variety of protected wildlife sanctuaries, and taking precautionary measures to prevent such harm.

International Treaties and National Laws Can Help to Protect Species

Several international treaties and conventions help to protect endangered or threatened wild species (**Concept 9-4**). One of the most far reaching is the 1975 *Convention on International Trade in Endangered Species (CITES).* This treaty, signed by 175 countries, bans the hunting, capturing, and selling of threatened or endangered species. It lists some 900 species that cannot be commercially traded as live specimens or for their parts or products because they are in danger of extinction. It also restricts international trade of roughly 5,000 species of animals and 28,000 species of plants that are at risk of becoming threatened.

CITES has helped to reduce the international trade of many threatened animals, including elephants, crocodiles, cheetahs, and chimpanzees. But the effects of this treaty are limited because enforcement varies from country to country, and convicted violators often pay only small fines. Also, member countries can exempt themselves from protecting any listed species, and much of the highly profitable illegal trade in wildlife and wildlife products goes on in countries that have not signed the treaty.

The *Convention on Biological Diversity (CBD),* ratified by 191 countries (but as of 2010, not by the United States), legally commits participating governments to reducing the global rate of biodiversity loss and to equitably sharing the benefits from use of the world's genetic resources. This includes efforts to prevent or control the spread of ecologically harmful invasive species.

This convention is a landmark in international law because it focuses on ecosystems rather than on individual species, and it links biodiversity protection to issues such as the traditional rights of indigenous peoples. However, because some key countries, including the United States, have not ratified it, implementation has been slow. Also, the law contains no severe penalties or other enforcement mechanisms.

The U.S. Endangered Species Act

The *Endangered Species Act of 1973* (ESA; amended in 1982, 1985, and 1988) was designed to identify and protect endangered species in the United States and abroad

(**Concept 9-4**). This act is probably the most far-reaching environmental law ever adopted by any nation, which has made it controversial.

Under the ESA, the National Marine Fisheries Service (NMFS) is responsible for identifying and listing endangered and threatened ocean species, while the U.S. Fish and Wildlife Service (USFWS) is to identify and list all other endangered and threatened species. Any decision by either agency to add a species to, or remove one from, the list must be based on biological factors alone, without consideration of economic or political factors. However, the two agencies can use economic factors in deciding whether and how to protect endangered habitat and in developing recovery plans for listed species. The ESA also forbids federal agencies (except the Defense Department) to carry out, fund, or authorize projects that would jeopardize any endangered or threatened species or destroy or modify its critical habitat.

For offenses committed on private lands, fines as high as $100,000 and 1 year in prison can be imposed to ensure protection of the habitats of endangered species, although this provision has rarely been used. This part of the act has been controversial because at least 90% of the listed species live totally or partially on private land. The ESA also makes it illegal for Americans to sell or buy any product made from an endangered or threatened species or to hunt, kill, collect, or injure such species in the United States.

Between 1973 and 2010, the number of U.S. species on the official endangered and threatened species lists increased from 92 to more than 1,370. According to a study by the Nature Conservancy, one-third of the country's species are at risk of extinction, and 15% of all species are at high risk—far more than the current number of listed species. (For the latest numbers and other current details, go to **http://ecos.fws.gov/tess_public/TESSBoxscore**, a U.S. Fish and Wildlife Service website. And for a clickable map listing endangered U.S. species by state, see **http://www.endangeredspecie.com/map.htm**.)

Steve Hillebrand/U.S. Fish and Wildlife Service

Figure 9-20 These confiscated products were made from endangered species. Because of a scarcity of funds and inspectors, probably no more than one-tenth of the illegal wildlife trade in the United States is discovered. The situation is even worse in most other countries.

The USFWS or the NMFS is supposed to prepare a plan to help each listed species recover, including designating and protecting critical habitat. In 2009, 90% of the protected species were covered by active recovery plans. Examples of successful recovery plans include those for the American alligator (Case Study, p. 99), the gray wolf, the peregrine falcon, the bald eagle, and the brown pelican.

GOOD NEWS

The ESA also protects an additional 573 species from other countries. The law requires that all commercial shipments of wildlife and wildlife products enter or leave the country through one of nine designated ports. The 120 full-time USFWS inspectors can inspect only a small fraction of the more than 200 million wild animals brought legally into the United States annually. Each year, tens of millions of wild animals are also brought in illegally, but few illegal shipments of endangered or threatened animals or plants are confiscated (Figure 9-20). Even when they are caught, many violators are not prosecuted, and convicted violators often pay only a small fine. Thus, this part of the Endangered Species Act need to be greatly strengthened.

Since 1982, the ESA has been amended to give private landowners economic incentives to help save endangered species living on their lands. The goal is to strike a compromise between the interests of private landowners and those of endangered and threatened species. For example, a developer, landowner, or logger may be allowed to destroy critical habitat for an endangered species by paying to relocate the species to another favorable habitat. The ESA has also been used to protect endangered and threatened marine reptiles (turtles) and mammals (especially whales, seals, and sea lions), as we discuss in Chapter 11.

Some believe that the Endangered Species Act should be weakened or repealed, and others believe it should be strengthened and modified to focus on protecting ecosystems. Opponents of the act contend that it puts the rights and welfare of endangered plants and animals above those of people. They also argue that it has not been effective in protecting endangered species and has caused severe economic losses by hindering development on private lands.

Since 1995, there have been numerous efforts to weaken the ESA and to reduce its already meager annual budget, which is less than what a beer company typically spends on two 30-second TV commercials during the annual U.S. football championship game, the Super Bowl. Other critics would go further and do away with the ESA.

Most conservation biologists and wildlife scientists agree that the ESA needs to be simplified and streamlined. But they contend that it has not been a failure (Science Focus, at right).

SCIENCE FOCUS

Accomplishments of the Endangered Species Act

Critics of the ESA call it an expensive failure because only 46 species have been removed from the endangered list. Most biologists insist that it has not been a failure, for four reasons.

First, species are listed only when they face serious danger of extinction. Arguing that the act is a failure is similar to arguing that a poorly funded hospital emergency room set up to take only the most desperate cases, often with little hope for recovery, should be shut down because it has not saved enough patients.

Second, it takes decades for most species to become endangered or threatened. Not surprisingly, it also takes decades to bring a species in critical condition back to the point where it can be removed from the critical list. Expecting the ESA—which has been in existence only since 1973—to quickly repair the biological depletion that took place over many decades is unrealistic.

Third, according to federal data, the conditions of more than half of the listed species are stable or improving, and 99% of the protected species are still surviving. A hospital emergency room taking only the most desperate cases and then stabilizing or improving the conditions of more than half of those patients while keeping 99% of them alive would be considered an astounding success.

Fourth, the 2010 budget for protecting endangered species amounted to an average expenditure of about 9¢ per U.S. citizen. To its supporters, it is amazing that the ESA, on such a small budget, has managed to stabilize or improve the conditions of more than half of the listed species.

Its supporters would agree that the act can be improved and that federal regulators have sometimes been too heavy handed in enforcing it. But instead of gutting or doing away with the ESA, some biologists call for it to be strengthened and modified. A study by the U.S. National Academy of Sciences recommended three major changes to make the ESA more scientifically sound and effective:

1. Greatly increase the meager funding for implementing the act.
2. Develop recovery plans more quickly. A 2006 study by the Government Accountability Office (GAO), found that species with recovery plans have a better chance of getting off the endangered list, and it recommended that any efforts to reform the law should continue to require recovery plans.
3. When a species is first listed, establish the core of its habitat as critical for its survival. This would be a temporary emergency measure that could support the species for 25–50 years.

Most biologists and wildlife conservationists believe that the United States also needs a new law that emphasizes protecting and sustaining biological diversity and ecosystem functioning rather than focusing mostly on saving individual species. (We discuss this idea further in Chapter 10.)

Critical Thinking

Should the U.S. Endangered Species Act be modified to protect and sustain the nation's overall biodiversity more effectively? Explain.

We Can Establish Wildlife Refuges and Other Protected Areas

In 1903, President Theodore Roosevelt established the first U.S. federal wildlife refuge at Pelican Island, Florida (Figure 9-21), to help protect birds such as the brown pelican (Figure 9-21, insert) from extinction. It took more than a century but this protection worked. In 2009, the brown pelican was removed from the U.S. Endangered Species list. Since then, the National Wildlife Refuge System has grown to include 548 refuges. Each year, more than 40 million Americans visit these refuges to hunt, fish, hike, and watch birds and other wildlife.

More than three-fourths of the refuges serve as wetland sanctuaries that are vital for protecting migratory waterfowl such as snow geese (see Figure 5-11, p. 112). One-fifth of U.S. endangered and threatened species have habitats in the refuge system, and some refuges have been set aside for specific endangered species (**Concept 9-4**). Such areas have helped Florida's key deer, the brown pelican, and the trumpeter swan to recover. National parks and other government sanctuaries have also been used to help protect species such as the American bison. **Explore More:** See a Case Study at **www.cengage.com/login** to learn about the return of the American bison from the brink of extinction.

George Gentry/U.S. Fish and Wildlife Service

Jeremy Woodhouse/Peter Arnold, Inc.

Figure 9-21 The Pelican Island National Wildlife Refuge in Florida was America's first National Wildlife Refuge. It was established in 1903 to help protect the brown pelican (see photo insert) and other birds from extinction. In 2009, the brown pelican was removed from the U.S. endangered species list.

But the news about refuges is not all good. According to a General Accounting Office study, activities considered harmful to wildlife such as mining, oil drilling, and use of off-road vehicles occur in nearly 60% of the nation's wildlife refuges. In addition, a 2008 study prepared for Congress found that, for years, the country's wildlife refuges have received so little funding that a third of them have no staff, and boardwalks, public buildings, and other structures in some refuges are in disrepair.

Biodiversity scientists in the United States are urging the government to set aside more refuges for endangered plants and to significantly increase the long-neglected budget for the refuge system. They are also calling on the U.S. Congress as well as on state legislatures to allow abandoned military lands that contain significant wildlife habitat to become national or state wildlife refuges.

Gene Banks, Botanical Gardens, and Wildlife Farms Can Help to Protect Species

Gene or *seed banks* preserve genetic information and endangered plant species by storing their seeds in refrigerated, low-humidity environments. More than 100 seed banks around the world collectively hold about 3 million samples.

But some species cannot be preserved in gene banks. The banks are of varying quality, expensive to operate, and can be destroyed by fires and other mishaps. However, a new underground vault on a remote island in the Arctic will eventually contain 100 million of the world's seeds. It is not vulnerable to power losses, fires, storms, or war.

The world's 1,600 *botanical gardens* and *arboreta* contain living plants that represent almost one-third of the world's known plant species. But they contain only about 3% of the world's rare and threatened plant species and have too little space and funding to preserve most of those species.

We can take pressure off some endangered or threatened species by raising individuals of these species on *farms* for commercial sale. In Florida, for example, alligators are raised on farms for their meat and hides. Butterfly farms established to raise and protect endangered species flourish in Papua New Guinea, where many butterfly species are threatened by development activities. These farms are also used to educate visitors about the need to protect butterfly species.

Zoos and Aquariums Can Protect Some Species

Zoos, aquariums, game parks, and animal research centers are being used to preserve some individuals of critically endangered animal species, with the long-term goal of reintroducing the species into protected wild habitats.

Two techniques for preserving endangered terrestrial species are egg pulling and captive breeding. *Egg pulling* involves collecting wild eggs laid by critically endangered bird species and then hatching them in zoos or research centers. In *captive breeding*, some or all of the wild individuals of a critically endangered species are collected for breeding in captivity, with the aim of reintroducing the offspring into the wild. Captive breeding has been used to save the peregrine falcon and the California condor (Figure 9-2c).

Other techniques for increasing the populations of captive species include artificial insemination, embryo transfer (surgical implantation of eggs of one species into a surrogate mother of another species), use of incubators, and cross fostering (in which the young of a rare species are raised by parents of a similar species). Scientists also use computer databases, which hold information on family lineages of species in zoos, and DNA analysis to match individuals for mating—a computer dating service for zoo animals. This method also prevents genetic erosion caused by inbreeding within small surviving populations.

The ultimate goal of captive breeding programs is to build up populations to a level where they can be reintroduced into the wild. But after more than two decades of captive breeding efforts, only a handful of endangered species have been returned to the wild. Examples include the black-footed ferret, the California condor (see the Case Study at right), and the golden lion tamarin (a highly endangered monkey species). But most reintroductions fail because of lack of suitable habitat, the inability of individuals bred in captivity to survive in the wild, renewed overhunting, or the poaching of some of the returned individuals.

The captive population of an endangered species must number 100–500 individuals in order for it to avoid extinction through accident, disease, or loss of genetic diversity through inbreeding. Recent genetic research indicates that 10,000 or more individuals are needed for an endangered species to maintain its capacity for biological evolution. Zoos and research centers do not have the funding or space to house such large populations.

Public aquariums that exhibit unusual and attractive species of fish and some marine animals such as seals and dolphins help to educate the public about the need to protect such species. But mostly because of limited funds, public aquariums have not served as effective gene banks for endangered marine species, especially marine mammals that need large volumes of water such as the endangered Southern sea otter (see Chapter 5 Core Case Study, p. 104).

Thus, use of zoos, aquariums, and botanical gardens is not a biologically or economically feasible solution for the growing problem of species extinction. Figure 9-22 lists some things you can do to help deal with this problem.

What Can You Do?

Protecting Species

- Do not buy furs, ivory products, or other items made from endangered or threatened animal species.
- Do not buy wood or paper products produced by cutting old-growth forests in the tropics.
- Do not buy birds, snakes, turtles, tropical fish, and other animals that are taken from the wild.
- Do not buy orchids, cacti, or other plants that are taken from the wild.
- Spread the word. Talk to your friends and relatives about this problem and what they can do about it.

Figure 9-22 **Individuals matter:** You can help prevent the extinction of species. **Questions:** Which two of these actions do you believe are the most important? Why?

■ **CASE STUDY**

Trying to Save the California Condor

In the early 1980s, the California condor (Figure 9-2c), North America's largest bird, was nearly extinct, with only 22 birds remaining in the wild. To help save this highly endangered vulture species, scientists captured the remaining birds and bred them in captivity at zoos for eventual return to the wild.

The captured birds were isolated from human contact as much as possible, and to reduce genetic defects, closely related individuals were prevented from breeding. As of 2009, there were 348 living condors. About 180 of them live in the wild throughout the southwestern United States and the rest live in zoos and bird sanctuaries.

A major threat to these birds is lead poisoning, which they can get when they ingest lead pellets from ammunition in the carcasses of animals such as coyotes and rabbits killed by farmers and ranchers and left in the field. They can also get these pellets from the internal organs of animals left by hunters who have field-cleaned their kills. A lead-poisoned condor quickly becomes weak and mentally impaired, and dies of starvation or is killed by predators.

A coalition of conservationist and health organizations is lobbying state game commissions and legislatures to ban the use of lead in ammunition and to require the use of less harmful substitutes. Such a ban has been enacted in California but it is difficult to enforce. Conservationists also urge people who hunt in condor ranges to remove all killed animals and to bury the animals' internal organs after they have field-cleaned their kills or to cover the remains with brush or rocks or put them in inaccessible areas.

Protecting the California condor from almost certain extinction has been expensive and controversial. So far, this program has cost about $35 million, with $25 million coming from federal and state funding. This makes it the most expensive conservation project in U.S. history. Some conservationists contend that this money could have been better spent on protecting a number of other endangered species.

THINKING ABOUT

The California Condor's Shaky Comeback

Do you believe that the funds used to protect the California condor would have been better spent on protecting other highly endangered species? If so, what are two species that you feel deserve more funding to help prevent their extinction?

The Precautionary Principle

Biodiversity scientists call for us to take precautionary action to avoid causing more extinctions and more loss of biodiversity. This approach is based on the **precautionary principle**: When substantial preliminary evidence indicates that an activity can harm human health or the environment, we should take precautionary measures to prevent or reduce such harm even if some of the cause-and-effect relationships have not been fully established scientifically. It is based on the common-sense idea behind many adages, including "Better safe than sorry," and "Look before you leap."

Scientists use the precautionary principle to argue for both the preservation of species and protections of entire ecosystems, which is the focus of the next chapter. The precautionary principle is also used as a strategy for preventing or sharply reducing exposure to harmful chemicals in the air we breathe, the water we drink, and the food we eat.

Using limited financial and human resources to protect biodiversity based on the precautionary principle involves dealing with three important questions:

1. How do we allocate limited resources between protecting species and protecting their habitats?
2. How do we decide which species should get the most attention in our efforts to protect as many species as possible? For example, should we focus on protecting the most threatened species or on protecting keystone and foundation species? Protecting species that are appealing to humans, such as tigers (see Figure 9-2a) and orangutans (Figure 9-6), can increase public awareness of the need for wildlife conservation. But some argue that we should instead protect more ecologically important endangered species.
3. How do we determine which habitat areas are the most critical to protect?

Here are this chapter's *three big ideas*:

- We are greatly increasing the extinction of wild species by destroying and degrading their habitats, introducing harmful invasive species, and increasing human population growth, pollution, climate change, and overexploitation.
- We should avoid causing the extinction of wild species because of the ecological and economic services they provide and because their existence should not depend primarily on their usefulness to us.
- We can work to prevent the extinction of species and to protect overall biodiversity by using laws and treaties, protecting wildlife sanctuaries, and making greater use of the precautionary principle.

REVISITING Polar Bears and Sustainability

CORE CASE STUDY

SUSTAINABILITY

We have learned a lot about how to protect species from extinction that results from our activities. We also know about the importance of wild species as key components of the earth's biodiversity—part of its natural capital—that supports all life and economies.

Yet, despite these efforts, there is overwhelming evidence that as many as half of the world's wild species, including the polar bear (**Core Case Study**), could go extinct during this century, largely as a result of human activities. Ecological ignorance accounts for some of the failure to deal with this problem. But many argue that the real cause of this failure is that we lack the political and ethical will to act on our current scientific knowledge.

In keeping with the three **principles of sustainability** (see back cover), acting to prevent the extinction of species as a result of human activities helps to preserve the earth's biodiversity, energy flow, and matter cycling in ecosystems. Thus, it is not only for these species that we ought to act, but also for the overall long-term health of the biosphere, on which we all depend, as well as for the health and well-being of our own species. Protecting wild species and their habitats is a way of protecting ourselves and our descendants.

Protecting biodiversity is no longer simply a matter of passing and enforcing endangered species laws and setting aside parks and preserves. It will also require slowing projected climate change, which severely threatens the polar bear (**Core Case Study**) and many other species and their habitats. It will also require reducing the size and impact of our ecological footprints.

The great challenge of the twenty-first century is to raise people everywhere to a decent standard of living while preserving as much of the rest of life as possible.

EDWARD O. WILSON

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 191. Describe how human activities threaten polar bears in the Arctic.

2. What is **biological extinction**? Define **background extinction rate** and **mass extinction**. How is an **extinction rate** expressed? What was the background extinction rate (as a percentage)? How can the extinction of a species affect other species and ecosystem services? Describe how scientists estimate extinction rates. Give three reasons why many extinction experts believe that human activities are now causing a new mass extinction. Distinguish between **endangered species** and **threatened species** and give an example of each. List four characteristics that make some species especially vulnerable to extinction. Describe the extinction of the passenger pigeon in North America.

3. What are three reasons for trying to avoid causing the extinction of wild species? Describe two economic and two ecological benefits of having the current variety of species.

4. What are the four underlying causes of species extinction that results from human activities? What is **HIPPCO**? In order, what are the six largest direct causes of extinction of species resulting largely from human activities? What is **habitat fragmentation**? Describe the major effects of habitat loss and fragmentation. Why are island species especially vulnerable to extinction?

5. Give two examples of the benefits of introducing some nonnative species. Give two examples of the harmful effects of nonnative species that have been introduced **(a)** deliberately and **(b)** accidentally. Describe the harmful and beneficial effects of kudzu. List four ways to limit the harmful impacts of nonnative species. Describe the roles of population growth, overconsumption, pollution, and climate change in the extinction of wild species. Explain how pesticides such as DDT can be biomagnified in food chains and webs. Describe the decline of some honeybee populations in the United States, and list possible causes

of the problem. What is colony collapse disorder and what might be causing it? What economic and ecological roles do honeybees play?

6. Describe the poaching of wild species and give three examples of species that are threatened by this illegal activity. Why are wild tigers likely to disappear within a few decades? Describe how Pilai Poonswad helped to protect rare rhinoceros hornbills in Thailand. Describe the threat to some forms of wildlife from increased hunting for bush meat.

7. Describe the major threats to bird species in the world and in the United States. List three reasons why we should be alarmed by the decline of many bird species. Describe the relationships between vultures, wild dogs, and rabies in parts of India.

8. Describe two international treaties that are used to help protect species. Summarize the history of the U.S. Endangered Species Act. How successful has it been, and why is it controversial?

9. Describe the roles and limitations of wildlife refuges, gene banks, botanical gardens, wildlife farms, zoos, and aquariums in protecting some species. Describe efforts to protect the California condor from extinction. What is the **precautionary principle** and how can we use it to help protect wild species and overall biodiversity? What are three important issues related to the use of this principle?

10. What are this chapter's *three big ideas*? Describe how the three **principles of sustainability** are related to protecting the polar bear and other wild species from extinction and to protecting the earth's overall biodiversity.

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. What are three aspects of your lifestyle that might directly or indirectly contribute to the endangerment of the polar bear (**Core Case Study**)?

2. Describe your gut-level reaction to the following statement: "Eventually, all species become extinct. So it does not really matter that the passenger pigeon is extinct, or that the polar bear (**Core Case Study**) or the world's remaining tiger species are endangered mostly because of human activities." Be honest about your reaction, and give arguments to support your position.

3. Do you accept the ethical position that each species has the inherent right to survive without human interference, regardless of whether it serves any useful purpose for humans? Explain. Would you extend this right to the *Anopheles* mosquito, which transmits malaria, and to infectious bacteria? Explain.

4. Wildlife ecologist and environmental philosopher Aldo Leopold wrote this with respect to preventing the extinction of wild species: "To keep every cog and wheel is the first precaution of intelligent tinkering." Explain how this statement relates to the material in this chapter.

5. What would you do if fire ants invaded your yard and house? Explain your reasoning behind your course of action. How might your actions affect other species or the ecosystem you are dealing with?

6. Which of the following statements best describes your feelings toward wildlife?
   a. As long as it stays in its space, wildlife is okay.
   b. As long as I do not need its space, wildlife is okay.
   c. I have the right to use wildlife habitat to meet my own needs.
   d. When you have seen one redwood tree, elephant, or some other form of wildlife, you have seen them all, so lock up a few of each species in a zoo or wildlife park and do not worry about protecting the rest.
   e. Wildlife should be protected in its current ranges.

7. Environmental groups in a heavily forested state want to restrict logging in some areas to save the habitat of an endangered squirrel. Timber company officials argue that the well-being of one type of squirrel is not as important as the well-being of the many families who would be affected if the restriction causes the company to lay off hundreds of workers. If you had the power to decide this issue, what would you do and why? Describe any trade-offs included in your solution.

8. Write an argument for **(a)** preserving a weed species in your yard, and for **(b)** not exterminating a colony of wood-damaging carpenter ants in your home.

9. Congratulations! You are in charge of preventing the extinction, caused by human activities, of a large share of the world's existing species. List the three most important policies you would implement to accomplish this goal.

10. List two questions that you would like to have answered as a result of reading this chapter.

DATA ANAYLSIS

Examine these data released by the World Resources Institute and answer the following questions:

Country	Total Land Area in Square Kilometers (Square Miles)	Protected Area as Percent of Total Land Area (2003)	Total Number of Known Breeding Bird Species (1992–2002)	Number of Threatened Breeding Bird Species (2002)	Threatened Breeding Bird Species as Percent of Total Number of Known Breeding Bird Species
Afghanistan	647,668 (250,000)	0.3	181	11	
Cambodia	181,088 (69,900)	23.7	183	19	
China	9,599,445 (3,705,386)	7.8	218	74	
Costa Rica	51,114 (19,730)	23.4	279	13	
Haiti	27,756 (10,714)	0.3	62	14	
India	3,288,570 (1,269,388)	5.2	458	72	
Rwanda	26,344 (10,169)	7.7	200	9	
United States	9,633,915 (3,718,691)	15.8	508	55	

Source of data: World Resources Institute, *Earth Trends, Biodiversity and Protected Areas, Country Profiles*; http://earthtrends.wri.org/country_profiles/index.php?theme=7

1. Complete the table by filling in the last column. For example, to calculate this value for Costa Rica, divide the number of threatened breeding bird species by the total number of known breeding bird species and multiply the answer by 100 to get the percentage.

2. Arrange the countries from largest to smallest according to total land area. Does there appear to be any correlation between the size of country and the percentage of threatened breeding bird species? Explain your reasoning.

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengagebrain.com/shop/ISBN/0538735341** and choose Chapter 9 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

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Sustaining Terrestrial Biodiversity: The Ecosystem Approach

10

Wangari Maathai and the Green Belt Movement

CORE CASE STUDY

In the mid-1970s, Wangari Maathai (Figure 10-1) took a hard look at environmental conditions in her native African country of Kenya. Tree-lined streams she had known as a child had dried up. Farms and plantations had displaced vast areas of forest and were draining the watersheds and degrading the soil. Clean drinking water, firewood, and nutritious foods were all in short supply.

United Nations Environment Programme

Figure 10-1 Wangari Maathai was the first Kenyan woman to earn a PhD and to head an academic department at the University of Nairobi. In 1977, she organized the internationally acclaimed Green Belt Movement to plant millions of trees throughout Kenya. For her work in protecting the environment and in promoting democracy and human rights, she has received many honors, including 13 honorary doctorate degrees, the Goldman Environmental Prize, the UN Africa Prize for Leadership, induction into the International Women's Hall of Fame, and the 2004 Nobel Peace Prize. This photo shows her receiving news of her Nobel Peace Prize award. After years of being harassed, beaten, and jailed for opposing government policies, she was elected to Kenya's parliament as a member of the Green Party in 2002.

Something inside her told Maathai that she had to do something about this environmental degradation. Starting with a small tree nursery in her backyard in 1977, she founded the Green Belt Movement, which continues today. The main goal of this highly regarded women's self-help group is to organize poor women in rural Kenya to plant and protect millions of trees in order to combat deforestation and provide fuelwood. Since 1977, the 50,000 members of this grassroots group have planted and protected more than 40 million trees.

The women are paid a small amount for each seedling they plant that survives. This gives them an income to help them break out of the cycle of poverty. The trees provide fruits, building materials, and fodder for livestock. They also provide more fuelwood, so that women and children do not have to walk so far to find fuel for cooking and heating. The trees also improve the environment by reducing soil erosion and providing shade and beauty. In addition, they help to slow projected climate change by removing CO_2 from the atmosphere.

The success of the Green Belt Movement has sparked the creation of similar programs in more than 30 other African countries. In 2004, Maathai became the first African woman and the first environmentalist to be awarded the Nobel Peace Prize for her lifelong efforts. Within an hour of learning that she had won the prize (Figure 10-1), Maathai planted a tree, telling onlookers it was "the best way to celebrate." She urged everyone in the world to plant a tree as a symbol of commitment and hope. Maathai tells her story in her book, *The Green Belt Movement: Sharing the Approach and the Experience*, published by Lantern Books in 2003.

Since 1980, *biodiversity* (see Figure 4-2, p. 81) has emerged as a key concept of biology, and it is the focus of one of the three **principles of sustainability** (see back cover). Biologists warn that human population growth, economic development, and poverty are exerting increasing pressure on terrestrial and aquatic ecosystems and on the services they provide that sustain biodiversity. In 2010, a report by two United Nations environmental bodies warned that unless radical and creative action is taken now to conserve the earth's biodiversity, many natural systems that support lives and livelihoods are at risk of collapsing.

This chapter is devoted to helping us understand the threats to the earth's forests, grasslands, and other storehouses of terrestrial biodiversity, and to seeking ways to help sustain these vital ecosystems. To many scientists, sustaining the world's vital biodiversity is one of our most important challenges. Without such biodiversity—a key component of the earth's natural capital—you would not be alive to read these words.

Key Questions and Concepts

10-1 What are the major threats to forest ecosystems?

CONCEPT 10-1A Forest ecosystems provide ecological services far greater in value than the value of raw materials obtained from forests.

CONCEPT 10-1B Unsustainable cutting and burning of forests, along with diseases and insects, all made worse by projected climate change, are the chief threats to forest ecosystems.

10-2 How should we manage and sustain forests?

CONCEPT 10-2 We can sustain forests by emphasizing the economic value of their ecological services, removing government subsidies that hasten their destruction, protecting old-growth forests, harvesting trees no faster than they are replenished, and planting trees.

10-3 How should we manage and sustain grasslands?

CONCEPT 10-3 We can sustain the productivity of grasslands by controlling the numbers and distribution of grazing livestock, and by restoring degraded grasslands.

10-4 How should we manage and sustain parks and nature reserves?

CONCEPT 10-4 Sustaining biodiversity will require more effective protection of existing parks and nature reserves, as well as the protection of much more of the earth's remaining undisturbed land area.

10-5 What is the ecosystem approach to sustaining biodiversity?

CONCEPT 10-5 We can help to sustain terrestrial biodiversity by identifying and protecting severely threatened areas (biodiversity hotspots), restoring damaged ecosystems (using restoration ecology), and sharing with other species much of the land we dominate (using reconciliation ecology).

Note: Supplements 2 (p. S3), 3 (p. S6), 6 (p. S20), and 8 (p. S30) can be used with this chapter.

There is no solution, I assure you, to save Earth's biodiversity other than preservation of natural environments in reserves large enough to maintain wild populations sustainably.

EDWARD O. WILSON

10-1 What Are the Major Threats to Forest Ecosystems?

▶ **CONCEPT 10-1A Forest ecosystems provide ecological services far greater in value than the value of raw materials obtained from forests.**

▶ **CONCEPT 10-1B Unsustainable cutting and burning of forests, along with diseases and insects, all made worse by projected climate change, are the chief threats to forest ecosystems.**

Forests Vary in Their Age, Makeup, and Origins

Natural and planted forests occupy about 30% of the earth's land surface (excluding Greenland and Antarctica). Figure 7-7 (p. 153) shows the distribution of the world's northern coniferous, temperate, and tropical forests. Tropical forests (see Figure 7-13, top, p. 160) account for more than half of the world's forest area, and *boreal*, or northern coniferous, forests (see Figure 7-13, bottom) account for about one-quarter of total forest area.

Forest managers and ecologists classify natural forests into two major types based on their age and structure: old-growth and second-growth forests. An **old-growth forest**, or **primary forest**, is an uncut or regenerated forest that has not been seriously disturbed by human activities or natural disasters for several hundred years or more (Figure 10-2). Old-growth forests are reservoirs of biodiversity because they provide ecological niches for a multitude of wildlife species (see Figure 7-14, p. 161, and Figure 7-15, p. 162).

A **second-growth forest** is a stand of trees resulting from secondary ecological succession (see Figure 5-20, p. 120, and Figure 7-13, center photo, p. 160). These forests develop after the trees in an area have been removed by human activities, such as clear-cutting for

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. GOOD NEWS refers to good news about the environmental challenges we face.

Figure 10-2 **Natural capital:** This old-growth forest is located in the U.S. state of Washington's Olympic National Forest.

timber or cropland, or by natural forces such as fire, hurricanes, or volcanic eruption. In many cases, forests regenerate when individuals plant and tend trees (**Core Case Study**).

CORE CASE STUDY

A **tree plantation**, also called a **tree farm** or **commercial forest**, (Figure 10-3) is a managed forest containing only one or two species of trees that are all of the same age. They are usually harvested by clear-cutting as soon as they become commercially valuable. The land is then replanted and clear-cut again in a regular cycle. When managed carefully, such plantations can produce wood at a fast rate and thus increase their owners' profits. Some analysts project that eventually, tree plantations could supply most of the wood used for industrial purposes such as papermaking. This would help to protect the world's remaining old-growth and secondary forests.

The downside of tree plantations is that, with only one or two tree species, they are much less biologically diverse and less sustainable than old-growth and second-growth forests because they violate nature's biodiversity **principle of sustainability**. In addition, repeated cycles of cutting and replanting eventually deplete the topsoil of nutrients and can lead to an irreversible ecological tipping point that hinders the regrowth of any type of forest on such land. There is also controversy over the increased use of genetically engineered tree species whose seeds could spread to other areas and threaten the natural diversity of second- and old-growth forests.

According to 2007 estimates by the UN Food and Agriculture Organization (FAO), about 60% of the world's forests are second-growth forests, 36% are old-growth or primary forests, and 4% are tree plantations (6% in the United States). The five countries with the largest areas of old-growth forests are Russia, Canada, Brazil, Indonesia, and Papua New Guinea, in that order. Together, they have more than three-fourths of the world's remaining old-growth forests.

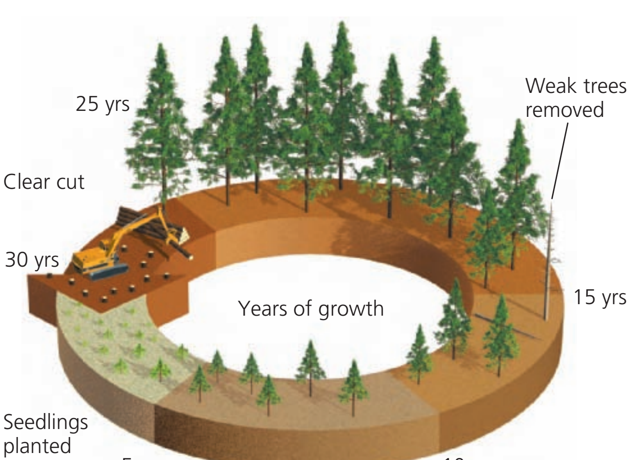


Figure 10-3 This diagram illustrates the short (25- to 30-year) rotation cycle of cutting and regrowth of a monoculture tree plantation. In tropical countries, where trees can grow more rapidly year-round, the rotation cycle can be 6–10 years. Most tree plantations (see photo, right) are grown on land that was cleared of old-growth or second-growth forests. **Question:** What are two ways in which this process can degrade an ecosystem?

Countries with the largest areas of tree plantations are China (which has little original forest left), India, the United States, Russia, Canada, and Sweden, in that order. They account for about 60% of the world's tree plantations. Some conservation biologists urge the establishment of tree plantations only on land that has already been cleared or degraded, instead of cutting down natural forests to make way for tree plantations, as is often done.

Forests Provide Important Economic and Ecological Services

Forests provide highly valuable ecological and economic services (Figure 10-4 and **Concept 10-1A**). For example, through photosynthesis, forests remove CO_2 from the atmosphere and store it in organic compounds (biomass). By performing this ecological service as a part of the global carbon cycle (see Figure 3-19, p. 70), forests help to stabilize average atmospheric temperatures and slow projected climate change. Forests also provide us with oxygen, hold soil in place, and aid in aquifer recharge and flood control. Scientists have attempted to estimate the economic value of this and other ecological services provided by the world's forests and other ecosystems (Science Focus, p. 221).

RESEARCH FRONTIER

Refining estimates of the economic values of ecological services provided by major ecosystems; see **www.cengage.com/login**.

Most biologists warn that the clearing and degrading of the world's remaining old-growth forests is a serious global environmental threat because of the important ecological and economic services they provide. For example, traditional medicines, used by 80% of the world's people, are derived mostly from plant species that are native to forests, and chemicals found in tropical forest plants are used as blueprints for making most of the world's prescription drugs (see Figure 9-7, p. 196). About half of all medications are devised from natural sources, mostly from plant species found in tropical forests. This includes 55 of the 100 most widely prescribed drugs in the United States.

Forests provide habitats for about two-thirds of the earth's terrestrial species. They are also home to more than 300 million people, and one of every four people depends on a forest for making a living.

Unsustainable Logging Is a Major Threat to Forest Ecosystems

Along with highly valuable ecological services, forests provide us with raw materials, especially wood. Harvesting wood is one of the world's major industries. More than half of the wood removed from the earth's forests is used as *biofuel* for cooking and heating. The remainder of the harvest, called *industrial wood*, is used primarily to make lumber and paper.

The first step in harvesting trees is to build roads for access and timber removal. Even carefully designed logging roads have a number of harmful effects (Figure 10-5)—namely, increased erosion and sediment runoff into waterways, habitat fragmentation, and loss of biodiversity. (See *The Habitable Planet*, Video 9, at **www.learner.org/resources/series209.html**). Logging roads also expose forests to invasion by nonnative pests, diseases, and wildlife species. And they open once-inaccessible forests to miners, ranchers, farmers, hunters, and off-road vehicles.

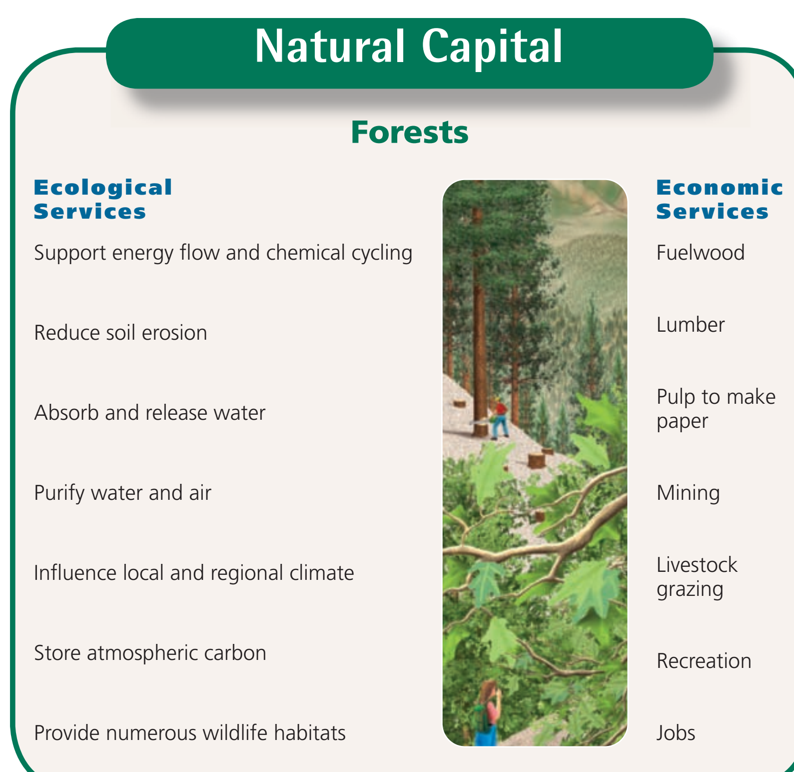


Figure 10-4 Forests provide many important ecological and economic services (**Concept 10-1A**). **Question:** Which two ecological services and which two economic services do you think are the most important?

SCIENCE FOCUS

Putting a Price Tag on Nature's Ecological Services

Currently, forests and other ecosystems are valued mostly for their economic services (Figure 10-4, right). But suppose we took into account the monetary value of the ecological services provided by forests (Figure 10-4, left).

In 1997, a team of ecologists, economists, and geographers, led by ecological economist Robert Costanza of the University of Vermont, estimated the monetary worth of the earth's ecological services, which can be thought of as *ecological income*, somewhat like interest income earned from a savings account. We can think of the earth's *natural capital*—the stock of natural resources that provide the ecological services—as the savings account from which the interest income flows.

Costanza's team estimated the monetary value of the earth's ecological services (the biological or interest income) to be at least $33.2 trillion per year—close to the economic value of all of the goods and services produced annually throughout the world. The researchers also estimated the amount of money that we would have to put into a savings account in order to earn interest income in the amount of $33.2 trillion per year. They arrived at an estimated amount of at least $500 trillion—an average of about $72,460 for each person on earth.

According to Costanza's study, the world's forests provide us with ecological services worth at least $4.7 trillion per year—hundreds of times more than their economic value in terms of lumber, paper, and other wood products. In addition, the researchers believe the data from these studies indicate that their estimates are very conservative.

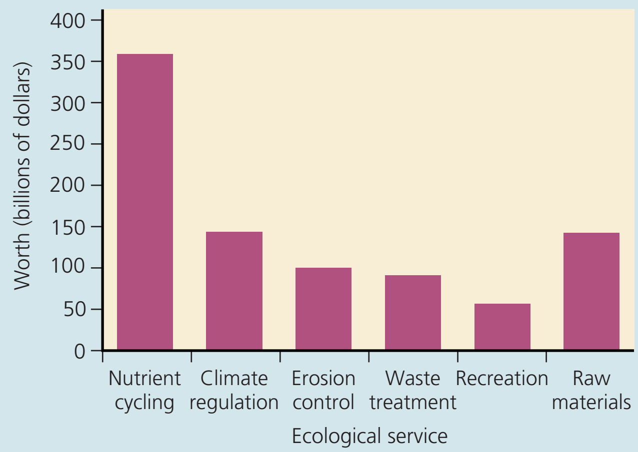


Figure 10-A This chart shows estimates of the annual global economic values of some ecological services provided by forests compared to the raw materials they produce (in billions of dollars). (Data from Robert Costanza)

Costanza's team examined many studies and a variety of methods used to estimate the values of ecosystems. For example, some researchers estimated people's *willingness to pay* for ecosystem services that are not marketed, such as natural flood control and carbon storage. These estimates were added to the known values of marketed goods like timber to arrive at a total value for an ecosystem.

The study by Costanza's team was a *synthesis*, or a combined analysis, of some of those methods and the results of those studies. The researchers estimated total global areas of 16 major categories of ecosystems, including forests, grasslands, and other terrestrial and aquatic systems. They multiplied those areas by the values per hectare of various ecosystem services to get the estimated economic values of these forms of natural capital. Some of the results for forests are shown in Figure 10-A. Note that the collective value of these ecosystem services is much greater than the value of timber and other raw materials extracted from forests (**Concept 10-1A**).

These researchers hope their estimates will alert people to three important facts: the earth's ecosystem services are essential for all humans and their economies; the economic value of these services is huge; and ecosystem services are an ongoing source of ecological income, as long as they are used sustainably.

Critical Thinking

Some analysts believe that we should not try to put economic values on the world's irreplaceable ecological services because their value is infinite. Do you agree with this view? Explain. What is the alternative?

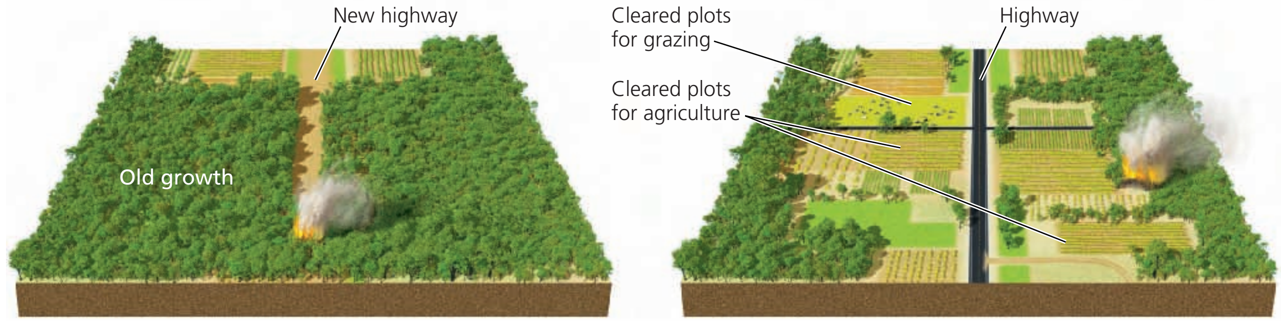


Figure 10-5 **Natural capital degradation:** Building roads into previously inaccessible forests is the first step to harvesting timber, but it also paves the way to fragmentation, destruction, and degradation of forest ecosystems.

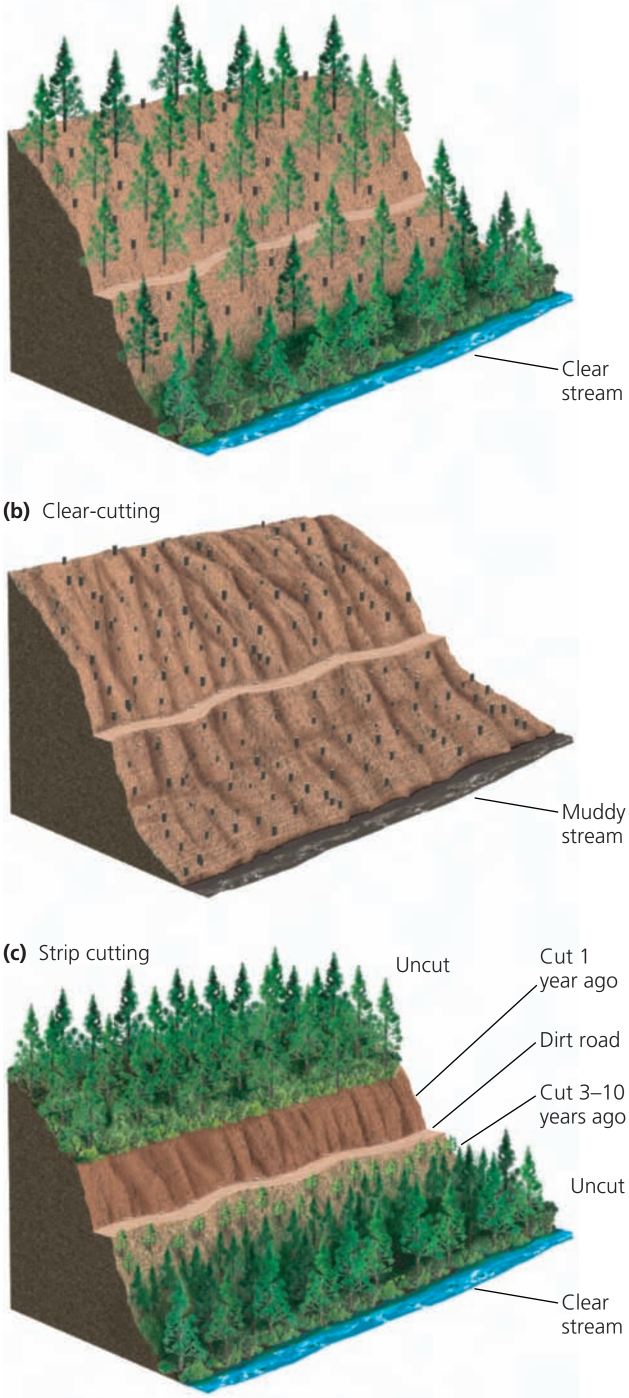


Figure 10-6 This diagram illustrates the three major tree harvesting methods. **Question:** If you were cutting trees in a forest you owned, which method would you choose and why?

Figure 10-7 This aerial photograph shows the results of clear-cut logging in the U.S. state of Washington.

Once loggers reach a forest area, they use a variety of methods to harvest the trees (Figure 10-6). With *selective cutting*, intermediate-aged or mature trees in a forest are cut singly or in small groups (Figure 10-6a). However, loggers often remove all the trees from an area in what is called a *clear-cut* (Figures 10-6b and 10-7). Clear-cutting is the most efficient way for a logging operation to harvest trees, but it can do considerable harm to an ecosystem. Figure 10-8 summarizes some advantages and disadvantages of clear-cutting.

CONNECTIONS

Clear-Cutting and Loss of Biodiversity

Scientists have found that removing all the tree cover from a forest area greatly increases water runoff and loss of soil nutrients (see Chapter 2 Core Case Study, p. 31, and Figure 2-6, p. 40). This increases topsoil erosion, which in turn causes more vegetation to die, leaving barren ground that can be eroded further. More erosion also means more pollution of streams in the watershed, and all of these effects can destroy terrestrial and aquatic habitats and degrade biodiversity.

CENGAGENOW™ Learn more about how deforestation can affect the drainage of a watershed and disturb its ecosystem at CengageNOW.

Trade-Offs

Clear-Cutting Forests

Advantages	Disadvantages
Higher timber yields	Reduces biodiversity
Maximum profits in shortest time	Destroys and fragments wildlife habitats
Can reforest with fast-growing trees	Increases water pollution, flooding, and erosion on steep slopes
Good for tree species needing full or moderate sunlight	Eliminates most recreational value

Figure 10-8 Clear-cutting forests has advantages and disadvantages. **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

A variation of clear-cutting that allows a more sustainable timber yield without widespread destruction is *strip cutting* (Figure 10-6c). It involves clear-cutting a strip of trees along the contour of the land within a corridor narrow enough to allow natural forest regeneration within a few years. After regeneration, loggers cut another strip next to the first, and so on.

GOOD NEWS

Biodiversity experts are alarmed at the growing practice of illegal, uncontrolled, and unsustainable logging taking place in 70 countries, especially in Africa and Southeast Asia (**Concept 10-1B**). Such logging has ravaged 37 of the 41 national parks in the African country of Kenya (**Core Case Study**) and now makes up 73–80% of all logging in Indonesia.

CORE CASE STUDY

Complicating this issue is the global trade in timber and wood products. For example, China, which has cut most of its own natural forests, imports more tropical rain forest timber than any other nation. Much of this timber is harvested illegally and unsustainably and is used to make furniture, plywood, flooring, and other products that are sold in the global marketplace.

Fire, Insects, and Climate Change Can Threaten Forest Ecosystems

Two types of fires can affect forest ecosystems. *Surface fires* (Figure 10-9, left) usually burn only undergrowth and leaf litter on the forest floor. They may kill seedlings and small trees, but they spare most mature trees and allow most wild animals to escape.

Occasional surface fires have a number of ecological benefits: they burn away flammable ground material such as dry brush and help to prevent more destructive fires; they also free valuable mineral nutrients tied up in slowly decomposing litter and undergrowth; they release seeds from the cones of tree species such as lodgepole pines; they stimulate the germination of certain tree seeds such as those of the giant sequoia and jack pine; and they help to control tree diseases and insects. Wildlife species including deer, moose, muskrat, and quail depend on occasional surface fires to maintain

David J. Moorhead/The University of Georgia

age fotostock/SuperStock

Figure 10-9 Surface fires (left) usually burn only undergrowth and leaf litter on a forest floor. They can help to prevent more destructive crown fires (right) by removing flammable ground material. In fact, carefully controlled surface fires sometimes are deliberately set to prevent the buildup of flammable ground material in forests. Surface fires also recycle nutrients and thus help to maintain the productivity of a variety of forest ecosystems. **Question:** What is another way in which a surface fire might benefit a forest?

their habitats and to provide food in the form of the young, tender vegetation that sprouts after fires.

Another type of fire, called a *crown fire* (Figure 10-9, right), is an extremely hot fire that leaps from treetop to treetop, burning whole trees. Crown fires usually occur in forests that have not experienced surface fires for several decades, a situation that allows dead wood, leaves, and other flammable ground litter to accumulate. These rapidly burning fires can destroy most vegetation, kill wildlife, increase soil erosion, and burn or damage human structures in their paths.

As part of a natural cycle based on secondary ecological succession (see Figures 5-20 and 5-21, p. 120), forest fires are not a major long-term threat to forest ecosystems. But they are serious short-term threats in parts of the world where people intentionally burn forests to clear the land, mostly to make way for crop plantations and grazing cattle (**Concept 10-1B**). This can result in dramatic habitat losses and increases in atmospheric CO_2 and other air pollutants.

Accidental or deliberate introductions of foreign diseases and insects are another major threat to forests in the United States and elsewhere. See Figure 10, p. S42, in Supplement 8 for a map that shows some nonnative species of pests and disease organisms that are causing serious damage to certain tree species in parts of the United States.

There are several ways to reduce the harmful impacts of tree diseases and insect pests on forests. One is to ban imported timber that might be carrying harmful new diseases or insects. Another is to remove or clear-cut infected and infested trees. We can also develop tree species that are genetically resistant to common tree diseases. Another approach is to control insect pests by applying conventional pesticides, but this can also kill beneficial insects that help to control insect pests. Scientists also use biological control (bugs that eat harmful bugs) combined with very small amounts of conventional pesticides.

On top of these threats, projected climate change could harm many forests. For example, sugar maples in the U.S. region of New England produce a sweet sap that is processed into maple syrup. The trees require cold winters followed by freezing nights and thawing days in early spring for sap production. Rising temperatures could interfere with this cycle and could even kill the trees, eliminating a valuable maple syrup industry.

CONNECTIONS

Climate Change and Forest Fires

Rising temperatures and increased drought from a projected warmer atmosphere will likely make many forest areas more suitable for insect pests, which would then multiply and kill more trees. The resulting combination of drier forests and more dead trees could increase the incidence and intensity of forest fires. This would add more of the greenhouse gas CO_2 to the atmosphere, further increasing atmospheric temperatures and causing even more forest fires in a spiraling positive feedback cycle (see Figure 2-18, p. 49) of increasingly harmful effects on the earth's climate.

Almost Half of the World's Forests Have Been Cut Down

Deforestation is the temporary or permanent removal of large expanses of forest for agriculture, settlements, or other uses. Surveys by the World Resources Institute (WRI) indicate that over the past 8,000 years, human activities have reduced the earth's original forest cover by about 46%, with most of this loss occurring in the last 60 years.

Deforestation continues at a rapid rate in many parts of the world. Surveys done by the FAO and the WRI indicate that the global rate of forest cover loss between 1990 and 2005 was between 0.2% and 0.5% per year, and that at least another 0.1–0.3% of the world's forests were degraded every year, mostly to grow crops and graze cattle. If these estimates are correct, the world's forests are being cleared or degraded at a rate of 0.3–0.8% per year, with much higher rates in some areas.

These losses are concentrated in less-developed countries, especially those in the tropical areas of Latin America, Indonesia, and Africa. However, scientists are also concerned about the increased clearing of the northern boreal forests of Alaska, Canada, Scandinavia, and Russia, which together make up about one-fourth of the world's forested area. In 2007, a group of 1,500 scientists from around the world signed a letter calling for the Canadian government to protect half of Canada's threatened boreal forests (of which only 10% are protected now) from logging, mining, and oil and gas extraction.

According to the WRI, if current deforestation rates continue, about 40% of the world's remaining intact forests will have been logged or converted to other uses within 2 decades if not sooner. Clearing large areas of forests, especially old-growth forests, has important short-term economic benefits (Figure 10-4, right), but it also has a number of harmful environmental effects (Figure 10-10).

HOW WOULD YOU VOTE?

Should there be a global effort to sharply reduce the cutting and burning of old-growth forests? Cast your vote online at **www.cengage.com/login**.

GOOD NEWS

In some countries, there is encouraging news about forest use. In 2007, the FAO reported that the net total forest cover in several countries, including the United States (see the Case Study at right), changed very little or even increased between 2000 and 2007. Some of the increases resulted from natural reforestation by secondary ecological succession on cleared forest areas and abandoned croplands (see Figure 5-20, p. 120). Other increases in forest cover were due to the spread of commercial tree plantations.

The fact that millions of trees are being planted throughout the world because of the dedication of individuals such as Wangari Maathai (**Core Case** CORE CASE STUDY

Natural Capital Degradation

Deforestation

- Decreased soil fertility from erosion
- Runoff of eroded soil into aquatic systems
- Premature extinction of species with specialized niches
- Loss of habitat for native species and migratory species such as birds and butterflies
- Regional climate change from extensive clearing
- Release of CO_2 into atmosphere
- Acceleration of flooding

Figure 10-10 Deforestation has some harmful environmental effects that can reduce biodiversity and degrade the ecological services provided by forests (Figure 10-4, left). **Question:** What are three products you have used recently that might have come from old-growth forests?

Study) and her Green Belt Movement is very encouraging to many scientists. However, some scientists are concerned about the growing amount of land occupied by commercial forests, because replacement of old-growth forests by these biologically simplified plantations represents a loss of biodiversity, and possibly of stability, in some forest ecosystems.

CASE STUDY

Many Cleared Forests in the United States Have Grown Back

Forests cover about 30% of the U.S. land area, providing habitats for more than 80% of the country's wildlife species and containing about two-thirds of the nation's surface water. Old-growth forests once covered more than half of the nation's land area. But between 1620, when European settlements were expanding rapidly in North America, and 1920, the old-growth forests of the eastern United States were decimated.

Today, forests in the United States (including tree plantations) cover more area than they did in 1920. The primary reason is that many of the old-growth forests that were cleared or partially cleared between 1620 and 1920 have grown back naturally through secondary ecological succession. There are now fairly diverse second-growth (and in some cases third-growth) forests in every region of the United States except much of the West. In 1995, environmental writer Bill McKibben cited forest regrowth in the United States—especially in the East—as "the great environmental story of the United States, and in some ways, the whole world."

Every year, more wood is grown in the United States than is cut and the total area planted with trees increases. Protected forests make up about 40% of the country's total forest area, mostly in the *National Forest System*, which consists of 155 national forests managed by the U.S. Forest Service (USFS).

On the other hand, since the mid-1960s, an increasing area of the nation's remaining old-growth (Figure 10-2) and fairly diverse second-growth forests has been cut down and replaced with biologically simplified tree plantations. According to biodiversity researchers, this reduces overall forest biodiversity and disrupts ecosystem processes such as energy flow and chemical cycling—in violation of all three **principles of sustainability**. Harvesting tree plantations too frequently also depletes forest topsoils of key nutrients. Many biodiversity researchers favor establishing tree plantations only on land that has already been degraded instead of cutting old-growth and second-growth forests and replacing them with tree plantations.

CONNECTIONS

Toilet Paper and Old-Growth Forest Losses

Toilet paper can be made from recycled materials as well as from wood pulp. However, millions of trees in North, Central, and South American countries are cut down just to make ultra-soft toilet paper. More than half of these trees are from old- or second-growth forests, according to the Natural Resources Defense Council, including some rare old-growth forests in Canada.

Tropical Forests Are Disappearing Rapidly

Tropical forests (see Figure 7-13, top, p. 160) cover about 6% of the earth's land area—roughly the area of the continental United States. Climatic and biological data suggest that mature tropical forests once covered at least twice as much area as they do today. Most of this loss of half of the world's tropical forests has taken place since 1950 (see Chapter 3 Core Case Study, p. 54).

Satellite scans and ground-level surveys indicate that large areas of tropical rain forests and tropical dry forests are being cut rapidly in parts of Africa (**Core Case Study**), Southeast Asia (Figure 10-11, p. 226), and South America (Figure 10-12, p. 226). According to the United Nations, Indonesia, has lost about 72% of its original intact forest—three-quarters of it from illegal logging in the country's parks, which are protected only on paper. In addition, 98% of its remaining forests will likely be gone by 2022. Estimates of the average rate of global tropical deforestation vary widely, but the area being cleared is equivalent to 16 to 54 football fields per minute. At this rate most of the world's tropical forests could disappear in the next 20 to 40 years.

Studies indicate that at least half of the world's known species of terrestrial plants, animals, and insects

S. Chamnanrith-UNEP/Peter Arnold, Inc.

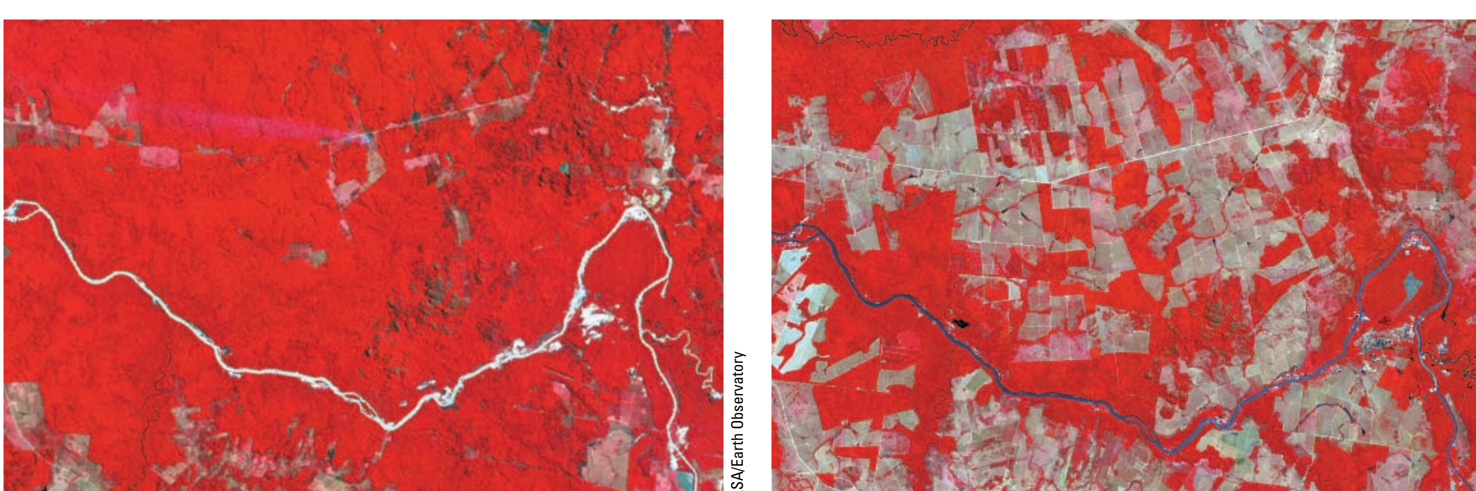
Figure 10-11 **Natural capital degradation:** This photo shows extreme tropical deforestation in Chiang Mai, Thailand. Such clearing of trees, which absorb carbon dioxide as they grow, helps to hasten climate change. It also dehydrates the topsoil by exposing it to sunlight. The dry topsoil can then blow away, which can lead to an irreversible ecological tipping point, beyond which a forest cannot grow back in the area.

live in tropical forests (Figure 10-13). Because of their specialized niches (see Figure 7-15, p. 162) these species are highly vulnerable to extinction when their forest habitats are destroyed or degraded. Tropical deforestation is the main reason that more than 8,000 known tree species—10% of the world's total—are threatened with extinction.

Brazil has more than 30% of the world's remaining tropical rain forests in its vast Amazon basin, which covers about 60% of Brazil and is larger than the area of India. According to Brazil's government and forest experts, the percentage of its Amazon basin that was deforested or degraded increased from 1% in 1970 to about 20% by 2008. The area of old-growth Amazon rain forest that has been lost since 1970 is about equal to that of the U.S. state of California.

In 2009, researcher Joe Wright of the Smithsonian Tropical Research Institute reported that in some cleared areas, forests are growing back as more poor farmers are abandoning their degraded land and moving to cities in hopes of improving their lives. Wright estimated that secondary tropical forests can grow on abandoned land within 15–20 years.

However, one of Wright's colleagues at the Smithsonian, biologist William Laurence, points out that these second-growth tropical forests do not have the



NASA/Earth Observatory

NASA/Earth Observatory

1992

2006

Figure 10-12 These satellite images show deforestation in Mato Grosso, Brazil, 1992–2006.

Roland Seitre/Peter Arnold, Inc.

Compost/Peter Arnold, Inc.

Figure 10-13 *Species diversity*: These two species found in tropical forests are part of the earth's biodiversity. On the left is an endangered *white ukari* in a Brazilian tropical forest. On the right is the world's largest flower, the *flesh flower* (Rafflesia) growing in a tropical rain forest of West Sumatra, Indonesia. The flower of this leafless plant can be as large 1 meter (4.3 feet) in diameter and weigh 7 kilograms (15 pounds). The plant gives off a smell like rotting meat, presumably to attract the flies and beetles that pollinate the flower. After blossoming once a year for a few weeks, the blood-red flower dissolves into a slimy black mass.

biological diversity—especially the diversity of animals—that only uninterrupted expanses of old-growth tropical forest can sustain. Such diverse regrowth does occur on small plots of land cleared by individual farmers, Laurence notes. But it is not at all clear what will happen to vast areas of land cleared for timber or industrial farming, which is the fastest growing type of agriculture in the tropics. Laurence observes that "one bulldozer does a lot more damage than 1,000 farmers with machetes."

RESEARCH FRONTIER

Improving estimates of rates of tropical deforestation and forest regrowth; see **www.cengage.com/login**.

Causes of Tropical Deforestation Are Varied and Complex

Tropical deforestation results from a number of underlying and direct causes (Figure 10-14, p. 228). Underlying causes, such as pressures from population growth and poverty, push subsistence farmers and the landless poor into tropical forests, where they try to grow enough food to survive. Government subsidies can accelerate the direct causes such as logging and ranching by reducing the costs of timber harvesting, cattle grazing, and the creation of vast plantations.

The major direct causes of deforestation vary in different tropical areas. Tropical forests in the Amazon and other South American countries are cleared or burned (Figure 10-15, p. 228) mostly for cattle grazing and large soybean plantations (see Figure 1-6, p. 10). But clearing these forests for tropical hardwood lumber and other products, used domestically and sold in the global marketplace, also plays a role.

In Indonesia, Malaysia, and other areas of Southeast Asia, tropical forests are being replaced with vast plantations of oil palm, which produces an oil used in cooking, cosmetics, and biodiesel fuel for motor vehicles (especially in Europe). In Africa, the primary direct cause of tropical deforestation and degradation is individuals struggling to survive by clearing plots for small-scale farming and by harvesting wood for fuel. However, women in the Green Belt Movement (**Core Case Study**) have helped to reestablish forest areas in several African countries.

The degradation of a tropical forest usually begins when a road is cut deep into the forest interior for logging and settlement (Figure 10-5). Loggers then use selective cutting (Figure 10-6a) to remove the largest and best trees. When these big trees fall, many other trees fall with them because of their shallow roots and the network of vines connecting the trees in the forest's canopy. This method causes considerable ecological damage in tropical forests, but much less than that from burning or clear-cutting forests.

Natural Capital Degradation

Major Causes of the Destruction and Degradation of Tropical Forests

Underlying Causes

- Not valuing ecological services
- Crop and timber exports
- Government policies
- Poverty
- Population growth

Direct Causes

- Roads
- Fires
- Settler farming
- Cash crops
- Cattle ranching
- Logging
- Tree plantations

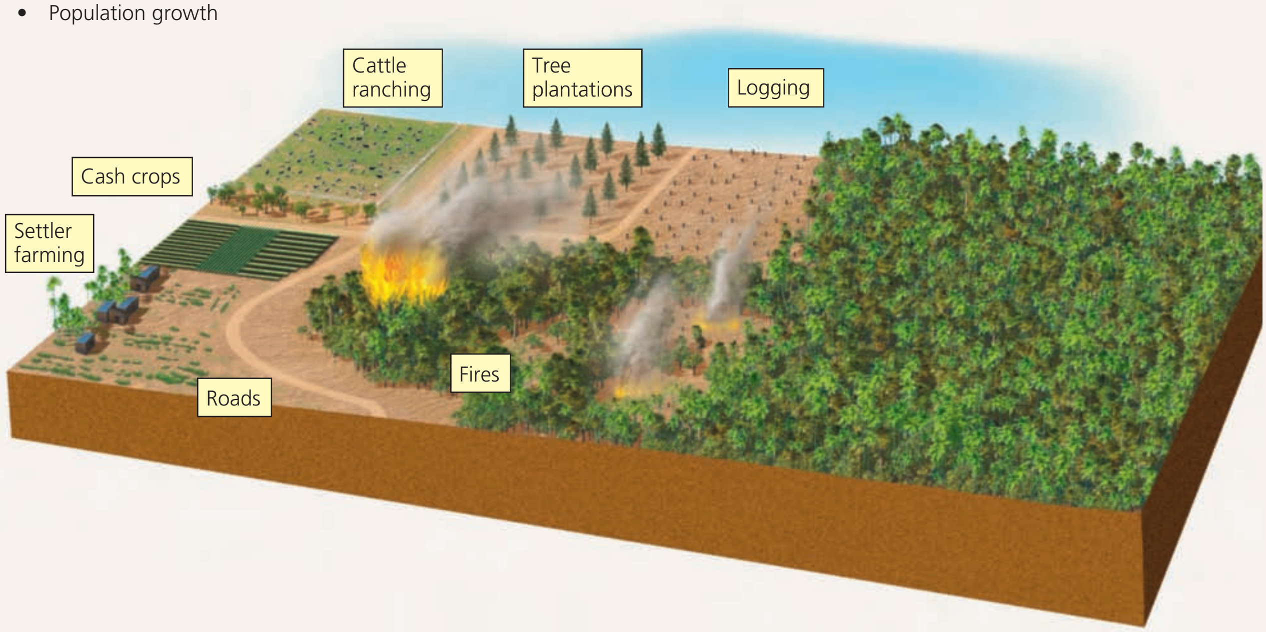


Figure 10-14 This diagram illustrates the major underlying and direct causes of the destruction and degradation of tropical forests. **Question:** If we could eliminate the underlying causes, which if any of the direct causes might automatically be eliminated?

Herbert Giradet/Peter Arnold, Inc.

Figure 10-15 **Natural capital degradation:** Large areas of tropical forest in Brazil's Amazon basin are burned each year to make way for cattle ranches, plantation crops such as soybeans (see Figure 1-6, p. 10), and small-scale farms. **Questions:** What are three ways in which your lifestyle may be contributing to this process? How, in turn, might this process affect your life?

Burning is widely used to clear forest areas for agriculture, settlement, and other purposes. Healthy rain forests do not burn naturally. But roads, settlements, and farming, grazing, and logging operations fragment them. The resulting patches of forest dry out and readily ignite.

According to a 2005 study by forest scientists, widespread fires in the Amazon basin (Figure 10-15) are changing weather patterns by raising temperatures and reducing rainfall. The resulting droughts dry out the forests and make them more likely to burn—another example of a runaway positive feedback loop (see Figure 2-18, p. 49). This process is converting large deforested areas of tropical forests to tropical grassland (savanna)—another example of an ecosystem reaching an irreversible ecological *tipping point*. Models project that if current burning and deforestation rates continue, 20–30% of the Amazon basin will be turned into savanna in the next 50 years, and most of it could become savanna by 2080.

CONNECTIONS

Burning Tropical Forests and Climate Change

The burning of tropical forests releases CO_2 into the atmosphere. Rising concentrations of this gas can help warm the atmosphere, which is projected to change the global climate during this century. Scientists estimate that tropical forest fires account for at least 17% of all human-created greenhouse gas emissions, and that each year they emit twice as much CO_2 as all of the world's cars and trucks emit. The large-scale burning of the Amazon rain forest (Figure 10-16) accounts for 75% of Brazil's greenhouse gas emissions, making Brazil the world's fourth largest emitter of such gases, according to the National Inventory of Greenhouse Gases. And with these forests gone, even if savannah or second-growth forests replace them, far less CO_2 will be absorbed for photosynthesis, resulting in even more atmospheric warming.

Foreign corporations operating under government concession contracts do much of the logging in tropical countries. Once a country's forests are gone, the companies move on to another country, leaving ecological devastation behind. For example, the Philippines and Nigeria have lost most of their once-abundant tropical hardwood forests and now are net importers of forest products. Several other tropical countries are following this ecologically and economically unsustainable path.

After the best timber has been removed, timber companies or the local government often sell the land to ranchers who burn the remaining timber to clear the land for cattle grazing. Within a few years, their cattle typically overgraze the land and the ranchers move their operations to another forest area. Then they sell the degraded land to farmers who plow it up for large plantations of crops such as soybeans (largely used for cattle feed), or to settlers who have migrated to tropical forests hoping to grow enough food on a small plot of land to survive. In tropical rain forests, plant nutrients are stored mostly in the quickly decomposed vegetation instead of in the soil. Thus, after a few years of crop growing and erosion from rain, the nutrient-poor soil is depleted of nutrients. Then the farmers and settlers move on to newly cleared land to repeat this environmentally destructive process.

THINKING ABOUT

Tropical Forests

Why should you care if most of the world's remaining tropical forests are burned or cleared and converted to savanna within your lifetime? What are three ways in which this might affect your life or the lives of any children and grandchildren that you might have?

10-2 How Should We Manage and Sustain Forests?

CONCEPT 10-2 We can sustain forests by emphasizing the economic value of their ecological services, removing government subsidies that hasten their destruction, protecting old-growth forests, harvesting trees no faster than they are replenished, and planting trees.

We Can Manage Forests More Sustainably

Biodiversity researchers and a growing number of foresters have called for more sustainable forest management. Figure 10-16 (p. 230) lists ways to achieve this goal (**Concept 10-2**). Certification of sustainably grown timber and of sustainably produced forest products can help consumers to play their part in reaching the goal (Science Focus, p. 230).

GOOD NEWS

Loggers can also use more sustainable practices in tropical forests. For example, they can use sustainable selective cutting (Figure 10-6a) and strip cutting (Figure 10-6c) to harvest tropical trees for lumber instead of clear-cutting the forests (Figure 10-6b). Loggers can also be more careful when cutting individual trees, taking care to cut canopy vines (lianas) before felling a tree and using the least obstructed paths to remove the logs. These practices would sharply reduce damage to neighboring trees.

Solutions

More Sustainable Forestry

- Identify and protect forest areas high in biodiversity
- Rely more on selective cutting and strip cutting
- Stop clear-cutting on steep slopes
- Stop logging in old-growth forests
- Sharply reduce road building in uncut forest areas
- Leave most standing dead trees and fallen timber for wildlife habitat and nutrient cycling
- Put tree plantations only on deforested and degraded land
- Certify timber grown by sustainable methods
- Include ecological services of forests in estimates of their economic value

Figure 10-16 There are a number of ways to grow and harvest trees more sustainably (**Concept 10-2**). **Questions:** Which three of these methods of more sustainable forestry do you think are the most important? Why?

Today's economic development systems in many countries devour tropical forests (and other resources) because they do not take into account the huge economic value of the ecological services that these forests provide (Figure 10-4, left, and Figure 10-A). Many economists call for replacing forest-degrading economic development strategies with more sustainable strategies that make it more profitable for the less-developed countries to manage and preserve their forests than to clear them in order to sell forest products or to create plantations.

One way to begin such a shift to new strategies is to phase out government subsidies and tax breaks that encourage degradation and deforestation and replace them with forest-sustaining economic rewards. (See the Guest Essay by Norman Myers on such *perverse subsidies* at CengageNOW™.) In addition, we could use massive tree planting programs such as those run by the Green Belt Movement (**Core Case Study**) to help restore degraded forests. **GREEN CAREER:** Sustainable forestry

CORE CASE STUDY

We Can Improve the Management of Forest Fires

In the United States, the Smokey Bear educational campaign undertaken by the Forest Service and the National Advertising Council has prevented countless forest fires. It has also saved many lives and prevented billions of dollars in losses of trees, wildlife, and human structures.

At the same time, this educational program has convinced much of the public that all forest fires are bad and should be prevented or put out. Ecologists warn that trying to prevent all forest fires increases the likelihood of destructive crown fires by allowing accumulation of highly flammable underbrush and smaller trees in some forests.

According to the U.S. Forest Service, severe fires could threaten 40% of all federal forest lands, mainly

SCIENCE FOCUS

Certifying Sustainably Grown Timber

Collins Pine is a forest products company that owns and manages a large area of productive timberland in the northeastern part of the U.S. state of California. Since 1940, the company has used selective cutting to help maintain the ecological and economic sustainability of its timberland.

Since 1993, Scientific Certification Systems (SCS) of Oakland, California, has evaluated the company's timber production at several of its forest sites in California, Oregon, and Pennsylvania. SCS, which is part of the nonprofit Forest Stewardship Council (FSC), was formed to develop environmentally sound practices for use in certifying timber and timber products. SCS is one of twelve FSC-accredited certifiers around the globe. According to Collins Pine's management, the FSC logo on a forest product represents the only credible certification program currently operating. The logo assures buyers that the product has come from a forest that was managed in an environmentally and socially responsible manner.

Each year, SCS evaluates Collins Pine's landholdings and has consistently found that their cutting of trees has not exceeded long-term forest regeneration; roads and harvesting systems have not caused unreasonable ecological damage; topsoil has not been damaged; and downed wood (boles) and standing dead trees (snags) are left to provide wildlife habitat. As a result, SCS judges the company to be a good employer and a good steward of its land and water resources.

The FSC reported that, by 2009, about 5% of the world's forest area in 82 countries had been certified according to FSC standards. The countries with the largest areas of FSC-certified forests are, in order, Canada, Russia, Sweden, the United States, Poland, and Brazil.

FSC also certifies 5,400 manufacturers and distributors of wood products. The paper used in this book was produced with the use of sustainably grown timber, as certified by the FSC, and contains recycled paper.

In 2008, several major environmental groups warned consumers that the paper and timber industries were setting up their own forest and wood product certification systems that have much lower standards than the FSC.

Critical Thinking

Should governments provide tax breaks for sustainably grown timber to encourage this practice? Explain.

because of fuel buildup resulting from rigorous fire protection programs of the Smokey Bear era. Increased logging in the 1980s, which left behind highly flammable logging debris (called *slash*), and greater public use of federal forest lands also contribute to this fire danger.

Ecologists and forest fire experts have proposed several strategies for reducing fire-related harm to forests and to people who use the forests. One approach is to set small, contained surface fires to remove flammable small trees and underbrush in the highest-risk forest areas. Such *prescribed burns* require careful planning and monitoring to keep them from getting out of control. As an alternative to prescribed burns, local officials in populated parts of fire-prone California use herds of goats (kept in moveable pens) to eat away underbrush.

A second strategy is to allow some fires on public lands to burn, thereby removing flammable underbrush and smaller trees, as long as the fires do not threaten human structures and life.

A third approach is to protect houses and other buildings in fire-prone areas by thinning a zone of about 60 meters (200 feet) around them and eliminating the use of highly flammable construction materials such as wood shingles.

A fourth approach is to thin forest areas that are vulnerable to fire by clearing away small fire-prone trees and underbrush under careful environmental controls. Many forest fire scientists warn that such thinning operations should not remove economically valuable medium-size and large trees for two reasons. *First*, these are the most fire-resistant trees. *Second*, their removal encourages dense growth of more flammable young trees and underbrush and leaves behind highly flammable slash. Many of the worst fires in U.S. history burned through cleared forest areas that contained slash. A 2006 study by Forest Service researchers found that thinning forests without using prescribed burning to remove the slash can greatly increase rather than decrease the risk of heavy fire damage.

We Can Reduce the Demand for Harvested Trees

One way to reduce the pressure on forest ecosystems is to improve the efficiency of wood use. According to the Worldwatch Institute and to forestry analysts, *up to 60% of the wood consumed in the United States is wasted unnecessarily*. This results from inefficient use of construction materials, excess packaging, overuse of junk mail, inadequate paper recycling, and failure to reuse or find substitutes for wooden shipping containers.

One reason for cutting trees is to provide pulp for making paper, but paper can be made from fiber that does not come from trees. China, which has cleared many of its forests, uses rice straw and other agricultural residues to make much of its paper. Most of the small amount of tree-free paper produced in the United States is made from the fibers of a rapidly growing woody annual plant called *kenaf* (pronounced "kuh-NAHF"; Figure 10-17). Kenaf and other non-tree fibers such as hemp yield more paper pulp per area of land than tree farms do and require fewer pesticides and herbicides.

A 1987 study by a Canadian paper mill found that newspaper pages made from kenaf fiber were brighter and stronger, and had less environmental impact than newspaper made from pine fibers. One reason for this is that kenaf fiber is lighter-colored than tree fiber and thus requires less bleaching with the use of potentially harmful chemicals. Some studies indicate that producing kenaf fiber takes about 20% less energy than producing tree fiber. Kenaf fiber can also be used to make insulation as well as a wood substitute and a type of cloth.

It is estimated, that within 2–3 decades, we could essentially eliminate the need to use trees to make paper. However, while timber companies successfully lobby for government subsidies to grow and harvest trees to make paper, there are no major lobbying efforts or subsidies for producing paper from kenaf

GOOD NEWS


U.S. Department of Agriculture

Figure 10-17 **Solutions:** The pressure to cut trees to make paper could be greatly reduced by planting and harvesting a fast-growing plant known as kenaf. According to the USDA, kenaf is "the best option for tree-free papermaking in the United States" and could replace wood-based paper within 20–30 years. **Question:** Would you invest in a kenaf plantation? Explain.

and other alternative sources. In addition, timber companies lobby against subsidies for using kenaf because it would cut into their profits.

Another serious strain on forest resources is the increasing use of wood as a fuel. In less-developed countries where deforestation would be a problem even without the harvesting of fuelwood, the demand for fuelwood for heating and cooking has reached crisis proportions (see the Case Study that follows).

■ **CASE STUDY**

Deforestation and the Fuelwood Crisis

About half of the wood harvested globally each year, and three-fourths of the wood harvested in less-developed countries, is used for fuel. More than 2 billion people in less-developed countries use fuelwood (see Figure 6-20, p. 141) and charcoal made from wood for heating and cooking. As the demand for fuelwood in urban areas exceeds the sustainable yield of nearby forests, expanding rings of deforested land encircle such cities. By 2050, the demand for fuelwood could easily be 50% greater than the amount that can be sustainably supplied.

Haiti, a country with 9.2 million people, was once a tropical paradise, much of it covered with forests. Now it is an ecological disaster. Largely because its trees were cut for fuelwood and to make charcoal (Figure 10-18), only about 2% of its land is now covered with trees. With the trees gone, soils have eroded away in many areas, making it much more difficult to grow crops. This unsustainable use of natural capital has led to a downward spiral of environmental degradation, poverty, disease, social injustice, crime, and violence. As a result, Haiti is classified as one of the world's *failing states*, which are countries that may not survive this century (see Figure 17, p. S64, in Supplement 9). Haiti's plight was made worse by a major earthquake in 2010.


Mark Edwards/Peter Arnold, Inc.

Figure 10-18 This seaside mangrove forest in Haiti was cut down and turned into a desert by poor farmers harvesting fuelwood to make charcoal.

One way to reduce the severity of the fuelwood crisis in less-developed countries is to establish small plantations of fast-growing fuelwood trees and shrubs around farms and in community woodlots. Another approach to this problem is to burn wood more efficiently by providing villagers with cheap, fuel-efficient, and less-polluting wood stoves. Other options are stoves that run on methane produced from crop and animal wastes, solar ovens, and electric hotplates powered by solar- or wind-generated electricity. Using such options would also greatly reduce premature deaths from indoor air pollution caused by open fires and poorly designed stoves.

In addition, villagers can switch to burning garden plant wastes such as roots of various gourds and squash plants. And scientists are looking for ways to produce charcoal out of such wastes for heating and cooking. For example, Professor Amy Smith, of MIT in Cambridge, Massachusetts (USA), is developing a way to make charcoal from the fibers in a waste product called *bagasse*, which is left over from sugar cane processing in Haiti. Because sugarcane charcoal burns cleaner than wood charcoal, using it could help Haitians reduce air pollution.

Countries such as South Korea, China, Nepal, and Senegal, have used such methods to reduce deforestation, which has also helped them to reduce fuelwood shortages, to sustain biodiversity through reforestation, and to reduce topsoil erosion. Indeed, South Korea is a global model for its successful reforestation following severe deforestation during the war between North and South Korea, which ended in 1953. Today, forests cover almost two-thirds of the country, and tree plantations near villages supply fuelwood on a sustainable basis.

However, most countries suffering from fuelwood shortages are cutting trees for fuelwood and forest products 10–20 times faster than new trees are being planted. Ending government subsidies that pay for new logging roads and subsidizing the planting of trees would help to increase forest cover worldwide.

Governments and Individuals Can Act to Reduce Tropical Deforestation

In addition to reducing fuelwood demand, analysts have suggested other ways to protect tropical forests and use them more sustainably. One way is to help new settlers in tropical forests learn how to practice small-scale sustainable agriculture and forestry. Another is to harvest some of the rain forests' renewable resources that have not always been used, such as fruits and nuts, on a sustainable basis.

Governments can also set aside and protect large areas of forest from deforestation and degradation. For example, the Brazilian government has set aside about 57% of the remaining Amazon rain forest area for the indigenous peoples who dwell there and for conservation. However, such protection is primarily on paper. The government does not have the resources to prevent the illegal use and harvesting of trees and other resources from such a huge area.

At the international level, *debt-for-nature swaps* can make it financially attractive for countries to protect their tropical forests. In such swaps, participating countries act as custodians of protected forest reserves in return for foreign aid or debt relief. In a similar strategy called *conservation concessions*, governments or private conservation organizations pay nations for agreeing to preserve their natural resources.

Some groups are highly creative in using this solution. For example, conservation organizations working in a state park in Brazil's endangered Atlantic Forest provided technical assistance to dairy farmers. In return, the farmers agreed to reforest and maintain part of this land in a conservation easement, which now serves as a buffer zone for the park. With this deal, the farmers were able to triple their milk yields and double their incomes.

Another approach is to allow corporations and countries that emit large amounts of CO_2 and other greenhouse gases to help offset such emissions by paying tropical countries to protect their CO_2-absorbing old-growth forests. In a 2008 British government report, scientists estimated that a coordinated global effort to finance forest preservation through carbon markets could cut deforestation rates by 75% by 2030.

Individuals can plant trees—a powerful example of the idea that all sustainability is local, as shown by Wangari Maathai's tree planting efforts (**Core Case Study**). Governments can provide resources for such replanting. In 2007, the UN Environment Programme (UNEP) announced a Billion Tree Campaign to plant 7 billion trees worldwide. The goal of the campaign is to plant trees that are well-adapted to each local setting, be it a farm, a degraded natural forest, or an urban environment. By mid-2009, thousands of people in 166 countries had planted more 7.4 billion trees.

Some analysts have suggested that replanting programs must include measures to protect newly forested and old-growth areas. The Brazilian government in 2008 announced a plan to replant an area of forest roughly equal to the combined areas of the U.S. states of Massachusetts and New Jersey. But more importantly, the plan includes increased federal patrols of forest areas to prevent illegal logging. It also includes funding for projects to help local people find ways to make a living that do not damage the forests.

Finally, as consumers, we can all reduce the demand for products that fuels illegal and unsustainable logging in tropical forests. For building projects, we can use recycled waste lumber. We can also use substitutes for wood such as recycled plastic building materials and bamboo, which can grow up to 0.9 meters (3 feet) in a single day. And we can sharply reduce the use of throwaway paper products and replace them with reusable plates, cups, and cloth napkins and handkerchiefs.

CONNECTIONS

Good and Bad Bamboo

Ironically, it is possible to add to an environmental problem while trying to be part of the solution. Bamboo, which is increasingly used for hardwood flooring, can be a highly sustainable building material if it is raised on degraded lands. However, some bamboo suppliers, seeing a growing market for this "green" building product, have cleared natural forests to plant rapidly growing bamboo. When buying bamboo, it is important for consumers to find out where and how it was produced. This makes it important to look for bamboo products that are certified as sustainably produced by the Forest Stewardship Council (FSC) (Science Focus, p. 230).

These and other ways to protect tropical forests are summarized in Figure 10-19.

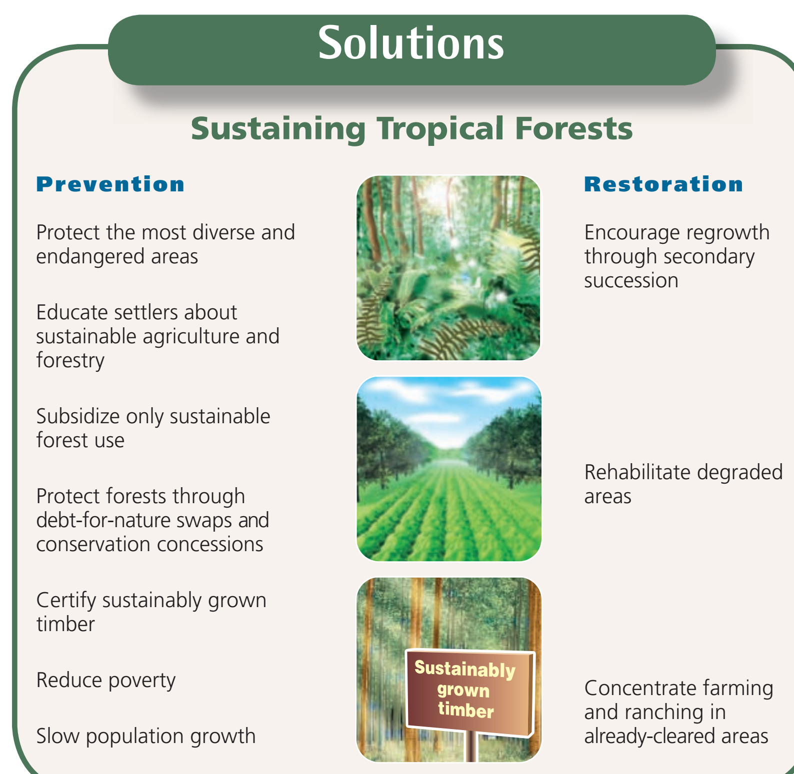


Figure 10-19 These are some effective ways to protect tropical forests and to use them more sustainably (**Concept 10-2**). **Questions:** Which three of these solutions do you think are the most important? Why?

10-3 How Should We Manage and Sustain Grasslands?

▶ **CONCEPT 10-3 We can sustain the productivity of grasslands by controlling the numbers and distribution of grazing livestock, and by restoring degraded grasslands.**

Some Rangelands Are Overgrazed

Grasslands provide many important ecological services, including soil formation, erosion control, chemical cycling, storage of atmospheric carbon dioxide in biomass, and maintenance of biodiversity.

After forests, grasslands are the ecosystems most widely used and altered by human activities. **Rangelands** are unfenced grasslands in temperate and tropical climates that supply *forage*, or vegetation for grazing (grass-eating) and browsing (shrub-eating) animals. Cattle, sheep, and goats graze on about 42% of the world's grassland. The 2005 Millennium Ecosystem Assessment estimated that this could increase to 70% by 2050. Livestock also graze in **pastures**, which are managed grasslands or fenced meadows usually planted with domesticated grasses or other forage crops such as alfalfa and clover.

Blades of rangeland grass grow from the base, not at the tip as broadleaf plants do. Thus, as long as only the upper half of the blade is eaten and its lower half remains, rangeland grass is a renewable resource that can be grazed again and again. Moderate levels of grazing are healthy for grasslands, because removal of mature vegetation stimulates rapid regrowth and encourages greater plant diversity.

Overgrazing occurs when too many animals graze for too long, damaging the grasses and their roots, and exceeding the carrying capacity of a rangeland area (Figure 10-20, left). Overgrazing reduces grass cover, exposes the soil to erosion by water and wind, and compacts the soil (which diminishes its capacity to hold water). Overgrazing also encourages the invasion of once-productive rangeland by species such as sagebrush, mesquite, cactus, and cheatgrass, which cattle will not eat. Limited data from FAO surveys in various countries indicate that overgrazing by livestock has caused as much as a fifth of the world's rangeland to lose productivity.

About 200 years ago, grasses may have covered nearly half the land in the southwestern United States. Today, they cover only about 20%, mostly because of a combination of prolonged droughts and overgrazing, which created footholds for invasive species that now cover many of the former grasslands.

The following Case Study is a story about overgrazing and what scientists learned from it. It also describes how the effects of overgrazing can be reversed.

■ **CASE STUDY**

The Malpai Borderlands

Scientists have learned that, before settlers made them into rangeland, natural grassland ecosystems were maintained partially by occasional wildfires sparked by lightning. Fires were important because they burned

USDA, Natural Resources Conservation Service

Figure 10-20 Natural capital degradation: Overgrazed rangeland is to the left of the fence, while lightly grazed rangeland is to the right.

away mesquite and other invasive shrubs, keeping the land open for native grasses.

In particular, ecologists have studied the grasslands of the Malpai Borderlands—an area on the border between the southwestern U.S. states of Arizona and New Mexico. Ranchers there, with the help of federal government policies, not only allowed overgrazing for more than a century, but also suppressed fires and kept the grasslands from burning. Consequently, trees and shrubs replaced grasses, the soil was badly eroded, and the area lost its value for grazing.

Since 1993, ranchers, scientists, environmentalists, and government agencies have joined forces to restore the native grasses and animal species to the Malpai Borderlands. Land managers conduct periodic controlled burns on the grasslands, and the ecosystem has now been largely reestablished. What was once a classic example of unsustainable resource management became a valuable scientific learning experience and a management success story.

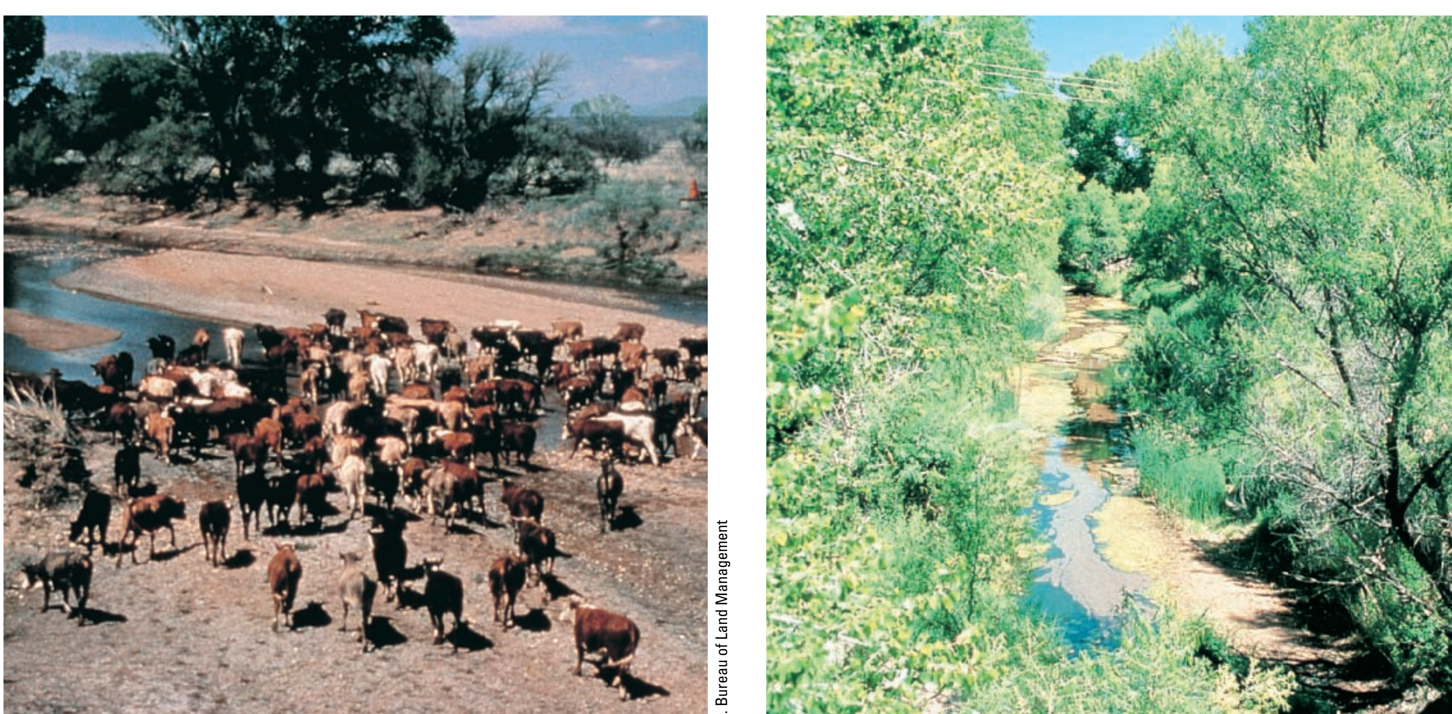
We Can Manage Rangelands More Sustainably

The most widely used method for more sustainable management of rangelands is to control the number of grazing animals and the duration of their grazing in a given area so the carrying capacity of the area is not exceeded (**Concept 10-3**). One way of doing this is *rotational grazing*, in which cattle are confined by portable fencing to one area for a short time (often only 1–2 days) and then moved to a new location.

Cattle tend to aggregate around natural water sources, especially along streams or rivers lined by thin strips of lush vegetation known as *riparian zones*, and around ponds created to provide water for livestock. Overgrazing by cattle can destroy the vegetation in such areas (Figure 10-21, left). Protecting overgrazed land from further grazing by moving livestock around and by fencing off these damaged areas eventually leads to their natural ecological restoration by ecological succession (Figure 10-21, right). Ranchers can also move cattle around by providing supplemental feed at selected sites and by strategically locating watering ponds and tanks and salt blocks.

A more expensive and less widely used method of rangeland management is to suppress the growth of unwanted invader plants by the use of herbicides, mechanical removal, or controlled burning. A cheaper way to discourage unwanted vegetation in some areas is through controlled, short-term trampling by large numbers of split-hoofed livestock such as sheep, goats, and cattle that destroy the plants' root systems.

Replanting severely degraded areas with native grass seeds and applying fertilizer can increase the growth of desirable vegetation and reduce soil erosion. But this is an expensive option. The better option is to prevent degradation by using the methods described above and in the following case study (p. 236).



U.S. Bureau of Land Management

U.S. Bureau of Land Management

Figure 10-21 **Natural capital restoration:** In the mid-1980s, cattle had degraded the vegetation and soil on this stream bank along the San Pedro River in the U.S. state of Arizona (left). Within 10 years, the area was restored through natural regeneration (right) after grazing and off-road vehicle use were banned (**Concept 10-3**).

■ CASE STUDY

Grazing and Urban Development in the American West—Cows or Condos?

The landscape is changing in U.S. ranch country. Since 1980, millions of people have moved to parts of the southwestern United States, and a growing number of ranchers have sold their land to developers. Housing developments, condos, and small "ranchettes" are creeping out from the edges of many southwestern cities and towns. Most people moving to the southwestern states value the landscape for its scenery and recreational opportunities, but uncontrolled urban development can degrade these very qualities.

For decades, some environmental scientists and environmentalists have sought to reduce overgrazing on these lands and, in particular, to reduce or eliminate livestock grazing permits on public lands. They have not had the support of ranchers or of local, state, and federal governments. These scientists have also pushed for decreased timber cutting and increased recreational opportunities in the national forests and grasslands. These efforts have made private tracts of land, especially near protected public lands, more desirable and valuable to people who enjoy outdoor activities and can afford to live in scenic areas.

Now, because of the population surge in the Southwest and the development that has resulted, ranchers, ecologists, and environmentalists are joining together to help preserve cattle ranches as the best hope for sustaining the key remaining grasslands and the habitats they provide for native species. They are working together to identify areas that are best for sustainable grazing, areas best for sustainable urban development, and areas that should be neither grazed nor developed. One strategy involves land trust groups, which pay ranchers for *conservation easements*—deed restrictions that bar future owners from developing the land. These groups are also pressuring local governments to zone the land in order to prevent large-scale development in ecologically fragile rangeland areas.

GOOD NEWS

Some ranchers are also reducing the harmful environmental impacts of their herds. They rotate their cattle away from riparian areas (Figure 10-21), use far less fertilizer and pesticides, and consult with range and wildlife scientists about ways to make their ranch operations more economically and ecologically sustainable.

10-4 How Should We Manage and Sustain Parks and Nature Reserves?

▶ **CONCEPT 10-4 Sustaining biodiversity will require more effective protection of existing parks and nature reserves, as well as the protection of much more of the earth's remaining undisturbed land area.**

National Parks Face Many Environmental Threats

Today, more than 1,100 major national parks are located in more than 120 countries (see Figure 7-16, p. 103). However, most of these national parks are too small to sustain many large animal species. And many parks suffer from invasions by nonnative species that compete with and reduce the populations of native species.

Parks in less-developed countries have the greatest biodiversity of all parks globally, but only about 1% of these parklands are protected. Local people in many of these countries enter the parks illegally in search of wood, cropland, game animals, and other natural products that they need for their daily survival. Loggers and miners operate illegally in many of these parks, as do wildlife poachers who kill animals to obtain and sell items such as rhino horns, elephant tusks, and furs. Park services in most of the less-developed countries have too little money and too few personnel to fight these invasions, either by force or through education.

■ CASE STUDY

Stresses on U.S. Public Parks

The U.S. national park system, established in 1912, includes 58 major national parks, sometimes called the country's crown jewels (Figure 10-22), along with 333 monuments and historic sites. States, counties, and cities also operate public parks.

Popularity is one of the biggest problems for many parks. Between 1960 and 2008, the number of visitors to U.S. national parks more than tripled, reaching 273 million yearly. The Great Smoky Mountains National Park in the states of Tennessee and North Carolina, the country's most frequently visited national park, hosts about 9 million visitors each year. Most state parks are located near urban areas and receive about twice as many visitors per year on average as do the national parks.

During the summer, visitors entering the most popular parks often face long backups and experience noise, congestion, eroded trails, and stress instead of peaceful solitude. In some parks and other public lands, noisy

gray718/Shutterstock

Figure 10-22 Grand Teton National Park (USA)

and polluting dirt bikes, dune buggies, jet skis, snowmobiles, and off-road vehicles degrade the aesthetic experience for many visitors, destroy or damage fragile vegetation, and disturb wildlife. There is controversy over whether these machines should be allowed in national parks and proposed wilderness areas within the parks (Figure 10-23).

Photo courtesy of Kevin Walker

Figure 10-23 **Natural capital degradation:** This photo shows the damage caused by off-road vehicles in a proposed wilderness area near the U.S. city of Moab, Utah. Such vehicles pollute the air, damage soils and vegetation, disturb and threaten wildlife, and degrade wetlands and streams.

Many visitors expect parks to have grocery stores, laundries, bars, and other such conveniences. They also expect cell phone service, which is now available in many parks, along with unsightly cell towers.

A number of parks also suffer damage from the migration or deliberate introduction of nonnative species. European wild boars, imported into the state of North Carolina in 1912 for hunting, threaten vegetation in parts of the Great Smoky Mountains National Park. Nonnative mountain goats in Washington State's Olympic National Park trample and destroy the root systems of native vegetation and accelerate soil erosion. Nonnative species of plants, insects, and worms entering the parks on vehicle tires and hikers' gear also degrade the biodiversity of parklands.

At the same time, native species—some of them threatened or endangered—are killed in, or illegally removed from, almost half of U.S. national parks. This is what happened to the gray wolf in Yellowstone National Park until it was successfully reintroduced there after a 50-year absence (Science Focus, p. 239). Not all park visitors understand the rules that protect species, and rangers have to spend an increasing amount of their time on law enforcement instead of on conservation management and education.

THINKING ABOUT
National Parks and Off-Road Vehicles

Do you support allowing off-road vehicles in national parks? Explain. If you do, what restrictions, if any, would you put on their use?

SCIENCE FOCUS

Reintroducing the Gray Wolf to Yellowstone National Park

Around 1800, at least 350,000 gray wolves (Figure 10-B) roamed over about three-quarters of America's lower 48 states, especially in the West. They survived mostly by preying on abundant bison, elk, caribou, and deer. But between 1850 and 1900, most of them were shot, trapped, or poisoned by ranchers, hunters, and government employees.

When Congress passed the U.S. Endangered Species Act in 1973, only a few hundred gray wolves remained outside of Alaska, primarily in Minnesota and Michigan. In 1974, the gray wolf was listed as an endangered species in the lower 48 states.

Ecologists recognize the important role that this keystone predator species once played in parts of the West, especially in the northern Rocky Mountain states of Montana, Wyoming, and Idaho, where Yellowstone National Park is located. The wolves culled herds of bison, elk, moose, and mule deer, and kept down coyote populations. By leaving some of their kills partially uneaten, they provided meat for scavengers such as ravens, bald eagles, ermines, grizzly bears, and foxes.

When wolves declined, herds of plant-browsing elk, moose, and mule deer expanded and devastated vegetation such as willow and aspen trees growing near streams and rivers. This led to increased soil erosion. It also threatened habitats of other wildlife species and the food supplies of beaver, which eat willow and aspen. This in turn affected species that depended on wetlands created by the beavers (see Figure 4-19, p. 100).

In 1987, the U.S. Fish and Wildlife Service (USFWS) proposed reintroducing gray wolves into the Yellowstone National Park ecosystem to help restore and sustain biodiversity and to prevent further environmental degradation of the ecosystem. The proposal brought angry protests, some from area ranchers who feared the wolves would leave the park and attack their cattle and sheep. Other objections came from hunters who feared the wolves would kill too many big-game animals, and from mining and logging companies that feared the government would halt their operations on wolf-populated federal lands.

In 1995 and 1996, federal wildlife officials caught gray wolves in Canada and relocated 31 of them to Yellowstone National Park. Scientists estimate that the long-term carrying capacity of the park is 110 to 150 gray wolves. By the end of 2009, the park had 116 gray wolves. According to wildlife officials, the population is down from a high of 174 in 2003, mostly because of viral infections, among the wolves. Also, because the wolves have reduced the park's elk population, there is more competition among the wolves for prey, which sometimes results in a fight to the death between wolves. Also, wolves wandering outside of the park's boundaries can be legally killed by landowners.

Tom Kitchin/Tom Stack & Associates

Figure 10-B **Natural capital restoration:** After becoming almost extinct in much of the western United States, the *gray wolf* was listed and protected as an endangered species in 1974. Despite intense opposition from ranchers, hunters, miners, and loggers, 31 members of this keystone species were reintroduced to their former habitat in Yellowstone National Park in 1995 and 1996. By the end of 2009, there were 116 gray wolves in 12 packs in the park.

For over a decade, wildlife ecologist Robert Crabtree and a number of other scientists have been studying the effects of reintroducing the gray wolf into Yellowstone National Park (see *The Habitable Planet*, Video 4, at **www.learner.org/resources/series209.html**). They have put radio-collars on most of the wolves to gather data and track their movements. They have also studied changes in vegetation and in the populations of various plant and animal species.

This research has suggested that the return of this keystone predator species has sent ecological ripples through the park's ecosystem. Because elk are a primary source of food for wolves, the return of wolves has contributed to a decline in elk populations, which had grown too large for the carrying capacity of the park. Leftovers of elk killed by wolves provide an important food source for grizzly bears and other scavengers such as bald eagles and ravens. And wary elk are gathering less near streams and rivers, which has helped to spur the regrowth of aspen, cottonwoods, and willow trees in riparian areas. This in turn has helped to stabilize and shade stream banks, lowering the water temperature and making better habitat for trout. Beavers seeking willow and aspen for food and for lodge and dam building have returned, and the dams they build establish additional wetlands and create more favorable habitat for aspens.

The wolves have also cut in half the population of coyotes—the top predators in the absence of wolves. This has reduced coyote attacks on cattle from surrounding ranches and has increased populations of smaller animals such as ground squirrels, mice, and gophers, which are hunted by coyotes, eagles, and hawks. Overall, this experiment in ecosystem restoration has helped to re-establish and sustain some of the biodiversity that the Yellowstone ecosystem once had. But decades of research will be needed to better understand the wolves and to unravel many other interacting factors in this complex ecosystem.

Critical Thinking

Do you approve or disapprove of the reintroduction of the gray wolf into the Yellowstone National Park system? Explain.

THINKING ABOUT
Protecting Wolves and Wild Lands

How do you think protecting wolves, in part by reintroducing them to areas such as Yellowstone National Park (Science Focus, p. 237), helps to protect the forest areas where they live?

Many U.S. national parks have become threatened islands of biodiversity surrounded by a sea of commercial development. Nearby human activities that threaten wildlife and recreational values in many national parks include mining, logging, livestock grazing, coal-fired power plants, water diversion, and urban development.

Polluted air, drifting hundreds of kilometers from cities, kills ancient trees in California's Sequoia National Park and often degrades the awesome views at Arizona's Grand Canyon National Park. The Great Smoky Mountains, named for the natural haze emitted by their lush vegetation, ironically have air quality similar to that of Los Angeles, California, and vegetation on their highest peaks has been damaged by acid rain. According to the National Park Service, air pollution, mostly from coal-fired power plants and dense vehicle traffic, degrades scenic views in U.S. national parks more than 90% of the time.

The National Park Service estimated that the national parks have an $8 billion to $9 billion backlog for long overdue maintenance and repairs to trails, buildings, and other park facilities. Some analysts say more of these funds could come from private concessionaires who provide campgrounds, restaurants, hotels, and other services for park visitors. They pay franchise fees averaging only about 6–7% of their gross receipts, and many large concessionaires with long-term contracts pay as little as 0.75%. Analysts say these percentages could reasonably be increased to around 20%.

CONNECTIONS
National Parks and Climate Change

According to Stephen Saunders, president of the Rocky Mountain Climate Change Organization and a former deputy assistant secretary of the U.S. Department of the Interior, projected climate change is "the greatest threat the parks have ever had." Low-lying U.S. park properties in places such as Key West, Florida, Ellis Island in New York Harbor, and large areas of Florida's Everglades National Park will likely be underwater later in this century if sea levels rise as projected. And as climate zones shift in a warmer world, by 2030, Glacier National Park may not have any glaciers and the saguaro cactus (see Figure 7-10, middle, p. 155) may disappear from Saguaro National Park.

Figure 10-24 lists ten suggestions made by various analysts for sustaining and expanding the national park system in the United States. The problem is that sustaining the national and state parks is not a high priority when it comes to funding. And the national park system has been attacked consistently by mining, oil, timber, ranching, and other interests that want to sell off these public lands for private use and profit.

Solutions

National Parks

- Integrate plans for managing parks and nearby federal lands
- Add new parkland near threatened parks
- Buy private land inside parks
- Locate visitor parking outside parks and provide shuttle buses for people touring heavily used parks
- Increase federal funds for park maintenance and repairs
- Raise entry fees for visitors and use resulting funds for park management and maintenance
- Seek private donations for park maintenance and repairs
- Limit the number of visitors in crowded park areas
- Increase the number of park rangers and their pay
- Encourage volunteers to give visitor lectures and tours

Figure 10-24 These are ten suggestions for sustaining and expanding the national park system in the United States. **Questions:** Which two of these proposals do you think are the most important? Why? (Data from Wilderness Society and National Parks and Conservation Association)

Nature Reserves Occupy Only a Small Part of the Earth's Land

Most ecologists and conservation biologists believe the best way to preserve biodiversity is to create a worldwide network of protected areas. Currently, less than 13% of the earth's land area is protected either strictly or partially in about 130,000 nature reserves, parks, wildlife refuges, wilderness, and other areas. This 13% figure is misleading because no more than 5% of the earth's land is strictly protected from potentially harmful human activities. In other words, *we have reserved 95% of the earth's land for human use* (see the map in Figure 7, pp. S38–39, in Supplement 8).

Conservation biologists call for full protection of at least 20% of the earth's land area in a global system of biodiversity reserves that would include multiple examples of all the earth's biomes (**Concept 10-4**). But powerful economic and political interests oppose this idea.

Protecting more of the earth's land from unsustainable use will require action and funding by national governments and private groups, bottom-up political pressure by concerned individuals, and cooperative ventures involving governments, businesses, and private conservation organizations. Such groups play an important role in establishing wildlife refuges and other reserves to protect biological diversity.

For example, since its founding by a group of professional ecologists in 1951, *The Nature Conservancy* (**http://www.nature.org/**)—with more than 1 million members worldwide—has created the world's

GOOD NEWS

Figure 10-25 The Silver Creek Nature Conservancy Preserve, a high-desert ecosystem near Sun Valley in the U.S. state of Idaho, is a project of The Nature Conservancy that is open to the public.

largest system of privately held nature reserves and wildlife sanctuaries in 30 countries (Figure 10-25) and in all 50 U.S. states. Globally, the conservancy has protected a total land area larger than Sweden and 8,000 kilometers (5,000 miles) of rivers. In the United States, efforts by The Nature Conservancy and private landowners have protected land, waterways, and wetlands in local and state trusts totaling roughly the area of the U.S. state of Georgia.

GOOD NEWS

In the United States, private, nonprofit *land trust groups* have protected large areas of land. Members pool their financial resources and accept tax-deductible donations to buy and protect farmlands, woodlands, and urban green spaces.

Most developers and resource extractors oppose protecting even the current 12% of the earth's remaining undisturbed ecosystems. They contend that these areas might contain valuable resources that would add to current economic growth. Ecologists and conservation biologists disagree. They view protected areas as islands of biodiversity and natural capital that help to sustain all life and economies indefinitely and that serve as centers of future evolution. In other words, they serve as an "ecological insurance policy" for us and other species. (See Norman Myer's Guest Essay on this topic at CengageNOW.)

HOW WOULD YOU VOTE?

Should at least 20% of the earth's land area be strictly protected from economic development? Cast your vote online at **www.cengage.com/login**.

Designing and Connecting Nature Reserves

Large reserves sustain more species and provide greater habitat diversity than do small reserves. They also minimize exposure to natural disturbances (such as fires and hurricanes), invading species, and human disturbances from nearby developed areas.

In 2007, scientists reported on the world's largest and longest running study of forest fragmentation, which took place in the Amazon. They found that conservation of large reserves in the Amazon was even more important than was previously thought. Because the Amazon rain forest is so diverse, a large expanse of it may contain dozens of ecosystem types, each of which is different enough from the others to support its own unique species. Therefore, developing just a part of such a large area could result in the elimination of many types of habitats and species. **Explore More:** See a Science Focus at **www.cengage.com/login** to learn about how scientists are studying the effects of forest fragmentation on old-growth forests.

However, research indicates that in other locales, several well-placed, medium-sized reserves may better protect a wider variety of habitats and preserve more biodiversity than would a single large reserve of the same total area. When deciding on whether to recommend large- or medium-sized reserves, conservation biologists must carefully consider variations in the ecosystems of a specific area.

Whenever possible, conservation biologists call for using the *buffer zone concept* to design and manage nature reserves. This means strictly protecting an inner core of a reserve, usually by establishing two buffer zones in which local people can extract resources sustainably without harming the inner core. Instead of shutting people out of the protected areas and likely creating enemies, this approach enlists local people as partners in protecting a reserve from unsustainable uses such as illegal logging and poaching. By 2009, the United Nations had used this principle to create a global network of 553 *biosphere reserves* in 107 countries.

GOOD NEWS

So far, most biosphere reserves fall short of these ideals and receive too little funding for their protection and management. An international fund to help make up the shortfall would cost about $100 million per year—equal to about what the world spends on military expenditures every 36 minutes.

Establishing protected *habitat corridors* between isolated reserves helps to support more species and allows migration by vertebrates that need large ranges. Corridors also permit the migration of a species' individuals or populations when environmental conditions in a reserve deteriorate, forcing animals to move to a new location. And corridors support animals that must make seasonal migrations to obtain food. Corridors may also enable some species to shift their ranges if global climate change makes their current ranges uninhabitable.

On the other hand, corridors can threaten isolated populations by allowing movement of pest species, disease, fire, and invasive species between reserves. They also increase exposure of migrating species to natural predators, human hunters, and pollution. In addition, corridors can be costly to acquire, protect, and manage. Nevertheless, an extensive study, reported in 2006, showed that areas connected by corridors can host a greater variety of birds, insects, small mammals, and plant species. In addition, the study's data indicated that nonnative species did not invade the connected areas.

The creation of large reserves connected by corridors on an eco-regional scale is a grand goal of many conservation biologists. This idea is being put into practice in places such as Costa Rica (see the Case Study that follows).

RESEARCH FRONTIER

Creation and management of effective nature preserves, corridors, and eco-regions; see **www.cengage.com/login**.

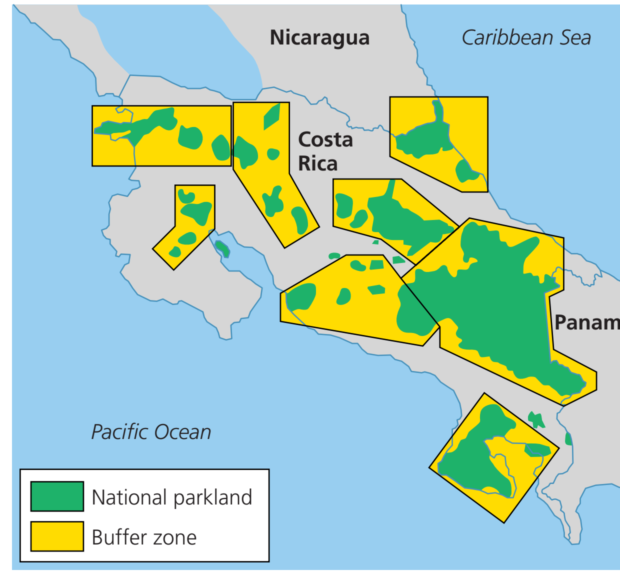


Figure 10-26 **Solutions:** Costa Rica has consolidated its parks and reserves into eight zoned *megareserves* designed to sustain about 80% of the country's rich biodiversity. Green areas are protected natural parklands and yellow areas are surrounding buffer zones, which can be used for sustainable forms of forestry, agriculture, hydropower, hunting, and other human activities.

■ **CASE STUDY**

Costa Rica—A Global Conservation Leader

Tropical forests once completely covered Central America's Costa Rica, which is smaller in area than the U.S. state of West Virginia and about one-tenth the size of France. Between 1963 and 1983, politically powerful ranching families cleared much of the country's forests to graze cattle.

Despite such widespread forest loss, tiny Costa Rica is a superpower of biodiversity, with an estimated 500,000 plant and animal species. A single park in Costa Rica is home to more bird species than are found in all of North America.

In the mid-1970s, Costa Rica established a system of nature reserves and national parks that, by 2008, included about a quarter of its land—6% of it reserved for indigenous peoples. Costa Rica now devotes a larger proportion of its land to biodiversity conservation than does any other country.

The country's parks and reserves (see Photo 5 in the Detailed Contents) are consolidated into eight zoned *megareserves* (Figure 10-26). Each reserve contains a protected inner core surrounded by two buffer zones that local and indigenous people can use for sustainable logging, crop farming, cattle grazing, hunting, fishing, and ecotourism.

Costa Rica's biodiversity conservation strategy has paid off. Today, the country's largest source of income is its $1-billion-a-year tourism industry, almost two-thirds of which involves ecotourism.

To reduce deforestation, the government has eliminated subsidies for converting forest to rangeland. It also pays landowners to maintain or restore tree cover. Between 2007 and 2008, the government planted nearly 14 million trees, which has helped to preserve the country's biodiversity, and it plans to plant 100 million trees by 2017. As they grow, the trees will remove carbon dioxide from the air and help Costa Rica to meet its goal of reducing net CO_2 emissions to zero by 2021.

The strategy has worked: Costa Rica has gone from having one of the world's highest deforestation rates to having one of the lowest. Between 1940 and 1987, forest cover in Costa Rica decreased from 75% to 21%. But by 2008, the country's forest cover had grown to more than 50%.

Protecting Wilderness Is an Important Way to Preserve Biodiversity

One way to protect undeveloped lands from human exploitation is to set them aside as **wilderness**—land officially designated as an area where natural communities have not been seriously disturbed by humans and where human activities are limited by law (**Concept 10-4**). Theodore Roosevelt, the first U.S. president to set aside protected areas, summarized what we should do with wilderness: "Leave it as it is. You cannot improve it."

Wilderness protection is not without controversy (see the Case Study, p. 242). Some critics oppose protecting large areas for their scenic and recreational value for a relatively small number of people. They believe this keeps some areas of the planet from being economically useful to people living today. But to most biologists, the most important reasons for protecting wilderness and other areas from exploitation and degradation involve long-term needs—to *preserve biodiversity* as a vital part of the earth's natural capital and to *protect wilderness areas as centers for evolution* in response to mostly unpredictable changes in environmental conditions. In other words, protecting wilderness areas is equivalent to investing in a biodiversity insurance policy for everyone.

■ **CASE STUDY**

Controversy over Wilderness Protection in the United States

In the United States, conservationists have been trying to save wild areas from development since 1900. Overall, they have fought a losing battle. Not until 1964 did Congress pass the Wilderness Act. It allowed the government to protect undeveloped tracts of public land from development as part of the National Wilderness Preservation System. Such lands get the highest level of protection from human activities such as logging, mining, and motor vehicle use.

GOOD NEWS

The area of protected wilderness in the United States increased tenfold between 1970 and 2010. Even so, only about 4.7% of U.S. land is protected as wilderness—almost three-fourths of it in Alaska. Only about 2% of the land area of the lower 48 states is protected, most of it in the West.

GOOD NEWS

However, in 2009 the U.S. government granted wilderness protection to over 800,000 hectares (2 million acres) of public land in 9 of the lower 48 states. It was the largest expansion of wilderness lands in 15 years. The new law also increased the total length of wild and scenic rivers (treated as wilderness areas) by 50%—the largest such increase ever.

One problem is that only 4 of the 413 wilderness areas in the lower 48 states are large enough to sustain all of the species they contain. Some species, such as wolves, need large areas in which to roam as packs, to find prey, and to mate and rear young. Also, the system includes only 81 of the country's 233 distinct ecosystems. Most wilderness areas in the lower 48 states are threatened habitat islands in a sea of development.

Scattered blocks of public lands with a total area roughly equal to that of the U.S. state of Montana could qualify for designation as wilderness. About 60% of such land is in the national forests. But for decades, the politically powerful oil, gas, mining, and timber industries have sought entry to these areas—owned jointly by all citizens of the United States—in hopes of locating and removing valuable resources. Under the law, as soon as such an area is accessed in this way, it automatically becomes disqualified for wilderness protection.

10-5 What Is the Ecosystem Approach to Sustaining Biodiversity?

▶ **CONCEPT 10-5 We can help to sustain terrestrial biodiversity by identifying and protecting severely threatened areas (biodiversity hotspots), restoring damaged ecosystems (using restoration ecology), and sharing with other species much of the land we dominate (using reconciliation ecology).**

We Can Use a Four-Point Strategy to Protect Ecosystems

Most biologists and wildlife conservationists believe that we must focus more on protecting and sustaining ecosystems, and the biodiversity contained within them, than on saving individual species. Their goals certainly include preventing premature extinction of species, but they argue the best way to do that is to protect threatened habitats and ecosystem services. This *ecosystems approach* would generally employ the following four-point plan:

1. Map the world's terrestrial ecosystems and create an inventory of the species contained in each of them and the natural services these ecosystems provide.
2. Locate and protect the most endangered ecosystems and species, with emphasis on protecting plant biodiversity and ecosystem services.
3. Seek to restore as many degraded ecosystems as possible.
4. Make development *biodiversity-friendly* by providing significant financial incentives (such as tax breaks and write-offs) and technical help to private landowners who agree to help protect endangered ecosystems.

Some scientists have argued that we need new laws to embody these principles. In the United States, for example, there is support for amending the Endangered Species Act, or possibly passing a new act, in order to implement widespread ecosystem and biodiversity protection.

Protecting Global Biodiversity Hotspots Is an Urgent Priority

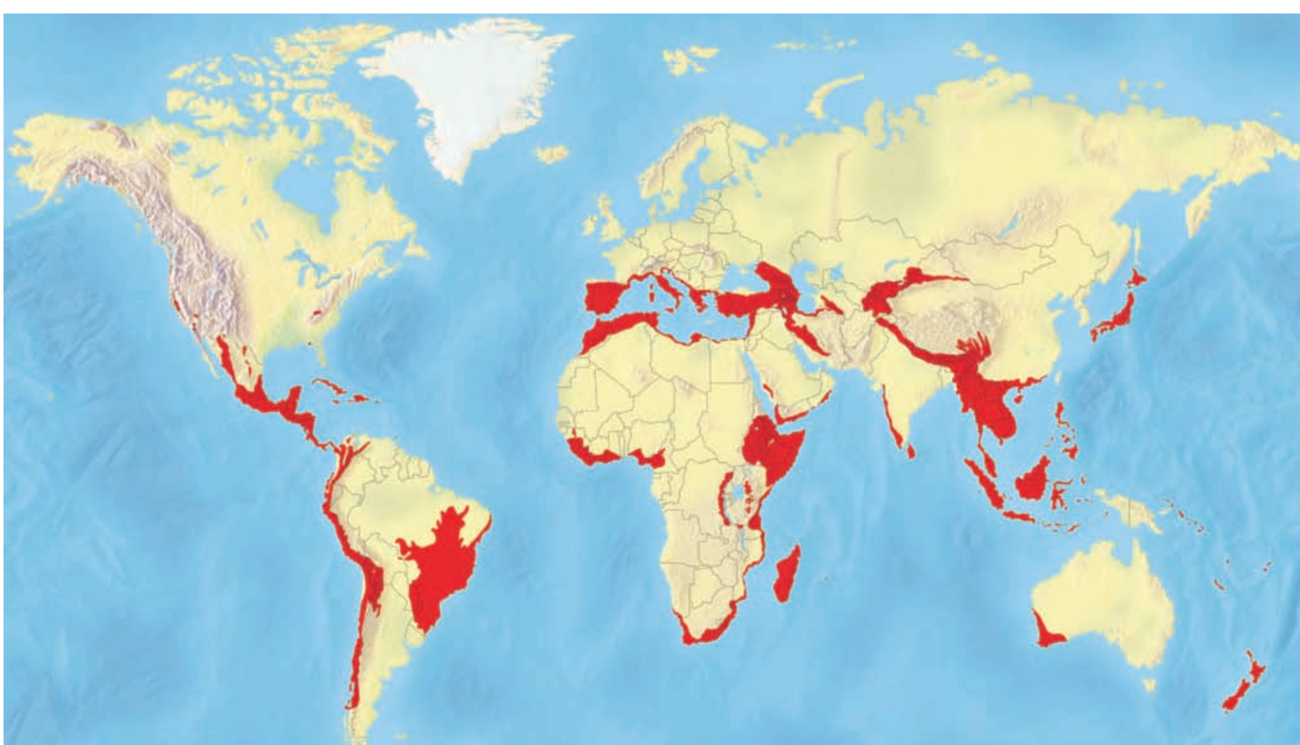
The earth's species are not evenly distributed. In fact, 17 megadiversity countries, most of them with large areas of tropical forest, contain more than two-thirds of all species. The leading megadiversity countries, in order, are Indonesia, Colombia, Mexico, Brazil, and Ecuador.

To protect as much of the earth's remaining biodiversity as possible, some biodiversity scientists urge the adoption of an *emergency action* strategy to identify and quickly protect **biodiversity hotspots**—areas especially rich in plant species that are found nowhere else and are in great danger of extinction (**Concept 10-5**). These areas suffer serious ecological disruption, mostly because of rapid human population growth and the resulting pressure on natural resources.

Environmental scientist Norman Myers first proposed this idea in 1988 (see his Guest Essay on this topic at CengageNOW). Myers and his colleagues at Conservation International relied primarily on the diversity of plant species to identify biodiversity hotspot areas because data on plant diversity was more readily available and plant diversity was also thought to be an indicator of animal diversity.

Figure 10-27 shows 34 global, terrestrial biodiversity hotspots identified by biologists. (For a map of hotspots in the United States, see Figure 27, p. S55, in Supplement 8.) In these areas, a total of 86% of the habitat has been destroyed. Although these hotspots cover only a little more than 2% of the earth's land surface, they contain an estimated 50% of the world's flowering plant species and 42% of all terrestrial vertebrates (mammals, birds, reptiles, and amphibians). They are also home for a large majority of the world's endangered or critically endangered species and 1.2 billion people—one-fifth of the world's population. Says Norman Myers, "I can think of no other biodiversity initiative that could achieve so much at a comparatively small cost, as the hotspots strategy."

One drawback of the biodiversity hotspots approach is that some areas that are rich in plant diversity are not necessarily rich in animal diversity. In addition, when hotspots are protected, local people can be displaced and can lose access to important resources. However, the goal of this approach is to protect the unique biodiversity in areas under great stress from human activities. Despite



CENGAGENOW™ **Active Figure 10-27 Endangered natural capital:** This map shows 34 biodiversity hotspots identified by ecologists as important and endangered centers of terrestrial biodiversity that contain a large number of species found nowhere else. Identifying and saving these critical habitats requires a vital emergency response (**Concept 10-5**). Compare these areas with those on the global map of the human ecological footprint, as shown in Figure 7, p. S38, in Supplement 8. According to the IUCN, the average proportion of biodiversity hotspot areas truly protected with funding and enforcement is only 5%. *See an animation based on this figure at* CengageNOW. **Questions:** Are any of these hotspots near where you live? Is there a smaller, localized hotspot in the area where you live? (Data from Center for Applied Biodiversity Science at Conservation International) its importance, this approach has not succeeded in capturing sufficient public support and funding. **Explore More:** See a Case Study at **www.cengage.com/login** that describes a biodiversity hotspot in East Africa.

CENGAGE**NOW**™ Learn more about biodiversity hotspots around the world, what is at stake there, and how they are threatened at CengageNOW.

RESEARCH FRONTIER

Identifying the world's biodiversity hotspots; see **www.cengage.com/login**.

Protecting Ecosystem Services Is Also an Urgent Priority

Another way to help sustain the earth's biodiversity is to identify and protect areas where vital natural or ecosystem services (see the orange boxed labels in Figure 1-4, p. 9) are being impaired enough to reduce biodiversity and harm local residents.

This approach has received more attention since the release of the 2005 UN *Millennium Ecosystem Assessment*—a 4-year study by 1,360 experts from 95 countries. It identified key ecosystem services that provide numerous ecological and economic benefits such as those provided by forests (Figure 10-4). The study pointed out that human activities are degrading or overusing about 60% of the earth's natural services in various ecosystems around the world, and it outlined ways to help sustain these vital ecosystem services.

This approach recognizes that most of the world's ecosystems are already dominated or influenced by human activities and that such pressures are increasing as population, urbanization, resource use, and the human ecological footprint increase (see Figure 1-13, p. 16, and the map in Figure 7, p. S38, in Supplement 8). Proponents of this approach recognize that setting aside and protecting reserves and wilderness areas, especially highly endangered biodiversity hot spots (Figure 10-26), is vital. But they contend that such efforts by themselves will not significantly slow the steady erosion of the earth's biodiversity and ecosystem services.

Proponents of this strategy would also identify highly stressed *life raft ecosystems*. These would be areas where poverty levels are high and where a large part of the economy depends on various ecosystem services that are being degraded severely enough to threaten the well-being of people and other forms of life. In such areas, residents, public officials, and conservation scientists would work together to develop strategies to help protect both human communities and natural biodiversity. Instead of emphasizing nature versus people, this approach focuses on finding "win–win" strategies for protecting both people and the ecosystem services that support all life and economies.

We Can Rehabilitate and Restore Ecosystems That We Have Damaged

Almost every natural place on the earth has been affected or degraded to some degree by human activities. We can at least partially reverse much of this harm through **ecological restoration**: the process of repairing damage caused by humans to the biodiversity and dynamics of natural ecosystems. Examples include replanting forests (**Core Case Study**), restoring grasslands, restoring coral reefs, restoring wetlands and stream banks (Figure 10-21, right), reintroducing native species (Science Focus, p. 245), removing invasive species, and freeing river flows by removing dams.

CORE CASE STUDY

Evidence indicates that in order to sustain biodiversity, we must make a global effort to rehabilitate and restore ecosystems we have damaged (**Concept 10-5**). An important strategy is to mimic nature and natural processes and let nature do most of the work, usually through secondary ecological succession (see Figure 5-20, p. 120).

By studying how natural ecosystems recover, scientists are learning how to speed up repair operations using a variety of approaches, including the following four:

1. *Restoration:* returning a degraded habitat or ecosystem to a condition as similar as possible to its natural state.

2. *Rehabilitation:* turning a degraded ecosystem into a functional or useful ecosystem without trying to restore it to its original condition. Examples include removing pollutants and replanting to reduce soil erosion in abandoned mining sites and landfills, and in clear-cut forests.

3. *Replacement:* replacing a degraded ecosystem with another type of ecosystem. For example, a degraded forest could be replaced by a productive pasture or tree plantation.

4. *Creating artificial ecosystems:* for example, creating artificial wetlands to help reduce flooding or to treat sewage.

Researchers have suggested a science-based, four-step strategy for carrying out most forms of ecological restoration and rehabilitation.

First, identify the causes of the degradation (such as pollution, farming, overgrazing, mining, or invasive species). *Second*, stop the abuse by eliminating or sharply reducing these factors. This would include removing toxic soil pollutants, improving depleted soil by adding nutrients and new topsoil, preventing fires, and controlling or eliminating disruptive nonnative species (Science Focus, p. 245).

Third, if necessary, reintroduce key species to help restore natural ecological processes, as was done with wolves in the Yellowstone ecosystem (Science Focus, p. 238). *Fourth*, protect the area from further degrada-

SCIENCE FOCUS

Ecological Restoration of a Tropical Dry Forest in Costa Rica

Costa Rica is the site of one of the world's largest *ecological restoration* projects. In the lowlands of its Guanacaste National Park, a small, tropical dry forest was burned, degraded, and fragmented for large-scale conversion of the area to cattle ranches and farms. Now it is being restored and relinked to a rain forest on nearby mountain slopes. The goal is to eliminate damaging nonnative grasses and reestablish a tropical dry-forest ecosystem over the next 100–300 years.

Daniel Janzen, professor of biology at the University of Pennsylvania and a leader in the field of restoration ecology, helped to galvanize international support for this restoration project. He used his own MacArthur grant money to purchase this Costa Rican land to be set aside as a national park. He also raised more than $10 million for restoring the park.

Janzen recognizes that ecological restoration and protection of the park will fail unless the people in the surrounding area believe they will benefit from such efforts. His vision is to see that the nearly 40,000 people who live near the park play an essential role in the restoration of the degraded forest, a concept he calls *biocultural restoration*.

By actively participating in the project, local residents reap educational, economic, and environmental benefits. Local farmers are paid to sow large areas with tree seeds and to plant tree seedlings started in Janzen's lab. Local grade school, high school, and university students and citizens' groups study the park's ecology during field trips. The park's location near the Pan American Highway makes it an ideal area for ecotourism, which stimulates the local economy.

The project also serves as a training ground in tropical forest restoration for scientists from all over the world. Research scientists working on the project give guest classroom lectures and lead field trips.

In a few decades, today's Costa Rican children will be running the park and the local political system. If they understand the ecological importance of their local environment, they will be more likely to protect and sustain its biological resources. Janzen believes that education, awareness, and involvement—not guards and fences—are the best ways to restore degraded ecosystems and to protect largely intact ecosystems from unsustainable use.

Critical Thinking

Would such an ecological restoration project be possible in the area where you live? Explain.

tion and allow secondary ecological succession to occur (Figure 10-21, right).

There are some outstanding examples of ecological restoration. For example, most of the tall-grass prairies in the United States have been plowed up and converted to crop fields. However, these prairies are ideal subjects for ecological restoration for three reasons. *First,* many residual or transplanted native plant species can be established within a few years. *Second*, the technology involved is similar to that of gardening and agriculture. *Third,* the process is well suited for volunteer labor needed to plant native species and weed out invading species until the natural species can take over. There are a number of successful prairie restoration projects in the United States and in other countries.

GOOD NEWS

RESEARCH FRONTIER

Improving ecological restoration efforts; see **www.cengage.com/login**.

Will Restoration Encourage Further Destruction?

Some analysts worry that ecological restoration could encourage continuing environmental destruction and degradation by suggesting that any ecological harm we do can be undone. Restoration ecologists disagree with that suggestion. They point out that preventing ecosystem damage in the first place is cheaper and more effective than any form of ecological restoration. But they strongly agree that restoration should not be used to help justify environmental destruction.

Restoration ecologists note that so far, we have been able to protect only about 5% of the earth's land from the effects of human activities, so ecological restoration is badly needed for many of the world's ecosystems. They argue that even if a restored ecosystem differs from the original system, the result is better than no restoration at all. In time, further experience with ecological restoration will improve its effectiveness. Chapter 11 describes examples of the ecological restoration of aquatic systems such as wetlands and rivers.

HOW WOULD YOU VOTE?

Should we mount a massive effort to restore the ecosystems we have degraded, even though this will be quite costly? Cast your vote online at **www.cengage.com/login**.

We Can Share Areas We Dominate with Other Species

Ecologist Michael L. Rosenzweig strongly supports efforts to help sustain the earth's biodiversity through species protection strategies such as the U.S. Endangered Species Act (see Chapter 9, pp. 209–211) and through preserving wilderness and other wildlife reserves. However, he contends that in the long run, these approaches will fail for two reasons. *First,* fully protected reserves currently are devoted to saving only about 5% of the world's terrestrial area, excluding polar regions and some other uninhabitable areas. To Rosenzweig, the real challenge is to help sustain wild species in the human-dominated portion of nature that makes up 95% of the planet's inhabitable terrestrial area (**Concept 10-5**).

Second, setting aside funds and refuges, and passing laws to protect endangered and threatened species are essentially desperate attempts to save species that are in deep trouble. These emergency efforts can help a few species, but it is equally important to learn how to keep more species away from the brink of extinction. This is a prevention approach.

Rosenzweig suggests that we develop a new form of conservation biology, called **reconciliation ecology**. This science focuses on inventing, establishing, and maintaining new habitats to conserve species diversity in places where people live, work, or play. In other words, we need to learn how to share with other species some of the spaces we dominate.

Implementing reconciliation ecology will involve the growing practice of *community-based conservation*, in which conservation biologists work with people to help them protect biodiversity in their local communities. With this approach, scientists, citizens, and sometimes national and international conservation organizations seek ways to preserve local biodiversity while allowing people who live in or near protected areas to make sustainable use of some of the resources there (see the Case Study that follows).

This was the approach used by Wangari Maathai (**Core Case Study**), as she established the Green Belt Movement. A major challenge for her was to get people to see the environment as something closely related to their daily lives.

CORE CASE STUDY

Some scientists have dealt with this challenge by getting people to realize that protecting local wildlife and ecosystems can provide economic resources for their communities by encouraging sustainable forms of ecotourism. In the Central American country of Belize, for example, conservation biologist Robert Horwich has helped to establish a local sanctuary for the black howler monkey. He convinced local farmers to set aside strips of forest to serve as habitats and corridors through which these monkeys can travel. The reserve, run by a local women's cooperative, has attracted ecotourists and biologists. The community has built a black howler museum, and local residents receive income by housing and guiding ecotourists and biological researchers.

GOOD NEWS

In other parts of the world, people are learning how to protect vital insect pollinators such as native butterflies and bees, which are vulnerable to insecticides and habitat loss. Neighborhoods and municipal governments are doing this by agreeing to reduce or eliminate the use of pesticides on their lawns, fields, golf courses, and parks. Neighbors also work together to plant gardens of flowering plants as a source of food for pollinating insect species. And some neighborhoods and farmers have built devices using wood and plastic straws, which serve as hives for pollinating bees.

There are many other examples of individuals and groups working together on projects to restore grasslands, wetlands, streams, and other degraded areas (see the Case Study that follows). **GREEN CAREER:** Reconciliation ecology specialist

CASE STUDY

The Blackfoot Challenge—Reconciliation Ecology in Action

The Blackfoot River flows among beautiful mountain ranges in the west-central part of the U.S. state of Montana. This large watershed is home to more than 600 species of plants, 21 species of waterfowl, bald eagles, peregrine falcons, grizzly bears, and rare species of trout. Some species, such as the Howell's gumweed and the bull trout, are threatened with extinction. In other words, this watershed is a precious jewel of biodiversity.

The Blackfoot River Valley is also home to people who live in seven communities and 2,500 rural households. A book and movie, both entitled *A River Runs Through It*, tell of how residents of the valley cherish their lifestyles.

In the 1970s, many of these people recognized that their beloved valley was threatened by poor mining, logging, and grazing practices, water and air pollution, and unsustainable commercial and residential development. They also understood that their way of life depended on wildlife and wild ecosystems located on private and public lands. They began meeting informally over kitchen tables to discuss how to maintain their way of life while sustaining the other species living in the valley. These small gatherings spawned community meetings attended by individual and corporate landowners, state and federal land managers, scientists, and local government officials. It was a case of people with different interests working together to help sustain the environment that sustained them.

Out of these meetings came action. Teams of residents organized weed-pulling parties, built nesting structures for waterfowl, and developed more sustainable grazing systems. Landowners agreed to create perpetual conservation easements, setting land aside for only conservation and sustainable uses such as hunting and fishing. They created corridors between large tracts of undeveloped land. In 1993, these efforts were organized under a charter called the Blackfoot Challenge.

The results were dramatic. Blackfoot Challenge members have restored and enhanced large areas of wetlands, streams, and native grasslands. They have reserved large areas of private land under perpetual conservation easements.

The pioneers in this project might not have known it, but they were initiating what has become a classic example of *reconciliation ecology*. They worked together, respected each other's views, accepted compromises, and found ways to share their land with the plants and animals that make it such a beautiful place to live.

THINKING ABOUT
The Green Belt Movement and Reconciliation Ecology

CORE CASE STUDY

List three ways in which the Green Belt Movement (**Core Case Study**) is a good example of reconciliation ecology at work.

RESEARCH FRONTIER

Determining where and how reconciliation ecology can work best; see **www.cengage.com/login**.

Figure 10-28 lists some ways in which you can help to sustain the earth's terrestrial biodiversity.

Here are this chapter's *three big ideas*:

- The economic values of the important ecological services provided by the world's ecosystems are far greater than the value of raw materials obtained from those systems.
- We can manage forests, grasslands, parks, and nature preserves more effectively by protecting more land, preventing over-use of these areas, and using renewable resources provided by them no faster than such resources can be replenished by natural processes.

What Can You Do?

Sustaining Terrestrial Biodiversity

- Adopt a forest
- Plant trees and take care of them
- Recycle paper and buy recycled paper products
- Buy sustainably produced wood and wood products
- Choose wood substitutes such as bamboo furniture and recycled plastic outdoor furniture, decking, and fencing
- Help to restore a nearby degraded forest or grassland
- Landscape your yard with a diversity of plants that are native to your area

Figure 10-28 **Individuals matter:** These are some ways in which you can help to sustain terrestrial biodiversity. **Questions:** Which two of these actions do you think are the most important? Why? Which of these things do you already do?

- We can sustain *terrestrial biodiversity* by protecting severely threatened areas, protecting remaining undisturbed areas, restoring damaged ecosystems, and sharing with other species much of the land we dominate.

REVISITING The Green Belt Movement and Sustainability

CORE CASE STUDY

SUSTAINABILITY

In this chapter, we looked at how humans are destroying or degrading terrestrial biodiversity in a variety of ecosystems. We also saw how we can reduce this destruction and degradation by using the earth's resources more sustainably. The **Core Case Study** showed us the importance of simply planting trees. And we learned the importance of protecting species and ecosystems in nature reserves such as parks and wilderness areas.

We also learned about the importance of preserving what remains of richly diverse and highly endangered ecosystems (biodiversity hotspots). We examined the key strategy of restoring or rehabilitating some of the ecosystems we have degraded (restoration ecology). In addition, we explored ways in which people can share with other species some of the land they occupy in order to help sustain biodiversity (reconciliation ecology).

Preserving terrestrial biodiversity as it is done in the Green Belt Movement involves applying the three **principles of sustainability** (see back cover). First, it means respecting biodiversity and understanding the value of sustaining it. Then, in helping to sustain biodiversity by planting trees for example, we also help to restore and preserve the flows of energy from the sun through food webs and the cycling of nutrients within ecosystems. Also, if we rely less on fossil fuels and more on direct solar energy and its indirect forms, such as wind and flowing water, we will generate less pollution and interfere less with natural chemical cycling and other forms of natural capital that sustain biodiversity and our own lives and societies.

We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect.

ALDO LEOPOLD

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 218. Describe the Green Belt Movement founded by Wangari Maathai (**Core Case Study**). CORE CASE STUDY
2. Distinguish among an **old-growth forest**, a **second-growth forest**, and a **tree plantation** (**tree farm** or **commercial forest**). What major ecological and

economic benefits do forests provide? Describe the efforts of scientists and economists to put a price tag on the major ecological services provided by forests and other ecosystems.

3. Describe the harm caused by building roads into previously inaccessible forests. Distinguish among selective cutting, clear-cutting, and strip cutting in the harvesting of trees. What are the major advantages and disadvantages of clear-cutting forests? What are two types of forest fires? What are some ecological benefits of occasional surface fires? What are four ways to reduce the harmful impacts of diseases and insects on forests? What effects might projected climate change have on forests?

4. What is **deforestation** and what parts of the world are experiencing the greatest forest losses? List some major harmful environmental effects of deforestation. Describe the encouraging news about deforestation in the United States. How serious is tropical deforestation? What are the major underlying and direct causes of tropical deforestation?

5. Describe four ways to manage forests more sustainably. What is certified timber? What are four ways to reduce the harm to forests and to people caused by forest fires? What is a prescribed fire? What are three ways to reduce the need to harvest trees? Describe the fuelwood crisis and list three ways to reduce its severity. What are five ways to protect tropical forests and use them more sustainably?

6. Distinguish between **rangelands** and **pastures**. What is **overgrazing** and what are its harmful environmental effects? Describe efforts to reduce overgrazing in the Malpai Borderlands. What are three ways to reduce overgrazing and use rangelands more sustainably? Describe the conflict among ranching, biodiversity protection, and urban development in the American West.

7. What major environmental threats affect national parks in the world and in the United States? How could national parks in the United States be used more sustainably? Describe some of the ecological effects of reintroducing the gray wolf to Yellowstone National Park in the United States. What percentage of the world's land has been set aside and protected as nature reserves, and what percentage do conservation biologists believe should be protected?

8. How should nature reserves be designed and connected? Describe what Costa Rica has done to establish nature reserves. What is **wilderness** and why is it important? Describe the controversy over protecting wilderness in the United States. Describe a four-point strategy for protecting ecosystems. What is a **biodiversity hotspot** and why is it important to protect such areas? Why is it also important to protect areas where deteriorating ecosystem services threaten people and other forms of life?

9. What is **ecological restoration**? Describe a science-based, four-point strategy for carrying out ecological restoration and rehabilitation. Describe the ecological restoration of a tropical dry forest in Costa Rica. Define and give three examples of **reconciliation ecology**. Describe the Blackfoot Challenge reconciliation ecology project.

10. What are four ways in which we can all help sustain the earth's terrestrial biodiversity? What are this chapter's *three big ideas*? Describe the relationship between preserving biodiversity as it is done by the Green Belt Movement and the three scientific **principles of sustainability**.

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. Describe some ecological, economic, and social benefits of the Green Belt Movement (**Core Case Study**). Is there an area near where you live that could benefit from such intensive planting of trees? If so, describe how it would benefit the area.

2. If we fail to protect a much larger percentage of the world's remaining old-growth forests and tropical rain forests, describe three harmful effects that this failure is likely to have on any children and grandchildren you might have.

3. In the early 1990s, Miguel Sanchez, a subsistence farmer in Costa Rica, was offered $600,000 by a hotel developer for a piece of land that he and his family had been using sustainably for many years. The land contained an old-growth rain forest and a black sand beach within an area under rapid development. Sanchez refused the offer. What would you have done if you were in Miguel Sanchez's position? Explain your decision.

4. There is controversy over whether Yellowstone National Park in the United States should be accessible by snowmobile during winter. Conservationists and backpackers who use cross-country skis or snowshoes for excursions in the park during winter say no. They contend that snowmobiles are noisy, pollute the air, and can destroy vegetation and disrupt some of the park's wildlife. Proponents say that snowmobiles should be allowed so that snowmobilers can enjoy the park during winter when cars are mostly banned. They point out that new snowmobiles are made to cut pollution and noise. A proposed compromise plan would allow no more than 950 of these new machines into the park per day, only on roads, and primarily on guided tours. What is your view on this issue? Explain.

5. In 2009, environmental analyst Lester R. Brown estimated that reforesting the earth and restoring the earth's degraded rangelands would cost about $15 billion a year. Suppose the United States, the world's most affluent country, agreed to put up half of this money, at an average annual cost of $25 per American. Would you support doing this? Explain. What other part or parts of the federal budget would you decrease to come up with these funds?

6. Should more-developed countries provide most of the money needed to help preserve remaining tropical forests in less-developed countries? Explain.

7. Are you in favor of establishing more wilderness areas in the United States, especially in the lower 48 states (or in the country where you live)? Explain. What might be some drawbacks of doing this?

8. You are a defense attorney arguing in court for sparing a large area of tropical rain forest from being cut down. Give your three strongest arguments for the defense of this ecosystem. If you had to choose between sparing a tropical rain forest and sparing a northern boreal forest of about the same size, which one would you try to save? Explain.

9. Congratulations! You are in charge of the world. List the three most important features of your policies for using and managing **(a)** forests, **(b)** grasslands, **(c)** nature reserves such as parks and wildlife refuges, **(d)** biological hotspots, and **(e)** areas with deteriorating ecosystem services.

10. List two questions that you would like to have answered as a result of reading this chapter.

ECOLOGICAL FOOTPRINT ANALYSIS

Use the table below to answer the questions that follow.

Country	Area of tropical rain forest (square kilometers)	Area of deforestation per year (square kilometers)	Annual rate of tropical forest loss
A	1,800,000	50,000	
B	55,000	3,000	
C	22,000	6,000	
D	530,000	12,000	
E	80,000	700	

1. What is the annual rate of tropical rain forest loss, as a percentage of total forest area, in each of the five countries? Answer by filling in the blank column on the table.

2. What is the annual rate of tropical deforestation collectively in all of the countries represented in the table?

3. According to the table, and assuming the rates of deforestation remain constant, which country's tropical rain forest will be completely destroyed first?

4. Assuming the rate of deforestation in country C remains constant, how many years will it take for all of its tropical rain forests to be destroyed?

5. Assuming that a hectare (1.0 hectare = 0.01 square kilometer) of tropical rain forest absorbs 0.85 metric tons (1 metric ton = 2,200 pounds) of carbon dioxide per year, what would be the total annual growth in the carbon footprint (carbon emitted but not absorbed by vegetation because of deforestation) in metric tons of carbon dioxide per year for each of the five countries in the table?

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengagebrain.com/shop/ISBN/0538735341** and choose Chapter 10 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

For students with access to premium online resources, log on to **www.cengage.com/login**.

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11 Sustaining Aquatic Biodiversity

CORE CASE STUDY Protecting Whales: A Success Story . . . So Far

Cetaceans are an order of mostly marine mammals ranging in size from the 0.9-meter (3-foot) porpoise to the giant 15- to 30-meter (50- to 100-foot) blue whale. They are divided into two major groups: *toothed whales* and *baleen whales* (Figure 11-1).

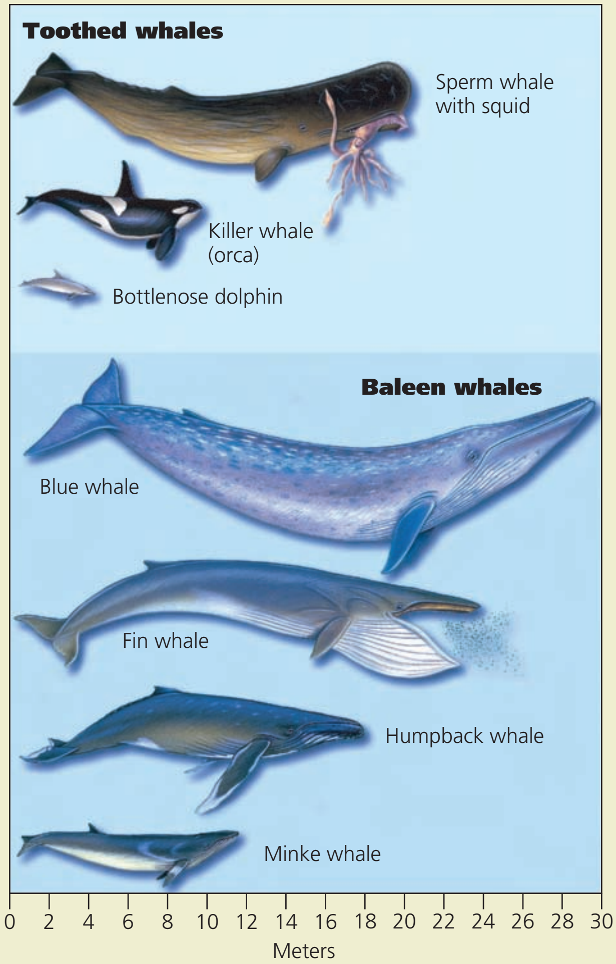


Figure 11-1 *Cetaceans* are classified as either toothed whales or baleen whales.

Toothed whales, such as the sperm whale, killer whale (orca) and the dolphin, bite and chew their food and feed mostly on squid, octopus, and other marine animals. *Baleen whales*, such as the blue, fin, humpback, and minke whales, are filter feeders. Attached to their upper jaws are plates made of baleen, or whalebone, which they use to filter plankton, especially tiny shrimp-like krill (see Figure 3-13, p. 64), from the seawater.

Whales are fairly easy to kill because of their large size in some cases and because of their need to come to the surface to breathe. Modern whale hunters have become efficient at hunting and killing whales using radar, spotters in airplanes, fast ships, and harpoon guns. Whale harvesting, mostly in international waters, has followed the classic pattern of a tragedy of the commons (see Chapter 1, p. 15), with whalers killing an estimated 1.5 million whales between 1925 and 1975. This overharvesting drove 8 of the 11 major species to *commercial extinction*, the point at which their numbers were so low that finding and harvesting the remaining individual whales was too costly.

In 1946, the International Whaling Commission (IWC) was established to regulate the whaling industry by setting annual quotas for various whale species to prevent overharvesting. But IWC quotas often were based on insufficient data or were ignored by whaling countries. Without enforcement powers, the IWC was not able to stop the decline of most commercially hunted whale species.

In 1970, the United States stopped all commercial whaling and banned all imports of whale products. Under pressure from conservationists and the governments of many nonwhaling nations, in 1986, the IWC began imposing a moratorium on commercial whaling. It worked. The estimated number of whales killed commercially worldwide dropped from 42,480 in 1970 to about 1,500 in 2009.

GOOD NEWS

However, despite the moratorium, more than 33,000 whales were hunted and killed between 1986 and 2010, mostly by the nations of Japan and Norway, which had officially objected to and ignored the moratorium. In 2006, the nation of Iceland also stopped observing the moratorium. These three nations are pressuring the IWC to revise the moratorium and allow for resumed commercial hunting of some whale species.

Whales are just one part of the incredible diversity of aquatic species and their habitats that we must help to sustain. In this chapter, we discuss this important challenge.

Key Questions and Concepts

11-1 **What are the major threats to aquatic biodiversity?**

CONCEPT 11-1 Aquatic species are threatened by habitat loss, invasive species, pollution, climate change, and overexploitation, all made worse by the growth of the human population.

11-2 **How can we protect and sustain marine biodiversity?**

CONCEPT 11-2 We can help to sustain marine biodiversity by using laws and economic incentives to protect species, setting aside marine reserves to protect ecosystems, and using community-based integrated coastal management.

11-3 **How should we manage and sustain marine fisheries?**

CONCEPT 11-3 Sustaining marine fisheries will require improved monitoring of fish and shellfish populations, cooperative fisheries management among communities and nations, reduction of fishing subsidies, and careful consumer choices in seafood markets.

11-4 **How should we protect and sustain wetlands?**

CONCEPT 11-4 To maintain the ecological and economic services of wetlands, we must maximize the preservation of remaining wetlands and the restoration of degraded wetlands.

11-5 **How should we protect and sustain freshwater lakes, rivers, and fisheries?**

CONCEPT 11-5 Freshwater ecosystems are strongly affected by human activities on adjacent lands, and protecting these ecosystems must include protection of their watersheds.

11-6 **What should be our priorities for sustaining aquatic biodiversity?**

CONCEPT 11-6 Sustaining the world's aquatic biodiversity requires mapping it, protecting aquatic hotspots, creating large, fully protected marine reserves, protecting freshwater ecosystems, and carrying out ecological restoration of degraded coastal and inland wetlands.

Note: Supplements 2 (p. S3) and 8 (p. S30) can be used with this chapter.

The coastal zone may be the single most important portion of our planet.
The loss of its biodiversity may have repercussions far beyond our worst fears.

G. CARLETON RAY

11-1 What Are the Major Threats to Aquatic Biodiversity?

▶ **CONCEPT 11-1** **Aquatic species are threatened by habitat loss, invasive species, pollution, climate change, and overexploitation, all made worse by the growth of the human population.**

We Have Much to Learn about Aquatic Biodiversity

Although we live on a watery planet, we have explored only about 5% of the earth's interconnected oceans (see Figure 8-2, p. 169) and know relatively little about its biodiversity and how it works. In 2009, marine biologist Chris Bowler estimated that only 1% of the life forms in the sea have been properly identified and studied. We also have limited knowledge about freshwater biodiversity.

However, scientists have observed three general patterns related to marine biodiversity. *First,* the greatest marine biodiversity occurs in coral reefs, estuaries, and on the deep-ocean floor. *Second,* biodiversity is higher near the coasts than in the open sea because of the greater variety of producers and habitats in coastal areas. *Third,* biodiversity is generally higher in the bottom region of the ocean than in the surface region because of the greater variety of habitats and food sources on the ocean bottom.

The deep part of ocean, where sunlight does not penetrate, is the planet's least explored environment. But this is changing. More than 2,400 scientists from 80 countries are working on a 10-year project to catalog the species in this region of the ocean. So far, they have used remotely operated deep-sea vehicles to identify 17,650 species living in this deepest ocean zone and they are adding a few thousand new species each year.

The world's marine systems provide important ecological and economic services (see Figure 8-5, p. 172). For example, a 2009 study, *Economics of Ecosystems and Biodiversity*, by a team of economists and scientists estimated that an area of coral reef roughly equal to the size of a city block provides economic and ecological services worth more than $1 million a year. Thus, scientific investigation of poorly understood marine aquatic systems is a *research frontier* that could lead to immense ecological and economic benefits. Freshwater systems, which occupy only 1% of the earth's surface, also provide important ecological and economic services (see Figure 8-15, p. 181).

RESEARCH FRONTIER

Exploring marine and freshwater ecosystems, their species, and species interactions; see **www.cengage.com/login**.

Human Activities Are Destroying and Degrading Aquatic Habitat

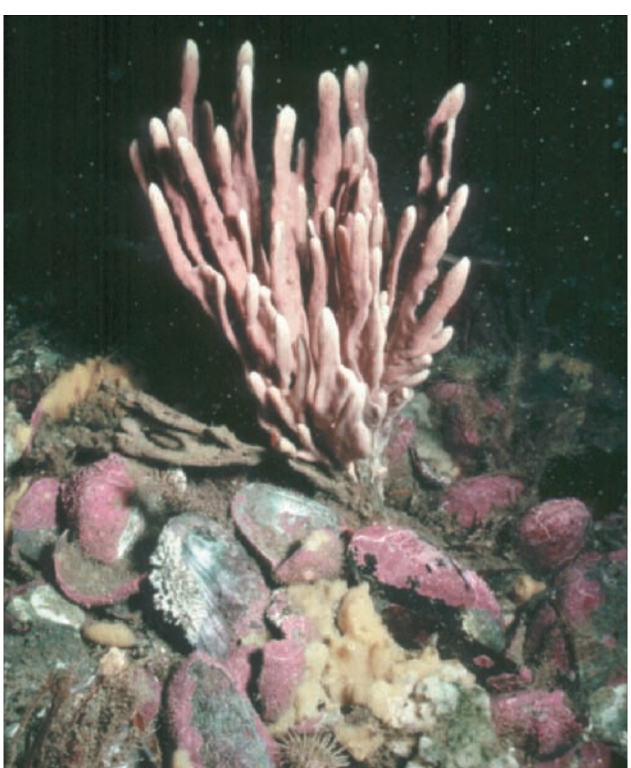
As with terrestrial biodiversity, the greatest threats to the biodiversity of the world's marine and freshwater ecosystems (**Concept 11-1**) can be remembered with the aid of the acronym HIPPCO, with H standing for *habitat loss and degradation*. Some 90% of fish living in the ocean spawn on coral reefs (see Figure 8-1, left, p. 168 and Figure 8-12, p. 177), in coastal wetlands and marshes (see Figure 8-8, p. 174), in mangrove forests (see Figure 8-10, p. 175), or in rivers.

All of these ecosystems are under intense pressure from human activities (see Figure 8-13, p. 179). Scientists reported in 2006 that these coastal habitats are disappearing at rates 2–10 times higher than the rate of tropical forest loss. Over half of the mangrove forests in tropical and subtropical countries have been lost. In industrial countries, the rate of coastal wetland destruction is even higher. **Explore More:** See a Science Focus at **www.cengage.com/login** to learn about sustaining ecosystem services by protecting and restoring mangroves.

Coastal sea-grass beds (see Figure 8-9, p. 175) are another important habitat. They serve as nurseries for many species of fish and shellfish, which in turn feed fishes in other marine habitats. A 2009 study revealed that 58% of the sea-grass meadows around the world have been degraded or destroyed, mostly by dredging and coastal development. Researcher William Dennison estimates that every 30 minutes on average, the world loses an area of sea grass the size of a soccer field.

During this century, if sea levels rise as projected because of climate change, this will destroy many coral reefs and swamp some low-lying islands along with their protective coastal mangrove forests. This loss of habitat is also a threat to some whale species (**Core Case Study**). CORE CASE STUDY

Sea-bottom habitats are faring no better, being threatened by dredging operations and trawler fishing boats. Like giant submerged bulldozers, trawlers drag huge nets weighted down with heavy chains and steel plates over ocean bottoms to harvest a few species of bottom fish and shellfish (Figure 11-2). Each year, thousands of trawlers scrape and disturb an area of ocean floor many times larger than the total global area of forests clear-cut annually.



Peter J. Auster/National Undersea Research Center

Peter J. Auster/National Undersea Research Center

Figure 11-2 **Natural capital degradation:** These photos show an area of ocean bottom before (left) and after (right) a trawler net scraped it like a gigantic bulldozer. These ocean-floor communities could take decades or centuries to recover. According to marine scientist Elliot Norse, "Bottom trawling is probably the largest human-caused disturbance to the biosphere." Trawler fishers disagree and claim that ocean bottom life recovers after trawling. **Question:** What land activities are comparable to this?

Coral reefs serve as habitat for many hundreds of marine species. They are threatened by shore development, pollution, and ocean acidification resulting from greatly increased levels of carbon dioxide emitted by human activities (see Figure 8-13, right, p. 179 and Chapter 8 Core Case Study, p. 168). Scientists of the Global Coral Reef Monitoring Network reported in 2008 that nearly one-fifth of the world's coral reefs had been destroyed or severely damaged, and another 35% could be lost within 10–40 years. In addition, 85% of the world's oyster reefs have been lost, according to a 2009 study by The Nature Conservancy. Australian scientist John Veron has projected that unless CO_2 emissions are sharply reduced well before 2050, increasing ocean temperatures and acidity could kill off most of the world's remaining coral reefs by 2100.

Habitat disruption is also a problem in freshwater aquatic zones. The main causes of disruption are dam building and excessive water withdrawal from rivers for irrigation and urban water supplies. These activities destroy aquatic habitats, degrade water flows, and disrupt freshwater biodiversity.

Bottom line: We are putting tremendous increasing pressure on aquatic habitats and species at a time when we know very little about the great majority of such species and about how they interact with one another (Science Focus, below).

Invasive Species Are Degrading Aquatic Biodiversity

Another problem that threatens aquatic biodiversity is the deliberate or accidental introduction of hundreds of harmful invasive species (see Figure 9-11, p. 200)—the I in HIPPCO—into coastal waters, wetlands, and lakes throughout the world (**Concept 11-1**). These bioinvaders can displace or cause the extinction of native species and disrupt ecosystem services and human economies (see Case Study, p. 254).

According to the U.S. Fish and Wildlife Service, bioinvaders are blamed for about two-thirds of fish extinctions in the United States since 1900. They cost the country an average of about $16 million *per hour*. Many of these invaders arrive in the ballast water that is stored in tanks in large cargo ships to keep them stable. These ships take in ballast water, and whatever microorganisms and tiny fish species it contains, from one harbor and dump it into another—an environmentally harmful effect of globalized trade.

Even if ballast water is flushed from a ship's tank before it enters a harbor—a measure now required in many ports—ships crossing the ocean could still bring invaders. Such was probably the case with an invasive brown seaweed called *Undaria*, or *wakame*, which is spreading along the California coast. This invasive seaweed may have been stuck to a ship's hull or hidden in a shipment of oysters from Asia. It grows rapidly and forms thick forests, choking out native kelps that provide habitat for sea otters (see Chapter 5 Core Case Study, p. 104), fish, and other marine life. Undaria is also invading coastal areas of the Mediterranean Sea as well as the Atlantic coasts of Europe and Argentina. A small amount of this seaweed is harvested and used in soups and salads, especially in Japan.

Consumers also introduce invasive species, sometimes unkowingly. For example, the *Asian swamp eel* has invaded the waterways of south Florida (USA), probably dumped from a home aquarium. This rapidly reproducing eel eats almost anything—including many prized fish species—by sucking them in like a vacuum cleaner. It can survive cold weather, drought, and predators by burrowing into mud banks. Also, it can wriggle across dry land to invade new waterways, ditches, canals, and marshes. Eventually, this eel could take over much of the waterways of the southeastern United States as far north as the Chesapeake Bay.

SCIENCE FOCUS

Oceanbots to the Rescue

A serious problem that we face in protecting ocean biodiversity is our lack of data on the status of ocean species and systems, how ocean ecosystems work, and how they are threatened by increasing levels of pollution and rising acidity and temperatures.

Researchers Jules Jaffe and Peter Frank at Scripps Institution of Oceanography plan to gather such urgently needed data. In the next few years, they intend to release swarms of small floating robotic devices that will move with ocean currents, take measurements, and send the data back to the researchers.

They call these miniature robots Autonomous Underwater Explorers (AUEs) or oceanbots. In the pilot phase of this research, they plan to release five or six soccer-ball-size oceanbots as well as 20 smaller versions. If successful, the program could be scaled up to provide a global network of such devices for studying the world's oceans.

The oceanbots can also be equipped with tiny microscopes on computer chips. The researchers envision using such devices to collect information and data about how small ocean organisms such as marine phytoplankton move and survive, as well as data on ocean temperature and acidity, harmful blooms of algae, and damage from oil spills. This will help them to know where to establish fully protected marine areas and how well such areas work. This will also increase scientific understanding of ocean ecosystems and lead to improved models of such systems.

Critical Thinking

List two questions about what is going on in the world's oceans that you would like oceanbots to help answer.

Cigdem Cooper/Shutterstock

Figure 11-3 One scientist has described this common lionfish as "an almost perfectly designed invasive species." It reaches sexual maturity rapidly, has large numbers of offspring, and is protected by venomous spines. In the eastern coastal waters of North America, it has few if any predators, except perhaps for people. It is hoped that commercial fishers can find ways to capture lionfish economically and that consumers will choose them from seafood menus.

Another invader that worries scientists and fishers on the east coast of North America is a species of lionfish native to the western Pacific Ocean (Figure 11-3). Scientists believe it escaped from outdoor aquariums in Miami, Florida, that were damaged by Hurricane Andrew in 1992. Lionfish populations have exploded at the highest rate ever recorded by scientists in this part of the world. They compete with popular reef fish species like grouper and snapper, taking their food and eating their young. One ray of hope for controlling this population is the fact that the lionfish tastes good. Scientists are hoping to develop a food market for the fish.

In addition to threatening native species, invasive species can disrupt and degrade whole ecosystems (see the Case Study that follows). This is the focus of study for a growing number of researchers (see Science Focus, at right).

■ **CASE STUDY**

Invaders Have Ravaged Lake Victoria

Lake Victoria, a large, shallow lake in East Africa (Figure 11-4, left), has been in ecological trouble for more than 2 decades. Until the early 1980s, the lake had 500 species of fish found nowhere else. About 80% of them were small fish known as cichlids (pronounced "SIK-lids"), which feed mostly on detritus, algae, and zooplankton. Since 1980, some 200 of the cichlid species have become extinct, and some of those that remain are in trouble.

Several factors caused this dramatic loss of aquatic biodiversity. First, there was a large increase in the population of the Nile perch (Figure 11-4, right). This large predatory fish was deliberately introduced into the lake during the 1950s and 1960s to stimulate the business of exporting fish from the lake to several European

Courtesy of the African Angler

Figure 11-4 **Natural capital degradation:** The Nile perch (right) is a fine food fish that can weigh more than 91 kilograms (200 pounds). However, this deliberately introduced fish has played a key role in a major loss of biodiversity in East Africa's Lake Victoria (left).

SCIENCE FOCUS

How Carp Have Muddied Some Waters

Lake Wingra lies within the city of Madison, Wisconsin (USA), surrounded mostly by a forest preserve. The lake contains a number of invasive plant and fish species, including purple loosestrife (see Figure 9-11, p. 200) and common carp. The carp, which were introduced in the late 1800s, and eventually made up about half of the fish biomass in the lake. They devour algae called *chara*, which would normally cover the lake bottom and stabilize its sediments. Consequently, fish movements and winds stir these sediments, which accounts for much of the water's excessive *turbidity*, or cloudiness.

Knowing this, Dr. Richard Lathrup, a limnologist (lake scientist) who works with Wisconsin's Department of Natural Resources, hypothesized that removing the carp would help to restore the natural ecosystem of Lake Wingra. Lathrop speculated that with the carp gone, the bottom sediments would settle and become stabilized, allowing the water to clear. Clearer water would in turn allow native plants to receive more sunlight and become reestablished on the lake bottom, replacing purple loosestrife and other invasive plants that now dominate its shallow shoreline waters.

Lathrop and his colleagues installed a thick, heavy vinyl curtain around a 1-hectare (2.5-acre), square-shaped perimeter that extends out from the shore (Figure 11-A). This barrier hangs from buoys on the surface to the bottom of the lake, isolating the volume of water within it. The researchers then removed all of the carp from this study area and began observing results. Within one month, the waters within the barrier were noticeably clearer, and within a year, the difference in clarity was dramatic, as Figure 11-A shows.

Lathrop notes that removing and keeping carp out of Lake Wingra would be a daunting task, perhaps impossible, but his controlled scientific experiment clearly shows the effects that an invasive species can have on an aquatic ecosystem. And it reminds us that preventing the introduction of invasive species in the first place is the best and cheapest way to avoid such effects.

Mike Kakuska

Figure 11-A *Lake Wingra* in Madison, Wisconsin (USA) has become clouded with sediment partly because of the introduction of invasive species such as the common carp. Removal of carp in the experimental area shown here resulted in a dramatic improvement in the clarity of the water and subsequent regrowth of native plant species in shallow water.

Critical Thinking

What are two other results of this controlled experiment that you might expect? (Hint: think food webs.)

countries, despite warnings from biologists that this fish would reduce or eliminate many defenseless native fish species. The population of the prolific Nile perch exploded, devoured the cichlids, and by 1986 had wiped out over 200 cichlid species.

Introducing the perch had other social and ecological effects. The mechanized perch-fishing industry that quickly developed put most small-scale fishers and fish vendors out of business, which led to increased poverty and malnutrition. And because people use wood-burning smokers to preserve the oily flesh of the perch, local forests were depleted for firewood.

Another factor in loss of biodiversity in Lake Victoria was frequent thick blooms of algae, which have led to the deaths of many fish. These blooms became more common in the 1980s, fed by nutrient runoff from surrounding farms and deforested land, and spills of untreated sewage. Yet another threat to the lake's biodiversity was the invasion in the late 1980s of water hyacinth. This rapidly growing plant has carpeted large areas of the lake (Figure 11-5), blocked sunlight, deprived fish and plankton of oxygen, and reduced the diversity of important aquatic plant species.

U.S. Geological Survey

Figure 11-5 Invasive water hyacinths, supported by nutrient runoff, blocked a ferry terminal on the Kenyan shores of Lake Victoria in 1997. By blocking sunlight and consuming oxygen, this invasion has reduced biodiversity in the lake. Scientists reduced the problem at strategic locations by removing the hyacinth and by introducing two weevils (a type of beetle) that feed on the invasive plant.

Now, the Nile perch population is decreasing because it severely reduced its own food supply of smaller fishes and because it, too, is being drastically overfished. The Ugandan government announced in 2008 that the Nile perch stocks had dropped by 81% in just three years. In an ironic turnaround, the government is now working to protect this species that once invaded and disrupted the Lake Victoria ecosystem.

This ecological story of the dynamics of large aquatic systems illustrates that when we intrude into poorly understood ecosystems, there are often unintended consequences.

THINKING ABOUT
The Nile Perch and Lake Victoria

Would most of the now extinct cichlid fish species in Lake Victoria still exist today if the Nile perch had not been introduced or might other factors come into play? Explain.

Population Growth and Pollution Can Reduce Aquatic Biodiversity

According to the U.N. Environment Programme (UNEP), in 2010, about 80% of the world's people were living along or near the coasts, mostly in large coastal cities. This coastal population growth—the first P in HIPPCO—has added to the already intense pressure on the world's coastal zones (see Figure 8-13, p. 179), primarily by destroying more aquatic habitat and increasing pollution (**Concept 11-1**).

One result of the growing coastal population is that, with more boats, off-shore construction, recreation, and oil and gas exploration and drilled wells, the oceans are becoming more crowded. This has resulted in more collisions between whales (**Core Case Study**) and ships. Another result of this increasing coastal activity is that the oceans are becoming noisier. This is a serious problem for whales and other marine mammals that depend on sound to communicate, to navigate, to find prey, and to mate.

CORE CASE STUDY

In 2004, the UNEP estimated that 80% of all ocean pollution—the second P in HIPPCO—comes from land-based coastal activities. Humans have doubled the flow of nitrogen, mostly from nitrate fertilizers, into the oceans since 1860, and the 2005 Millennium Ecosystem Assessment estimates this flow will increase by another two-thirds by 2050. These inputs of nitrogen (and similar inputs of phosphorus) result in eutrophication of marine and freshwater systems, which can lead to algal blooms (see Figure 8-17, right, p. 182), fish die-offs, and degradation of ecosystem services.

Toxic pollutants from industrial and urban areas can kill some forms of aquatic life by poisoning them. Whales and dolphins (**Core Case Study**) along with many species of fish are subject to this threat. For example, Irrawaddy dolphins living in parts of the Mekong River of Southeast Asia are on the edge of extinction because of high levels of toxic chemicals such as DDT, PCBs, and mercury that are polluting their habitat.

CORE CASE STUDY

Another growing form of pollution is plastics of all kinds. Each year, plastic items dumped from ships and garbage barges, and left as litter on beaches, kill up to 1 million seabirds and 100,000 mammals and sea turtles. Also, plastic garbage that often contains toxic compounds breaks down into tiny pieces that are ingested by birds and other wildlife, which are in turn eaten by other animals in the food web. Scientists working on a 5-year study of seabirds called *fulmars* in Europe's North Sea region reported in 2009 that 95% of the birds studied had plastic in their stomachs.

Such pollutants threaten the lives of millions of marine mammals (Figure 11-6) and countless fish that ingest, become entangled in, or are poisoned by them. These forms of pollution have led to an overall reduction in aquatic biodiversity and degradation of ecosystem services.

Climate Change Is a Growing Threat

Projected climate change—the C in HIPPCO—threatens aquatic biodiversity (**Concept 11-1**) and ecosystem services, partly by causing sea levels to rise. During the past 100 years, for example average sea levels have risen by 10–20 centimeters (4–8 inches), and sophisticated computer models developed by climate scientists estimate they will rise another 18–59 centimeters (0.6–1.9 feet) and perhaps as high as 1–1.6 meters (3.2–5.2 feet) between 2050 and 2100.

Such a rise in sea level would destroy more coral reefs, swamp some low-lying islands, drown many highly productive coastal wetlands, and put many coastal areas such as a large part of the U.S. Gulf Coast, including the city of New Orleans, under water (see Figure 8-19, p. 185). In addition, some Pacific island

Doris Alcorn/U.S. National Maritime Fisheries

Figure 11-6 This Hawaiian monk seal was slowly starving to death before a discarded piece of plastic was removed from its snout. Each year, plastic items dumped from ships and garbage barges, and left as litter on beaches threaten the lives of millions of marine mammals, turtles, and seabirds that ingest, become entangled in, or are poisoned by such debris.

nations could lose more than half of their protective coastal mangrove forests by 2100, according to a 2006 study by UNEP. (See *The Habitable Planet*, Video 5, at **www.learner.org/resources/series209.html** for the effects of a projected rise in sea level on densely populated coastal areas such as those in Vietnam and New York City.)

CONNECTIONS

Protecting Mangroves and Dealing with Climate Change

Mangrove forests (see Figure 8-10, p. 175) provide a dramatic damping effect on storm-driven waves and earthquake-generated tsunamis, and thus they help to reduce damages from these huge waves in some coastal areas of tropical countries. Protecting mangroves and restoring them in areas where they have been destroyed are important ways to reduce the impacts of rising sea levels and more intense storm surges. These ecosystem services will become more important if tropical storms become more intense as a result of climate change, as some scientists project. Protecting and restoring these natural coastal barriers is much cheaper than building concrete sea walls or moving threatened coastal towns and cities inland.

Corals will be more challenged to survive and grow as oceans become warmer and more acidic due to increased levels of dissolved carbon dioxide (which reacts with the water to form a weak acid) mostly from our burning of fossil fuels. Increasing acidity will also make the environment even noisier for whales (**Core Case Study**), which depend on using sound to survive. As seawater becomes more acidic, it is less able to absorb sounds generated by human activities. Such changes in ocean chemistry will be irreversible for many thousands of years, and the effects on biodiversity could last even longer, according to scientists at the Monterey Bay Aquarium in California (USA).

CORE CASE STUDY

Overfishing and Extinction: Gone Fishing, Fish Gone

Overfishing—the O in HIPPCO—is not new. Archaeological evidence indicates that for thousands of years, humans living in some coastal areas have overharvested fishes, shellfish, seals, turtles, whales, and other marine mammals (**Concept 11-1**). But today, fish are hunted throughout the world's oceans by a global fleet of about 4 million fishing boats. Modern industrial fishing (see Case Study, p. 258) has caused as much as 80% depletion of some wild fish species in only 10–15 years.

The human demand for seafood has been met historically through fisheries. A **fishery** is a concentration of a particular wild aquatic species suitable for commercial harvesting in a given ocean area or inland body of water. A **fishprint** is defined as the area of ocean needed to sustain the fish consumption of an average person, a nation, or the world. The global fishprint has become unsustainable. According to the *Fishprint of Nations 2006*, a study based on the concept of the human ecological footprint (see **Concept 1-2**, p. 13, and Figure 1-13, p. 16), all nations together are overfishing the world's global oceans taking 57% more than the sustainable yield. This means that we are harvesting more than half again as many wild fish as these species' populations can sustain in the long run.

In most cases, overfishing leads to *commercial extinction,* which occurs when it is no longer profitable to continue harvesting the affected species. Overfishing usually results in only a temporary depletion of fish stocks, as long as depleted areas and fisheries are allowed to recover. But as industrialized fishing fleets vacuum up more and more of the world's available fish and shellfish, recovery times for severely depleted populations are increasing and can be 2 decades or more.

In 1992, for example, off the coast of Newfoundland, Canada, the 500-year-old Atlantic cod fishery had collapsed and was closed to fishing. This put at least 20,000 fishers and fish processors out of work and severely damaged Newfoundland's economy. As Figure 11-7 shows, this cod population has not recovered, despite a total ban on fishing.

One result of the increasingly efficient global hunt for fish is that larger individuals of commercially valuable wild species—including cod, tuna, marlin, swordfish, and mackerel—are becoming scarce. Fishers have

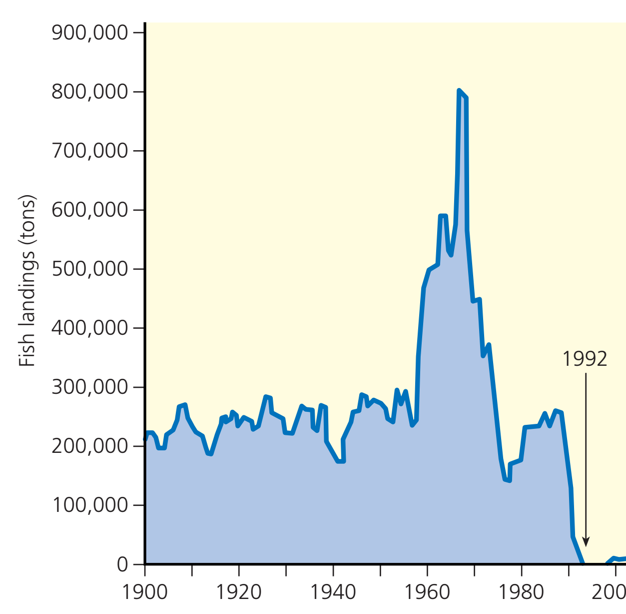


Figure 11-7 **Natural capital degradation:** This graph illustrates the collapse of Canada's 500-year-old Atlantic cod fishery off the coast of Newfoundland in the northwest Atlantic. Beginning in the late 1950s, fishers used bottom trawlers to capture more of the stock, reflected in the sharp rise in this graph. This resulted in extreme overexploitation of the fishery, which began a steady decline throughout the 1970s, followed by a slight recovery in the 1980s, and then total collapse by 1992, when the fishery was shut down. Despite a total ban on fishing, the cod population has not recovered. The fishery was reopened on a limited basis in 1998 but then closed indefinitely in 2003 and today shows no signs of recovery. (Data from Millennium Ecosystem Assessment)

turned to other species such as sharks, which are now being overfished (see Chapter 4 Core Case Study, p. 81 and Connections, p. 99). Also, as large species are overfished, the fishing industry is shifting to smaller marine species such as herring, sardines, and squid. One researcher referred to this as "stealing the ocean's food supply," because these smaller species make up much of the diet of larger predator fish, seabirds, and toothed whales (**Core Case Study**).

CORE CASE STUDY

Another effect of overfishing is that, when larger predatory species dwindle, rapidly reproducing invasive species can more easily take over and disrupt ocean food webs. **Explore More:** Go to **www.cengage.com/login** to find out how jellyfish are taking over some aquatic systems and why jellyfish burgers may become one of the main menu items in seafood restaurants of the future.

According to a 2003 study by conservation biologist Boris Worm and his colleagues, 90% or more of the large, predatory, open-ocean fishes such as tuna, swordfish, and marlin had disappeared since 1950 (see *The Habitable Planet*, Video 9, at **www.learner.org/resources/series209.html**). To the alarm of many, Worm projected that by 2048, almost all of the major commercial fish species would be driven to commercial extinction. Other scientists objected to these claims. In a classic case of how the scientific process works, Worm and his opponents worked together to arrive at a new hypothesis—a revised and slightly more hopeful projection (Science Focus, below).

GOOD NEWS

CASE STUDY

Industrial Fish Harvesting Methods

Industrial fishing fleets dominate the world's marine fishing industry. They use global satellite positioning equipment, sonar fish-finding devices, huge nets and long fishing lines, spotter planes, and gigantic refrigerated factory ships that can process and freeze their enormous catches. These fleets help to supply the growing demand for seafood. But critics say that these highly efficient fleets are vacuuming the seas, decreasing marine biodiversity, and degrading important marine ecosystem services.

Figure 11-8 shows the major methods used for the commercial harvesting of various marine fishes and shellfish. Until the mid-1980s, fishing fleets from more-developed countries dominated the ocean harvest. Today, most fleets come from less-developed countries, especially those in Asia.

Let us look at a few of these methods. *Trawler fishing* is used to catch fishes and shellfish—especially cod, flounder, shrimp, and scallops—that live on or near the ocean floor. It involves dragging a funnel-shaped net held open at the neck along the ocean bottom. The net is weighted down with chains or metal plates. This equipment scrapes up almost everything that lies on the ocean floor and often destroys bottom habitats—somewhat like clear-cutting the ocean floor (Figure 11-2, right). Newer trawling nets are large enough to swallow 12 jumbo jet planes and even larger ones are on the way.

SCIENCE FOCUS

Clashing Scientific Views Can Lead to Cooperation and Progress

In 2006, Canadian ecologist Boris Worm and his colleagues projected that overfishing, pollution, and other stresses could wipe out global wild seafood stocks by 2048. In response, Ray Hilborn¸ an American fisheries management scientist sharply objected to the report, calling it baseless and overblown. Thus, there arose a classic conflict between a scientist whose focus was on conserving a resource and a scientist who was interested in how to manage fish populations and how to exploit the resource safely.

Worm and Hilborn soon found themselves debating this topic on a radio program. In the process, each gained new respect for the other, and they decided to work together on the issue of overfishing.

The two researchers started by agreeing on new methods for relating the catch of a given species to its estimated total population. In addition to catch data, they agreed to use scientific trawl sampling, small-scale fishery reports, and computer modeling. They reexamined databases and invented new analytical tools for surveying the data. One of the measures they examined was the *maximum sustainable yield*, or the number of a given fish species that fisheries managers had assumed could be harvested without endangering the stock. They agreed that these numbers should no longer be used as targets. Instead, they formulated new targets based on fish population data but also on the overall health of the aquatic ecosystems involved.

Worm and Hilborn studied 10 areas of the world. In 2009, they reported that significant overfishing continued in three of the areas. However, in five other areas where measures were being taken to curb overfishing, fish stocks were recovering. The two remaining areas were being managed well and overfishing was not a problem. Still, the two scientists agreed that on a global scale, overfishing is still a concern with at least 63% of global fish stocks being overexploited or depleted.

The report concluded that certain changes in the way fishers were operating in the recovering areas of the fisheries were making a dramatic difference. These measures included establishing large no-fishing zones, restricting use of certain destructive fishing gear, and allocating shares of the total catch to individual fishers. The researchers reported they were confident that effects of overfishing could be reversed globally if some or all of these new measures were applied consistently everywhere. They agreed that much would depend on finding the political will to make these changes worldwide.

Critical Thinking

What might be a basic point of disagreement between an ecologist studying a fish species and its ecosystem and a scientist trained to help manage a fishery?

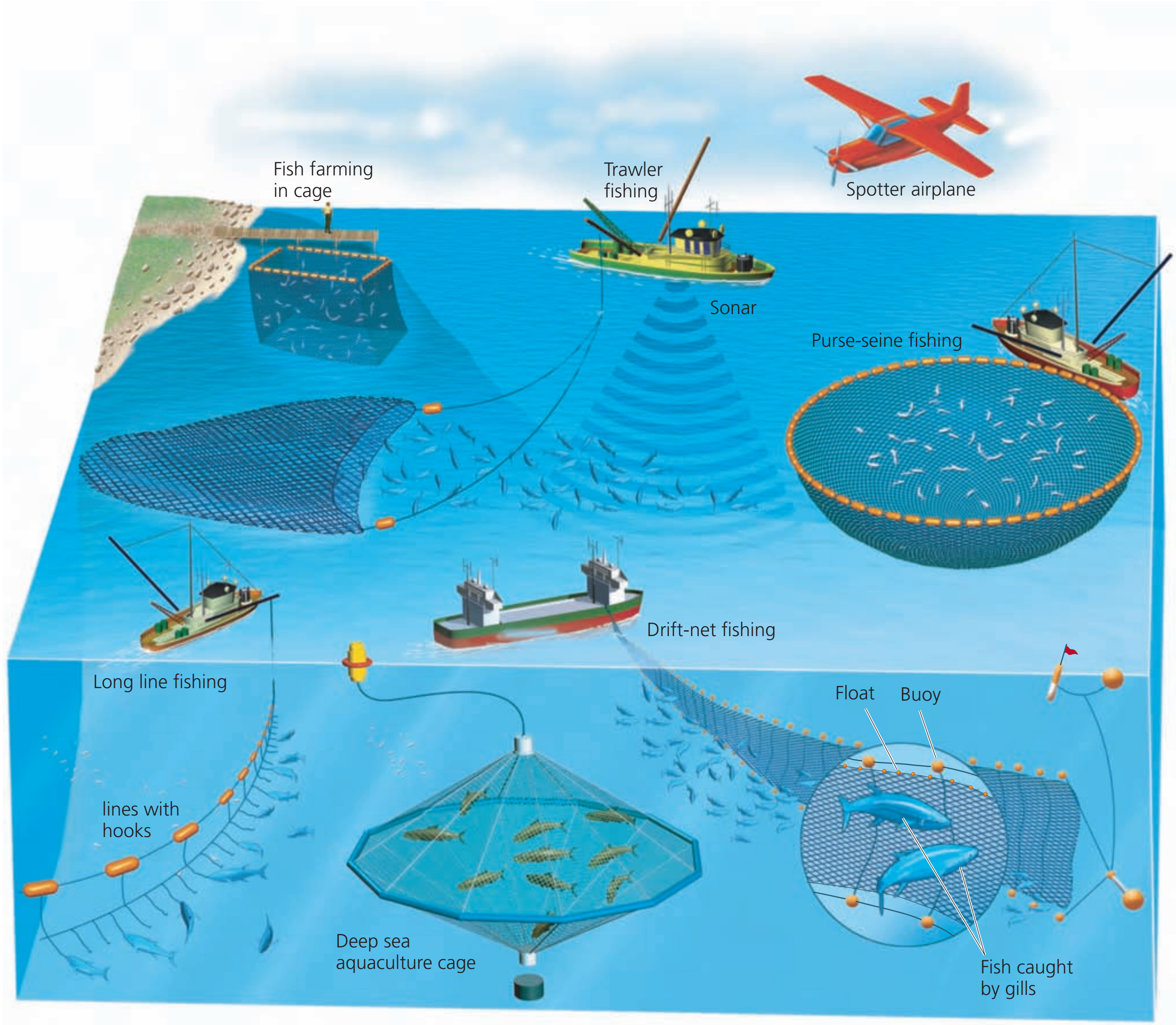


Figure 11-8 This diagram illustrates several major commercial fishing methods used to harvest various marine species (along with methods used to raise fish through aquaculture). These fishing methods have become so effective that many fish species have become commercially extinct.

Another method, *purse-seine fishing*, is used to catch surface-dwelling species such as tuna, mackerel, anchovies, and herring, which tend to feed in schools near the surface or in shallow areas. After a spotter plane locates a school, the fishing vessel encloses it with a large net called a purse seine. Nets that are used to capture yellowfin tuna in the eastern tropical Pacific Ocean have killed large numbers of dolphins that swim on the surface above schools of tuna.

Fishing vessels also use *long-lining*, which involves putting out lines up to 100 kilometers (60 miles) long, hung with thousands of baited hooks. The depth of the lines can be adjusted to catch open-ocean fish species such as swordfish, tuna, and sharks or ocean-bottom species such as halibut and cod. Longlines also hook and kill large numbers of endangered sea turtles, dolphins, and seabirds each year (see Figure 9-19, p. 208). Making simple modifications to fishing gear and fishing practices can decrease seabird deaths.

With *drift-net fishing*, fish are caught by huge drifting nets that can hang as deep as 15 meters (50 feet) below the surface and extend to 64 kilometers (40 miles) long. This method can lead to overfishing of the desired species and may trap and kill large quantities of unwanted fish, called *bycatch*, along with marine mammals, sea turtles, and seabirds. Almost one-third of the world's annual fish catch by weight consists of bycatch species, which are mostly thrown overboard dead or dying. This adds to the depletion of these species.

Since 1992, a U.N. ban on the use of drift nets longer than 2.5 kilometers (1.6 miles) in international waters has sharply reduced use of this technique. But longer nets continue to be used because compliance is voluntary and it is difficult to monitor fishing fleets over vast ocean areas. Also, the decrease in drift net use has led to increased use of longlines, which often have similar harmful effects on marine wildlife.

Extinction of Aquatic Species Is a Growing Threat

Beyond the collapse of commercial fisheries, many fish species are also threatened with *biological* extinction, mostly from overfishing, water pollution, wetlands destruction, and excessive removal of water from rivers and lakes. According to the 2009 International Union for Conservation of Nature (IUCN) Red List of Threatened Species, 37% of the world's marine species that were evaluated and 71% of the world's freshwater fish species that were evaluated face extinction within the next 6 to 7 decades. Indeed, marine and freshwater fishes are threatened with extinction by human activities more than any other group of species.

Some marine mammals have also been threatened with extinction by overharvesting. The most prominent example is the giant blue whale (Figure 11-1). CORE CASE STUDY The endangered blue whale is the world's largest animal. Fully grown, it is the length of two city buses and weighs more than 25 adult elephants. The adult has a heart the size of a compact car, some of its arteries are big enough for a child to swim through, and its tongue alone is as heavy as an adult elephant.

Blue whales spend about 8 months of the year in Antarctic waters feeding on tiny shrimp-like animals called krill (Figure 3-13, p. 64). During the winter, they migrate north to warmer waters where their young are born. Before large-scale commercial whaling began during the early 1900s, an estimated 250,000 blue whales roamed the Antarctic Ocean. But the whaling industry hunted the species to the brink of biological extinction for its oil, meat, and bone.

In 2010, there were probably fewer than 5,000 blue whales left. They take 25 years to mature sexually and have only one offspring every 2–5 years. This low reproductive rate makes it difficult for the blue whale population to recover.

Blue whales have been classified as an endangered species since 1975. Despite this protection, some marine biologists fear that there are not enough whales left for the species to recover and to avoid extinction. Others believe that with continued protection, they will make a slow comeback.

RESEARCH FRONTIER

The functioning of aquatic systems and how human activities affect aquatic biodiversity and aquatic ecosystem services; see **www.cengage.com/login**.

11-2 How Can We Protect and Sustain Marine Biodiversity?

CONCEPT 11-2 We can help to sustain marine biodiversity by using laws and economic incentives to protect species, setting aside marine reserves to protect ecosystems, and using community-based integrated coastal management.

Laws and Treaties Have Protected Some Endangered and Threatened Marine Species

Protecting marine biodiversity is difficult for several reasons. *First*, the human ecological footprint (see Figure 1-13, p. 16) and fishprint are expanding so rapidly that it is difficult to monitor their impacts. *Second*, much of the damage to the oceans and other bodies of water is not visible to most people. *Third*, many people incorrectly view the seas as an inexhaustible resource that can absorb an almost infinite amount of waste and pollution and still produce all the seafood we want. *Fourth*, most of the world's ocean area lies outside the legal jurisdiction of any country. Thus, much of it is an open-access resource, subject to overexploitation—a classic case of the tragedy of the commons (see Chapter 1, p. 15).

Nevertheless, there are several ways to protect and sustain marine biodiversity, one of which is the regulatory approach (**Concept 11-2**). National and international laws and treaties to help protect marine species include the 1975 Convention on International Trade in Endangered Species (CITES), the 1979 Global Treaty on Migratory Species, the U.S. Marine Mammal Protection Act of 1972, the U.S. Endangered Species Act of 1973, the U.S. Whale Conservation and Protection Act of 1976, and the 1995 International Convention on Biological Diversity.

The U.S. Endangered Species Act (see Chapter 9, pp. 209–11) and several international agreements have been used to identify and protect endangered and threatened marine species such as whales, seals, sea lions, and sea turtles. The problem is that with some international agreements, it is hard to get all nations to comply, which can weaken the effectiveness of such agreements (see the Case Study that follows).

In 2004, for example, some 1,134 scientists signed a statement urging the United Nations to declare a moratorium on bottom trawling on the high seas by 2006 and to eliminate it globally by 2010. Fishing nations led by Iceland, Russia, China, and South Korea blocked such a ban. But in 2007, those countries (except for Iceland) and 18 others agreed to voluntary restrictions on bottom trawling in the South Pacific. Although monitoring and enforcement will be difficult, this agreement partially protects about one-quarter of the world's ocean bottom from destructive trawling. GOOD NEWS

CASE STUDY
The International Whaling Commission Moratorium on Commercial Whaling

Some scientists argue that the IWC moratorium on whaling (**Core Case Study**) has helped some whale species to recover. That is why some nations argue that the moratorium should be lifted. Others disagree, saying it must be continued to ensure the complete recovery of as many whale species as possible. CORE CASE STUDY

Presently, Japan hunts and kills at least 900 whales a year, including endangered minke, fin, and sei whales for what it claims are scientific purposes. Critics see this annual whale hunt as poorly disguised commercial whaling because the whale meat is sold to wholesalers for sale in restaurants and grocery stores. Norway openly defies the whaling moratorium and harvests 500 to 800 minke whales a year. Iceland allows for the killing of about 150 minke and 100 endangered fin whales each year.

Japan, Norway, and Iceland hope to overthrow the IWC moratorium on commercial whaling and reverse the separate international ban on buying and selling whale products. They argue that commercial whaling should be allowed because it has been a traditional part of their economies and cultures. Proponents of whaling also contend that the ban is emotionally motivated. This claim is disputed by many conservationists who argue that whales are intelligent and highly social mammals that should be protected for ethical reasons.

Whaling proponents contend that the moratorium should be lifted because populations of minke, humpback, and several other whale other species have rebounded. Whaling opponents question IWC estimates of the allegedly recovered whale species, noting the inaccuracy of such estimates in the past.

HOW WOULD YOU VOTE?

Should controlled commercial whaling be resumed for species with populations judged to be stable? Cast your vote online at **www.cengage.com/login**.

Economic Incentives Can Help Sustain Aquatic Biodiversity

Other ways to protect endangered and threatened aquatic species involve using economic incentives (**Concept 11-2**). For example, according to a 2004 World Wildlife Fund study, sea turtles are worth more to local communities alive than dead. The report estimates that sea turtle tourism brings in almost three times more money than the sale of turtle products such as meat, leather, and eggs brings in. Educating citizens about this issue could inspire communities to protect the turtles (see the Case Study that follows).

CONNECTIONS

Protecting Whales and Drawing Tourists CORE CASE STUDY

Some coastal communities have an interest in maintaining the moratorium on whale hunting (**Core Case Study**) because they can provide jobs and bring in revenues through increasingly popular whale watching. For example, The Nature Conservancy promoted whale watching in the Dominican Republic town of Samaná and has helped to train fishermen to work as whale-watching guides. The once rundown community has become a whale watcher's hot spot, with renovated hotels. Local residents now have an economic interest in protecting the whales. In 2008, more than 13 million people went whale watching in 119 countries, bringing more than $1 billion in tourism revenue to those economies.

CASE STUDY
Holding Out Hope for Marine Turtles

Of the seven species of marine turtles (Figure 11-9, p. 262), six are either critically endangered or endangered. Among the latter is the leatherback sea turtle, a species that has survived for roughly 100 million years, but now faces possible extinction. While its population is stable in the Atlantic Ocean, its numbers have declined by 95% in the Pacific.

The leatherback, named for its leathery shell, is the largest of all sea turtles, and is the only warm-blooded species. An adult leatherback can weigh as much as 91 kilograms (200 pounds). It swims great distances, migrating across the Atlantic and Pacific Oceans, and it can dive as deep as 1,200 meters (3,900 feet).

The leatherback female lays her eggs on sandy ocean beaches in the dark of night and then returns to the sea. The babies hatch simultaneously in large numbers and immediately scamper across the sand and into the water, attempting to survive to adulthood in the oceans. As naturalist Carl Safina describes it, "They start out the size of a cookie, and come back the size of a dinosaur."

While leatherbacks survived the impact of the giant asteroid that probably wiped out the dinosaurs, they may not survive the growing human impact on their environment. Bottom trawlers are destroying the coral gardens that serve as their feeding grounds. The turtles are hunted for meat and leather, and their eggs are

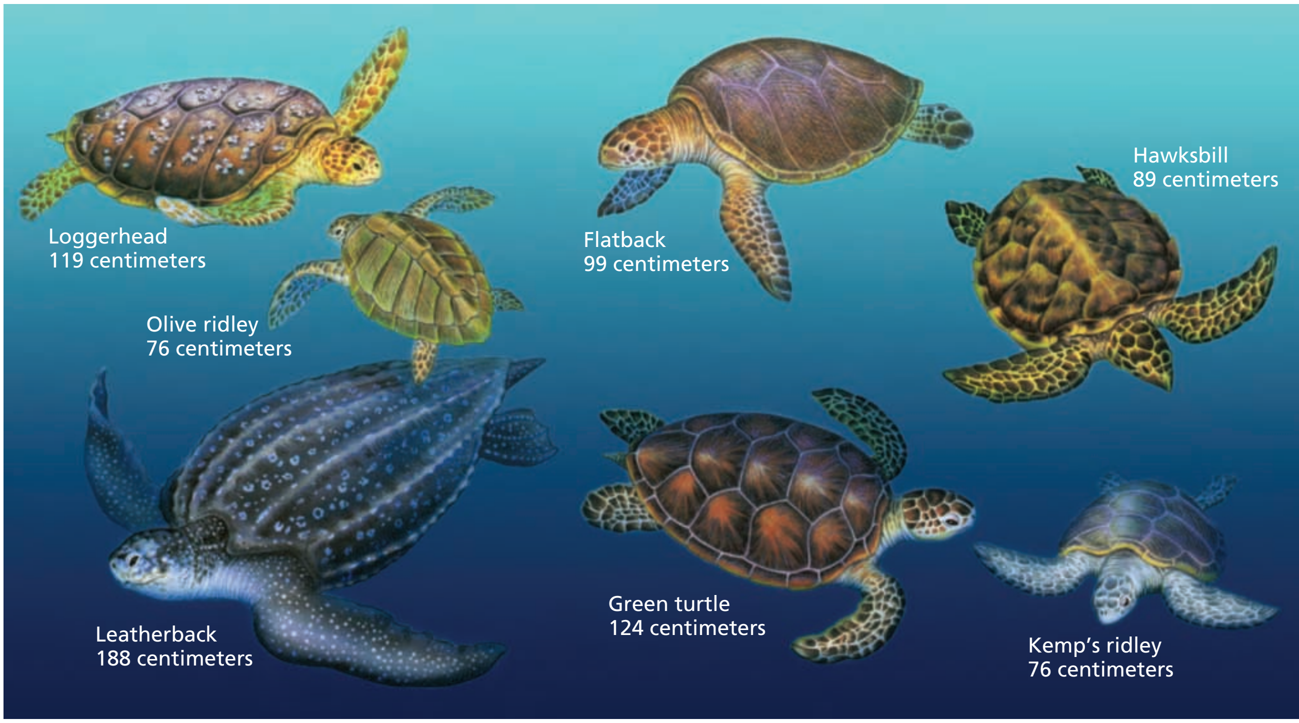


Figure 11-9 Several major species of sea turtles have roamed the sea for 150 million years. The hawksbill, Kemp's ridley, and leatherback turtles are *critically endangered*. Flatbacks live along the coasts of northern Australia and Papua, New Guinea, and are not classified as endangered because they nest in very remote places, but the Australian government classifies them as *vulnerable*. The loggerhead, green, and olive ridley are classified as *endangered*. See the photo of an endangered green sea turtle on the title page.

taken for food. They often drown after becoming entangled in fishing nets and lines (Figure 11-10) as well as in lobster and crab traps.

Pollution is another threat. Sea turtles can mistake discarded plastic bags for jellyfish and choke to death on them. Beachgoers sometimes trample their nests. Artificial lights can disorient hatchlings as they try to find their way to the ocean; going in the wrong direction increases their chances of ending up as food for predators. Add to this the threat of rising sea levels from projected climate change. This will flood nesting and feeding habitats, and change ocean currents, which could disrupt the turtles' migration routes.

GOOD NEWS

Many people are working to protect the leatherbacks. On some Florida beaches, lights are turned off or blacked out during hatching season. Nesting areas are roped off, and people generally respect the turtles. Since 1991, the U.S. government has required offshore shrimp trawlers to use turtle excluder devices (TEDs) that help to keep sea turtles from being caught in their nets or that allow netted turtles to escape. TEDs have been adopted in 15 countries that export shrimp to the United States. In 2004, the United States also banned long-lining for swordfish off the Pacific coast to help save dwindling sea turtle populations there.

On Costa Rica's northwest coast, the community of Playa Junquillal is an important leatherback nesting area, and residents have learned that tourism can bring in almost three times as much income as selling turtle products can earn. In 2004, with the help of World

Renatura Congo. www.renatura.asso.eu.org

Figure 11-10 This endangered leatherback sea turtle was entangled in a fishing net and could have starved to death had it not been rescued.

Wildlife Fund biologists, volunteers went out to find and rescue turtle nests before they could be poached, and they built hatcheries to protect the eggs. This program was a success. In 2004, all known nests on the local beaches had been poached, but the following year, all known nests were protected and none were poached. The leatherback had become an important economic resource for all, rather than for just a few, of the residents of Playa Junquillal.

Marine Sanctuaries Protect Ecosystems and Species

By international law, a country's offshore fishing zone extends to 370 kilometers (200 nautical miles) from its shores. Foreign fishing vessels can take certain quotas of fish within such zones, called *exclusive economic zones,* but only with a government's permission. Ocean areas beyond the legal jurisdiction of any country are known as the *high seas,* and laws and treaties pertaining to them are difficult to monitor and enforce.

Through the Law of the Sea Treaty, the world's coastal nations have jurisdiction over 36% of the ocean surface and 90% of the world's fish stocks. Instead of using this law to protect their fishing grounds, many governments have promoted overfishing by subsidizing fishing fleets and failing to establish and enforce stricter regulation of fish catches in their coastal waters.

GOOD NEWS Some countries are attempting to protect marine biodiversity and to sustain fisheries by establishing marine sanctuaries. Since 1986, the IUCN has helped to establish a global system of *marine protected areas* (MPAs)—areas of ocean partially protected from human activities. There are more than 4,000 MPAs worldwide.

Despite their name, most MPAs are only partially protected. Nearly all allow dredging, trawler fishing, and other ecologically harmful resource extraction activities. However, in 2007 the U.S. state of California began establishing the nation's most extensive network of MPAs in which fishing will be banned or strictly limited. Conservation biologists say this could be a model for other MPAs in the United States and other countries.

Establishing a Global Network of Marine Reserves: An Ecosystem Approach to Marine Sustainability

Many scientists and policymakers call for the widespread use of a new approach to managing and sustaining marine biodiversity and the important ecological and economic services provided by the seas. The primary objective of this *ecosystem approach* is to protect and sustain the whole marine ecosystem for current and future generations instead of focusing primarily on protecting individual species.

The foundation of this ecological approach is to establish a global network of fully protected *marine reserves*, some of which already exist. These areas are declared off-limits to destructive human activities in order to enable their ecosystems to recover and flourish. This global network would include large reserves on the high seas, especially near extremely productive nutrient upwelling areas (see Figure 7-2, p. 149), and a mixture of smaller reserves in coastal zones that are adjacent to well-managed, sustainable commercial fishing areas. This would encourage local fishers and coastal communities to support the reserves and participate in determining their locations. Some reserves could be made temporary or moveable to protect migrating species such as turtles.

Such reserves would be closed to activities such as commercial fishing, dredging, and mining, as well as to waste disposal. Most reserves in the proposed global network would permit less-harmful activities such as recreational boating, shipping, and in some cases, certain levels of small-scale, nondestructive fishing. However, most reserves would contain core zones where no human activity would be allowed. Outside the reserves, commercial fisheries would be managed more sustainably by use of an ecosystem approach instead of the current approach, which focuses on individual species.

GOOD NEWS Marine reserves work and they work quickly. Scientific studies show that within fully protected marine reserves, commercially valuable fish populations double, fish size grows by almost a third, fish reproduction triples, and species diversity increases by almost one-fourth. Furthermore, these improvements happen within 2–4 years after strict protection begins, and they last for decades (**Concept 11-2**). Research also shows that reserves benefit nearby fisheries, because fish move into and out of the reserves, and currents carry fish larvae produced inside reserves to adjacent fishing grounds, thus bolstering the populations there.

In 2009, a group of western Pacific island nations, seeking to save the world's last great tuna stocks, put four areas of international waters off limits to fishing, creating the largest protected marine reserve in history. The combined area of these reserves is more than three times the area of the U.S. state of California. Another huge reserve—about the size of California—was established by the Pacific island nation of Kiribati in 2008 between the Pacific islands of Fiji and Hawaii. Another large reserve, created in 2006 by the United States, is located northwest of the Hawaiian Islands.

Despite the importance of such protection, less than 1% of the world's oceans are in marine reserves, closed to fishing and other harmful human activities, and only 0.1% are fully protected. In other words, 99.9% of the world's oceans are not effectively protected from harmful human activities. Furthermore, many marine reserves are too small to protect most of the species within them and do not provide adequate protection against illegal fishing, garbage dumping, or pollution that flows from the land into coastal waters.

Many marine scientists call for 30–50% of the world's oceans to be fully protected as marine reserves. They also urge that protected corridors be established to connect the global network of marine reserves, especially those in coastal waters. This would also help species to move to different habitats in the process of adapting to the effects of ocean warming, acidification, and many forms of ocean pollution. A 2004 study by a team of U.K. scientists led by Andrew Balmford studied 83 well-managed reserves and concluded that it would cost $12–14 billion a year to manage reserves covering 30% of the world's oceans—roughly equal to the annual subsidies that promote overfishing, which governments provide to the global fishing industry.

THINKING ABOUT
Marine Reserves

Do you support setting aside at least 30% of the world's oceans as fully protected marine reserves? Explain. How would this affect your life?

RESEARCH FRONTIER

Determining how best to protect marine reserves; see **www.cengage.com/login**.

Some Marine Systems Can Be Restored

Some individuals find personal and economic rewards in restoring and sustaining aquatic systems. One example of reef restoration is an application of *reconciliation ecology* (see Chapter 10, pp. 245–247) by a restaurant owner (Individuals Matter, below).

Another dramatic example of reef restoration concerns Japan's attempt to restore its largest coral reef—90% of which has died—by seeding it with new corals. Divers drill holes into the dead reefs and insert ceramic discs holding sprigs of fledgling coral. Survival rates of the young corals were only at about 33% in 2009 but were rising, according to the Japanese government. Scientists see this experiment as possibly leading to more global efforts to save reefs by transplanting corals. But critics note that all such efforts may fail if problems that caused the reefs to deteriorate are not addressed.

Other ecosystems that could be restored are mangrove forests, coastal marshes, and sea-grass beds. In addition, as examples of marine reserves have demonstrated, these coastal ecosystems can sometimes restore themselves naturally if left undisturbed. But again, restoration efforts may be doomed unless the causes of degradation of marine systems are removed.

Protecting Marine Biodiversity Requires Commitments from Individuals and Communities

There is hope for significant progress in sustaining marine biodiversity, but it will require that we change our ways—and soon. For example, IUCN and scientists from The Nature Conservancy reported in 2006 that the world's coral reefs and mangrove forests could survive currently projected climate change if we relieve other threats such as overfishing and pollution. Further, while some coral species may be able to adapt to warmer temperatures, they may not have enough time to do this unless we act now to slow down the projected rapid rate of climate change during this century.

As a result of increasing carbon dioxide concentrations and atmospheric temperatures, the oceans have become about 30% more acidic than they were before the Industrial Revolution began in the 18th century. Increasing ocean acidity could have a major impact on

INDIVIDUALS MATTER

Creating an Artificial Coral Reef in Israel

Near the city of Eliat, Israel, at the northern tip of the Red Sea, is a magnificent coral reef, which is a major tourist attraction. To help protect the reef from excessive development and destructive tourism, Israel set aside part of the reef as a nature reserve.

But tourism, industrial pollution, and inadequate sewage treatment have destroyed most of the remaining reef. Enter Reuven Yosef, a pioneer in reconciliation ecology, who has developed an underwater restaurant called the Red Sea Star Restaurant. Patrons take an elevator down two floors below street level and walk into a restaurant surrounded with windows looking out into a beautiful coral reef.

This part of the reef was created from pieces of broken coral. Typically, when coral breaks, the pieces become infected and die. But researchers have learned how to treat the coral fragments with antibiotics and to store them while they are healing in large tanks of fresh seawater. Yosef has such a facility, and when divers find broken pieces of coral in the reserve near Yosef's restaurant, they bring them to his coral hospital. After several months of healing, the fragments are taken to the underwater area outside the Red Sea Star Restaurant's windows where they are wired to panels of iron mesh cloth. The corals grow and cover the iron matrix. Then fish and other creatures begin to appear in and around the new reef.

Using his creativity and working with nature, Yosef has helped to create a small coral reef that people can view and enjoy while they dine at his restaurant. At the same time, he has helped to restore and preserve aquatic biodiversity. And diners can appreciate the beauty and importance of protecting coral reef ecosystems.

corals, shellfish, and other marine organisms that build their structures out of calcium carbonate, because at certain acidity levels, the calcium carbonate dissolves (see Chapter 8, p. 179). In 2009, a paper by oceanographer Samar Khatiwala and his colleagues, as well as a paper by oceanographer Fiona A. McLaughlin, reported that the acidity levels in the Arctic Ocean are harming the calcium-carbonate-rich shells of some sea creatures there. Thus, high-latitude oceans may be reaching an acidity tipping point, which poses a serious threat to sea life. This could serve as an early warning about a problem that is likely to become more widespread later in this century. Also, some coral reefs are vulnerable to a one-two punch of rising temperatures and higher ocean acidity.

To deal with problems of pollution and overfishing, communities must closely monitor and regulate fishing and coastal land development, and greatly reduce pollution from land-based activities. Coastal residents must also think carefully about the chemicals they put on their lawns and the kinds of waste they generate.

More important, each of us can make careful choices in purchasing only sustainably harvested and farmed seafood. Individuals can also reduce their carbon footprints in order to slow projected climate change and its numerous harmful effects on marine and other ecosystems, as discussed in more detail in Chapter 19.

One strategy emerging in some coastal communities is *integrated coastal management*—a community-based effort to develop and use coastal resources more sustainably (**Concept 11-2**). Australia manages its huge Great Barrier Reef Marine Park in this way, and more than 100 integrated coastal management programs are being developed throughout the world. Another example of such management in the United States is the Chesapeake Bay Program (see Chapter 8, Case Study, p. 179).

The overall aim of such programs is for fishers, business owners, developers, scientists, citizens, and politicians to identify shared problems and goals in their use of marine resources. The idea is to develop workable, cost-effective, and adaptable solutions that will help to preserve biodiversity and environmental quality, while also meeting economic and social goals.

This requires all participants to seek reasonable short-term trade-offs that can lead to long-term ecological and economic benefits. For example, fishers might have to give up harvesting marine species in certain areas until stocks recover enough to restore biodiversity in those areas. This might help to provide fishers with a more sustainable future for their businesses.

11-3 How Should We Manage and Sustain Marine Fisheries?

▶ **CONCEPT 11-3 Sustaining marine fisheries will require improved monitoring of fish and shellfish populations, cooperative fisheries management among communities and nations, reduction of fishing subsidies, and careful consumer choices in seafood markets.**

Estimating and Monitoring Fishery Populations Is the First Step

The first step in protecting and sustaining the world's marine fisheries is to make the best possible estimates of their fish and shellfish populations (**Concept 11-3**). The traditional approach has used a *maximum sustained yield (MSY)* model to project the maximum number of individuals that can be harvested annually from fish or shellfish stocks without causing a population drop. However, the MSY concept has not worked very well because of the difficulty in estimating the populations and growth rates of fish and shellfish stocks (see Science Focus, p. 258). Also, harvesting a particular species at its estimated maximum sustainable level can affect the populations of other target and nontarget marine species.

In recent years, some fishery biologists and managers have begun using the *optimum sustained yield (OSY)* concept. It attempts to take into account interactions among species and to provide more room for error. Similarly, another approach is *multispecies management* of a number of interacting species, which takes into account their competitive and predator–prey interactions. An even more ambitious approach is to develop complex computer models for managing multispecies fisheries in *large marine systems*. However, it is a political challenge to get groups of nations to cooperate in planning and managing such large systems.

There are uncertainties built into using any of these approaches because of poorly understood biology of marine species and their interactions, and because of limited data on changing ocean conditions. As a result, many fishery and environmental scientists are increasingly interested in using the *precautionary principle* for managing fisheries and large marine systems. This means sharply reducing fish harvests and closing some overfished areas until they recover and we have more information about what levels of fishing they can sustain.

RESEARCH FRONTIER

Studying fish and their habitats to make better estimates of optimum sustained yields for fisheries; see **www.cengage.com/login**.

Some Communities Cooperate to Regulate Fish Harvests

An obvious step to take in protecting marine biodiversity—and therefore fisheries—is to regulate fishing. Traditionally, many coastal fishing communities have developed allotment and enforcement systems for controlling fish catches in which each fisher gets a share of the total allowable catch. Such *catch-share systems* have sustained fisheries and jobs in many communities for hundreds and sometimes thousands of years. An example is Norway's Lofoten fishery, one of the world's largest cod fisheries. For 100 years, it has been self-regulated, with no participation by the Norwegian government. Fishers in New England (USA) are planning to institute a similar system.

GOOD NEWS

However, the influx of large modern fishing boats and international fishing fleets has weakened the ability of many coastal communities to regulate and sustain local fisheries. Community management systems have often been replaced by *co-management,* in which coastal communities and the government work together to manage fisheries.

With this approach, a central government typically sets quotas for various species and divides the quotas among communities. The government may also limit fishing seasons and regulate the types of fishing gear that can be used to harvest a particular species. Each community then allocates and enforces its quota among its members based on its own rules. Often, communities focus on managing inshore fisheries, and the central government manages the offshore fisheries. When it works, community-based co-management illustrates that overfishing and the tragedy of the commons (see Chapter 1, p. 15) are not inevitable.

Government Subsidies Can Encourage Overfishing

A 2006 study by fishery experts U.R. Sumaila and Daniel Pauly estimated that governments around the world give a total of about $30–34 billion per year in subsidies to fishers to help keep their businesses running. That represents about a third of all revenues earned through commercial fishing. Of that amount, about $20 billion helps fishers to buy ships, fuel, and fishing equipment; the remaining money pays for research and management of fisheries.

Some marine scientists argue that, each year, $10–14 billion of these subsidies is spent to encourage overfishing and expansion of the fishing industry. The result is too many boats chasing too few fish. According to a 2008 World Bank report, economic losses from ocean overfishing total $50 billion each year. Some argue that such subsidies are not a wise investment and that they do not promote the sustainability of targeted fish species. **Explore More:** Go to **www.cengage.com/login** to learn about how some countries are using the marketplace to help control overfishing by distributing *individual transfer rights (ITRs)*, or *fish shares*, to fishing vessel owners, allowing them to catch certain quantities of fish and to sell or lease their shares.

CONNECTIONS

Subsidies and Whaling

CORE CASE STUDY

Japan and Norway give large subsidies to their whaling industries (**Core Case Study**), according to a 2009 World Wildlife Fund report. Due to the rising costs of whaling and a declining demand for whale meat, whaling has become unprofitable in those countries. Thus, government subsidies are being used to prop up an industry that is out of favor with much of the world and would likely fail without those subsidies.

THINKING ABOUT

Fishing Subsidies

What are three possible harmful effects of eliminating government fishing subsidies? Do you think they outweigh the benefits of such an action? Explain.

Consumer Choices Can Help Sustain Fisheries and Aquatic Biodiversity

An important component of sustaining aquatic biodiversity and ecosystem services is bottom-up pressure from consumers demanding *sustainable seafood,* which will encourage more responsible fishing practices. In choosing seafood at home and in restaurants, consumers can make choices that will further help to sustain fisheries (**Concept 11-3**).

One way to enable this is through labeling of fresh and frozen seafood to inform consumers about how and where the fish and shellfish were caught. In the United Kingdom, the Waitrose supermarket chain provides such information for all of the seafood sold at its fresh fish counters. See information on more sustainable seafood choices and download a convenient pocket guide at **www.seafoodwatch.org**.

GOOD NEWS

Another important component is certification of sustainably caught seafood. The London-based Marine Stewardship Council (MSC, see **http://www.msc.org/**) was created in 1999 to support sustainable fishing and to certify sustainably produced seafood. Only certified fisheries are allowed to use the MSC's "Fish Forever" eco-label, which certifies that the fish were caught by fishers who used environmentally sound and socially responsible practices. Another approach is to certify and label products of sustainable *aquaculture*, or fish farming operations.

Figure 11-11 There are a number of ways to manage fisheries more sustainably and protect marine biodiversity. **Questions:** Which four of these solutions do you think are the most important? Why?

An important way for seafood consumers to help sustain aquatic biodiversity is to choose plant-eating species of fish raised through aquaculture, such as tilapia. Carnivorous fish raised through aquaculture are fed fishmeal made from wild-caught fish. Some ocean fish species used to make fishmeal are being overfished at higher rates every year.

Figure 11-11 summarizes actions that individuals, organizations, and governments can take to manage global fisheries more sustainably and to protect marine biodiversity and ecosystem services. History shows that most attempts to improve environmental quality and promote environmental sustainability require bottom-up political and economic pressure by concerned citizens. Individuals matter.

11-4 How Should We Protect and Sustain Wetlands?

CONCEPT 11-4 To maintain the ecological and economic services of wetlands, we must maximize the preservation of remaining wetlands and the restoration of degraded wetlands.

Coastal and Inland Wetlands Are Disappearing around the World

Coastal wetlands and marshes (see Figure 8-8, p. 174) and inland wetlands are important reservoirs of aquatic biodiversity that provide vital ecological and economic services. Despite their ecological value, the United States has lost more than half of its coastal and inland wetlands since 1900, and other countries have lost even more. New Zealand, for example, has lost 92% of its original coastal wetlands, and Italy has lost 95%.

For centuries, people have drained, filled in, or covered over swamps, marshes, and other wetlands to create rice fields or other cropland, to accommodate expanding cities and suburbs, and to build roads. Wetlands have also been destroyed in order to extract minerals, oil, and natural gas, and to eliminate breeding grounds for insects that cause diseases such as malaria.

To make matters worse, coastal wetlands in many parts of the world will probably be under water within your lifetime because of rising sea levels caused by a warmer atmosphere. This could seriously degrade the aquatic biodiversity supported by coastal wetlands, including commercially important fish and shellfish species as well as millions of migratory waterfowl and other birds. Rising sea levels will also reduce many of the other ecological and economic services provided by these wetlands.

We Can Preserve and Restore Wetlands

Scientists, land managers, landowners, and environmental groups are involved in intensive efforts to preserve existing wetlands and restore degraded ones (**Concept 11-4**), and laws have been passed to protect wetlands. In the United States, zoning laws have been used to steer development away from wetlands. For example, the U.S. government requires a federal permit to fill in wetlands occupying more than 1.2 hectares (3.0 acres) or to deposit dredged material on them. According to the U.S. Fish and Wildlife Service, this law helped cut the average annual wetland loss by 80% since 1969. However, there are continuing attempts by land developers to weaken such wetlands protection. Only about 6% of remaining inland wetlands are federally protected, and state and local wetland protection is inconsistent and generally weak.

The stated goal of current U.S. federal policy is zero net loss in the function and value of coastal and inland wetlands. A policy known as *mitigation banking* allows destruction of existing wetlands as long as an equal area of the same type of wetland is created or restored. However, a 2001 study by the National Academy of Sciences found that at least half of the attempts to create new wetlands failed to replace lost ones, and most of the created wetlands did not provide the ecological functions of natural wetlands. The study also found that wetland creation projects often fail to meet the standards set for them and are not adequately monitored.

Creating and restoring wetlands has become a profitable business. Private investment bankers make money by buying wetland areas and restoring or upgrading them by working with the U.S. Army Corps of Engineers and the EPA. This creates wetlands banks or credits that the bankers can then sell to developers.

It is difficult to restore or create wetlands. Thus, most U.S. wetland banking systems require replacing each hectare of destroyed wetland with two or more hectares of restored or created wetland (Figure 11-12) as a built-in ecological insurance policy. **GREEN CAREER:** Wetlands restoration expert

Ecologists urge that mitigation banking should be used only as a last resort. They also call for making sure that new replacement wetlands are created and evaluated *before* existing wetlands are destroyed. This example of applying the precautionary principle is often the reverse of what is actually done.

THINKING ABOUT
Wetlands Mitigation

Should a new wetland be created and evaluated before anyone is allowed to destroy the wetland it is supposed to replace? Explain.

RESEARCH FRONTIER

Evaluating ecological services provided by wetlands, human impacts on wetlands, and how to preserve and restore wetlands; see **www.cengage.com/login**.

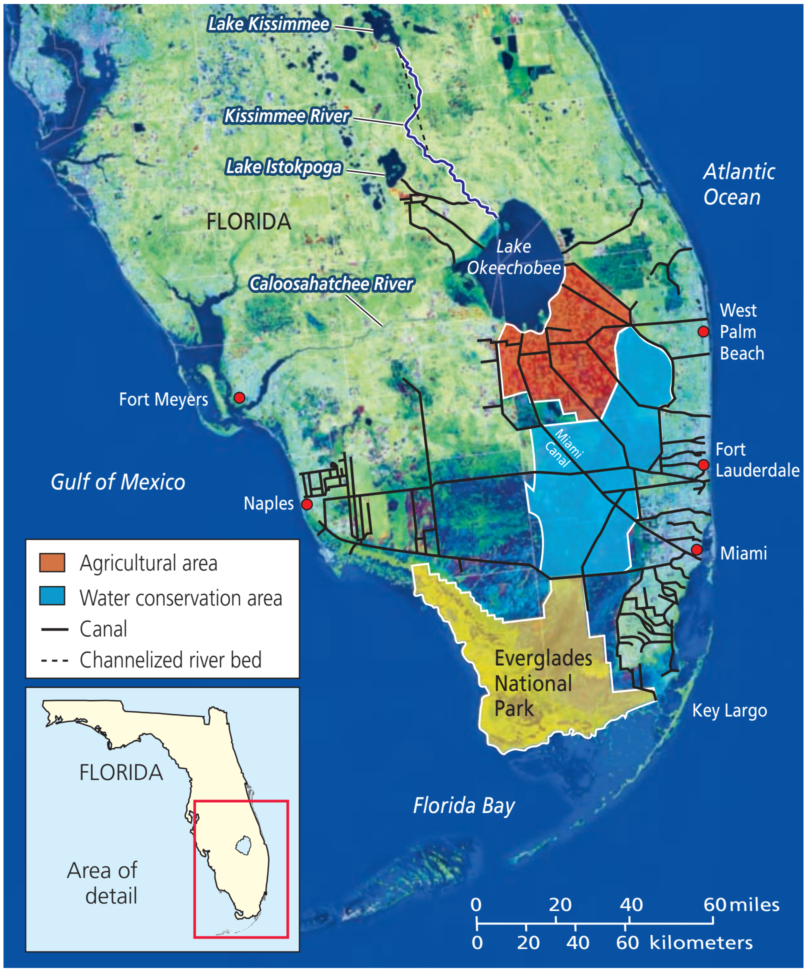
A good example of an attempt to restore a once-massive wetland is that of the Everglades in the U.S. state of Florida, as described in the following case study.

CASE STUDY
Can We Restore the Florida Everglades?

South Florida's Everglades (USA) was once a 100-kilometer-wide (60-mile-wide), knee-deep sheet of water flowing slowly south from Lake Okeechobee to Florida Bay (Figure 11-13). As this shallow body of water—known as the "River of Grass"—trickled south, it created a vast network of wetlands (Figure 11-13, photo) with a variety of wildlife habitats.

JAP/Shutterstock

Figure 11-12 This human-created wetland is located near Orlando, Florida (USA).




slowfish/Shutterstock

Figure 11-13 The world's largest ecological restoration project is an attempt to undo and redo an engineering project that has been destroying Florida's Everglades (USA, see photo) and threatening water supplies for south Florida's rapidly growing population.

To help preserve the wilderness in the lower end of the Everglades system, in 1947, the U.S. government established Everglades National Park, which contains about a fifth of the remaining Everglades. But this protection effort did not work—as conservationists had predicted—because of a massive water distribution and land development project to the north. Between 1962 and 1971, the U.S. Army Corps of Engineers transformed the wandering 166-kilometer-long (103-mile-long) Kissimmee River (Figure 11-13) into a mostly straight 84-kilometer (56-mile) canal flowing into Lake Okeechobee. The canal provided flood control by speeding the flow of water, but it drained large wetlands north of Lake Okeechobee, which farmers then turned into grazing land.

This and other projects have provided south Florida's rapidly growing population with a reliable water supply and flood protection. But as a result, much of the original Everglades has been drained, diverted, paved over, polluted by agricultural runoff, and invaded by a number of plant and animal species. The Everglades is now less than half its original size and much of it has dried out, leaving large areas vulnerable to summer wildfires. About 90% of the wading birds in Everglades National Park (Figure 11-13) have vanished, and populations of other vertebrates, from deer to turtles, are down 75–95%.

Another result is the degradation of Florida Bay, a shallow estuary with many tiny islands, or keys, south of Everglades National Park. Because the large volumes of freshwater that once flowed through the park into Florida Bay have been diverted for crops and cities, the bay has become saltier and warmer. This, along with increased nutrient input from croplands and cities, has stimulated the growth of large algal blooms that sometimes cover 40% of the bay. This has threatened the coral reefs and the diving, fishing, and tourism industries of the bay and the Florida Keys—another example of unintended consequences.

By the 1970s, state and federal officials recognized that this huge plumbing project was reducing species of native plants and wildlife—a major source of tourism revenues for Florida—as well as the water supply for the more than 5 million residents of south Florida. In 1990, after more than 20 years of political haggling, Florida's state government and the federal government agreed on the world's largest ecological restoration project, known as the Comprehensive Everglades Restoration Plan (CERP). The U.S. Army Corps of Engineers is supposed to carry out this joint federal and state plan to partially restore the Everglades.

The project has several ambitious goals. *First,* restore the curving flow of more than half of the Kissimmee River. *Second,* remove 400 kilometers (250 miles) of canals and levees blocking water flow south of Lake Okeechobee. *Third,* buy 240 square kilometers (93 square miles) of farmland and allow it to be flooded to create artificial marshes that will filter out agricultural runoff before it reaches Everglades National Park. *Fourth,* create 18 large reservoirs and underground water storage areas to ensure an adequate water supply for the lower Everglades and for south Florida's current and projected population. *Fifth,* build new canals, reservoirs, and huge pumping systems to capture 80% of the water currently flowing out to sea and return it to the Everglades.

Will this huge ecological restoration project work? It depends not only on the abilities of scientists and engineers but also on prolonged political and economic support from citizens, the state's powerful sugarcane and agricultural industries, and elected state and federal officials.

This carefully negotiated plan is already beginning to unravel. In 2003, sugarcane growers persuaded the Florida legislature to increase the amount of phosphorus they could discharge and to extend the deadline for reducing such discharge from 2006 to 2016. The project has had serious cost overruns, and funding for the project, especially federal funding, has fallen short of the projected needs. Federal and state agencies are far behind on almost every component of the project. As a result, it could take another 50 years to complete, or it could be abandoned because of a lack of political support and funding.

The need to make expensive and politically controversial efforts to undo some of the ecological damage done to the Everglades, caused by 120 years of agricultural and urban development, is another example of failure to heed two fundamental lessons from nature: prevention of environmental harm works better and is less costly then trying to undo it; and when we intervene in nature, unintended and often harmful consequences usually result. Some scientists argue that this is a classic case of where applying the precautionary principle (see Chapter 9, p. 213) would have been the wisest choice.

THINKING ABOUT
Everglades Restoration

Do you support carrying out the proposed plan for partially restoring the Florida Everglades, including having the federal government provide half of the funding? Explain.

11-5 How Should We Protect and Sustain Freshwater Lakes, Rivers, and Fisheries?

▶ **CONCEPT 11-5 Freshwater ecosystems are strongly affected by human activities on adjacent lands, and protecting these ecosystems must include protection of their watersheds.**

Freshwater Ecosystems Are under Major Threats

The ecological and economic services provided by many of the world's freshwater lakes, rivers, and fisheries (see Figure 8-15, p. 181) are severely threatened by human activities (**Concept 11-5**). Freshwater species diversity varies widely. You can have 3,000 different fish species in a river in South America and less than 50 in a river in the Pacific Northwest.

Again, we can use the acronym HIPPCO to summarize these threats. As 40% of the world's rivers have been dammed or otherwise engineered, and as many of the world's freshwater wetlands have been destroyed, aquatic species have been crowded out of at least half of the world's freshwater habitat areas. Invasive species, pollution, and climate change threaten the ecosystems of many lakes, rivers, and wetlands. Freshwater fish stocks are overharvested. And increasing human population pressures and projected climate change during this century will make these threats worse.

Sustaining and restoring the biodiversity and ecological services provided by freshwater lakes and rivers is a complex and challenging task, as shown by the following Case Study.

■ CASE STUDY
Can the Great Lakes Survive Repeated Invasions by Alien Species?

Invasions by nonnative species are a major threat to the biodiversity and ecological functioning of many lakes, as illustrated by what has happened to the five Great Lakes, which are located between the United States and Canada.

Collectively, the Great Lakes are the world's largest body of fresh water. Since the 1920s, they have been invaded by at least 162 nonnative species and the number keeps rising. Many of the alien invaders arrive on the hulls of, or in bilge-water discharges of, oceangoing ships that have been entering the Great Lakes through the St. Lawrence Seaway since 1959.

One of the biggest threats, the *sea lamprey,* reached the western-most Great Lakes as early as 1920. This parasite attaches itself to almost any kind of fish and kills the victim by sucking out its blood (see Figure 5-7, p. 110). Over the years, it has depleted populations of many important sport fish species such as lake trout. The United States and Canada keep the lamprey population down by applying a chemical that kills lamprey larvae where they spawn in streams that feed into the lakes—at a cost of about $15 million a year.

In 1986, larvae of the *zebra mussel* (see Figure 9-11, p. 200) arrived in ballast water discharged from a European ship near Detroit, Michigan (USA). This thumbnail-sized mollusk reproduces rapidly and has no known natural enemies in the Great Lakes. As a result, it has displaced other mussel species and thus depleted the food supply for some other Great Lakes aquatic species. The mussels have also clogged irrigation pipes, shut down water intake pipes for power plants and city water supplies, fouled beaches, jammed ships' rudders, and grown in huge masses on boat hulls, piers, pipes, rocks, and almost any exposed aquatic surface (Figure 11-14). This mussel has also spread to freshwater communities in parts of southern Canada and 18 U.S. states. The mussels cost the two countries about $1 billion a year—an average of $114,000 per hour.

Sometimes, nature aids us in controlling an invasive alien species. For example, populations of zebra mussels are declining in some parts of the Great Lakes because a native sponge growing on their shells is preventing them from opening up their shells to breathe. However, it is not clear whether the sponges will be effective in controlling the invasive mussels in the long run.

In 1989, a larger and potentially more destructive species, the *quagga mussel,* invaded the Great Lakes, probably discharged in the ballast water of a Russian freighter. It can survive at greater depths and tolerate more extreme temperatures than the zebra mussel can. In 2009, scientists reported that quagga mussels had rapidly replaced many other bottom-dwellers in Lake Michigan. This has reduced the food supply for many fish and other species, thus leading to a major disruption of the lake's food web. There is concern that quagga mussels may spread by river transport and eventually colonize eastern U.S. ecosystems such as the Chesapeake Bay (see Chapter 8, Case Study, p. 179) and waterways in parts of Florida. In 2007, it was found to have crossed the United States, probably hitching a ride on a boat or trailer being hauled cross-country. It now resides in the Colorado River and its reservoir system.

The *Asian* or *grass carp* (Figure 11-15) is the most recent threat to the Great Lakes system. In the 1970s, catfish farmers in the southern United States imported

NOAA

Figure 11-14 These *zebra mussels* are attached to a water current meter in Lake Michigan. This invader entered the Great Lakes through ballast water dumped from a European ship. It has become a major nuisance and a threat to commerce as well as to biodiversity in the Great Lakes.

Michigan Sea Grant College Program

Figure 11-15 According to U.S. Environmental Protection Agency, two species of Asian carp were close to invading Lake Michigan in 2010. If they become established in Lake Michigan, they are likely to spread rapidly and disrupt the food web that supports the lakes' native fish populations. Eventually, they could become the dominant fish species in the interconnected Great Lakes.

two species of Asian carp to help remove suspended matter and algae from their aquaculture farm ponds. Heavy flooding during the 1990s caused many of these ponds to overflow, which resulted in the release of some of the carp into the Mississippi River. Since then they have moved north into the Illinois River, and in 2010, a few of these hardy and aggressive invaders were found within a few miles of Lake Michigan.

These highly prolific fish can quickly grow as long as 1.2 meters (4 feet) and weigh up to 50 kilograms (110 pounds), and they have a voracious appetite. They also have the ability to jump clear of the water, and several boaters have been injured when they have collided with jumping carp. These fish have no natural predators in the Mississippi and Illinois Rivers, sections of which they now dominate, or in the Great Lakes. In 2009, Joel Brammeler, president of the Alliance for the Great Lakes warned that "If Asian carp get into Lake Michigan, there is no stopping them."

THINKING ABOUT
Invasive Species in Lakes

What are three ways in which people could avoid introducing more harmful invasive species into lakes?

Managing River Basins is Complex and Controversial

Rivers and streams provide important ecological and economic services (Figure 11-16). But overfishing, pollution, dams, and water withdrawal for irrigation (see Chapter 8, p. 186) disrupt these services.

An example of such disruption—one that especially illustrates biodiversity loss—is what happened in the Columbia River, which runs through parts of southwestern Canada and the northwestern United States. It has 119 dams, 19 of which are major generators of inexpensive hydroelectric power. It also supplies water for major urban areas and large irrigation projects.

Natural Capital

Ecological Services of Rivers

- Deliver nutrients to sea to help sustain coastal fisheries
- Deposit silt that maintains deltas
- Purify water
- Renew and renourish wetlands
- Provide habitats for wildlife

Figure 11-16 Rivers provide some important ecological services. Currently, the services are given little or no monetary value when the costs and benefits of dam and reservoir projects are assessed. According to environmental economists, attaching even crudely estimated monetary values to these ecosystem services would help to sustain them. **Questions:** Which two of these services do you believe are the most important? Why?

The Columbia River dam system has benefited many people, but it has sharply reduced populations of wild salmon. These migratory fish hatch in the upper reaches of the streams and rivers that form the headwaters of the Columbia River, migrate to the ocean where they spend most of their adult lives, and then swim upstream to return to the place where they were hatched to spawn and die. Dams interrupt their life cycle by interfering with the migration of young fish downstream, and blocking the return of mature fish attempting to swim upstream to their spawning grounds.

Since the dams were built, the Columbia River's wild Pacific salmon population has dropped by 94% and nine of the Pacific Northwest salmon species are listed as endangered or threatened. Since 1980, the U.S. federal government has spent more than $3 billion in efforts to save the salmon, but none have been effective.

In another such case—on the lower Snake River in the U.S. state of Washington—conservationists, Native American tribes, and commercial salmon fishers want the government to remove four small hydroelectric dams to restore salmon spawning habitat. Farmers, barge operators, and aluminum workers argue that removing the dams would hurt local economies by reducing irrigation water, eliminating shipping in the affected areas, and reducing the supply of cheap electricity for industries and consumers.

We Can Protect Freshwater Ecosystems by Protecting Watersheds

Sustaining freshwater aquatic systems begins with understanding that land and water are always connected in some way. For example, lakes and streams receive many of their nutrients from the ecosystems of bordering land. Such nutrient inputs come from falling leaves, animal feces, and pollutants generated by people, all of which are washed into bodies of water by rainstorms and melting snow. Therefore, to protect a stream or lake from excessive inputs of nutrients and pollutants, we must protect its watershed (**Concept 11-5**).

As with marine systems, freshwater ecosystems can be protected through laws, economic incentives, and restoration efforts. For example, restoring and sustaining the ecological and economic services of rivers will probably require taking down some dams and restoring river flows, as may be the case with the Snake River, as mentioned earlier. In addition, some scientists and politicians have argued for protecting all remaining free-flowing rivers.

With that in mind, in 1968 the U.S. Congress passed the National Wild and Scenic Rivers Act to establish protection of rivers with outstanding wildlife, geological, scenic, recreational, historical, or cultural values. The law classified *wild rivers* as those that are relatively inaccessible (except by trail), and *scenic rivers* as rivers of great scenic value that are free of dams, mostly undeveloped, and accessible in only a few places by roads. These rivers are now protected from widening, straightening, dredging, filling, and damming.

In 2009, the U.S. Congress passed a law increasing the total length of wild and scenic rivers by half. But the Wild and Scenic Rivers System keeps only 3% of U.S. rivers free-flowing and protects less than 1% of the country's total river length.

HOW WOULD YOU VOTE?

Should more rivers be protected by law from damming and development? Cast your vote online at **www.cengage.com/login**.

Freshwater Fisheries Need Better Protection

Sustainable management of freshwater fisheries involves supporting populations of commercial and sport fish species, preventing such species from being overfished, and reducing or eliminating populations of harmful invasive species. The traditional way of managing freshwater fish species is to regulate the time and length of fishing seasons and the number and size of fish that can be taken.

Other techniques include building reservoirs and ponds and stocking them with fish, and protecting and creating fish spawning sites. In addition, some fishery managers try to protect fish habitats from sediment buildup and other forms of pollution and from excessive growth of aquatic plants due to large inputs of plant nutrients by working to reduce or prevent such inputs.

Some fishery managers seek to control predators, parasites, and diseases by improving habitats, breeding genetically resistant fish varieties, and using antibiotics and disinfectants. Hatcheries can be used to restock ponds, lakes, and streams with prized species such as trout, and entire river basins can be managed to protect valued species such as salmon. However, all of these practices should be based on continuing studies of their effects on aquatic ecosystems and biodiversity. **GREEN CAREERS:** limnology and fishery management

RESEARCH FRONTIER

Studying the effects of resource management techniques on aquatic ecosystems.

11-6 What Should Be Our Priorities for Sustaining Aquatic Biodiversity?

CONCEPT 11-6 Sustaining the world's aquatic biodiversity requires mapping it, protecting aquatic hotspots, creating large, fully protected marine reserves, protecting freshwater ecosystems, and carrying out ecological restoration of degraded coastal and inland wetlands.

Use an Ecosystem Approach to Sustaining Aquatic Biodiversity

In Chapter 10, based on the research of Edward O. Wilson and other biodiversity experts, we described an ecosystem approach to sustaining terrestrial biodiversity. We can adapt such an approach and apply it to sustaining aquatic biodiversity, as well (**Concept 11-6**). With that in mind, Wilson has proposed the following priorities:

- Complete the mapping of the world's aquatic biodiversity, identifying and locating as many plant and animal species as possible in order to make conservation efforts more precise and cost-effective.
- Identify and preserve the world's aquatic biodiversity hotspots and areas where deteriorating ecosystem services threaten people and many other forms of life.
- Create large and fully protected marine reserves to allow damaged marine ecosystems to recover and to allow fish stocks to be replenished.
- Protect and restore the world's lakes and river systems, which are the most threatened ecosystems of all.
- Initiate ecological restoration projects worldwide in systems such as coral reefs and inland and coastal wetlands to help preserve the biodiversity and important natural services in those systems.
- Find ways to raise the incomes of people who live in or near protected lands and waters so that they can become partners in the protection and sustainable use of ecosystems.

There is growing evidence that the current harmful effects of human activities on aquatic biodiversity and ecosystem services could be reversed

GOOD NEWS

over the next 2 decades. Doing this will require implementing an ecosystem approach to sustaining both terrestrial and aquatic ecosystems. According to Edward O. Wilson (see Individuals Matter, p. 85), such a conservation strategy would cost about $30 billion per year—an amount that could be provided by a tax of one penny per cup of coffee consumed in the world each year.

This strategy for protecting the earth's vital biodiversity will not be implemented without bottom-up political pressure on elected officials from individual citizens and groups. It will also require cooperation among scientists, engineers, and key people in government and the private sector. And will be important for individuals to "vote with their wallets" by trying to buy only products and services that do not have harmful impacts on terrestrial and aquatic biodiversity.

Here are this chapter's *three big ideas*:

- The world's aquatic systems provide important ecological and economic services, and scientific investigation of these poorly understood ecosystems could lead to immense ecological and economic benefits.
- Aquatic ecosystems and fisheries are being severely degraded by human activities that lead to aquatic habitat disruption and loss of biodiversity.
- We can sustain aquatic biodiversity by establishing protected sanctuaries, managing coastal development, reducing water pollution, and preventing overfishing.

REVISITING Whales and Sustainability

CORE CASE STUDY

SUSTAINABILITY

This chapter began with a look at how human activities have threatened whale populations in several ways (**Core Case Study**). First, whales were hunted and killed to the point where several species were critically endangered and most were commercially extinct. Human population growth has resulted in more crowded marine environments where noise and chemical pollution threaten the survival of whales and other cetaceans. Invasive species in some aquatic systems have disrupted food webs of which whales are a part, and overfishing has had the same effect. In addition, projected climate change could prove to be the biggest challenge as warmer, more acidic ocean waters damage and destroy more coral reefs and other aquatic habitats and further disrupt aquatic food webs. Rising sea levels resulting from warming seas and melting land-based ice would also degrade aquatic habitats and biodiversity.

However, the story of the whales also reveals that we can reverse the harmful effects of some of our activities. Since a moratorium on whale hunting was established and because most nations have complied with it, several whale species are recovering. Similarly, when areas of the oceans are left undisturbed, ecosystems seem to recover their natural functions, and fish populations rebound fairly quickly. We also explored ways to manage the world's wetlands, lakes, and rivers more sustainably.

We can achieve greater success in sustaining aquatic biodiversity by applying the three **principles of sustainability** (see back cover). This means reducing inputs of sediments and excess nutrients, which cloud water, lessen the input of solar energy, and upset aquatic food webs and the natural cycling of nutrients in aquatic systems. It also means valuing aquatic biodiversity and putting a high priority on preserving the biodiversity and ecological functioning of aquatic systems.

By treating the oceans with more respect and by using them more wisely, we can obtain more from these life-supporting waters while also maintaining healthy and diverse marine ecosystems.

BRIAN HALWEIL

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 251. Describe how human activities have threatened whale populations (**Core Case Study**). What is the International Whaling Commission and what has it done to protect whales?

   CORE CASE STUDY

2. How much do we know about the habitats and species that make up the earth's aquatic biodiversity? What are three general patterns of marine biodiversity? Describe the threat to marine biodiversity from bottom trawling. How have coral reefs been threatened? What are two causes of disruption of freshwater habitats? Give two examples of threats to marine aquatic systems from invasive species and two examples of the same for freshwater systems. Describe the ecological experiment of carp removal in Wisconsin's Lake Wingra. Summarize the story

of how invasive species have disrupted Lake Victoria's ecosystem.

3. What are two harmful effects on aquatic systems resulting from the increase in the human population in coastal areas? Give two examples of how pollution is affecting aquatic systems. What are three ways in which projected climate change could threaten aquatic biodiversity? Define **fishery**. What are three major harmful effects of overfishing? Describe the collapse of the Atlantic cod fishery and the resulting effects on the fishery's ecosystem. What is a **fishprint**? Describe factors leading to the near extinction of the blue whale. Describe the effects of trawler fishing, purse-seine fishing, long-lining, and drift-net fishing. What is bycatch?

4. How have laws and treaties been used to help sustain aquatic species? What is the main problem that interferes with enforcing international agreements? Describe international efforts to protect whales from overhunting and premature extinction. How can economic incentives help to sustain aquatic biodiversity? Give two examples of where this has happened. Describe threats to the leatherback turtle and efforts by some people to help protect the species.

5. Describe the use of marine protected areas and marine reserves to help sustain aquatic biodiversity and ecosystem services. What percentage of the world's oceans is strictly protected from harmful human activities in marine reserves? Describe the role of fishing communities and individual consumers in regulating fishing and coastal development. Give two examples of the restoration of marine systems. Describe threats from increasing ocean acidity. What is integrated coastal management?

6. Describe and discuss the limitations of three ways of estimating the sizes of fish populations. How can the precautionary principle help in managing fisheries and large marine systems? Describe the efforts of local fishing communities in helping to sustain fisheries. How can government subsidies encourage overfishing?

7. Describe how consumer choices can help to sustain fisheries and aquatic biodiversity and ecosystem services. List five ways to manage global fisheries more sustainably.

8. What percentage of the U.S. coastal and inland wetlands have been destroyed since 1900? What are major ecological services provided by wetlands? How does the United States attempt to reduce wetland losses? Describe efforts to restore the Florida Everglades.

9. Describe the major threats to the world's rivers and other freshwater systems. What major ecological services do rivers provide? Describe invasions of the U.S. Great Lakes by nonnative species. Describe ways to help sustain rivers. What are three ways to protect freshwater habitats and fisheries?

10. How can we apply the ecosystem approach to sustaining aquatic biodiversity? List six steps that we can take to do so. What are the three big ideas of this chapter? How can we apply the three **principles of sustainability** to protecting whales (**Core Case Study**) and other aquatic species and to sustaining aquatic biodiversity and ecosystem services?

SUSTAINABILITY

CORE CASE STUDY

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. Explain how hunting some whale species to the brink of extinction (**Core Case Study**) has violated at least two of the **principles of sustainability**.

CORE CASE STUDY

SUSTAINABILITY

2. Write a short essay describing how each of the six factors summarized by HIPPCO has affected whales (**Core Case Study**) or will affect them further. Look for and describe connections among these factors. For example, how does one factor enhance the effects of one or more other factors? Suggest ways in which each of the factors could be reduced.

CORE CASE STUDY

3. What do you think are the three greatest threats to aquatic biodiversity and ecosystem services? Why? Overall, why are aquatic species more vulnerable to premature extinction from human activities than terrestrial species are? Why is it more difficult to identify and protect endangered marine species than to protect endangered terrestrial species?

4. Why is marine biodiversity higher **(a)** near coasts than in the open sea and **(b)** on the ocean's bottom than at its surface?

5. Why do you think no-fishing marine reserves recover their biodiversity faster and more effectively than do protected areas where fishing is allowed but restricted?

6. How might continued overfishing of marine species affect your lifestyle? How could it affect the lives of any children or grandchildren you might have? What are three things you could do to help prevent overfishing?

7. Should fishers who harvest fish from a country's publicly owned waters be required to pay the government fees for the fish they catch? Explain. If your livelihood depended on commercial fishing, would you be for or against such fees?

8. Do you think the plan for restoring Florida's Everglades will succeed? Give three reasons why or why not.

9. Congratulations! You are in charge of protecting the world's aquatic biodiversity and ecosystem services. List the three most important points of your policy to accomplish this goal.

10. List two questions that you would like to have answered as a result of reading this chapter.

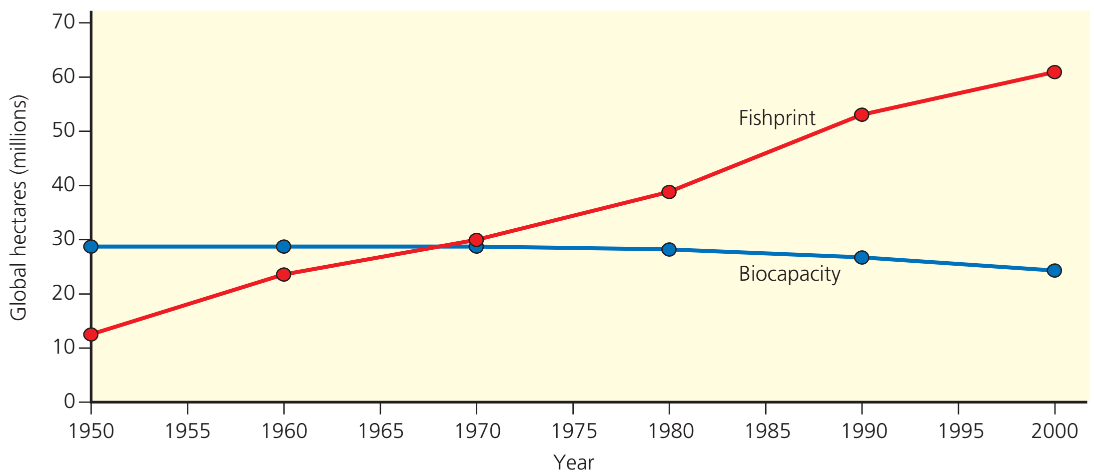
ECOLOGICAL FOOTPRINT ANALYSIS

A fishprint provides a measure of a country's fish harvest in terms of area. The unit of area used in fishprint analysis is the global hectare (gha), a unit weighted to reflect the relative ecological productivity of the area fished. When compared with the fishing area's sustainable biocapacity, its ability to provide a stable supply of fish year after year in terms of area, its fishprint indicates whether the country's fishing intensity is sustainable. The fishprint and biocapacity are calculated using the following formulae:

$$\text{Fishprint in (gha)} = \frac{\text{metric tons of fish harvested per year}}{\text{productivity in metric tons per hectare}} \times \text{weighting factor}$$

$$\text{Biocapacity in (gha)} = \frac{\text{sustained yield of fish in metric tons per year}}{\text{productivity in metric tons per hectare}} \times \text{weighting factor}$$

The following graph shows the earth's total fishprint and biocapacity. Study it and answer the following questions.



1. Based on the graph,
   a. What is the current status of the global fisheries with respect to sustainability?
   b. In what year did the global fishprint begin to exceed the biological capacity of the world's oceans?
   c. By how much did the global fishprint exceed the biological capacity of the world's oceans in 2000?

2. Assume a country harvests 18 million metric tons of fish annually from an ocean area with an average productivity of 1.3 metric tons per hectare and a weighting factor of 2.68. What is the annual fishprint of that country?

3. If biologists determine that this country's sustained yield of fish is 17 million metric tons per year,
   a. what is the country's sustainable biological capacity?
   b. is the county's fishing intensity sustainable?
   c. to what extent, as a percentage, is the country under- or overshooting its biological capacity?

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengagebrain.com/shop/ISBN/0538735341** and choose Chapter 11 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

For students with access to premium online resources, log on to **www.cengage.com/login**.

Find the latest news and research, (including videos and podcasts), at the GLOBAL ENVIRONMENT WATCH. Visit **www.CengageBrain.com** for more information.

Food, Soil, and Pest Management

12

Organic Agriculture Is On the Rise

CORE CASE STUDY

How can we increase food production for our rapidly growing human population without causing serious environmental harm? Each day, there are about 224,000 more mouths to feed and by 2050 there will likely be 2.6 billion more people on the planet. This population increase is twice China's current population and more than eight times the current U.S. population.

Sustainability experts call for us to develop and phase in more sustainable agricultural systems over the next few decades. One component of more sustainable agriculture is **organic agriculture**, in which crops are grown without the use of synthetic pesticides, synthetic inorganic fertilizers, or genetically engineered seeds, and animals are grown without the use of antibiotics or synthetic growth hormones. Figure 12-1 compares organic agriculture with industrialized agriculture.

Between 2002 and 2008, the global market for certified organic food doubled. However, certified organic farming is practiced on less than 1% of the world's cropland and only 0.6% of U.S. cropland, and organic food accounted for only 3.5% of U.S. food sales in 2008. In Australia and New Zealand, almost one-third of the land under cultivation is used to raise organic crops and beef. In many European countries, 6–18% of the cropland is devoted to organic farming.

Over 2 decades of research indicates that organic farming has a number of environmental advantages over industrialized farming. On the other hand, conventional agriculture usually can produce higher yields of crops on smaller areas of land than organic agriculture can. Another drawback is that most organically grown food costs 10–100% more than conventionally produced food (depending on specific items), primarily because organic farming is more labor intensive.

But suppose food prices included the estimated costs of the harmful environmental and health impacts of industrialized food production. According to some economists, organic food would then be cheaper than food produced by industrialized agriculture. In this chapter, we look at different ways to produce food, the environmental effects of food production, and how to produce food more sustainably.

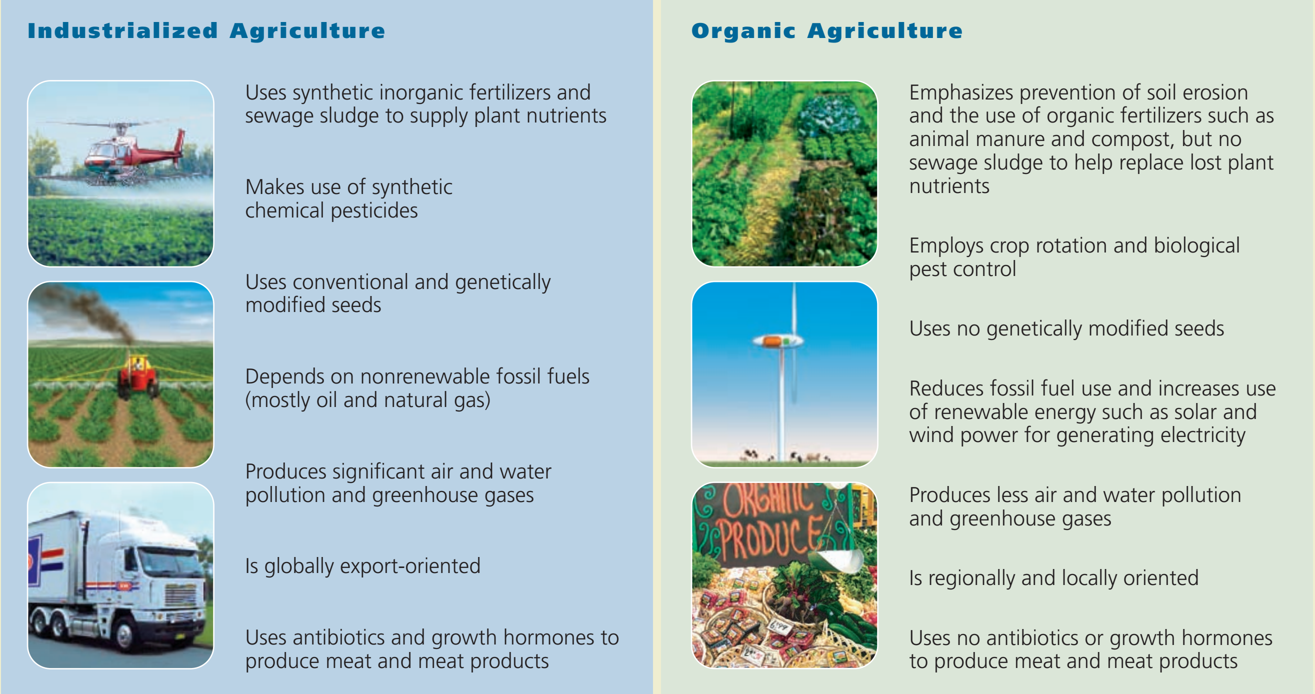


Figure 12-1 There are major differences between conventional industrialized agriculture and organic agriculture. In the United States, a label of *100 percent organic* means that a product is raised only by organic methods and contains all organic ingredients. Products labeled *organic* must contain at least 95% organic ingredients. In addition, products labeled *made with organic ingredients* must contain at least 70% organic ingredients but cannot display the U.S. Department of Agriculture *Organic* seal on their packages.

Key Questions and Concepts

12-1 What is food security and why is it difficult to attain?

CONCEPT 12-1A Many people in less-developed countries have health problems from not getting enough food, while many people in more-developed countries suffer health problems from eating too much food.

CONCEPT 12-1B The greatest obstacles to providing enough food for everyone are poverty, corruption, political upheaval, war, bad weather, and the harmful environmental effects of industrialized food production.

12-2 How is food produced?

CONCEPT 12-2 We have used high-input industrialized agriculture and lower-input traditional methods to greatly increase supplies of food.

12-3 What environmental problems arise from industrialized food production?

CONCEPT 12-3 Future food production may be limited by soil erosion and degradation, desertification, water and air pollution, climate change from greenhouse gas emissions, and loss of biodiversity.

12-4 How can we protect crops from pests more sustainably?

CONCEPT 12-4 We can sharply cut pesticide use without decreasing crop yields by using a mix of cultivation techniques, biological pest controls, and small amounts of selected chemical pesticides as a last resort (integrated pest management).

12-5 How can we improve food security?

CONCEPT 12-5 We can improve food security by creating programs to reduce poverty and chronic malnutrition, relying more on locally grown food, and cutting food waste.

12-6 How can we produce food more sustainably?

CONCEPT 12-6 More sustainable food production will require using resources more efficiently, sharply decreasing the harmful environmental effects of industrialized food production, and eliminating government subsidies that promote such harmful impacts.

Note: Supplements 2 (p. S3), 3 (p. S6), 4 (p. S11), and 8 (p. S30) can be used with this chapter.

There are two spiritual dangers in not owning a farm. One is the danger of supposing that breakfast comes from the grocery, and the other that heat comes from the furnace.

ALDO LEOPOLD

12-1 What Is Food Security and Why Is It Difficult to Attain?

▶ **CONCEPT 12-1A Many people in less-developed countries have health problems from not getting enough food, while many people in more-developed countries suffer health problems from eating too much food.**

▶ **CONCEPT 12-1B The greatest obstacles to providing enough food for everyone are poverty, corruption, political upheaval, war, bad weather, and the harmful environmental effects of industrialized food production.**

Many People Have Health Problems from Not Getting Enough to Eat

In a country that enjoys **food security**, all or most of the people in the country have daily access to enough nutritious food to live active and healthy lives. GOOD NEWS Today, we produce more than enough food to meet the basic nutritional needs of every person on the earth. But even with this food surplus, one of every six people in less-developed countries is not getting enough to eat because of unequal access to available food. These people face **food insecurity**—living with chronic hunger and poor nutrition, which threatens their ability to lead healthy and productive lives (**Concept 12-1A**).

Most agricultural experts agree that *the root cause of food insecurity is poverty*, which prevents poor people from growing or buying enough food. Other obstacles to food security are political upheaval, war (Figure 12-2), corruption, and bad weather such as prolonged drought or heat waves (**Concept 12-1B**). These problems interfere with food distribution and transportation systems and can result in people going hungry while stored foods

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. GOOD NEWS refers to good news about the environmental challenges we face.

Figure 12-2 These starving children were collecting ants to eat in famine-stricken Sudan, Africa, where a civil war lasted from 1983 until 2005. The effects of war are still being felt, and prolonged drought has made the problem worse.

spoil. In addition, according to a 2007 study by climate scientist David Battisti and food scientist Rosamond Naylor, there is a higher-than 90% chance that by the end of this century, half of the world's population will face serious food shortages because of projected climate change caused by a rapidly warming atmosphere.

Achieving food security on regional and global levels for both poor and affluent people also depends on greatly reducing the harmful environmental and health effects of industrialized agriculture and on promoting more sustainable agriculture. We explore these challenges further throughout this chapter.

Many People Suffer from Chronic Hunger and Malnutrition

To maintain good health and resist disease, individuals need fairly large amounts of *macronutrients* (such as carbohydrates, proteins, and fats; see Table 12-1 and Figures 7, 8, and 11, pp. S14–S15, in Supplement 4), and smaller amounts of *micronutrients*—vitamins (such as A, B, C, and E) and minerals (such as iron and iodine).

People who cannot grow or buy enough food to meet their basic energy needs suffer from **chronic undernutrition**, or **hunger** (**Concept 12-1A**). Most of the world's chronically undernourished children live in low-income, less-developed countries.

Table 12-1 Key Nutrients for a Healthy Human Life

Nutrient	Food Source	Function
Proteins	Animals and some plants	Help to build and repair body tissues
Carbohydrates	Wheat, corn, and rice	Provide short-term energy
Lipids (oils and fats)	Animal fats, nuts, oils	Help to build membrane tissues and create hormones

Many of the world's poor can afford only to live on a low-protein, high-carbohydrate, vegetarian diet consisting mainly of grains such as wheat, rice, or corn. They often suffer from **chronic malnutrition**—deficiencies of protein and other key nutrients. This weakens them, makes them more vulnerable to disease, and hinders the normal physical and mental development of children.

The UN Food and Agriculture Organization (FAO) estimated that rising food prices and a sharp drop in international food aid increased the worlds' number of hungry and malnourished people from 825 million in the mid-1990s to more than 1 billion by 2009. This number is nearly equal to the population of China and is more than 3 times the entire U.S. population. (See Figure 15, p. S47, in Supplement 8 for a map of the countries with the most undernourished people.)

In less-developed countries, one of every six people (including about one of every three children younger than age 5) is chronically undernourished or malnourished. The FAO estimates that each year, nearly 6 million children under age five die prematurely from these conditions and from increased susceptibility to normally nonfatal infectious diseases (such as measles and diarrheal diseases) because of their weakened condition. This means that each day, an average of 16,400 children under age five die prematurely from these mostly poverty-related causes.

Perhaps the worst form of food shortage is **famine**, which occurs when there is a severe shortage of food in an area and which can result in mass starvation, many deaths, economic chaos, and social disruption. Faced with starvation, desperate people eat the seed grain they have stored to grow crops in future years, and they sometimes slaughter their breeding livestock. Famines often result in mass migrations of starving people to other areas or to refugee camps in a search for food, water, and medical help. Famines are usually caused by crop failures from drought, flooding, war (Figure 12-2), and other catastrophic events (**Concept 12-1B**).

RESEARCH FRONTIER

Learning more about connections between food supplies, poverty, and environmental problems; see **www.cengage.com/login**.

Many People Do Not Get Enough Vitamins and Minerals

According to the World Health Organization (WHO), one of every three people suffers from a deficiency of one or more vitamins and minerals, usually *vitamin A*, *iron*, and *iodine* (**Concept 12-1A**). Most of these people live in less-developed countries. Some 250,000–500,000 children younger than age 6 go blind each year from a lack of vitamin A, and within a year, more than half of them die.

Having too little *iron* (Fe)—a component of the hemoglobin that transports oxygen in the blood—causes *anemia*. It results in fatigue, makes infection more likely, and increases a woman's chances of dying from hemorrhage in childbirth. According to the WHO, one of every five people in the world—mostly women and children in less-developed countries—suffers from iron deficiency.

Elemental *iodine* is essential for proper functioning of the thyroid gland, which produces hormones that control the body's rate of metabolism. A chronic lack of iodine can cause stunted growth, mental retardation, and goiter—a swollen thyroid gland that can lead to deafness (Figure 12-3). Almost one-third of the world's people do not get enough iodine in their food and water. According to the United Nations, some 600 million people (almost twice the current U.S. population) suffer from goiter. And 26 million children suffer irreversible brain damage each year from lack of iodine. According to the FAO and the WHO, eliminating this serious health problem would cost the equivalent of only 2–3 cents per year for every person in the world.


John Paul Kay/Peter Arnold, Inc.

Figure 12-3 This woman in Bangladesh has a goiter, an enlargement of the thyroid gland caused by a diet containing too little iodine. Adding traces of iodine to salt has largely eliminated this problem in more-developed countries. But iodine deficiency is a serious problem in many less-developed countries, especially in South and Southeast Asia.

Many People Have Health Problems from Eating Too Much

Overnutrition occurs when food energy intake exceeds energy use and causes excess body fat. Too many calories, too little exercise, or both can cause overnutrition. People who are underfed and underweight and people who are overfed and overweight face similar health problems: *lower life expectancy*, *greater susceptibility to disease and illness*, and *lower productivity and life quality* (**Concept 12-1A**).

We live in a world where more than 1 billion people face health problems because they do not get enough to eat and another 1.2 billion have health problems from eating too much. In 2008, the U.S. Centers for Disease Control and Prevention (CDC) found that about two of every three American adults are overweight and one of every three are obese. This means the United States has the highest overnutrition rate in the world. Today's Americans, on average, will each eat about 27 metric tons (30 tons) of food—roughly the weight of 5 adult male elephants—during their lifetime. If current trends continue, about 86% of Americans will be overweight or obese by 2030, according to a 2008 study by human nutrition scientist Youfa Wang and other researchers.

Today in America, four of the top ten causes of death are diseases related to diet—heart disease, stroke, Type 2 diabetes, and some forms of cancer. Treatment for illnesses stemming from obesity adds about $147 billion a year to the U.S. health-care bill. And the roughly $58 billion that Americans spend each year trying to lose weight (according to the research firm MarketData Enterprises) is more than twice the $24 billion per year that the United Nations estimates is needed to eliminate undernutrition and malnutrition in the world.

12-2 How Is Food Produced?

▶ **CONCEPT 12-2 We have used high-input industrialized agriculture and lower-input traditional methods to greatly increase supplies of food.**

Food Production Has Increased Dramatically

About 10,000 years ago, humans began to shift from hunting and gathering their food to growing it. They gradually developed agriculture, which involves growing edible plants in nutrient-rich topsoil and raising animals for food and labor.

Today, three systems supply most of our food, using about 40% of the world's land. *Croplands* produce mostly grains and provide about 77% of the world's food using 11% of its land area. *Rangelands*, *pastures*, and *feedlots* produce meat and meat products and supply about 16% of the world's food using about 29% of the world's land area. In addition, *fisheries* and *aquaculture* (fish farming) supply about 7% of the world's food.

These three systems depend on a small number of plant and animal species. Of the estimated 50,000 plant species that people can eat, only 14 of them supply an estimated 90% of the world's food calories. Just three grain crops—*rice*, *wheat*, and *corn*—provide about 48% of the calories that people consume directly. Two-thirds of the world's people survive primarily on these three grains. And a few species of mammals and fish provide most of the world's meat and seafood.

Such food specialization puts us in a vulnerable position should any of the small number of crop strains, livestock breeds, and fish and shellfish species we depend on disappear as a result of factors such as disease, environmental degradation, and climate change. This violates the biodiversity **principle of sustainability**, which calls for depending on a variety of food sources as an ecological insurance policy for dealing with changes in environmental conditions that have occurred throughout human history.

Despite such vulnerability, since 1960, there has been a staggering increase in global food production from all three of the major food production systems (**Concept 12-2**). This has occurred because of technological advances such as increased use of tractors and other farm machinery and high-tech fishing equipment (see Figure 11-8, p. 259). Another major advance has been the development of **irrigation**, or supplying water to crops by artificial means. Other technological developments include the manufacturing of inorganic chemical fertilizers and pesticides, the development of high-yield grain varieties, and industrialized production of large numbers of livestock and fish.

Brenda Carson/Shutterstock

Figure 12-4 This farmer, harvesting a wheat crop in the midwestern United States, relies on expensive heavy equipment and uses large amounts of seed, manufactured inorganic fertilizer, and fossil fuels to produce the crop.

Industrialized Crop Production Relies on High-Input Monocultures

Croplands represent the first of the major food-producing systems. We can roughly divide agriculture used to grow food crops into two types: industrialized agriculture and subsistence agriculture. **Industrialized agriculture**, or **high-input agriculture**, uses heavy equipment and large amounts of financial capital, fossil fuels, water, commercial inorganic fertilizers, and pesticides to produce single crops, or *monocultures* (Figure 12-4). The major goal of industrialized agriculture is to steadily increase each crop's *yield*—the amount of food produced per unit of land. Industrialized agriculture is practiced on one-fourth of all cropland, mostly in more-developed countries, and now produces about 80% of the world's food (**Concept 12-2**).

Plantation agriculture is a form of industrialized agriculture used primarily in tropical less-developed countries. It involves growing *cash crops* such as bananas, soybeans (mostly to feed livestock; see Figure 1-6, p. 10), sugarcane (to produce sugar and ethanol fuel), coffee, palm oil (used as a cooking oil and to produce biodiesel fuel, Figure 12-5), and vegetables on large monoculture plantations, mostly for export to more-developed countries.

A newer form of industrialized agriculture uses large arrays of greenhouses to raise crops indoors. In sunny areas, greenhouses can be used to grow crops year round and in some areas such as Iceland and parts of the western United States they are heated with geothermal energy. In water-short, arid areas, farmers can save

age fotostock/SuperStock

Figure 12-5 These large plantations of oil palms on the island of Borneo in Malaysia were planted in an area once covered with tropical rain forest, as seen in the surrounding area. The fruit of the oil palm yields palm oil, which is widely used as cooking oil and to make biodiesel fuel for cars.

water by using greenhouses, because they can deliver water more efficiently to greenhouse crops than they can to outdoor crops. In addition, because the water can be purified and recycled, water use and water pollution are reduced sharply in such systems, compared to conventional crop irrigation systems. Also, crops can be grown in greenhouses without the use of soil (see Case Study, p. 282).

It costs more to raise crops in greenhouses than it does to raise crops using conventional industrialized agriculture. But the costs of using greenhouses are coming down as the costs of conventional industrialized agriculture are rising because of its harmful environmental effects and because of higher fossil fuel prices.

Modern industrialized agriculture produces large amounts of food at reasonable prices. But is it sustainable? A growing number of analysts say it is not because it violates the three **principles of sustainability**. It relies heavily on nonrenewable fossil fuels, does not rely on a diversity of crops as a form of ecological insurance, and neglects the conservation and recycling of nutrients in topsoil. What promotes unsustainable industrialized agriculture is that our economic systems do not include the harmful environmental and health costs of such food production in the market prices of food. Because of these hidden costs, food costs appear to be lower than they really are.

THINKING ABOUT
Industrialized Agriculture and Sustainability

For each of the three **principles of sustainability**, think of an example of how industrialized agriculture could be changed to be more in keeping with the principle.

CASE STUDY

Hydroponics: Growing Crops without Soil

Plants need sunlight, carbon dioxide (from the air), and mineral nutrients such as nitrogen and phosphorus. Traditionally, farmers have obtained these nutrients from soil. **Hydroponics** involves growing plants by exposing their roots to a nutrient-rich water solution instead of soil, usually inside of a greenhouse (Figure 12-6).

Indoor hydroponic farming has a number of advantages over conventional outdoor growing systems:

- Crops can be grown indoors under controlled conditions almost anywhere.
- Yields and availability are increased because crops are grown year round, regardless of weather conditions.
- In dense urban areas, crops can be grown on rooftops, underground with artificial lighting (as is now done in Tokyo, Japan), and on floating barges, thus requiring much less land.


Khoo Si Lin/Shutterstock

Figure 12-6 These salad greens are being grown hydroponically (without soil) in a greenhouse. The plant roots are immersed in a trough and exposed to nutrients dissolved in running water that can be reused.

- Fertilizer and water use are reduced through the recycling of nutrient and water solutions. There is no runoff of excess fertilizer into streams or other waterways.
- In the controlled greenhouse environment, there is little or no need for pesticides. There is no soil erosion or buildup of excess mineral salts (common problems on heavily irrigated cropland).

With these advantages, we could use hydroponics to produce an increasing amount of the world's food without causing most of the serious harmful environmental effects of producing food through industrialized agriculture. However, there are three major reasons why this is not happening now. *First*, it takes a lot of money to establish such systems although they typically are cheaper to use in the long run. *Second*, many growers fear that hydroponics requires substantial technical knowledge, while in reality it is very similar to traditional gardening and crop production. *Third*, it could threaten the profits of large and politically powerful industrialized companies that produce farming-related products such as pesticides, manufactured inorganic fertilizers, and farm equipment.

Despite these obstacles to the use of hydroponics, large hydroponic facilities are found in a number of countries, including New Zealand, Germany, the Netherlands, and the United States. Hydroponics is unlikely to replace conventional industrialized agriculture. But a number of analysts project that, with further research and development, hydroponics could play an increasing role in helping us to make the transition to more sustainable agriculture over the next several decades.

Traditional Agriculture Often Relies on Low-Input Polycultures

Some 2.7 billion people (39% of the world's people) in less-developed countries practice *traditional agriculture*. It provides about one-fifth of the world's food crops on about three-fourths of its cultivated land.

There are two main types of traditional agriculture. **Traditional subsistence agriculture** supplements energy from the sun with the labor of humans and draft animals to produce enough crops for a farm family's survival, with little left over to sell or store as a reserve for hard times. In **traditional intensive agriculture**, farmers increase their inputs of human and draft-animal labor, animal manure for fertilizer, and water to obtain higher crop yields. If the weather cooperates, they produce enough food to feed their families and to sell some for income.

Some traditional farmers focus on cultivating a single crop, but many grow several crops on the same plot simultaneously, a practice known as **polyculture**. Such crop diversity—an example of implementing the biodiversity **principle of sustainability**—reduces the chance of losing most or all of the year's food supply to pests, bad weather, and other misfortunes.

One type of polyculture is known as **slash-and-burn agriculture**. This type of subsistence agriculture involves burning and clearing small plots in tropical forests, growing a variety of crops for a few years until the soil is depleted of nutrients, and then shifting to other plots to begin the process again. Early users of this method learned that each abandoned patch normally had to be left fallow (unplanted) for 10–30 years before the soil became fertile enough to grow crops again.

In parts of South America and Africa, some traditional farmers using slash-and-burn methods grow as many as 20 different crops together on small cleared plots in tropical forests. The crops rely on sunshine and natural fertilizers such as animal manure for their growth, and they mature at different times. They provide food throughout the year and keep the soil covered to reduce erosion from wind and water. Slash-and-burn polyculture lessens the need for fertilizer and water, because root systems at different depths in the soil capture nutrients and moisture efficiently, and ashes from the burning provide soil nutrients. Insecticides and herbicides are rarely needed because multiple habitats are created for natural predators of crop-eating insects, and weeds have trouble competing with the multitude and density of crop plants.

GOOD NEWS

Research shows that, on average, such low-input polyculture produces higher yields than does high-input monoculture. For example, ecologists Peter Reich and David Tilman found that carefully controlled polyculture plots with 16 different species of plants consistently out-produced plots with 9, 4, or only 1 type of plant species. Therefore, some analysts argue for greatly increased use of polyculture to produce food more sustainably.

RESEARCH FRONTIER

Investigating the design and benefits of polyculture; see **www.cengage.com/login**.

All types of conventional crop production depend on having fertile topsoil (Science Focus, p. 284).

CENGAGENOW™ Compare soil profiles from grassland, desert, and three types of forests at CengageNOW.

A Closer Look at Industrialized Crop Production

Farmers have two ways to produce more food: farming more land or getting higher yields from existing cropland. Since 1950, about 88% of the increase in global food production has come from using high-input industrialized agriculture (Figure 12-1, left and Figure 12-4) to increase crop yields in a process called the **green revolution**.

A green revolution involves three steps. *First*, develop and plant monocultures of selectively bred or genetically engineered high-yield varieties of key crops such as rice, wheat, and corn. *Second*, produce high yields by using large inputs of water and manufactured inorganic fertilizers, and pesticides. *Third*, increase the number of crops grown per year on a plot of land through *multiple cropping*. Between 1950 and 1970, this high-input approach dramatically increased crop yields in most of the world's more-developed countries, especially the United States (see the Case Study on p. 285), in what was called the *first green revolution*.

A *second green revolution* has been taking place since 1967. Fast-growing dwarf varieties of rice and wheat, specially bred for tropical and subtropical climates, have been introduced into middle-income, less-developed countries such as India, China, and Brazil. Producing more food on less land has helped to protect some biodiversity by preserving large areas of forests, grasslands, wetlands, and easily eroded mountain terrain that might otherwise be used for farming.

SCIENCE FOCUS

Soil Is the Base of Life on Land

Soil is a complex mixture of eroded rock, mineral nutrients, decaying organic matter, water, air, and billions of living organisms, most of them microscopic decomposers. Soil formation begins when bedrock is slowly broken down into fragments and particles by physical, chemical, and biological processes, called *weathering*. Figure 12-A shows profiles of different-aged soils.

Soil, on which all terrestrial life depends, is a key component of the earth's natural capital. It supplies most of the nutrients needed for plant growth (see Figure 3-6, p. 59) and purifies and stores water, while organisms living in the soil help to control the earth's climate by removing carbon dioxide from the atmosphere and storing it as organic carbon compounds, as part of the carbon cycle (Figure 3-19, p. 70).

Most mature soils contain horizontal layers, or *horizons*, (Figure 12-A), each with a distinct texture and composition that vary with different types of soils. Most mature soils have at least three of the four possible horizons. Think of them as the top three floors in the geological building of life underneath your feet.

The roots of most plants and the majority of a soil's organic matter are concentrated in the soil's two upper layers, the *O horizon* of leaf litter and the *A horizon* of topsoil. In most mature soils, these two layers teem with bacteria, fungi, earthworms, and small insects, all interacting in complex ways. Bacteria and other decomposer microorganisms, found by the billions in every handful of topsoil, break down some of the soil's complex organic compounds into a porous mixture of the partially decomposed bodies of dead plants and animals, called *humus*, and inorganic materials such as clay, silt, and sand. Soil moisture carrying these dissolved nutrients is drawn up by the roots of plants and transported through stems and into leaves as part of the earth's chemical cycling processes.

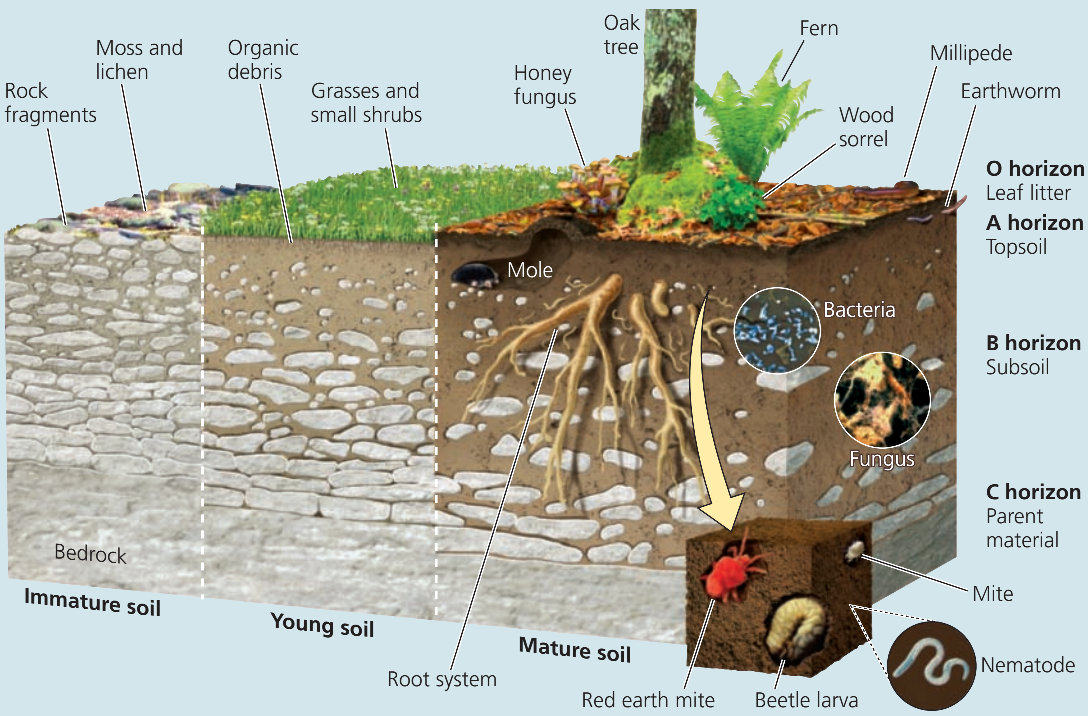
The *B horizon* (*subsoil*) and the *C horizon* (*parent material*) contain most of a soil's inorganic matter, mostly broken-down rock consisting of varying mixtures of sand, silt, clay, and gravel. Much of it is transported by water from the A horizon (Figure 12-A). The C horizon lies on a base of parent material, which is often *bedrock*.

The spaces, or *pores*, between the solid organic and inorganic particles in the upper and lower soil layers contain varying amounts of air (mostly nitrogen and oxygen gas) and water. Plant roots use the oxygen for cellular respiration (see Chapter 3, pp. 60–61). As long as the O and A horizons are anchored by vegetation, the soil layers as a whole act as a sponge, storing water and nutrients, and releasing them in a nourishing trickle.

Although topsoil is a renewable resource, it is renewed very slowly, which means it can be depleted. Just 1 centimeter (0.4 inch) of topsoil can take hundreds of years to form, but it can be washed or blown away in a matter of weeks or months when we plow grassland or clear a forest and leave its topsoil unprotected.

Critical Thinking

How does soil contribute to each of the four components of biodiversity described in Figure 4-2, p. 82?



CENGAGENOW™ **Active Figure 12-A** This diagram shows a generalized soil profile and illustrates how soil is formed. Horizons, or layers, vary in number, composition, and thickness, depending on the type of soil. *See an animation based on this figure at* CengageNOW. **Questions:** What role do you think the tree in this figure plays in soil formation? How might the soil formation process change if the tree were removed?

Largely because of the two green revolutions, world grain production tripled between 1961 and 2009 (Figure 12-7, left). Per capita food production increased by 31% between 1961 and 1985, but since then it has declined slightly (Figure 12-7, right). GOOD NEWS

About 48% of the world's grain production is consumed directly by people and 35% is used to feed livestock and thus is indirectly consumed by people who eat meat and meat products. The remaining 17%, mostly corn, is used to make biofuels such as ethanol for cars.

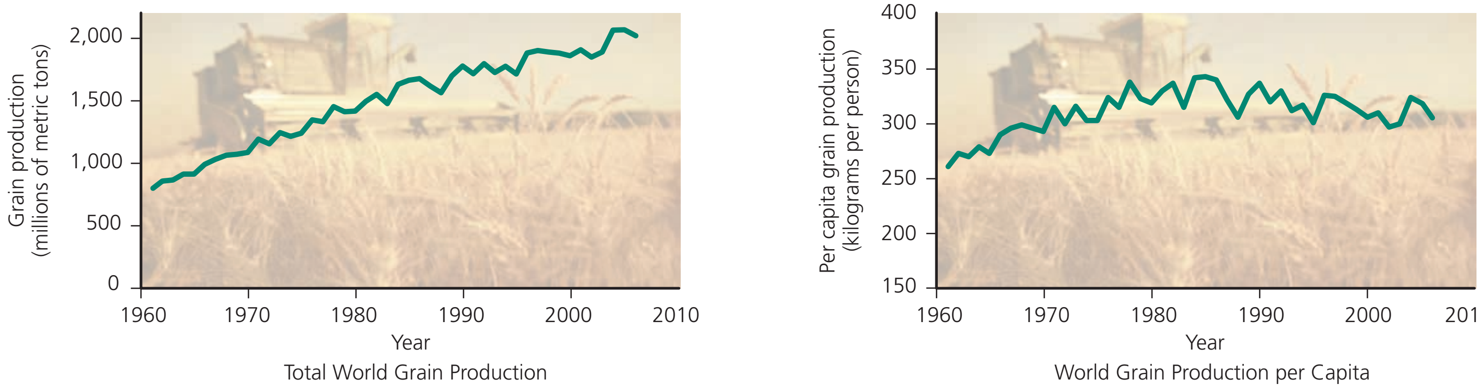


Figure 12-7 *Global outlook:* These graphs show that worldwide grain production of wheat, corn, and rice (left), and per capita grain production (right) grew sharply between1961 and 2009. The world's three largest grain-producing countries—China, India, and the United States, in that order—produce almost half of the world's grains. In contrast to the United States, most wheat produced in China and India is irrigated. **Question:** Why do you think grain production per capita has grown less consistently than total grain production? (Data from U.S. Department of Agriculture, Worldwatch Institute, UN Food and Agriculture Organization, and Earth Policy Institute)

Since 2009, about 25% of the corn crop and parts of other grain crops grown in the U.S. have been used to produce biofuels for cars rather than to feed people.

CASE STUDY
Industrialized Food Production in the United States—The First Green Revolution

In the United States, industrialized farming has evolved into *agribusiness*, as a small number of giant multinational corporations increasingly control the growing, processing, distribution, and sale of food in U.S. and global markets. As a result, the average U.S. farmer now feeds 129 people compared to 19 people in the 1940s.

In total annual sales, agriculture is bigger than the country's automotive, steel, and housing industries combined. The entire agricultural system (from farm to grocery store and restaurant) employs more people than any other industry. Yet with only 3 of every 1,000 of the world's farm workers, U.S. farms use industrialized agriculture to produce about 17% of the world's grain.

Since 1950, U.S. industrialized agriculture has become very efficient and has more than doubled the yields of key crops such as wheat, corn, and soybeans without cultivating more land. Such yield increases have kept large areas of U.S. forests, grasslands, and wetlands from being converted to farmland.

People in less-developed countries typically spend up to 40% of their income on food. The world's 1.4 billion poorest people, struggling to live on the equivalent of less than $2.25 a day, typically spend about 70% of their meager income on food. By contrast, because of the efficiency of U.S. agriculture, Americans spend an average of less than 10% of their household income on food, down from 18% in 1966.

However, because of a number of hidden costs related to their food consumption, most American consumers are not aware that their total food costs are much higher than the market prices they pay. Such hidden costs include taxes to pay for farm subsidies—mostly to producers of corn, wheat, soybeans, and rice—and the costs of pollution and environmental degradation caused by industrialized agriculture (discussed later in this chapter). Consumers, on average, also pay higher health insurance bills related to the harmful environmental and health effects of industrialized agriculture.

Crossbreeding and Genetic Engineering Can Produce New Varieties of Crops and Livestock

For centuries, farmers and scientists have used *crossbreeding* through *artificial selection* to develop genetically improved varieties of crops and livestock animals. Such selective breeding in this first *gene revolution* has yielded amazing results. Ancient ears of corn were about the size of your little finger, and wild tomatoes were once the size of grapes.

Traditional crossbreeding is a slow process, typically taking 15 years or more to produce a commercially valuable new crop variety, and it can combine traits only from species that are genetically similar. Typically, resulting varieties remain useful for only 5–10 years before pests and diseases reduce their effectiveness. But important advances are still being made with this method.

Today, scientists are creating a second *gene revolution* by using *genetic engineering* to develop genetically improved strains of crops and livestock animals. It involves altering an organism's genetic material through adding, deleting, or changing segments of its DNA (see Figure 10, p. S15, in Supplement 4) to produce desirable traits or to eliminate undesirable ones—a process called *gene splicing*. It enables scientists to transfer genes between different species that would not normally interbreed in nature. The resulting organisms are called *genetically modified organisms (GMOs)*. Compared to traditional crossbreeding, developing a new crop variety through gene splicing takes about half as long, usually costs less, and allows for the insertion of genes from almost any other organism into crop cells.

Ready or not, much of the world is entering the *age of genetic engineering*. So far, genetically modified (GM) crops are planted on only about 12% of the world's cropland in 23 countries, with half of this cropland in the United States. Most GM crops are soybeans, corn, cotton, and canola. Other countries with large GM crop areas are Argentina and Brazil. However, the European Union severely restricts the use of GM seeds and the importation of products containing genetically modified food.

More than 80% of the corn, soybean, and cotton crops grown in the United States are genetically engineered. At least 70% of the food products on U.S. supermarket shelves contain some form of genetically modified food or ingredients, and the proportion is increasing rapidly. You won't find GM ingredient information on food labels because no labeling of GM products is required by law. However, certified organic food (**Core Case Study**) makes no use of genetically modified seeds or ingredients. CORE CASE STUDY

CONNECTIONS

Detecting How Fruit Was Grown

Genetically modified food does not have to be labeled. But you can detect how fruit was grown. To do this, look at the price look-up (PLU) code numbers on their labels or stickers that are used to speed up the scanning process at the checkout stand. The PLU number on conventionally grown fruit consists of four digits (such as 4011 for bananas); the number on organically grown fruit has five digits beginning with 9 (such as 94011 for bananas); and the number on GM fruit has five digits beginning with the number 8 (such as 84011 for bananas).

Bioengineers plan to develop new GM varieties of crops that are resistant to heat, cold, herbicides, insect pests, parasites, viral diseases, drought, and salty or acidic soil. Several seed companies are in the final stages of offering a drought-tolerant GM version of corn. They also hope to develop crop plants that can grow faster and survive with little or no irrigation and with less fertilizer and pesticides. For example, bioengineers have altered citrus trees, which normally take 6 years to produce fruit, to yield fruit in only 1 year. They hope to go further and use *advanced tissue culture* techniques to mass-produce only orange juice sacs. This would eliminate the need for citrus orchards and would free large amounts of land for other purposes such as biodiversity protection.

RESEARCH FRONTIER

Genetic engineering to use cell cultures for food factory systems; see **www.cengage.com/login**.

Many scientists believe that such innovations hold great promise for helping to improve global food security. Others warn that genetic engineering is not free of drawbacks, which we examine later in this chapter.

Meat Production Has Grown Steadily

Meat and animal products such as eggs and milk are good sources of high-quality protein and represent the world's second major food-producing system. Between 1961 and 2007, world meat production—mostly beef, pork, and poultry—increased more than fourfold and average meat consumption per person more than doubled. Each year, some 56 billion animals—8 times the human population—are raised and slaughtered for food.

Globally, some 3 billion people—nearly three times the population of China—hope to eat more meat and animal products such as milk and cheese. Global meat production is likely to more than double again by 2050 as affluence rises and more middle-income people begin consuming more meat and animal products in rapidly developing countries such as China and India.

About half of the world's meat comes from livestock grazing on grass in unfenced rangelands and enclosed pastures. The other half is produced through an industrialized factory farm system. It involves raising large numbers of animals bred to gain weight quickly, mostly in crowded *feedlots* (Figure 12-8) and large buildings, called *concentrated animal feeding operations (CAFOs)*. They are fed varying combinations of grain, fishmeal, and fish oil, which are usually doctored with growth hormones and antibiotics.

Most veal calves, pigs, chickens, and turkeys that are raised in more-developed countries spend their lives in crowded pens or cages, often in huge buildings. As a result, CAFOs and feedlots and the animal wastes that they produce create serious environmental impacts, which we examine later in this chapter.

As a country's income grows, more of its people tend to eat more meat, much of it produced by feeding large amounts of grain to livestock. The resulting increased demand for grain, often accompanied by a loss of cropland to urban development, can lead to increased reliance on grain imports. Within a few decades, a rapidly developing country can go from producing all the grain it needs to importing most of its grain requirements.

As a result of this process, Japan, Taiwan, and South Korea now import 70% of the grain they consume and China and India are likely to follow this trend as they become more industrialized. If China were to import just one-fifth of the grain it uses, its imports would equal the amount of grain the United States typically exports each year—roughly half the world's entire grain exports. The Earth Policy Institute and the U.S. Central Intelligence Agency warn that if such a scenario comes to pass, no country or combination of countries will have the ability to supply even a small fraction of

Matt Meadows/Peter Arnold, Inc.

Figure 12-8 *Industrialized beef production:* On this cattle feedlot in Imperial Valley, California (USA) 40,000 cattle are fattened up on grain for a few months before being slaughtered. Cattle in such feedlots often stand knee-deep in manure and are covered with feces when they arrive at slaughterhouses.

China's potential food supply deficit. This is one reason why countries such as China, South Korea, Saudi Arabia, India, Egypt, and the United Arab Emirates are buying or leasing cropland in other countries, including Ethiopia, Sudan, the Republic of Congo, Zambia, Turkey, Indonesia, Russia, Ukraine, Brazil, and Vietnam. Environmental scientists warn that some of these countries could be selling their future ability to produce enough food for their own people.

Fish and Shellfish Production Have Increased Dramatically

The world's third major food-producing system consists of fisheries and aquaculture. A **fishery** is a concentration of particular aquatic species suitable for commercial harvesting in a given ocean area or inland body of water. Industrial fishing fleets harvest most of the world's marine catch of wild fish (see Chapter 11, Case Study, p. 258). In 2010, according to the FAO, half of all the fish eaten in the world were produced through **aquaculture**—the practice of raising marine and freshwater fish in freshwater ponds or underwater cages in coastal or open ocean waters.

Figure 12-9 shows the effects of the global efforts to boost seafood production through both the harvesting of wild fish and the industrialized production, or farming, of fish using aquaculture (**Concept 12-2**). GOOD NEWS

Scientific studies have estimated that at least 63% of the world's ocean fisheries are being depleted or overexploited (see Science Focus, p. 258). According to a 2006 FAO study and research by a number of fishery scientists, unless we reduce overfishing and ocean pollution and slow projected climate change, most of the world's major ocean fisheries could collapse sometime during this century. This would sharply decrease food security for up to 2.6 billion people who now depend on fish for at least 20% of their animal protein.

Using large fleets of ships to find, catch, and freeze ocean fish consumes huge amounts of energy and adds large amounts of greenhouse gases and other pollutants to the atmosphere. According to ecological economists, without fuel payments and other subsidies provided by their governments, most of these fleets could not afford to exist.

Aquaculture, the world's fastest-growing type of food production, is sometimes called the *blue revolution*. It involves cultivating fish in freshwater ponds, lakes, reservoirs, or rice paddies, or in underwater cages in coastal saltwater lagoons, estuaries, or offshore in deeper ocean waters (see Figure 11-8, p. 259). The fish are harvested when they reach marketable size. China raises 70% of the world's farmed fish, mostly in inland ponds and rice fields. India and Indonesia account for another 12% of the world's aquaculture production.

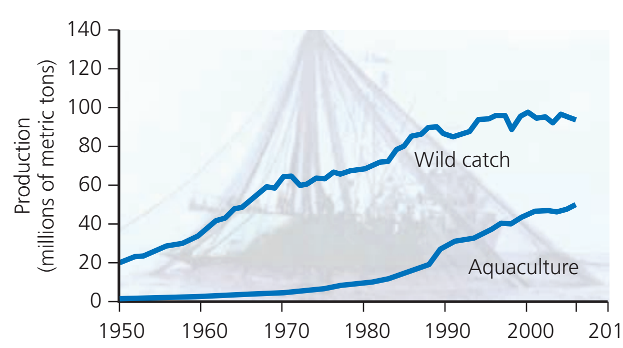


Figure 12-9 World seafood production, including both wild catch and aquaculture, increased sharply between 1950 and 2007. **Question:** What are two trends that you can see in these data? (Data from UN Food and Agriculture Organization, U.S. Census Bureau, and Worldwatch Institute)

The worldwide amount of fish produced through aquaculture has grown steadily by an average of 9% a year since 1970. China is by far the world leader in consumption of seafood. It consumes two-thirds of the global production of fish and shellfish and nearly half of all farmed fish.

Globally, aquaculture is devoted mostly to raising species that feed on algae or other plants—mainly carp in China and India, catfish in the United States, tilapia in several countries, and shellfish in several coastal countries. But the farming of meat-eating species such as shrimp and salmon is growing rapidly, especially in more developed countries. As a result, about 37% of the global catch of wild fish is converted to fish meal and fish oil, which are fed to farmed meat-eating fish, as well as to cattle and pigs. In addition, since 1995, a growing number of fish farms that raise carp and tilapia, both herbivores, have been increasing their yields by adding fish meal to their feed. In the next major section, we examine the harmful environmental impacts of aquaculture that could limit its growth.

Industrialized Food Production Requires Huge Inputs of Energy

The industrialization of food production has been made possible by the availability of energy, mostly from nonrenewable oil and natural gas. It is used to run farm machinery, irrigate crops, and produce pesticides (mostly from petrochemicals produced when oil is refined) and commercial inorganic fertilizers. Fossil fuels are also used to process food and transport it long distances within and between countries.

Putting food on the table consumes about 19% of the fossil fuel energy used in the United States each year—more than any other sector of the economy except motor vehicles. About a third of this is used to produce crops and livestock, a little over another third of it goes into food processing such as cooking and canning on an industrial scale, and the rest is used to transport food and to prepare meals.

In 1940, it took about 1 unit of fossil fuel energy to put 2.3 units of food energy on the table in the United States. Since then, crop production has increased in efficiency, so that most crops in the United States provide an amount of energy in the form of food that is considerably greater than that produced in 1940. However, when we consider the energy used to grow, store, process, package, transport, refrigerate, and cook all plant and animal food, *it takes about 10 units of nonrenewable fossil fuel energy to put 1 unit of food energy on the table*.

Much of the food produced today is transported across countries and between countries from producers to consumers. For example, in the United States, food travels an average of 2,400 kilometers (1,300 miles) from farm to plate. This is just one reason why modern food production and consumption are dependent on oil and other fossil fuels that are projected to become more costly. In addition, according to a 2005 study by ecological economist Peter Tyedmers and his colleagues, the large-scale hunting and gathering operation carried out by the world's fishing fleets uses about 12.5 times as much energy (mostly from fossil fuels) as that provided by the fish to the people who eat them.

Bottom line: producing, processing, transporting, and consuming industrialized food is highly dependent on fossil fuels and results in a large *net energy loss*.

THINKING ABOUT
Food and Oil

What might happen to industrialized food production and to your lifestyle if oil prices rise sharply in the next 2 decades, as many analysts predict they will? How would you deal with these changes?

12-3 What Environmental Problems Arise from Industrialized Food Production?

▶ **CONCEPT 12-3 Future food production may be limited by soil erosion and degradation, desertification, water and air pollution, climate change from greenhouse gas emissions, and loss of biodiversity.**

Producing Food Has Major Environmental Impacts

Agricultural systems have produced spectacular increases in the world's food production since 1950. And the increase in food produced per unit of cropland has decreased the amount of land used to grow food. This has helped to protect overall biodiversity by reducing the destruction of forests and grasslands for purposes of growing crops and raising livestock. GOOD NEWS

However, despite these encouraging steps toward sustainability, many analysts point out that industrialized

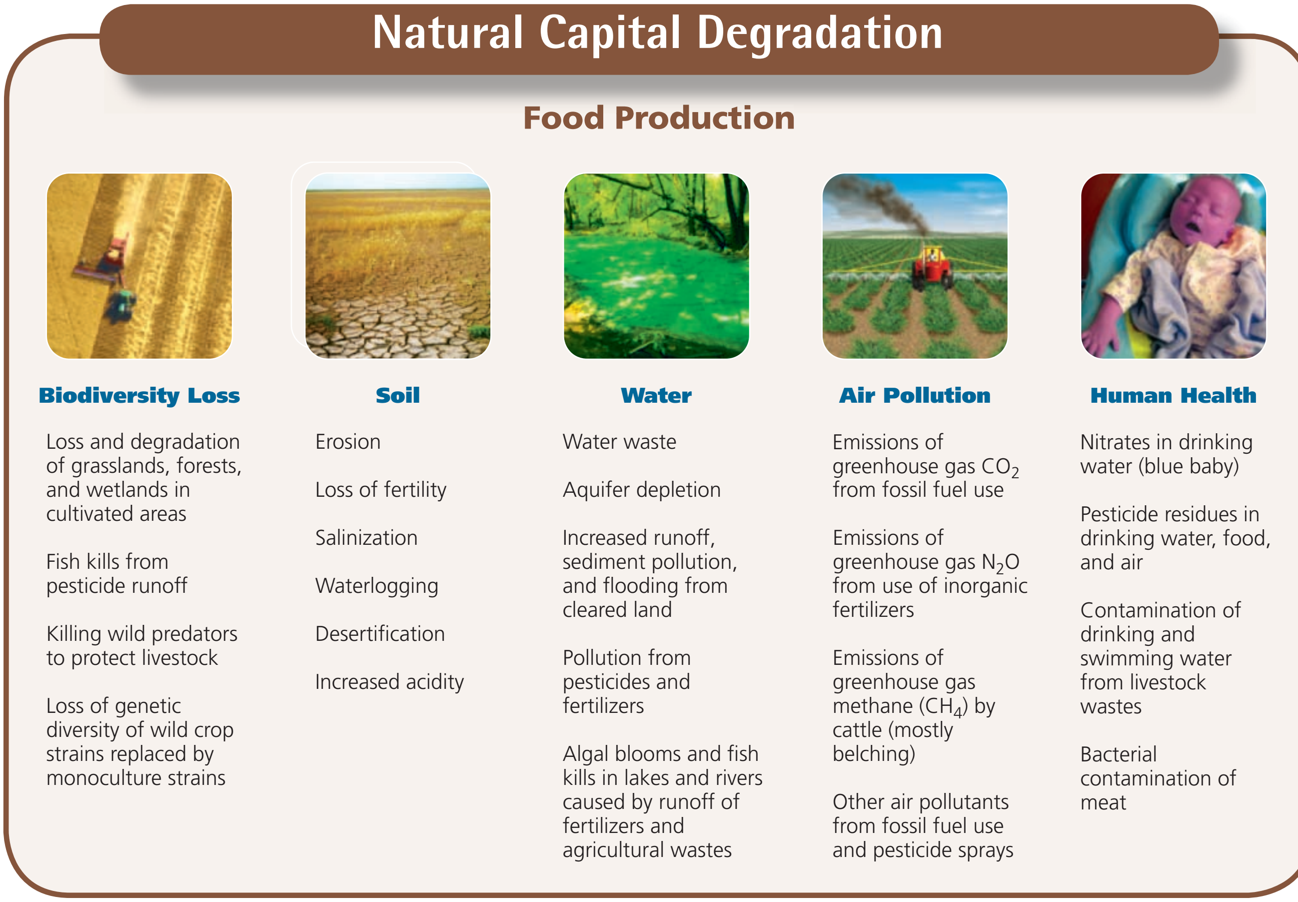


Figure 12-10 Food production has a number of harmful environmental effects (**Concept 12-3**). According to a 2008 study by the FAO, more than 20% of the world's cropland (65% in Africa) has been degraded to some degree by soil erosion, salt buildup, and chemical pollution. **Question:** Which item in each of these categories do you believe is the most harmful?

agriculture has greater harmful environmental impacts than any other human activity and these environmental effects may limit future food production (**Concept 12-3**).

Crop yields in some areas may decline because of environmental factors such as erosion and degradation of topsoil, depletion and pollution of underground and surface water supplies used for irrigation, emission of greenhouse gases that contribute to projected climate change, and loss of croplands to urbanization. Figure 12-10 summarizes the harmful environmental and health effects of modern agriculture. We now explore such effects in greater depth, starting with the problems of erosion and degradation of soils.

Topsoil Erosion Is a Serious Problem in Parts of the World

Soil erosion is the movement of soil components, especially surface litter and topsoil (Figure 12-A), from one place to another by the actions of wind and water. Some erosion of topsoil is natural, and some is caused by human activities. In undisturbed, vegetated ecosystems, the roots of plants help to anchor the topsoil and to prevent some erosion. Undisturbed topsoil can also store the water and nutrients needed by plants.

Flowing water, the largest cause of erosion, carries away particles of topsoil that have been loosened by rainfall (Figure 12-11). Severe erosion of this type leads

Tim McCabe/USDA Natural Resources Conservation Service

Figure 12-11 Flowing water from rainfall is the leading cause of topsoil erosion as seen on this farm in the U.S. state of Tennessee.

Ron Giling/Peter Arnold, Inc

Figure 12-12 **Natural capital degradation:** Severe gully erosion is a serious problem on this cropland in Bolivia.

Lynn Betts/USDA Natural Resources Conservation Service

Figure 12-13 Wind is an important cause of topsoil erosion in dry areas that are not covered by vegetation such as this bare crop field in the U.S. state of Iowa.

to the formation of gullies (Figure 12-12). Wind also loosens and blows topsoil particles away, especially in areas with a dry climate and relatively flat and exposed land (Figure 12-13). We lose natural capital in the form of fertile topsoil when we destroy soil-holding vegetation through activities such as farming (see Figure 7-12, p. 158), deforestation (see Figure 10-11, p. 226), overgrazing (see Figure 10-21, left, p. 235), and off-road vehicle use (see Figure 10-23, p. 237).

Erosion of topsoil has two major harmful effects. One is *loss of soil fertility* through depletion of plant nutrients in topsoil. The other is *water pollution* in nearby surface waters, where eroded topsoil ends up as sediment. This can kill fish and shellfish and clog irrigation ditches, boat channels, reservoirs, and lakes. Additional water pollution occurs when the eroded sediment contains pesticide residues. By removing vital plant nutrients from topsoil and adding excess plant nutrients to aquatic systems, we degrade the topsoil and pollute the water, and thus alter the carbon, nitrogen, and phosphorus cycles. In other words, we are violating part of the earth's chemical cycling **principle of sustainability**.

A joint survey by the UN Environment Programme (UNEP) and the World Resources Institute estimated that topsoil is eroding faster than it forms on about 38% of the world's cropland (Figure 12-14). (See the Guest Essay on soil erosion by David Pimentel at CengageNOW™. And for more information on topsoil erosion, see *The Habitable Planet*, Video 15, at **www.learner.org/resources/series209.html**.)

Some analysts contend that topsoil erosion estimates are overstated because they do not account for the abilities of some local farmers to restore degraded land. They also point out that eroded topsoil does not always move very far and is sometimes deposited on the same slope, valley, or plain from which it came. Consequently, in some farmlands, the loss in crop yields in one area can be offset by increased yields in another area nearby.

Drought and Human Activities Are Degrading Drylands

In arid and semiarid parts of the world, the contribution to the world's food supply from livestock and crops is being threatened by **desertification**. It occurs when the productive potential of topsoil falls by 10% or more because of a combination of prolonged drought and human activities such as overgrazing and deforestation that reduce or degrade topsoil.

Desertification can be *moderate* (a 10–25% drop in productivity), *severe* (a 25–50% drop), or *very severe* (a drop of more than 50%, usually resulting in huge gullies and sand dunes (Figure 12-15). Only in extreme cases does desertification lead to what we call desert. But severe desertification can expand existing desert areas or create new desert. (For more information on desertification see *The Habitable Planet*, Video 22, at **www.learner.org/resources/series209.html**.)

Over thousands of years, the earth's deserts have expanded and contracted, mostly because of natural climate change. However, human use of the land, especially for agricultural purposes, has accelerated desertification

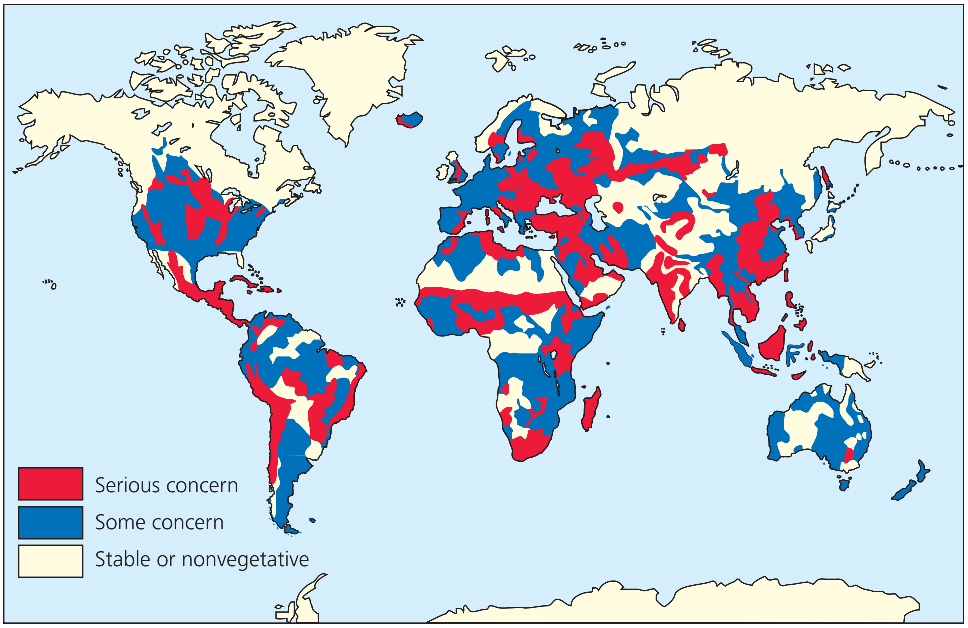


Figure 12-14 **Natural capital degradation:** Topsoil erosion is a serious problem in some parts of the world. In 2008, the Chinese government estimated that one-third of China's land suffers from serious topsoil erosion. **Question:** Can you see any geographical pattern associated with this problem? (Data from UN Environment Programme and the World Resources Institute)

in some parts of the world mostly because of deforestation, overplowing, and overgrazing (Figure 12-16, p. 292).

In its 2007 report on the *Status of the World's Forests,* the FAO estimated that some 70% of world's drylands used for agriculture are degraded and threatened by desertification. Most of these lands are in Africa (Figure 12-15) and Asia.

According to a 2007 study by the Intergovernmental Panel on Climate Change (IPCC), projected climate change during this century is expected to greatly increase severe and prolonged drought, which will expand desertification and threaten food supplies in various areas of the world.

Excessive Use of Irrigation Water Has Serious Consequences

A major reason for the boost in productivity on farms is the use of irrigation, which accounts for about 70% of the water that humanity uses. Currently, about 45%

Voltchev-UNEP/Peter Arnold, Inc.

Figure 12-15 *Severe desertification:* Sand dunes threaten to take over an oasis in the Sahel region of West Africa. Such severe desertification is the result of prolonged drought from natural climate change and destruction of natural vegetation as a result of human activities such as farming and overgrazing.

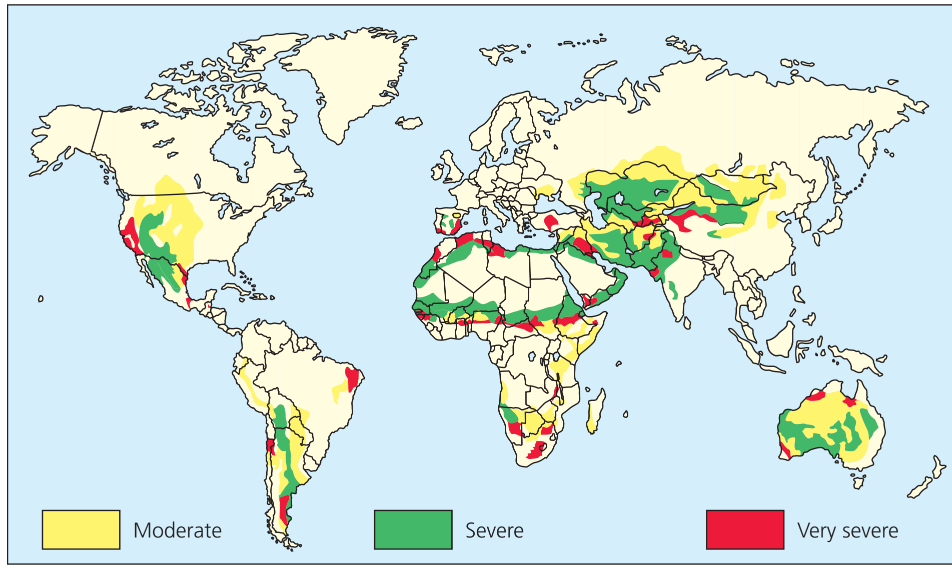


Figure 12-16 **Natural capital degradation:** This map shows how desertification of arid and semiarid lands varied in 2007. It is caused by a combination of prolonged drought and human activities that expose topsoil to erosion. **Question:** Can you see any geographical pattern associated with this problem? (Data from UN Environment Programme, Harold E. Drengue, U.S. Department of Agriculture, and the Central Intelligence Agency's World Factbook, 2008)

of the world's food is produced on the one-fifth of the world's cropland that is irrigated.

But irrigation has a downside. Most irrigation water is a dilute solution of various salts, such as sodium chloride (NaCl), that are picked up as the water flows over or through soil and rocks. Irrigation water that has not been absorbed into the topsoil evaporates, leaving behind a thin crust of dissolved mineral salts in the topsoil. Repeated applications of irrigation water in dry climates lead to the gradual accumulation of salts in the upper soil layers—a soil degradation process called **salinization**. It stunts crop growth, lowers crop yields, and can eventually kill plants and ruin the land.

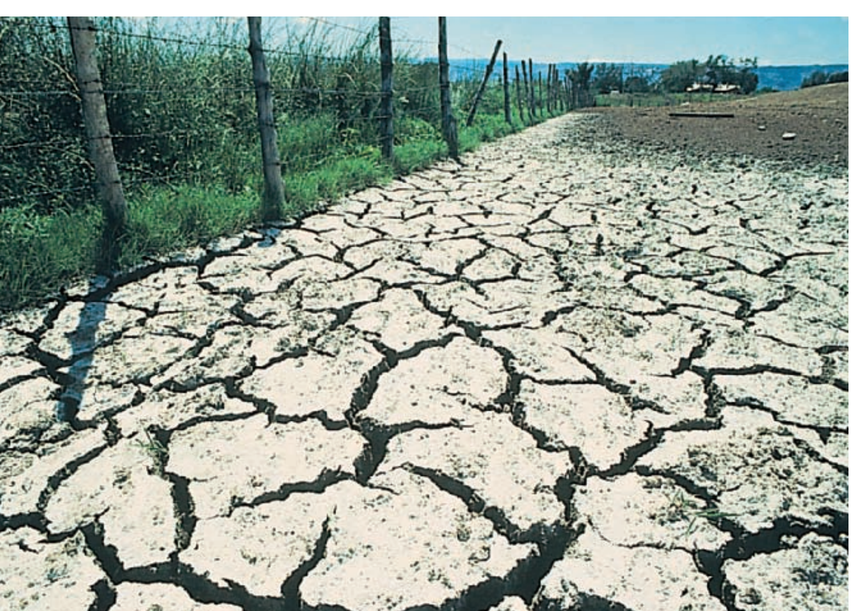

USDA Natural Resources Conservation Service

Figure 12-17 **Natural capital degradation:** Because of high evaporation, poor drainage, and severe salinization, white alkaline salts have displaced crops that once grew on this heavily irrigated land in the U.S. state of Colorado.

The United Nations estimates that severe salinization has reduced yields on at least one-tenth of the world's irrigated cropland, and that by 2020, 30% of the world's arable land will be salty. The most severe salinization occurs in China, India, Egypt, Pakistan, Mexico, Australia, and Iraq. Salinization affects almost one-fourth of irrigated cropland in the United States, especially in western states (Figure 12-17).

Another problem with irrigation is **waterlogging**, in which water accumulates underground and gradually raises the water table, especially when farmers apply large amounts of irrigation water in an effort to leach salts deeper into the soil. Waterlogging deprives plants of the oxygen they need to survive. Without adequate drainage, waterlogging lowers the productivity of crop plants and kills them after prolonged exposure. At least one-tenth of the world's irrigated land suffers from waterlogging, and the problem is getting worse.

Perhaps the biggest problem resulting from excessive irrigation in agriculture is that it has contributed to depletion of groundwater and surface water supplies in many areas of the world. We discuss this in Chapter 13.

Agriculture Contributes to Air Pollution and Projected Climate Change

Agricultural activities, including the clearing and burning of forests (see Figure 10-15, p. 228) to raise crops or livestock, create a great deal of air pollution. They also account for more than a quarter of the human-generated emissions of the greenhouse gases carbon dioxide, methane, and nitrous oxide, which are helping to warm the atmosphere to the point where regional climates are changing. Atmospheric warming is increasing and is projected to make some areas unsuitable for growing crops during this century.

Industrialized livestock production alone generates about 18% of the world's climate-changing greenhouse gases. This is more than all of the world's cars, buses, and planes emit, according to the 2006 FAO study, *Livestock's Long Shadow*. In particular, cattle and dairy cows release the powerful greenhouse gas methane, mostly through belching. Along with the methane generated by liquid animal manure stored in waste lagoons, this accounts for 16% of the global annual emissions of methane. According to the Center for Science in the Public Interest, the methane that cattle produce each year in the United States has an atmospheric warming effect equal to that of 33 million automobiles.

Such methane emissions can be sharply reduced by allowing cattle to graze in grasslands and pastures instead of fattening them on grains in confined feedlots. In addition, well-managed grazing can increase grassland and pasture vegetation, which helps to remove CO_2 from the atmosphere.

Nitrous oxide, with about 300 times the warming capacity of CO_2, is released in huge quantities by manufactured inorganic soil fertilizers. It also comes from the burning of forests and from livestock manure.

Food and Biofuel Production Systems Have Caused Major Losses of Biodiversity

By growing more crops on less land, industrialized agriculture has helped to reduce the overall need to clear forests and plow grasslands to grow crops. At the same time, in areas of the world now dominated by farming, the clearing of forests and plowing of grasslands has reduced biodiversity (**Concept 12-3**).

For example, one of the fastest-growing threats to the world's biodiversity is the cutting or burning of large areas of tropical forest in Brazil's Amazon basin (see Figure 10-15, p. 228) and the clearing of areas of its *cerrado*, a huge tropical grassland region south of the Amazon basin. This land is being burned or cleared for cattle ranches, large plantations of soybeans grown for cattle feed (see Figure 1-6, p. 10), and sugarcane used for making ethanol fuel for cars.

Other tropical forests are burned to make way for plantations of oil palm trees (Figure 12-5) increasingly used to produce biodiesel fuel for cars. These activities threaten biodiversity and contribute to projected climate change by releasing large quantities greenhouse gases carbon dioxide, methane, and nitrous oxide into the atmosphere faster than they can be removed by the earth's carbon and nitrogen cycles.

A related problem is the increasing loss of *agrobiodiversity*—the world's genetic variety of animal and plant species used to provide food. Scientists estimate that since 1900, we have lost three-fourths of the genetic diversity of agricultural crops.

For example, India once planted 30,000 varieties of rice. Now more than 75% of its rice production comes from only ten varieties and soon, almost all of its production may come from just one or two varieties. In the United States, about 97% of the food plant varieties available to farmers in the 1940s no longer exist, except perhaps in small amounts in seed banks, in the backyards of a few gardeners, and in non-profit organizations such as Seed Savers Exchange.

Traditionally, farmers have saved seeds from year to year to save money and to have the ability to grow food in times of famine. Families in India and most other less-developed countries still do this. But in the United States, this tradition is disappearing as more farmers plant seeds for genetically engineered crops. Companies selling these seeds have patents on them, forbid users to save them, and have prosecuted a number of farmers caught saving such seeds.

In losing agrobiodiversity, we are rapidly shrinking the world's genetic "library," which is critical for increasing food yields. In fact, we might soon need it more than ever to develop, through crossbreeding or genetic engineering, new plant and livestock varieties that can adapt to the effects of projected climate change in different parts of the world. This failure to preserve agrobiodiversity as an ecological insurance policy is a serious violation of the biodiversity **principle of sustainability**.

Wild and endangered varieties of crops important to the world's food supply are stored in about 1,400 refrigerated gene or seed banks, agricultural research centers, and botanical gardens scattered around the world. But power failures, fires, storms, war, and unintentional disposal of seeds are causing irreversible losses of these stored plants and seeds. A new underground seed vault on a frozen Norwegian arctic island will eventually contain duplicates of many of the world's seed collections. It is not vulnerable to power losses, fires, or storms.

However, the seeds of many plants cannot be stored successfully in gene banks. And because stored seeds do not remain alive indefinitely, they must be planted and germinated periodically, and new seeds must be collected for storage. Unless this is done, seed banks become *seed morgues*.

Genetic Engineering Could Solve Some Problems but Create Others

Despite its promise, controversy has arisen over the use of *genetically modified (GM) food* and other products of genetic engineering. Its producers and investors see GM food as a potentially sustainable way to solve world hunger problems and improve human health while making significant amounts of money in the process.

Trade-Offs

Genetically Modified Crops and Foods

Advantages	Disadvantages
Need less fertilizer	Unpredictable genetic and ecological effects
Need less water	Harmful toxins and new allergens in food
More resistant to insects, disease, frost, and drought	No increase in yields
Grow faster	More pesticide-resistant insects and herbicide-resistant weeds
May need less pesticides or tolerate higher levels of herbicides	Could disrupt seed market
May reduce energy needs	Lower genetic diversity

Figure 12-18 Genetically modified crops and foods can have some or all of the advantages and disadvantages listed here. **Questions:** Which two advantages and which two disadvantages do you think are the most important? Why?

But some critics warn of the disadvantages of GM food. Figure 12-18 summarizes the projected advantages and disadvantages of this new technology. **Explore More:** See a Case Study at **www.cengage.com/login** to learn about the controversy over the greatly increased use of a genetically engineered form of rice called golden rice.

Critics recognize the potential benefits of GM crops (Figure 12-18, left) but they point out most of the GM crops developed so far provide very few of these benefits. In 2009, for example, biologist and genetic engineering expert Doug Gurian-Sherman pointed out that despite 20 years of research and 13 years of commercial sales, genetically engineered crops have failed to significantly increase U.S. crop yields.

Critics also warn that we know too little about the long-term potential harm to human health and ecosystems from the widespread use of such crops. So far, GM crops have largely been assumed to be innocent of any serious harm until proven guilty. Critics point out that if GM organisms that are released into the environment cause some unintended harmful genetic and ecological effects, as some scientists expect, those organisms cannot be recalled.

For example, genes in plant pollen from genetically engineered crops can spread among nonengineered species. The new strains can then form hybrids with wild crop varieties, which could reduce the natural genetic biodiversity of wild strains. This could in turn reduce the gene pool needed to crossbreed new crop varieties and to develop new genetically engineered varieties.

CONNECTIONS

GM Crops and Organic Food Prices CORE CASE STUDY

The possible unintended spread of GM crop genes threatens the production of certified organic crops (**Core Case Study**), which must be grown in the absence of such genes. Because organic farmers have to perform expensive tests to detect GMOs or take costly measures to prevent the spread of GMOs to their fields from nearby crop fields, they have to raise the prices of their produce. This makes it more difficult for these farmers to compete with the industrial farming operations that generate the GM genes in the first place.

Most scientists and economists who have evaluated the genetic engineering of crops believe that its potential benefits will eventually outweigh its risks. However, critics, including scientists of the Ecological Society of America, call for more controlled field experiments, long-term testing to better understand the ecological and health risks, and stricter regulation of this rapidly growing technology. Indeed, a 2008 International Assessment of Agricultural Knowledge by 400 scientists with input from more than 50 countries raised serious doubts about the ability of GM crops to increase food security compared to other more effective and sustainable alternative solutions (which we discuss later in this chapter).

There Are Limits to Expansion of the Green Revolutions

Several factors have limited the success of the green revolutions to date and may limit them in the future (**Concept 12-3**). Without huge inputs of inorganic fertilizer, pesticides, and water, most green revolution and genetically engineered crop varieties produce yields that are no higher (and are sometimes lower) than those from traditional strains. And these high-inputs cost too much for most subsistence farmers in less-developed countries.

Scientists point out that continuing to increase these inputs eventually produces no additional increase in crop yields. This helps to explain the slowdown in the growth rate of global grain yields from an average increase of 2.1% a year between 1950 and 1990 to 1.3% annually between 1990 and 2009.

Can we expand the green revolutions by irrigating more cropland? Since 1978, the amount of irrigated land per person has been declining, and it is projected to fall much more between 2010 and 2050. One reason for this is population growth, which is projected to add 2.3 billion more people between 2010 and 2050. Other factors are wasteful use of irrigation water, increasing soil salinization, and the fact that most of the world's farmers are too poor to irrigate their crops.

A major and growing factor in many areas is depletion of both underground water supplies (aquifers) and surface water used for agricultural and urban needs. In addition, projected climate change during this century will make matters worse by melting mountain glaciers that provide irrigation and drinking water for many millions of people in China, India, and South America.

The good news is that we can get more crops per drop of irrigation water by using known methods and technologies to greatly improve the efficiency of irrigation. We discuss this more fully in Chapter 13.

Can we increase the food supply by cultivating more land? Clearing tropical forests and irrigating arid land could more than double the area of the world's cropland. But much of this land has poor soil fertility, steep slopes, or both. Cultivating such land usually is expensive, it is unlikely to be sustainable, and it degrades and destroys wildlife habitat and reduces biodiversity.

In addition, during this century, fertile croplands in coastal areas, including many of the major rice-growing floodplains and river deltas in Asia, are likely to be flooded by rising sea levels resulting from projected climate change. Further, food production could drop sharply in some food-producing areas because of increased drought and longer and more intense heat waves, also resulting from projected climate change.

Crop yields could be increased with the use of conventional or genetically engineered crops that are more tolerant of drought and cold. But so far, such crops have not been developed and time is running out as the speed of climate change is projected to increase in the next few decades.

Commercial fertilizer use in most of the more-developed countries has reached a level of diminishing returns in terms of increased crop yields. There are parts of the world, especially in Africa, where additional fertilizer could boost crop production. However, in China, crop yields are being threatened by an increase in soil acidity from a combination of acid deposition, air pollutants produced by the burning of coal, and excessive use of fertilizers over the past 30 years.

Industrialized Meat Production Has Harmful Environmental Consequences

Proponents of industrialized meat production point out that it has increased meat supplies, reduced overgrazing, kept food prices down, and yielded higher profits. But environmental scientists point out that such systems use large amounts of energy (mostly fossil fuels) and water, and produce huge amounts of animal wastes that sometimes pollute surface water and groundwater while saturating the air with their odors. Figure 12-19 summarizes the advantages and disadvantages of industrialized meat production.

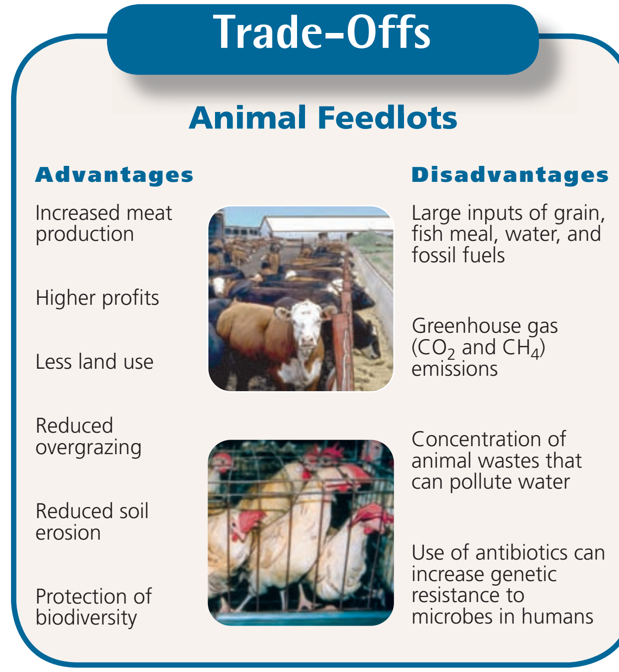


Figure 12-19 Animal feedlots and confined animal feeding operations have advantages and disadvantages. **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

Brazil is the world's largest exporter of beef. And a 2009 study showed that the biggest threat to Brazil's Amazon forests is the clearing and burning of these tropical forests to make way for cattle ranches (see Figure 10-15, p. 228).

In 2008, the FAO reported that overgrazing, soil compaction, and erosion by livestock have degraded about one-fifth of the world's grasslands and pastures. The same report estimated that rangeland grazing and industrialized livestock production cause 55% of all topsoil erosion and sediment pollution and a third of the water pollution that results from excessive inputs of nitrogen and phosphorous from fertilizers.

CONNECTIONS

Corn, Meat Production, and Ocean Dead Zones

Huge amounts of manufactured inorganic fertilizers are used in the mid-western United States to produce corn for animal feed and for conversion to ethanol fuel. Much of this fertilizer runs off cropland and eventually goes into the Mississippi River, and the added nitrate and phosphate nutrients overfertilize coastal waters in the Gulf of Mexico, where the river flows into the ocean. Each year, this creates a "dead zone" often larger than the size of the U.S. state of Massachusetts. This oxygen-depleted zone threatens one-fifth of the nation's seafood yield. In other words, growing corn in the Midwest largely to feed cattle and fuel cars degrades aquatic biodiversity and seafood production in the Gulf of Mexico.

Fossil fuel energy (mostly from oil) is also an essential ingredient in industrialized meat production. Using this energy pollutes the air and water and emits greenhouse gases that contribute to projected climate change as discussed above.

Another growing problem is the use of antibiotics in industrialized livestock production facilities. A 2009 study by the Union of Concerned Scientists (UCS) found that 70% of all antibiotics used in the United States (and 50% of those used in the world) are added to animal feed. This is done in an effort to prevent the spread of diseases in crowded feedlots and CAFOs and to make the livestock animals grow faster.

The UCS study, as well as several others, concluded that the widespread use of antibiotics in livestock production is an important factor in the rise of genetic resistance among many disease-causing microbes (see Figure 4-7, p. 87). It can reduce the effectiveness of some antibiotics used to treat infectious diseases in humans and promote the development of new and aggressive disease organisms that are resistant to all but a very few antibiotics currently available. In 2009, the U.S. Centers for Disease Control and Prevention reported that antibiotic-resistant infections killed about 65,000 people in the United States—more than the number of deaths from breast and prostrate cancer combined.

Finally, according to the U. S. Department of Agriculture (USDA), animal waste produced by the American meat industry amounts to about 130 times the amount of waste produced by the country's human population. Globally, only about half of all manure is returned to the land as nutrient-rich fertilizer—a violation of the nutrient recycling **principle of sustainability**. Much of the other half of this waste ends up polluting the air, water, and soil, and producing foul odors.

Aquaculture Can Harm Aquatic Ecosystems

Figure 12-20 lists the major advantages and disadvantages of aquaculture, which in 2010 accounted for roughly half of global seafood production. Some analysts warn that the harmful environmental effects of aquaculture could limit its future production potential (**Concept 12-3**).

One environmental problem associated with aquaculture is that using fish meal and fish oil to feed farmed fish can deplete populations of wild fish because about 37% of the wild marine fish catch goes to making fish meal and fish oil. This is also a very inefficient process. According to marine scientist John Volpe, it takes about 3 kilograms (6.6 pounds) of wild fish to produce 1 kilogram (2.2 pounds) of farmed salmon, and this ratio increases to 5 to 1 for farmed cod and 20 to 1 for farmed tuna. In addition, about 90% of the energy needed to raise farmed salmon goes into providing the fish meal and fish oil the salmon eat.

Another problem is that fish raised on fish meal or fish oil can be contaminated with long-lived toxins such as PCBs found on ocean bottoms. In 2003, samples

Figure 12-20 Aquaculture has advantages and disadvantages. **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

from various U.S. grocery stores revealed that farmed salmon had 7 times more PCBs than wild salmon had and 4 times more than those found in feedlot beef. A 2004 study found that farmed salmon also had levels of toxic dioxin that were 11 times higher than those of wild salmon. Aquaculture producers contend that the concentrations of these chemicals are not high enough to threaten human health.

Fish farms, especially those that raise carnivorous fish such as salmon and tuna, also produce large amounts of wastes. Along with pesticides and antibiotics used in fish farms, these wastes can pollute aquatic ecosystems and fisheries.

Yet another problem is that farmed fish can escape their pens and mix with wild fish, changing and possibly disrupting the gene pools of wild populations. Similarly, aquaculture can end up promoting the spread of invasive plant species. An Asian kelp called *wakame* or *undaria* is a popular food product raised on some farms. But this invasive seaweed is disrupting coastal aquatic systems in several parts of the world.

HOW WOULD YOU VOTE?

Do the advantages of aquaculture outweigh its disadvantages? Cast your vote online at **www.cengage.com/login**.

In Section 12-5 of this chapter, we consider some possible solutions to the serious environmental problems that result from food production and some ways to produce food more sustainably. But first, let us consider a special set of environmental problems and solutions related to protecting food supply systems from pests.

12-4 How Can We Protect Crops from Pests More Sustainably?

▶ **CONCEPT 12-4 We can sharply cut pesticide use without decreasing crop yields by using a mix of cultivation techniques, biological pest controls, and small amounts of selected chemical pesticides as a last resort (integrated pest management).**

Nature Controls the Populations of Most Pests

A **pest** is any species that interferes with human welfare by competing with us for food, invading lawns and gardens, destroying building materials, spreading disease, invading ecosystems, or simply being a nuisance. Worldwide, only about 100 species of plants ("weeds"), animals (mostly insects), fungi, and microbes cause most of the damage to the crops we grow.

In natural ecosystems and many polyculture agroecosystems, *natural enemies* (predators, parasites, and disease organisms) control the populations of most potential pest species as part of the earth's natural capital. For example, the world's 30,000 known species of spiders, including the wolf spider (Figure 12-21), kill far more insects every year than humans do by using chemicals.

When we clear forests and grasslands, plant monoculture crops, and douse fields with chemicals that kill pests, we upset many of these natural population checks and balances that help to implement the biodiversity **principle of sustainability** (see back cover). Then we must devise and pay for ways to protect our monoculture crops, tree plantations, lawns, and golf courses from insects and other pests that nature once largely controlled at no charge.

Peter J. Bryant/Biological Photo Service

Figure 12-21 **Natural capital:** Spiders are important insect predators that are killed by some pesticides. Most spiders, including this ferocious-looking wolf spider, do not harm humans.

We Use Pesticides to Help Control Pest Populations

We have developed a variety of **pesticides**—chemicals used to kill or control populations of organisms that we consider undesirable. Common types of pesticides include *insecticides* (insect killers), *herbicides* (weed killers), *fungicides* (fungus killers), and *rodenticides* (rat and mouse killers).

We did not invent the use of chemicals to repel or kill other species. For nearly 225 million years, plants have been producing chemicals to ward off, deceive, or poison the insects and herbivores that feed on them. This battle produces a never-ending, ever-changing coevolutionary process: insects and herbivores overcome various plant defenses through natural selection, then new plant defenses are favored by natural selection, and the process is repeated in this ongoing cycle of evolutionary punch and counterpunch.

In the 1600s, farmers used nicotine sulfate, extracted from tobacco leaves, as an insecticide. Eventually, other *first-generation pesticides*—mainly natural chemicals borrowed from plants—were developed. Farmers were copying nature's solutions to pest problems, developed, tested, and modified through natural selection over millions of years.

A major pest control revolution began in 1939, when entomologist Paul Müller discovered that the chemical DDT (dichlorodiphenyltrichloroethane) was a potent insecticide. DDT was the first of the so-called *second-generation pesticides* that were produced in the laboratory. It soon became the world's most-used pesticide, and Müller received the Nobel Prize in Physiology or Medicine in 1948 for his discovery. Since then, chemists have created hundreds of other pesticides by making slight modifications in the molecules of various classes of chemicals.

Some second-generation pesticides, however, have turned out to be hazardous as well as helpful. In 1962, biologist Rachel Carson (Individuals Matter on p. 298) sounded a warning that eventually led to strict controls on the use of DDT and several other widely used pesticides.

Since 1970, chemists have increased their use of natural repellents, poisons, and other chemicals produced by plants, generally referred to as *biopesticides*. They are again copying nature to improve first-generation biopesticides. Recently there has been increased use of

INDIVIDUALS MATTER

Rachel Carson

Rachel Carson (Figure 12-B) began her professional career as a biologist for the Bureau of U.S. Fisheries (now called the U.S. Fish and Wildlife Service). In that capacity, she carried out research in oceanography and marine biology, and wrote articles and books about the oceans and topics related to the environment.

In 1958, the commonly used pesticide DDT was sprayed to control mosquitoes near the home and private bird sanctuary of one of Carson's friends. After the spraying, her friend witnessed the agonizing deaths of several birds. She begged Carson to find someone to investigate the effects of pesticides on birds and other wildlife.

Carson decided to look into the issue herself and found very little independent research on the environmental effects of pesticides. As a well-trained scientist, she surveyed the scientific literature, became convinced that pesticides could harm wildlife and humans, and gathered information about the harmful effects of the widespread use of pesticides.

In 1962, she published her findings in popular form in *Silent Spring*, a book whose title warned of the potential silencing of "robins, catbirds, doves, jays, wrens, and scores of other bird voices" because of their exposure to pesticides. Many scientists, politicians, and policy makers read *Silent Spring*, and the public embraced it.

Chemical manufacturers understandably saw the book as a serious threat to their booming pesticide business, and they mounted a campaign to discredit Carson. A parade of critical reviewers and industry scientists claimed that her book was full of inaccuracies, made selective use of research findings, and failed to give a balanced account of the benefits of pesticides.

Some critics even claimed that, as a woman, Carson was incapable of understanding such a highly scientific and technical subject. Others charged that she was just a hysterical woman and radical nature lover who was trying to scare the public in an effort to sell books.

During these intense attacks, Carson was a single mother and the sole caretaker of an aged parent. She was also suffering from terminal breast cancer. Yet she strongly defended her research and countered her critics. She died in 1964—about 18 months after the publication of *Silent Spring*—without knowing that many historians would consider her work to be an important contribution to the modern environmental movement then emerging in the United States.

It has been correctly noted that Carson made some errors in *Silent Spring*. But critics concede that the threat to birds and ecosystems—one of Carson's main messages—was real and that most of her errors can be attributed to the primitive state of research on the topics she covered in her day. Further, her critics cannot dispute the fact that her wake-up call got the public and the scientific community focused on the potential threats from the uncontrolled use of pesticides. This eventually led to the banning of many pesticides in the United States and other countries. Carson's pioneering work also led to much more scientific research on the potential hazards of pesticides and other chemicals.

U.S. Fish and Wildlife Service

Figure 12-B Biologist Rachel Carson (1907–1964) greatly increased our understanding of the importance of nature and of the harmful effects of the widespread use of pesticides.

biopesticides that contain essential oils from common kitchen spices such as clove, mint, rosemary and thyme. Chemists have thus increased the arsenal of natural pesticides that organic growers (**Core Case Study**) CORE CASE STUDY can use to combat pests.

After 1950, pesticide use increased more than 50-fold. But most of today's pesticides are 10–100 times more toxic than those used in the 1950s. About three-fourths of these chemicals are used in more-developed countries, but their use in less-developed countries is soaring. Use of biopesticides is also on the rise.

Some pesticides, called *broad-spectrum agents*, are toxic to many pests, but also to beneficial species. Examples are chlorinated hydrocarbon compounds such as DDT and organophosphate compounds such as malathion and parathion. Others, called *selective*, or *narrow-spectrum, agents*, are effective against a narrowly defined group of organisms.

Pesticides vary in their *persistence*, the length of time they remain deadly in the environment. Some, such as DDT and related compounds, remain in the environment for years and can be biologically magnified in food chains and webs (see Figure 9-15, p. 203). Others, such as organophosphates, are active for days or weeks and are not biologically magnified but can be highly toxic to humans. About one-fourth of the pesticides used in the United States are aimed at ridding houses, gardens, lawns, parks, playing fields, swimming pools, and golf courses of pests. According to the U.S. Environmental Protection Agency (EPA), the average lawn in the

United States is doused with ten times more synthetic pesticides per unit of land area than what is put on an equivalent amount of U.S. cropland.

Modern Synthetic Pesticides Have Several Advantages

Conventional chemical pesticides have advantages and disadvantages. Proponents contend that their benefits (Figure 12-22, left) outweigh their harmful effects (Figure 12-22, right). They point to the following benefits:

- *They save human lives.* Since 1945, DDT and other insecticides probably have prevented the premature deaths of at least 7 million people (some say as many as 500 million) from insect-transmitted diseases such as malaria (carried by the *Anopheles* mosquito), bubonic plague (carried by rat fleas), and typhus (carried by body lice and fleas).
- *They have helped us to increase food supplies* by reducing food losses to pests, for some crops in some areas.
- *They increase profits for farmers.* Officials of pesticide companies estimate that every dollar spent on pesticides leads to an increase in U.S. crop yields worth approximately $4.
- *They work fast.* Pesticides control most pests quickly, have a long shelf life, and are easily shipped and applied. When genetic resistance (see Figure 4-7, p. 87) occurs, farmers can use stronger doses or switch to other pesticides.
- *When used properly, the health risks of some pesticides are very low, relative to their benefits*, according to pesticide industry scientists.
- *Newer pest control methods are safer and more effective than many older ones.* Greater use is being made of biopesticides, which are safer to use and less damaging to the environment than are many older pesticides. Genetic engineering is also being used to develop pest-resistant crop strains and genetically altered crops that produce natural pesticides.

Modern Synthetic Pesticides Have Several Disadvantages

Opponents of widespread pesticide use believe that the harmful effects of these chemicals (Figure 12-21, right) outweigh their benefits (Figure 12-21, left). They cite several serious problems with the use of conventional pesticides.

- *They accelerate the development of genetic resistance to pesticides in pest organisms.* Insects breed rapidly, and within 5–10 years (much sooner in tropical areas) they can develop immunity to widely used pesticides through natural selection and then come back stronger than before. Since 1945, about 1,000 species of insects and rodents (mostly rats) and 550 types of weeds and plant diseases have developed genetic resistance to one or more pesticides. Since 1996 the use of glyphosate herbicides on GM crops designed to thrive on higher doses of this herbicide has increased. This has led to at least 10 species of "superweeds" that are now genetically resistant to this widely used herbicide.
- *They can put farmers on a financial treadmill.* Because of genetic resistance, farmers can find themselves having to pay more and more for a pest control program that can become less and less effective.
- *Some insecticides kill natural predators and parasites that help control the pest populations.* About 100 of the 300 most destructive insect pests in the United States were minor pests until widespread use of insecticides wiped out many of their natural predators.
- *Pesticides do not stay put and can pollute the environment.* According to the USDA, about 98–99.9% of the insecticides and more than 95% of the herbicides we apply by aerial spraying or ground spraying do not reach the target pests and end up in the air, surface water, groundwater, bottom sediments, food, and on nontarget organisms, including humans and wildlife.

Figure 12-22 Conventional chemical pesticides have advantages and disadvantages. **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

- *Some pesticides harm wildlife.* According to the USDA and the U.S. Fish and Wildlife Service, each year, pesticides applied to cropland wipe out about 20% of U.S. honeybee colonies and damage another 15% (see Chapter 9 Case Study, p. 204). Each year, pesticides also kill more than 67 million birds and 6–14 million fish. According to a 2004 study by the Center for Biological Diversity, pesticides also menace one of every three endangered and threatened species in the United States.
- *Some pesticides threaten human health.* The WHO and UNEP estimate conservatively that, each year, pesticides seriously poison at least 3 million agricultural workers in less-developed countries and at least 300,000 workers in the United States. They also cause 20,000–40,000 deaths per year, worldwide. Each year, more than 250,000 people in the United States become ill because of household pesticide use. In addition, such pesticides are a major source of accidental poisonings and deaths of young children. According to studies by the National Academy of Sciences, pesticide residues in food cause 4,000–20,000 cases of cancer per year in the United States. (See more on this topic in Chapter 17 and in *The Habitable Planet*, Video 7, at **www.learner.org/resources/series209.html**).

The pesticide industry disputes these claims, arguing that the exposures are not high enough to cause serious environmental or health harms. Figure 12-23 lists some ways in which you can reduce your exposure to pesticides.

Pesticide Use Has Not Reduced U.S. Crop Losses to Pests

Largely because of genetic resistance and reduction of natural predators, pesticides have not succeeded in reducing U.S. crop losses overall. When David Pimentel, an expert on insect ecology, evaluated data from more than 300 agricultural scientists and economists, he reached three major conclusions. *First*, between 1942 and 1997, estimated crop losses from insects almost doubled from 7% to 13%, despite a tenfold increase in the use of synthetic insecticides. *Second*, according to the International Food Policy Research Institute, the estimated environmental, health, and social costs of pesticide use in the United States are $5–10 in damages for every dollar spent on pesticides. *Third*, experience indicates that alternative pest management practices could cut by half the use of chemical pesticides on 40 major U.S. crops without reducing crop yields (**Concept 12-4**).

The pesticide industry disputes these findings. However, numerous studies and experience show that we can reduce pesticide use sharply without reducing yields. Sweden has cut pesticide use in half with almost no decrease in crop yields. Campbell Soup uses no pesticides on tomatoes it grows in Mexico, and yields have not dropped. And after a two-thirds cut in pesticide use on rice in Indonesia, yields increased by 15%.

What Can You Do?

Reducing Exposure to Pesticides

- Grow some of your food using organic methods
- Buy certified organic food
- Wash and scrub all fresh fruits, vegetables, and wild foods you pick
- Eat less meat, no meat, or certified organically produced meat
- Trim the fat from meat

Figure 12-23 **Individuals matter:** You can reduce your exposure to pesticides. Because food prices do not include the harmful health and environmental effects of industrialized agriculture, some of these options will cost you more money. **Questions:** Which three of these steps do you think are the most important ones to take? Why?

CASE STUDY

Ecological Surprises: The Law of Unintended Consequences

Malaria once infected nine of every ten people in North Borneo, now known as the eastern Malaysian state of Sabah. In 1955, the WHO began spraying the island with dieldrin (a DDT relative) to kill malaria-carrying mosquitoes. The program was so successful that the dreaded disease was nearly eliminated.

Then unexpected things began to happen. The dieldrin also killed other insects, including flies and cockroaches living in houses. The islanders applauded. Next, small insect-eating lizards that also lived in the houses died after gorging themselves on dieldrin-contaminated insects.

Cats began dying after feeding on the lizards. In the absence of cats, rats flourished and overran the villages. When the people became threatened by sylvatic plague carried by rat fleas, the WHO parachuted healthy cats onto the island to help control the rats. Operation Cat Drop worked.

But then the villagers' roofs began to fall in. The dieldrin had killed wasps and other insects that fed on a type of caterpillar that had either avoided or was not affected by the insecticide. With most of its predators eliminated, the caterpillar population exploded, munching its way through its favorite food: the leaves used to thatch roofs.

Ultimately, this episode ended well: both malaria and the unexpected effects of the spraying program were brought under control. Nevertheless, this chain of unintended and unforeseen events emphasizes the unpredictability of using insecticides. It reminds us that when we intervene in nature, our actions always have consequences, and we need to ask, "Now what will happen?"

HOW WOULD YOU VOTE?

Do the advantages of using synthetic chemical pesticides outweigh their disadvantages? Cast your vote online at **www.cengage.com/login**.

Laws and Treaties Can Help to Protect Us from the Harmful Effects of Pesticides

More than 25,000 different commercial pesticide products are used in the United States. Three U.S. federal agencies, the EPA, the USDA, and the Food and Drug Administration (FDA), regulate the sale and use of these pesticides under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), first passed in 1947 and amended in 1972.

Under FIFRA, the EPA was supposed to assess the health risks of the active ingredients in pesticide products already in use. But after more than 30 years, less than 10% of the active ingredients in pesticide products have been tested for chronic health effects. Serious evaluation of the health effects of the 1,200 inactive ingredients used in pesticide products began only recently. The EPA says that it has not had the funds to carry out this complex and lengthy evaluation process.

In 1996, Congress passed the Food Quality Protection Act, mostly because of growing scientific evidence and citizen pressure concerning the effects of small amounts of pesticides on children. This act requires the EPA to reduce the allowed levels of pesticide residues in food by a factor of 10 when there is inadequate information on the potentially harmful effects on children.

Between 1972 and 2009, the EPA used FIFRA to ban or severely restrict the use of 64 active pesticide ingredients, including DDT and most other chlorinated hydrocarbon insecticides. However, according to studies by the National Academy of Sciences, federal laws regulating pesticide use in the United States are inadequate and poorly enforced by the three agencies. One such study found that as much as 98% of the potential risk of developing cancer from pesticide residues on food grown in the United States would be eliminated if EPA standards were as strict for pre-1972 pesticides as they are for later ones.

CONNECTIONS

Pesticides and Organic Foods

CORE CASE STUDY

According to the Environmental Working Group (EWG), you could reduce your pesticide intake by up to 90% by eating only organic versions (**Core Case Study**) of 12 types of fruits and vegetables that tend to have the highest pesticide residues. These foods, which the EWG calls the "dirty dozen," are peaches, apples, bell peppers, celery, nectarines, cherries, strawberries, lettuce, grapes, spinach, pears, and potatoes. Pesticide proponents say the residue concentrations in those foods are too low to cause harm. But some scientists urge consumers to follow the precautionary principle and buy only organic versions of the dirty dozen foods.

Although laws within countries protect citizens to some extent, banned or unregistered pesticides may be manufactured in one country and exported to other countries. For example, U.S. pesticide companies make and export to other countries pesticides that have been banned or severely restricted—or never even evaluated—in the United States. Other industrial countries also export banned or unapproved pesticides.

But what goes around can come around. In what environmental scientists call a *circle of poison*, or the *boomerang effect*, residues of some banned or unapproved chemicals exported to other countries can return to the exporting countries on imported food. The wind can also carry persistent pesticides from one country to another.

Environmental and health scientists have urged the U.S. Congress—without success—to ban such exports. Supporters of the exports argue that such sales increase economic growth and provide jobs, and that banned pesticides are exported only with the consent of the importing countries. They also contend that if the United States did not export pesticides, other countries would.

In 1998, more than 50 countries developed an international treaty that requires exporting countries to have informed consent from importing counties for exports of 22 pesticides and 5 industrial chemicals. In 2000, more than 100 countries developed an international agreement to ban or phase out the use of 12 especially hazardous persistent organic pollutants (POPs)—9 of them persistent hydrocarbon pesticides such as DDT and other chemically similar pesticides. The United States has not ratified this agreement.

THINKING ABOUT

Exporting Pesticides

Should companies be allowed to export pesticides that have been banned, severely restricted, or not approved for use in their home countries? Explain.

There Are Alternatives to Conventional Pesticides

Many scientists believe we should greatly increase the use of biological, ecological, and other alternative methods for controlling pests and diseases that affect crops and human health (**Concept 12-4**). Here are some of these alternatives:

- *Fool the pest.* A variety of *cultivation practices* can be used to fake out pests. Examples include rotating the types of crops planted in a field each year and adjusting planting times so that major insect pests either starve or get eaten by their natural predators.
- *Provide homes for pest enemies.* Farmers can increase the use of polyculture, which uses plant diversity to reduce losses to pests by providing habitats for the pests' natural enemies.


Monsanto

Figure 12-24 **Solutions:** This is one example of using *genetic engineering* to reduce pest damage. Both tomato plants were exposed to destructive caterpillars. The unaltered plant's leaves are almost gone (left), whereas the genetically altered plant shows little damage (right). **Questions:** Would you have any concerns about eating a tomato from the genetically engineered plant? Why or why not?

- *Implant genetic resistance.* Use genetic engineering to develop pest- and disease-resistant crop strains (Figure 12-24). But controversy persists over whether the advantages of using GM plants outweigh their disadvantages (Figure 12-18).
- *Bring in natural enemies*. Use *biological control* by importing natural enemy predators (Figures 12-21 and 12-25), parasites, and disease-causing bacteria and viruses to help regulate pest populations. This approach is generally nontoxic to other species, minimizes genetic resistance, and is usually less costly than applying pesticides. However, some biological control agents are difficult to mass produce, are often slower acting, and are more difficult to apply than conventional pesticides. Sometimes the agents can multiply and become pests themselves. A 2009 study found that biological pest control on organic farms was no more effective than using pesticides on conventional farms. But the use of biological agents produces much less air and water pollution.
- *Use insect perfumes:* Trace amounts of *sex attractants* (called *pheromones*) can lure pests into traps or attract their natural enemies into crop fields. These chemicals have little chance of causing genetic resistance and are not harmful to nontarget species. However, they are costly and time-consuming to produce.
- *Bring in the hormones:* Hormones are chemicals produced by animals to control their developmental processes at different stages of life. Scientists have learned how to identify and use hormones that disrupt an insect's normal life cycle, thereby preventing it from reaching maturity and reproducing. Insect hormones have some of the same advantages and disadvantages of sex attractants. Also, they take weeks to kill an insect, are often ineffective with large infestations of insects, and sometimes break down before they can act.
- *Reduce use of synthetic herbicides to control weeds:* Organic farmers (**Core Case Study**) control weeds by methods such as crop rotation and the use of cover crops and mulches. CORE CASE STUDY


Scott Bauer/USDA Agricultural Research Service

Figure 12-25 **Natural capital:** In this example of biological pest control, a wasp is parasitizing a gypsy moth caterpillar.

Integrated Pest Management Is a Component of More Sustainable Agriculture

Many pest control experts and farmers believe the best way to control crop pests is a carefully designed **integrated pest management (IPM)** program. In this more sustainable approach, each crop and its pests are evaluated as parts of an ecological system. Then farmers develop a carefully designed control program that uses a combination of cultivation, biological, and chemical tools and techniques, applied in a coordinated process tailored to each situation (**Concept 12-4**).

The overall aim of IPM is to reduce crop damage to an economically tolerable level. Each year, crops are rotated, or moved from field to field, in an effort to disrupt pest infestations, and fields are monitored carefully. When any pest reaches an economically damaging level, farmers first use biological methods (natural predators, parasites, and disease organisms) and cultivation controls (such as altering planting time or using large machines to vacuum up harmful bugs). They apply small amounts of insecticides or herbicides—mostly based on those naturally produced by plants—only when insect or weed populations reach a threshold where the potential cost of pest damage to crops outweighs the cost of applying the pesticide. Broad-spectrum, long-lived pesticides are not used, and different chemicals are used alternately to slow the development of genetic resistance and to avoid killing predators of pest species.

In 1986, the Indonesian government banned 57 of the 66 pesticides used on rice and phased out pesticide subsidies over a 2-year period. It also launched a nationwide education program to help farmers switch to IPM. The results were dramatic: Between 1987 and 1992, pesticide use dropped by 65%, rice production rose by 15%, and more than 250,000 farmers were trained in IPM techniques. (For more information and animations see *The Habitable Planet*, Video 7, at **www.learner.org/resources/series209.html**.) Sweden and Denmark have used IPM to cut their pesticide use by more than half. Cuba, which uses organic farming to grow its crops, makes extensive use of IPM. In Brazil, IPM has reduced pesticide use on soybeans by as much as 90%.

GOOD NEWS

According to a 2003 study by the U.S. National Academy of Sciences, these and other experiences show that a well-designed IPM program can reduce pesticide use and pest control costs by 50–65%, without reducing crop yields and food quality. IPM can also reduce inputs of fertilizer and irrigation water, and slow the development of genetic resistance, because pests are attacked less often and with lower doses of pesticides. IPM is an important form of *pollution prevention* that reduces risks to wildlife and human health and applies the biodiversity **principle of sustainability**.

Despite its promise, IPM—like any other form of pest control—has some disadvantages. It requires expert knowledge about each pest situation and takes more time than does using conventional pesticides. Methods developed for a crop in one area might not apply to other areas with even slightly different growing conditions. Initial costs may be higher, although long-term costs typically are lower than those of using conventional pesticides. Widespread use of IPM is hindered in the United States and in a number of other countries by government subsidies for using conventional chemical pesticides, opposition by pesticide manufacturers, and a shortage of IPM experts. **GREEN CAREER:** integrated pest management

A growing number of scientists are urging the USDA to use a three-point strategy to promote IPM in the United States. *First*, add a 2% sales tax on pesticides and use the revenue to fund IPM research and education. *Second*, set up a federally supported IPM demonstration project on at least one farm in every county in the United States. *Third*, train USDA field personnel and county farm agents in IPM so they can help farmers use this alternative. Because these measures would reduce its profits, the pesticide industry has vigorously, and successfully, opposed them.

HOW WOULD YOU VOTE?

Should governments heavily subsidize a switch to integrated pest management? Cast your vote online at **www.cengage.com./login**.

Several UN agencies and the World Bank have joined together to establish an IPM facility. Its goal is to promote the use of IPM by disseminating information and establishing networks among researchers, farmers, and agricultural extension agents involved in IPM.

GOOD NEWS

12-5 How Can We Improve Food Security?

CONCEPT 12-5 We can improve food security by creating programs to reduce poverty and chronic malnutrition, relying more on locally grown food, and cutting food waste.

Government Subsidies Can Help or Hinder Food Security

Agriculture is a financially risky business. Whether farmers have a good or bad year depends on factors over which they have little control: weather, crop prices, crop pests and diseases, loan interest rates, and global markets.

Governments use two main approaches to influence food production. *First*, they can *control prices* by putting a legally mandated upper limit on prices in order to keep food prices artificially low. This makes consumers happy but makes it harder for farmers to make a living.

Second, they can *provide subsidies* by giving farmers price supports, tax breaks, and other financial support to keep them in business and to encourage them to increase food production. For example, food production and farm jobs in the African country of Kenya greatly increased after the government invested

GOOD NEWS

in giving small rural farmers access to seeds, tools, irrigation systems, and storage facilities. However, if government subsidies are too generous and the weather is good, farmers and livestock producers may produce more food than can be sold. Globally, government farm subsidies in more-developed countries average about $533,000 per minute and account for almost a third of global farm income.

Some analysts call for ending such subsidies. For example, in 1984, New Zealand ended farm subsidies. After the shock wore off, innovation took over and production of some foods such as milk quadrupled. Brazil has also ended most of its farm subsidies. Some analysts call for replacing traditional subsidies for farmers with subsidies that promote more sustainable farming practices.

Similarly, government subsidies to fishing fleets (see Chapter 11, p. 266) can promote overfishing and the reduction of aquatic biodiversity. For example, governments give the highly destructive bottom-trawling industry (see Figure 11-2, right, p. 252) about $150 million in subsidies a year, which is the main reason that fishers who use this practice can stay in business. Many analysts call for replacing those subsidies with payments that promote more sustainable fishing and aquaculture.

HOW WOULD YOU VOTE?

Should governments phase out subsidies for conventional industrialized agriculture and fishing, and phase in subsidies for more sustainable practices in these food production systems? Cast your vote online at **www.cengage.com/login**.

Other Government and Private Programs are Increasing Food Security

Government programs that reduce poverty by helping the poor to help themselves can improve food security (**Concept 12-1B**). In 2008, the UN World Food Program announced a new system of buying food from small farmers to increase their economic security.

Some aid programs also support government efforts to reduce the rate of population growth. Such programs promote family planning, education and jobs (especially for women), and small loans to poor people to help them start businesses or buy land to grow their own food.

Some analysts urge governments to establish special programs focused on saving children from the harmful health effects of poverty. Studies by the United Nations Children's Fund (UNICEF) indicate that one-half to two-thirds of nutrition-related childhood deaths could be prevented at an average annual cost of $5–10 per child. This would involve simple measures such as immunizing more children against childhood diseases, preventing dehydration from diarrhea by giving infants a mixture of sugar and salt in their water, and preventing blindness by giving children an inexpensive vitamin A capsule twice a year.

Some farmers and plant breeders are working on preserving a diverse gene pool as another way to improve food security. For example an organization called the Global Crop Diversity Trust is seeking to prevent the disappearance of 100,000 varieties of food crops. The trust is working with about 50 gene banks around the world to cultivate and store seeds from endangered varieties of many food plant species.

12-6 How Can We Produce Food More Sustainably?

CONCEPT 12-6 More sustainable food production will require using resources more efficiently, sharply decreasing the harmful environmental effects of industrialized food production, and eliminating government subsidies that promote such harmful impacts.

Reduce Soil Erosion

Land used for food production must have fertile topsoil (Figure 12-A), and it takes hundreds of years for fertile topsoil to form. Thus, sharply reducing topsoil erosion is the single most important component of more sustainable agriculture.

Soil conservation involves using a variety of methods to reduce topsoil erosion and to restore soil fertility, mostly by keeping the land covered with vegetation. Farmers have used a number of methods to reduce topsoil erosion. For example, *terracing* is a way to grow food on steep slopes without depleting its topsoil. It is done by converting steeply sloped land into a series of broad, nearly level terraces that run across the land's contours (Figure 12-26). The terraces retain water for crops at each level and reduce topsoil erosion by controlling runoff.

On land with a significant slope, *contour planting* (Figure 12-27) can be used to reduce topsoil erosion. It involves plowing and planting crops in rows across the slope of the land rather than up and down. Each

Lim Yong Hian/Shutterstock

Figure 12-26 **Solutions:** In Bali, Indonesia, terraced rice fields help to reduce topsoil erosion.

Ron Nichols/USDA Natural Resources Conservation Service

Figure 12-27 **Solutions:** A mixture of monoculture crops has been planted in strips on a farm in central Wisconsin (USA). The farmer plants crops across the contours of the land (*contour planting*) and in alternating strips of land (*strip cropping*) to help reduce topsoil erosion and the depletion of soil nutrients.

row acts as a small dam to help hold topsoil and to slow water runoff.

Strip cropping (Figure 12-27) helps to reduce erosion and to restore soil fertility. It involves planting alternating strips of a row crop (such as corn or cotton) and another crop that completely covers the soil, called a *cover crop* (such as alfalfa, clover, oats, or rye). The cover crop traps topsoil that erodes from the row crop and catches and reduces water runoff. Some cover crops also add nitrogen to the soil. When one crop is harvested the other crop is left to catch and reduce water runoff. Other ways to reduce topsoil erosion are to leave crop residues on the land after the crops are harvested or to plant cover crops immediately after harvest to help protect and hold the topsoil.

Alley cropping, or *agroforestry* (Figure 12-28), is yet another way to slow the erosion of topsoil and to maintain soil fertility. One or more crops, usually crops that

Manfred Mielke, USDA Forest Service, Bugwood.org

Figure 12-28 **Solutions:** Many farmers reduce topsoil erosion in orchards by growing crops in rows or alleys between trees.

add nitrogen to the soil, are planted together in alleys between orchard trees or fruit-bearing shrubs, which provide shade. This reduces water loss by evaporation and helps to retain and slowly release soil moisture—an insurance policy during prolonged drought. The trees also can provide fruit, and tree trimmings can be used as fuelwood, mulch, and green manure for the crops. Agroforestry is widely used in South America, Southeast Asia, and sub-Saharan Africa.

Farmers can also establish *windbreaks*, or *shelterbelts*, of trees around crop fields to reduce wind erosion (Figure 12-29). The trees retain soil moisture, supply wood for fuel, increase crop productivity by 5–10%, and provide habitats for birds and for insects that help with pest control and pollination.

However, many farmers do not practice these effective ways to reduce soil erosion because they are in a desperate struggle to survive, or they are more interested in increasing short-term income, even if it leads to long-term environmental degradation.

GOOD NEWS

Eliminating or minimizing the plowing and tilling of topsoil and leaving crop residues on the ground greatly reduce topsoil erosion. Many farmers in the United States and several other countries do this by practicing *conservation-tillage farming*, using special tillers and planting machines that drill seeds directly through crop residues into the undisturbed topsoil. The only disturbance to the soil is a narrow slit cut by the planter, and weeds are controlled with herbicides. Such *no-till* and *low-till* farming increases crop yields and reduces the threat of projected climate change by storing more carbon in the soil. It also reduces water pollution from sediment and fertilizer runoff and lowers the use of water and tractor fuel. A study showed that erosion from a conventionally tilled watershed was 700 times greater than that from a no-till watershed.


Fedorov Oleksiy/Shutterstock

Figure 12-29 **Solutions:** Windbreaks along the edges of these crop fields help to protect topsoil against wind erosion.

In 2008, farmers used conservation tillage on about 41% of U.S. cropland, helped by the use of herbicides. The USDA estimates that using conservation tillage on 80% of U.S. cropland would reduce topsoil erosion by at least half. No-till cultivation is used on less than 7% of the world's cropland, although it is widely used in some countries, including the United States, Brazil, Argentina, Canada, and Australia. It has great potential to reduce topsoil erosion and raise crop yields in dry regions in Africa and the Middle East.

However, conservation tillage is not a cure-all. It requires costly machinery and works better in some soils than in others. It is not useful for wetland rice and root crops such as potatoes, and it can result in increased use of herbicides. **Explore More:** See a Science Focus at **www.cengage.com/login** on the advantages and disadvantages of the widespread use of the herbicide glyphosphate.

An additional way to conserve the earth's topsoil is to retire the estimated one-tenth of the world's marginal cropland that is highly erodible and accounts for the majority of the world's topsoil erosion. The goal would be to identify *erosion hotspots*, withdraw these areas from cultivation, and plant them with grasses or trees, at least until their topsoil has been renewed.

CASE STUDY

Soil Erosion in the United States

In the United States, a third of the country's original topsoil is gone and much of the rest is degraded. In the state of Iowa, which has the world's highest concentration of prime farmland, half of the topsoil is gone after a century of industrialized farming. According to the Natural Resources Conservation Service, 90% of American farmland is, on average, losing topsoil 17 times faster than new topsoil is being formed.

Americans learned a harsh environmental lesson in the 1930s, when much of the topsoil in several dry and windy midwestern states was lost because of a combination of poor cultivation practices and prolonged drought. This threatened to turn much of the U.S. Great Plains into a vast desert.

Before settlers began grazing livestock and planting crops there in the 1870s, the deep and tangled root systems of native prairie grasses anchored the fertile topsoil firmly in place. But plowing the prairie tore up these roots, and the crops that settlers planted annually in their place had less extensive root systems. After each harvest, the land was plowed and left bare for several months, exposing the topsoil to high winds. Overgrazing by livestock in some areas also destroyed large expanses of grass, denuding the ground.

The stage was set for severe wind erosion and crop failures; all that was needed was a long drought. It came between 1926 and 1937 when the annual precipitation dropped by almost two-thirds. In the 1930s, dust clouds created by hot, dry windstorms blowing across the barren, exposed soil darkened the sky at midday in some areas. Rabbits and birds choked to death on the dust.

During May of 1934, a cloud of topsoil blown off the Great Plains traveled some 2,400 kilometers (1,500 miles) and blanketed most of the eastern United States with dust. Laundry hung out to dry in the state of Georgia quickly became covered with dust blown in from the Midwest. Journalists gave the most eroded part of the Great Plains a new name: the *Dust Bowl* (Figure 12-30).

This environmental disaster triggered one of the largest internal migrations in U.S. history. Thousands of farm families from the Dust Bowl states became environmental refugees, abandoning their dust-choked farms and dead livestock, and migrating to other parts of the country.

In 1935, the United States passed the *Soil Erosion Act*, which established the Soil Conservation Service (SCS) as part of the USDA. (The SCS is now called the Natural Resources Conservation Service, or NRCS.) Farmers and ranchers were given technical assistance to set up soil conservation programs, and thanks to this and secondary ecological succession (see Figure 5-20, p. 120) most of the Dust Bowl has become highly productive farmland.

Of the world's major food-producing nations, only the United States is sharply reducing some of its topsoil losses through a combination of conservation-tillage farming and government-sponsored soil conservation programs (**Concept 12-6**). Under the 1985 Food Security Act (Farm Act), more than 400,000 farmers participated in the Conservation Reserve Program. They received subsidy payments for taking highly erodible land—totaling an area larger than the U.S. state of New York—out of production and replanting it with grass or trees for 10–15 years. Since 1985, these efforts have cut topsoil losses on U.S. cropland by 40%. However, effective topsoil conservation is practiced today on only half of all U.S. agricultural land.

GOOD NEWS

Figure 12-30 **Natural capital degradation:** This map shows the *Dust Bowl* of the U.S. Great Plains, where a combination of extreme drought and poor topsoil conservation practices led to severe wind erosion of topsoil in the 1930s.

CONNECTIONS

Corn, Ethanol, and Soil Conservation

In recent years, some U.S. farmers have been taking erodible land out of the conservation reserve in order to receive generous government subsidies for planting corn (which removes nitrogen from the soil) to make ethanol for use as a motor vehicle fuel. This has led to mounting political pressure to abandon or sharply cut back on the nation's highly successful topsoil conservation reserve program, which would likely lead to more soil erosion and lower soil fertility.

Restore Soil Fertility

The best way to maintain soil fertility is through topsoil conservation. The next best option is to restore some of the lost plant nutrients that have been washed, blown, or leached out of topsoil, or that have been removed by repeated crop harvesting. To do this, farmers can use **organic fertilizer** from plant and animal materials or **manufactured inorganic fertilizer** produced from various minerals, which are mined from the earth's crust.

There are several types of *organic fertilizers*. One is **animal manure**: the dung and urine of cattle, horses, poultry, and other farm animals. It improves topsoil structure, adds organic nitrogen and stimulates the growth of beneficial soil bacteria and fungi. Another type, called **green manure**, consists of freshly cut or growing green vegetation that is plowed into the topsoil to increase the organic matter and humus available to the next crop. A third type is **compost**, produced when microorganisms in topsoil break down organic matter such as leaves, crop residues, food wastes, paper, and wood in the presence of oxygen. Organic agriculture (**Core Case Study**) uses only these types of fertilizers.

CORE CASE STUDY

Crops such as corn and cotton can deplete nutrients in the topsoil (especially nitrogen) if they are planted on the same land several years in a row. *Crop rotation* provides one way to reduce these losses. Farmers plant areas or strips with nutrient-depleting crops one year. The next year, they plant the same areas with legumes, whose root nodules add nitrogen to the soil. This not only helps to restore topsoil nutrients but also reduces erosion by keeping the topsoil covered with vegetation.

Many farmers (especially in more-developed countries) rely on manufactured inorganic fertilizers. The active ingredients typically are inorganic compounds that contain nitrogen, phosphorus, and potassium. Other plant nutrients may be present in low or trace amounts. Manufactured inorganic fertilizer use has grown more than ninefold since 1950, and it now accounts for about one-fourth of the world's crop yield. Without careful control, these fertilizers can run off the land and pollute nearby bodies of water and coastal estuaries. While these fertilizers can replace depleted inorganic nutrients,

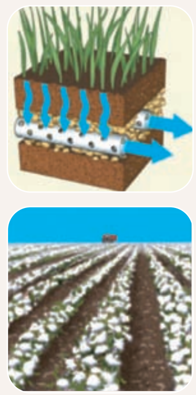
Solutions

Soil Salinization

Prevention

Reduce irrigation

Switch to salt-tolerant crops



Cleanup

Flush soil (expensive and wastes water)

Stop growing crops for 2–5 years

Install underground drainage systems (expensive)

Figure 12-31 There are several ways to prevent and clean up soil salinization (**Concept 12-6**). **Questions:** Which two of these solutions do you think are the most important? Why?

they do not replace organic matter. To completely restore nutrients to topsoil, both inorganic and organic fertilizers should be used.

Reduce Soil Salinization and Desertification

We know how to prevent and deal with soil salinization, as summarized in Figure 12-31. The problem is that most of these solutions are costly in one way or another.

Desertification is not an easy problem to solve. We cannot control the timing and location of prolonged droughts caused by natural factors. But we can reduce population growth, overgrazing, deforestation, and destructive forms of planting, irrigation, and mining, which have left much land vulnerable to desertification. We can also work to decrease the human contribution to projected climate change, which is expected to increase severe and prolonged droughts in larger areas of the world during this century.

It is possible to restore land suffering from desertification by planting trees (see Chapter 10 Core Case Study, p. 215) and other plants that anchor topsoil and hold water, by growing trees and crops together (Figure 12-28), and by establishing windbreaks (Figure 12-29).

Practice More Sustainable Aquaculture

Figure 12-32 lists some ways to make aquaculture more sustainable and to reduce its harmful environmental effects. One such approach is open-ocean aquaculture, which involves raising large carnivorous fish in underwater pens located up to 300 kilometers (190 miles) offshore (see Figure 11-8, p. 259). The fish are fattened with fish meal supplied by automated buoys, and surrounding ocean water and currents dilute the wastes. Some farmed fish can escape and breed with similar wild fish species. But overall, the environmental impact of raising fish far offshore is smaller than that of raising fish near shore and much smaller than that of industrialized commercial fishing.

Some fish farmers are reducing damage from aquaculture to coastal areas in Florida by raising shrimp and fish species such as cobia and pompano far inland in zero-discharge freshwater ponds and tanks. These recirculating aquaculture systems (called RAS) are closed-loop facilities that capture and treat the water for reuse. This reduces the discharge of polluting wastes and the need for antibiotics and other chemicals used to combat disease. It also eliminates the problem of farmed fish escaping into natural aquatic systems. **GREEN CAREER:** sustainable aquaculture

However, making aquaculture more sustainable will require some fundamental changes. One such change would be for more consumers to choose fish species that eat algae and other vegetation rather than other fish. Raising meat-eating fishes such as salmon, tuna, and cod contributes to overfishing of species used to feed these carnivores, and eventually, it will be unsustainable. Raising plant-eating fishes such as carp, tilapia, and catfish avoids this problem. However, it becomes less sustainable when aquaculture producers try to increase yields by feeding fish meal to such plant-eating species, as many of them are now doing.

Another change would be for fish farmers to emphasize *polyaquaculture*, which has been part of aquaculture for centuries, especially in Southeast Asia. Polyaquaculture operations (see the Case Study that follows) raise fish or shrimp along with algae, seaweeds, and shellfish in coastal lagoons, ponds, and tanks. The wastes of the

Solutions

More Sustainable Aquaculture

- Protect mangrove forests and estuaries
- Improve management of wastes
- Reduce escape of aquaculture species into the wild
- Raise some species in deeply submerged cages
- Set up self-sustaining aquaculture systems that combine aquatic plants, fish, and shellfish
- Certify and label sustainable forms of aquaculture

Figure 12-32 We can make aquaculture more sustainable and reduce its harmful effects. **Questions:** Which two of these solutions do you think are the most important? Why?

fish or shrimp feed the other species, and in the best of these operations, there are just enough wastes from the first group to feed the second group. This approach applies the recycling and biodiversity **principles of sustainability**.

■ **CASE STUDY**

Raising Salmon in an Artificial Ecosystem

Cooke Aquaculture is the largest salmon producer of eastern Canada. In the Bay of Fundy in the province of New Brunswick, Cooke is running a salmon farm that could become a model of more sustainable aquaculture in North America.

The key to this model, as reported in the 2008 Worldwatch Institute report *Farming Fish for the Future*, is that it mimics a coastal ecosystem in some important ways. For example, the farm employs polyaquaculture by raising three different species that interact much as they do in nature. Located strategically near the farm's large salmon cages are structures that hold long socks full of blue mussels. In another nearby location, rafts with long ribbons of kelp dangle down into the water.

Most salmon farms release large amounts of feed, fish waste, and other nutrients into the waters surrounding the salmon cages. The Cooke facility turns those pollutants into resources. The socks of shellfish are positioned in such a way that they filter the wastes flowing from the salmon cages. At the same time, the kelp uses some of the dissolved nitrogen, phosphorus, and other nutrients that are released by the operation. In addition, the salmon are less subject to health problems because their waters are cleansed of excess nutrients by the other species.

By mimicking a natural ecosystem, this Cooke fish farm applies all three of the **principles of sustainability**.

Produce Meat More Efficiently and Eat Less Meat

Food production, especially meat production, has a huge environmental impact. Eating meat is the largest factor contributing to the growing ecological and carbon footprints of individuals in affluent nations.

Meat production is also highly inefficient. Currently, about 38% of the world's grain harvest and 37% of the world's fish catch are used to produce animal protein. If everyone in the world today had the average U.S. meat-based diet, the world's current annual grain harvest could feed only about 2.5 billion people—a little over a third of the current world population.

A more sustainable form of meat production and consumption would involve shifting from less grain-efficient forms of animal protein, such as beef, pork, and carnivorous fish produced by aquaculture, to more grain-efficient forms, such as poultry and plant-eating farmed fish (Figure 12-33). Such a shift is under way. Since 1996, poultry has taken the lead over beef in the marketplace, and within a decade or so, herbivorous fish farming may exceed beef production.

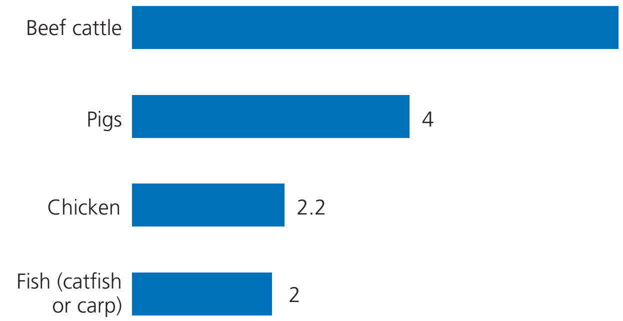


Figure 12-33 The efficiency of converting grain into animal protein varies with different types of meat. This bar graph show the kilograms of grain required for each kilogram of body weight added for each type of animal. **Question:** If you eat meat, what changes could you make to your diet that would reduce your environmental impact? (Data from U.S. Department of Agriculture)

Another important shift would be increased use of well-managed, nonindustrialized beef production on rangelands and pastures instead of in feedlots. This would be an important way to avoid the harmful environmental and health costs of industrialized beef production. In addition, feedlot conditions for animals can be improved. In 2008, California instituted new regulations that guarantee livestock animals at least enough space to stand up, turn around, and lie down.

We can also find alternatives to growing grain to feed livestock. In 1997, India became the world's largest producer of milk and other dairy products. Indian dairy farmers feed their cows mostly roughage such as rice straw, wheat straw, corn stalks, and grass gathered from roadsides.

A number of people are eating less meat, some of them by having one or two meatless days per week. This saves them money and reduces their ecological and carbon footprints. According to agricultural science writer Michael Pollan, if all Americans picked one day per week to have no meat, the reduction in greenhouse gas emissions would be equivalent to taking 30 to 40 million cars off the road for a year.

Many doctors argue that reducing meat consumption also improves health and can increase life expectancy. Research indicates that people who live on a Mediterranean-style diet that includes poultry, seafood, cheese, raw fruits and vegetables, and olive oil tend to be healthier and live longer than those who eat a lot of red meat.

Other people are going further and eliminating most or all meat from their diets. They are replacing it with a balanced vegetarian diet that includes a healthy combination of organically grown fruits and vegetables (**Core Case Study**) and protein-rich foods such as peas, beans, and lentils.

THINKING ABOUT
Meat Consumption

Would you be willing to live lower on the food chain (see **Concept 3-3**, p. 63) by eating much less meat, or even no meat at all? Explain.

Shift to More Sustainable Food Production

Modern industrialized agriculture produces large amounts of food at prices that are relatively low, mostly because the harmful environmental and health costs of such agriculture are not included in the market prices of food. But to a growing number of analysts, this form of agriculture is unsustainable, because it violates the three **principles of sustainability**. It relies heavily on use of fossil fuels, which adds greenhouse gases to the atmosphere and thus contributes to climate change. It also reduces biodiversity in areas where food is grown and agrobiodiversity, and it reduces the cycling of plant nutrients back to topsoil.

Sustainability experts agree that shifting to more sustainable food production will have to include phasing in more low-input agricultural systems over the next few decades. Figure 12-34 lists the major components of more sustainable agriculture. Compared to high-input farming, low-input agriculture produces similar yields with less energy input per unit of yield and lower carbon dioxide emissions. It improves topsoil fertility and reduces topsoil erosion, can often be more profitable for farmers, and can help poor families feed themselves (**Concept 12-6**).

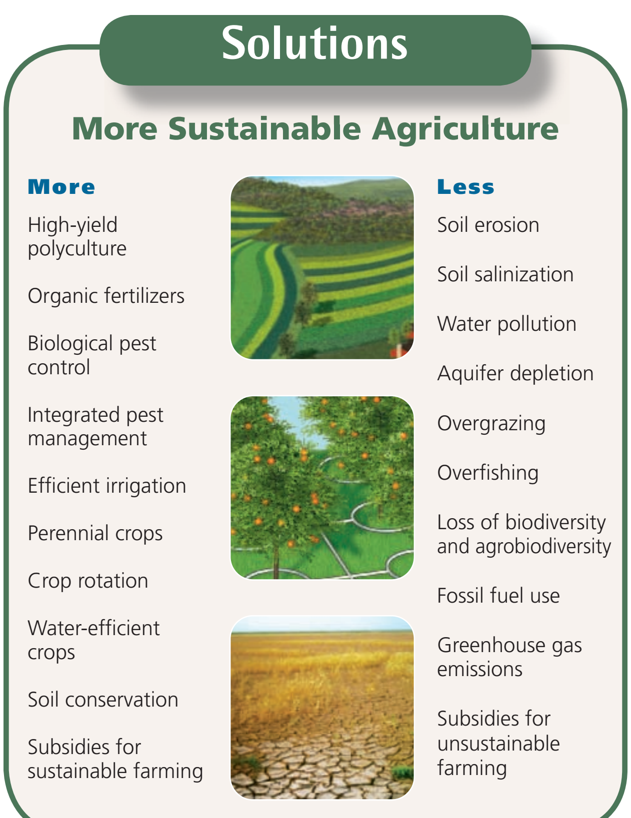


Figure 12-34 More sustainable, low-input agriculture based mostly on mimicking and working with nature has a number of major components. (**Concept 12-6**). **Questions:** Which two solutions do you think are the most important? Why?

In 2009, food expert Lester R. Brown warned that global food security will decrease unless the world's countries work together on an urgent basis to "stabilize population, stabilize climate, stabilize aquifers, conserve soils, protect cropland, and restrict the use of grain to produce fuel for cars."

One component of more sustainable agriculture is organic agriculture (**Core Case Study**). From a nutrient standpoint there is no clear-cut evidence that organic foods are nutritionally healthier to eat than conventional foods. But organic foods are thought to be more healthful because they are free of pesticide residues. Still, according to agricultural science writer Michael Pollan, less than 2% of the food we eat is produced by certified organic farming.

Many experts support a shift to organic farming mostly because it sharply reduces the harmful environmental effects of industrialized farming (Figure 12-10). In 2002, agricultural scientists Paul Mader and David Dubois reported the results of a 22-year study comparing organic and conventional farming at the Rodale Institute in Kutztown, Pennsylvania (USA). Figure 12-35 summarizes their conclusions, along with those from a 2005 evaluation of the study by David Pimentel and other researchers.

According to these studies, yields of organic crops in more-developed countries can be as much as 20% lower than yields of conventionally raised crops. This is largely because most agriculture in these countries is done on an industrial scale. However, in less-developed countries, it is done on a smaller scale. A 2008 study by UNEP surveyed 114 small-scale farms in 24 African countries and found that yields more than doubled where organic farming practices had been used. In some East African operations, the yield increased by 128% with these changes.

These studies also showed that organic farming methods use 28–32% less energy per unit of crop yield and remove and store more climate-changing carbon dioxide from the atmosphere. These results suggest that organic agriculture can play an important role in slowing projected climate change by reducing fossil fuel use and greenhouse gas emissions.

However, a drawback of organic farming is that it requires more human labor to use methods such as integrated pest management, crop rotation and cultivation, and multi-cropping than conventional industrial farming requires. But it can be an important source of jobs and income, especially in less-developed countries, and for a growing number of younger farmers in more-developed countries who want to apply ecological principles to agriculture and to help reduce its harmful environmental impacts.

Solutions

Organic Farming

- Improves soil fertility
- Reduces soil erosion
- Retains more water in soil during drought years
- Uses about 30% less energy per unit of yield
- Lowers CO_2 emissions
- Reduces water pollution by recycling livestock wastes
- Eliminates pollution from pesticides
- Increases biodiversity above and below ground
- Benefits wildlife such as birds and bats

Figure 12-35 The results of 22 years of research at the Rodale Institute in Kutztown, Pennsylvania (USA) show some of the major benefits of organic farming over conventional industrialized farming. (Data from Paul Mader, David Dubois, and David Pimentel)

While yields with organic farming are sometimes lower, farmers often make up for this by not having to use or pay for expensive pesticides, herbicides, and synthetic fertilizers, and usually by getting higher prices for their crops. As a result, the net economic return per unit of land from organic crop production is often equal to or higher than that from conventional crop production. If the harmful environmental and health effects of industrialized agriculture were included in the market prices of food, organic and other more sustainable forms of food production would be less costly and would take a bigger share of the market. **Explore More:** See a Science Focus at **www.cengage.com/login** to learn about how scientists are studying the benefits and costs of organic farming.

Scientists and engineers are also investigating ways to use hydroponics (Figure 12-6) to grow food more sustainably in urban areas. One such prototype effort is the floating Science Barge (Figure 12-36) in Yonkers, New York. This facility was originally developed by a team of environmental engineers and plant biologists at Sun Works. The nonprofit Groundwork Hudson Valley (**www.groundworkhv.org**) operates the barge as an environmental education center for thousands of annual visitors. It uses high-yield hydroponics irrigated solely by collected rainwater and river water that is continuously purified and recirculated to grow tomatoes, lettuce, and cucumbers year round. It is powered solely by renewable solar, wind, and biofuel energy.

Another important component of more sustainable agriculture could be to rely less on monoculture and more on *organic polyculture*—in which many organic crops are grown on the same plot. For example, a diversified organic vegetable farm could grow forty or more different crops on one piece of land. Of particular interest to some scientists is the idea of using polyculture to grow *perennial crops*—crops that grow back year after year on their own (Science Focus, p. 312).

Well-designed organic polyculture helps to conserve and replenish topsoil, requires less water, and reduces the need for fertilizers. It also involves much less of the air and water pollution and greenhouse gas emissions associated with industrialized agriculture.

Most proponents of more sustainable agriculture are not completely opposed to high-yield monoculture. They see it as a way to protect some of the earth's biodiversity and to reduce the need to cultivate new and often marginal land. They call for using more environmentally sustainable high-yield forms of

Groundwork Hudson Valley

Figure 12-36 The Science Barge located in Yonkers, New York is a prototype for a sustainable urban farm. It uses a water purification and recirculating system and renewable energy to raise vegetables hydroponically (Figure 12-6) with no use of pesticides, no runoff of polluted water, and no net emissions of carbon dioxide.

SCIENCE FOCUS

The Land Institute and Perennial Polyculture

Some scientists call for greater reliance on conventional and organic polycultures of perennial crops as a component of more sustainable agriculture. Such crops can live for many years without having to be replanted and are better adapted to regional soil and climate conditions than most annual crops.

Over 3 decades ago, plant geneticist Wes Jackson cofounded The Land Institute in the U.S. state of Kansas. One of the institute's goals has been to grow a diverse mixture (polyculture) of edible perennial plants to supplement traditional annual monoculture crops and to help reduce the latter's harmful environmental effects. Examples in this polycuture mix include perennial grasses, plants that add nitrogen to the soil, sunflowers, grain crops, and plants that provide natural insecticides. Some of these plants could also be used as a source of renewable biofuel for motor vehicles.

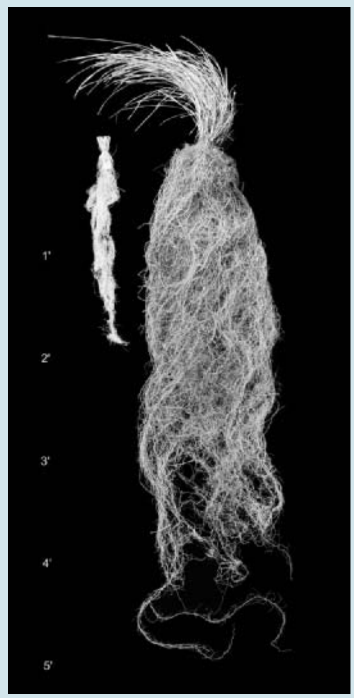
Researchers are busy trying to improve yields of different varieties of these perennial crops, which are not all as high as yields of annual crops. However, in the U.S. state of Washington, researchers have bred perennial wheat varieties that have a 70% higher yield than current commercially grown annual wheat varieties.

The Land Institute's approach, called *natural systems agriculture*, copies nature by growing a diversity of perennial crops, ideally by using organic methods. It has a number of environmental benefits. Because the plants are perennials, there is no need to till the soil and replant seeds each year. This reduces topsoil erosion and water pollution from eroded sediment, because the unplowed topsoil is not exposed to wind and rain. In addition, it reduces the need for irrigation because the deep roots of such perennials retain more water than do the shorter roots of annuals (Figure 12-C). Also, there is little or no need for chemical fertilizers and pesticides, and thus little or no pollution from these sources. Perennial polycultures also remove and store more carbon from the atmosphere, and raising them requires less energy than does growing crops in conventional monocultures.

Wes Jackson calls for governments to promote this and other forms of more sustainable agriculture. He argues that they will help us to reduce topsoil erosion, sustain nitrogen nutrients in topsoil, cut the wasteful use of irrigation water, reduce dependence on fossil fuels, and reduce dead zones in coastal areas (Connections, p. 307). He reminds us that "if our agriculture is not sustainable, then our food supply is not sustainable."

Critical Thinking

Why do you think large seed companies generally oppose this form of more sustainable agriculture?



Scott Bontz/The Land Institute

Figure 12-C The roots of an annual wheat crop plant (left) are much shorter than those of big bluestem (right), a tallgrass prairie perennial plant. The perennial plant is in the ground year-round and is much better at using water and nutrients, and at helping to maintain healthy topsoil. It also needs less fertilizer.

polyculture and monoculture, with increasing emphasis on organic farming methods. They also call for including the harmful environmental costs of growing food in market prices.

RESEARCH FRONTIER

Organic polyculture; see **www.cengage.com/login**.

Another key to developing more sustainable agriculture is to shift from using fossil fuels to relying more on solar energy for food production—an important application of the solar energy **principle of sustainability**. Farmers can make greater use renewable energy sources such as wind, flowing water, natural gas (produced from farm wastes in tanks called *biogas digesters*) to produce electricity and fuels needed for food production. Agricultural science writer Michael Pollan refers to this shift toward using more renewable energy for farming as "re-solarizing our food chain."

Proponents of more sustainable agricultural systems point out that we have all of the components needed for making a shift to such systems; we need only the political and ethical will to make it happen. They say that over the next 5 decades, a combination of education and economic policies that reward more sustainable agriculture can lead to such a shift.

Critics say that this approach will not produce enough food and will lead to food shortages. But experience and research show that well-designed forms of more sustainable polyculture can produce much higher crop yields than conventional monocultural industrial farming can. They can also greatly reduce the huge harmful environmental impact of conventional industrialized agriculture. Shifting to such agriculture could increase the world's food supply by up to 50%, according to a recent study by University of Michigan scientists.

Analysts suggest five major strategies to help farmers and consumers make the transition to more sustainable agriculture over the next 50 years (**Concept 12-6**). *First*, greatly increase research on more sustainable organic farming (**Core Case Study**) and perennial polyculture (Science Focus at left), and on improving human nutrition. *Second*, establish education and training programs in more sustainable agriculture for students, farmers, and government agricultural officials. *Third*, set up an international fund to give farmers in poor countries access to forms of more sustainable agriculture. *Fourth*, replace government subsidies for environmentally harmful forms of industrialized agriculture with subsidies that encourage more sustainable agriculture. *Fifth*, mount a massive program to educate consumers about the true costs of the food they buy. This would help them understand why the current system is unsustainable, and it would build political support for including the harmful costs of food production in the market prices of food.

Buy Locally Grown Food, Grow More Food Locally, and Cut Food Waste

Figure 12-37 lists ways in which you can promote more sustainable agriculture.

According to some experts, one component of more sustainable agriculture is to grow more of our food locally or regionally, ideally with certified organic farming practices. A growing number of consumers are becoming "locavores" and buying more of their food from local and regional producers in farmers' markets. Some people are participating in *community-supported agriculture (CSA)* programs in which they buy shares of a local farmer's crop and receive a box of fruits or vegetables each week during the summer and fall. (Local Harvest has a searchable online directory of the roughly 1,500 CSA farms in the United States at **localharvest.org/csa**.)

Yale University is committed to growing food locally and more sustainably. It has a plot of land less than half the area of a typical city block that produces more than 300 varieties of vegetables, fruits, and flowers to be used on campus and for sale locally. According to the school's food service director, up to 49% of the food served is local, seasonal, or organic.

Buying locally supports local economies and farm families, and it might help to slow the rapid conversion of farmland to suburban development. Buying food locally can also reduce fossil fuel energy costs as well as the greenhouse gas emissions from food production, because locally grown food does not have to be transported very far from producer to consumer.

An increase in the demand for locally grown food could result in more small, diversified farms that produce organic, minimally processed food from plants and animals. Such eco-farming could be one of this century's challenging new careers for many young people. There is a lot of room for growth in this area. According to Michael Pollan, locally grown food currently accounts for less than 1% of the food consumed in the United States. **GREEN CAREER:** small-scale sustainable agriculture

People living in urban areas could grow more of their own food. According to the USDA, around 15% of the world's food is grown in urban areas, and this percentage could easily be doubled. People plant gardens and raise chickens in suburban backyards. In cities, they grow food on rooftops and balconies, on patios, and in raised beds in unused or partially used parking lots (a growing practice known as *asphalt gardening*). Also, dwarf fruit trees can be planted in large containers of soil to be raised indoors. One visionary professor sees the day when much of our food will be grown downtown in high-rise buildings. We discuss such vertical urban farming in Chapter 22.

CONNECTIONS

Urban Gardening and Toxic Lead Exposure

Health scientists urge gardeners to test their soil for lead content before growing food in urban and suburban areas. Because toxic and indestructible lead was once a common ingredient of gasoline, paints, plumbing, and some pesticides, it is present in high levels in many urban and suburban soils. Soil found to have lead in it can be treated or removed from urban gardens and replaced with uncontaminated soil.

What Can You Do?

Sustainable Organic Agriculture

- Eat less meat, no meat, or organically certified meat
- Use organic farming to grow some of your food
- Buy certified organic food
- Eat locally grown food
- Compost food wastes
- Cut food waste

Figure 12-37 **Individuals matter:** There are a number of ways to promote more sustainable agriculture (**Concept 12-6**). **Questions:** Which three of these actions do you think are the most important? Why?

Finally, people can sharply cut food waste as an important component of improving food security (**Concept 12-5**). In 2008, environmental scientist Vaclav Smil estimated that Americans waste 35–45% of their food supply. Research at the University of Arizona puts this figure at around 50%. Scientists at Cornell University found that food production accounted for about 20% of this waste, distribution for another 20%, and consumption for the remaining 60%. This wasted food is worth at least $43 billion a year, almost twice as much as the $24 billion needed to eliminate undernutrition and malnutrition in the world, according to the UN. Many of the world's more-developed countries have similarly high rates of food waste. And in some less-developed countries, food waste can be high due to spoilage from heat, pests, and lack of refrigeration.

We are at a fork in the road. We can keep on using our current food production systems, which some experts argue are unsustainable and could collapse if fossil fuel prices rise sharply. Or we can try a new, more sustainable path that will sharply reduce the harmful environmental impacts of industrialized agriculture. This is an urgent and exciting challenge,

Here are this chapter's *three big ideas*:

- More than 1 billion people have health problems because they do not get enough to eat and 1.1 billion people face health problems from eating too much.
- Modern industrialized agriculture has a greater harmful impact on the environment than any other human activity.
- More sustainable forms of food production will greatly reduce the harmful environmental impacts of current systems while increasing food security.

REVISITING Organic Agriculture and Sustainability

CORE CASE STUDY SUSTAINABILITY

This chapter began with a look at how we can produce food through organic agriculture, a rapidly growing component of more sustainable agriculture (**Core Case Study**). Putting more emphasis on diverse organic farming and perennial polyculture could help to reduce the enormous harmful environmental impacts of agriculture as a whole (Figure 12-10).

Making the transition to more sustainable agriculture involves applying the three **principles of sustainability** (see back cover). All of these principles are violated by modern industrialized agriculture, because it depends heavily on nonrenewable fossil fuels and includes too little recycling of crop and animal wastes. It accelerates topsoil erosion and water pollution, and does too little to preserve agrobiodiversity. Further, it can destroy or degrade wildlife habitats and disrupt natural species interactions that help to control pest population sizes. Conventional aquaculture and other forms of industrialized food production violate these principles of sustainability in similar ways.

Thus, making this transition means relying more on solar and other forms of renewable energy and less on fossil fuels. It also means sustaining chemical cycling by returning crop residues and animal wastes to the soil. It involves helping to sustain natural and agricultural biodiversity by relying on a greater variety of crop and animal strains. Controlling pest populations through broader use of conventional and perennial polyculture, integrated pest management, and hydroponic food production will also help to sustain biodiversity.

Such efforts will be enhanced if we can control the growth of the human population and our wasteful use of food and resources. Governments could help these efforts by replacing environmentally harmful agricultural subsides and tax breaks with more environmentally beneficial ones. The transition to more sustainable food production would be accelerated if we could find ways to include the harmful environmental and health costs of food production in the market prices of foods.

Making the transition to more sustainable forms of food production will not be easy. But it can be done if we mimic nature by using the three **principles of sustainability** to meet our food needs.

While there are alternatives to oil, there are no alternatives to food.

MICHAEL POLLAN

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 278. Define **organic agriculture** and compare its main components with those of conventional industrialized agriculture.
2. Define **food security** and **food insecurity**. What is the root cause of food insecurity? Distinguish between **chronic undernutrition (hunger)** and **chronic malnutrition** and describe their harmful effects. What is a **famine**? Describe the effects of diet deficiencies in vitamin A, iron, and iodine. What is **overnutrition**, and what are its harmful effects?
3. What three systems supply most of the world's food? Define **irrigation**. Define and distinguish among **industrialized agriculture (high-input agriculture)**, **plantation agriculture**, **hydroponics**, **traditional subsistence agriculture**, **traditional intensive agriculture**, **polyculture**, and **slash-and-burn agriculture**. What are the major advantages and disadvantages of raising food

hydroponically in greenhouses? How does conventional industrialized agriculture violate the three principles of sustainability? Define **soil** and describe its formation and the major layers in mature soils. What is a **green revolution**? Describe industrialized food production in the United States.

4. Distinguish between crossbreeding through artificial selection and genetic engineering. Describe the second gene revolution based on genetic engineering. Describe the growth of industrialized meat production. What is a **fishery**? What is **aquaculture**? Summarize the use of energy in industrialized food production. Why does it result in a net energy loss?

5. What are two major advantages of high-yield modern agriculture? What are the major harmful environmental impacts of agriculture? What is **soil erosion** and what are its two major harmful environmental effects? What is **desertification** and what are its harmful environmental effects? Distinguish between **salinization** and **waterlogging** of soil and describe their harmful environmental effects. What is the biggest problem resulting from excessive use of water for irrigation in agriculture?

6. Summarize agriculture's contribution to projected climate change. Explain how industrialized food production systems reduce biodiversity in areas where crops are growing. What is agrobiodiversity and how is it being affected by industrialized food production? Describe the advantages and disadvantages of using genetic engineering in food production. What factors can limit green revolutions? Compare the advantages and disadvantages of industrialized meat production. What is the connection between feeding livestock and the formation of ocean dead zones? Compare the advantages and disadvantages of aquaculture.

7. What is a **pest**? Define and give two examples of a **pesticide**. Describe Rachel Carson's contributions to environmental science. Describe the advantages and disadvantages of modern pesticides. Describe the use of laws and treaties to help protect us from the harmful effects of pesticides. List and briefly describe seven alternatives to conventional pesticides. Define **integrated pest management (IPM)** and discuss its advantages and disadvantages.

8. What are the two main approaches used by governments to influence food production? How have governments used subsidies to influence food production and what have been some of their effects? What are three other ways in which organizations are improving food security?

9. What is **soil conservation**? Describe six ways to reduce topsoil erosion. Summarize the history of soil erosion and soil conservation in the United States. Distinguish among the uses of **organic fertilizer**, **manufactured inorganic fertilizer**, **animal manure**, **green manure**, and **compost** as ways to help restore topsoil fertility. Describe ways to prevent and clean up soil salinization. How can we reduce desertification? How can we make aquaculture more sustainable? Describe ways to produce meat more efficiently and sustainably. Summarize three important aspects of making a shift to more sustainable food production. Describe the advantages of organic farming and its role in shifting to more sustainable agriculture. What five strategies could help farmers and consumers shift to more sustainable agriculture? List the advantages of relying more on organic polyculture and perennial crops. What are three important ways in which individual consumers can help to promote more sustainable agriculture?

10. What are the three big ideas of this chapter? Describe the relationship between industrialized agriculture and the three **principles of sustainability**. How can these principles be applied toward making a shift to more sustainable food production systems? SUSTAINABILITY

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. Do you think that the advantages of organic agriculture (**Core Case Study**) outweigh its disadvantages? CORE CASE STUDY Explain. Do you eat or grow organic foods? If so, explain your reasoning for making this choice. If not, explain your reasoning for the food choices you do make.

2. What are the three most important actions you would take to reduce chronic hunger and malnutrition **(a)** in the country where you live and **(b)** in the world?

3. Explain why you support or oppose greatly increased use of **(a)** genetically modified (GM) food, **(b)** organic polyculture, and **(c)** hydroponic agriculture.

4. Suppose you live near a coastal area and a company wants to use a fairly large area of coastal marshland for an aquaculture operation. If you were an elected local official, would you support or oppose such a project? Explain. What safeguards or regulations would you impose on the operation?

5. Explain how widespread use of a pesticide can **(a)** increase the damage done by a particular pest and **(b)** create new pest organisms.

6. If a local mosquito population threatened you with malaria or West Nile virus, would you want to spray DDT in your yard and inside your home to reduce the risk? Explain. What are the alternatives?

7. List three ways in which your lifestyle directly or indirectly contributes to topsoil erosion.

8. According to physicist Albert Einstein, "Nothing will benefit human health and increase the chances of survival of life on Earth as much as the evolution to a vegetarian diet." Are you willing to eat less meat or no meat? Explain.

9. Congratulations! You are in charge of the world. List the three most important features of your **(a)** agricultural policy, **(b)** plan to reduce topsoil erosion, **(c)** plan for more sustainable harvesting and farming of fish and shellfish, and **(d)** global pest management strategy.

10. List two questions that you would like to have answered as a result of reading this chapter.

DATA ANALYSIS

The following table gives the world's fish harvest and population data for the years 1990 through 2003. Study the data and answer the questions below.

	World Fish Harvest				
Years	**Fish Catch (million metric tons)**	**Aquaculture (million metric tons)**	**Total (million metric tons)**	**World Population (in billions)**	**Per Capita Fish Consumption (kilograms/person)**
1990	84.8	13.1	97.9	5.27	
1991	83.7	13.7	97.4	5.36	
1992	85.2	15.4	100.6	5.44	
1993	86.6	17.8	104.4	5.52	
1994	92.1	20.8	112.9	5.60	
1995	92.4	24.4	116.8	5.68	
1996	93.8	26.6	120.4	5.76	
1997	94.3	28.6	122.9	5.84	
1998	87.6	30.5	118.1	5.92	
1999	93.7	33.4	127.1	5.995	
2000	95.5	35.5	131.0	6.07	
2001	92.8	37.8	130.6	6.15	
2002	93.0	40.0	133.0	6.22	
2003	90.2	42.3	132.5	6.20	

1. Use the world fish harvest and population data in the table to calculate the per capita fish consumption from 1990–2003 in kilograms/person. (*Hints:* 1 million metric tons equals 1 billion kilograms; and per capita consumption can be calculated directly by dividing the total amount consumed by a population figure for any year.)

2. Has per capita fish consumption generally increased or generally decreased between 1990 and 2003?

3. In what years has per capita fish consumption decreased?

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengagebrain.com/shop/ISBN/0538735341** and choose Chapter 12 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

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Water Resources

13

The Colorado River Story

CORE CASE STUDY

The Colorado River, the major river of the arid southwestern United States, flows 2,300 kilometers (1,400 miles) through seven states to the Gulf of California (Figure 13-1). Most of its water comes from snowmelt in the Rocky Mountains. During the past 50 years, this once free-flowing river has been tamed by a gigantic plumbing system consisting of 14 major dams and reservoirs (Figure 13-2), and canals that supply water to farmers, ranchers, industries, and cities.

This system of dams and reservoirs provides water and electricity from hydroelectric plants at the major dams for roughly 30 million people in seven states—about one of every ten people in the United States. The river's water is used to produce about 15% of the nation's crops and livestock. It also supplies water to some of the nation's driest and hottest cities. Take away this tamed river and Las Vegas, Nevada, would be a mostly uninhabited desert area; San Diego and Los Angeles, California, could not support their present populations; and California's Imperial Valley, which grows much of the nation's vegetables, would consist mostly of cactus and mesquite plants.

But so much water is withdrawn from this river to grow crops and support cities in a dry, desertlike climate, that very little of it reaches the sea. To make matters worse, the system has experienced severe *drought*, or prolonged dry weather, since 1999. This overuse of the Colorado River illustrates the challenges faced by governments and people living in arid and semiarid regions with shared river systems, as growing populations and economies place increasing demands on limited or decreasing supplies of surface water.

To many analysts, emerging shortages of water for drinking and irrigation in many parts of the world—along with the related problems of biodiversity loss and climate change—are the three most serious environmental problems the world faces during this century.

Figure 13-1 The *Colorado River basin*: The area drained by this basin is equal to more than one-twelfth of the land area of the lower 48 states. Two large reservoirs—Lake Mead behind the Hoover Dam and Lake Powell behind the Glen Canyon Dam—store about 80% of the water in this basin.

Jim Wark/Peter Arnold, Inc.

Figure 13-2 The Glen Canyon Dam across the Colorado River was completed in 1963. Lake Powell behind the dam is the second largest reservoir in the United States.

Key Questions and Concepts

13-1 Will we have enough usable water?

CONCEPT 13-1A We are using available freshwater unsustainably by wasting it, polluting it, and charging too little for this irreplaceable natural resource.

CONCEPT 13-1B One of every six people does not have sufficient access to clean water, and this situation will almost certainly get worse.

13-2 Is extracting groundwater the answer?

CONCEPT 13-2 Groundwater used to supply cities and grow food is being pumped from aquifers in some areas faster than it is renewed by precipitation.

13-3 Is building more dams the answer?

CONCEPT 13-3 Building dam-and-reservoir systems has greatly increased water supplies in some areas, but has also disrupted ecosystems and displaced people.

13-4 Is transferring water from one place to another the answer?

CONCEPT 13-4 Transferring water from one place to another has greatly increased water supplies in some areas but has also disrupted ecosystems.

13-5 Is converting salty seawater to freshwater the answer?

CONCEPT 13-5 We can convert salty ocean water to freshwater, but the cost is high, and the resulting salty brine must be disposed of without harming aquatic or terrestrial ecosystems.

13-6 How can we use water more sustainably?

CONCEPT 13-6 We can use water more sustainably by cutting water waste, raising water prices, slowing population growth, and protecting aquifers, forests, and other ecosystems that store and release water.

13-7 How can we reduce the threat of flooding?

CONCEPT 13-7 We can lessen the threat of flooding by protecting more wetlands and natural vegetation in watersheds, and by not building in areas subject to frequent flooding.

Note: Supplements 2 (p. S3), 3 (p. S6), and 8 (p. S30) can be used with this chapter.

Our liquid planet glows like a soft blue sapphire in the hard-edged darkness of space. There is nothing else like it in the solar system. It is because of water.

JOHN TODD

13-1 Will We Have Enough Usable Water?

▶ **CONCEPT 13-1A We are using available freshwater unsustainably by wasting it, polluting it, and charging too little for this irreplaceable natural resource.**

▶ **CONCEPT 13-1B One of every six people does not have sufficient access to clean water, and this situation will almost certainly get worse.**

Freshwater Is an Irreplaceable Resource That We Are Managing Poorly

We live on a water planet, with a precious layer of water—most of it saltwater—covering about 71% of the earth's surface (see Figure 8-2, p. 169). Look in the mirror. What you see is about 60% water, most of it inside your cells.

Water is an amazing and irreplaceable chemical with unique properties that keep us and other forms of life alive (see Chapter 3, Science Focus, p. 68).

We could survive for several weeks without food, but for only a few days without water. In addition, it takes huge amounts of water to supply us with food, energy and most of the other things that we use to meet our daily needs and wants. Water also plays a key role in sculpting the earth's surface (see Figure 3-18, p. 69), controlling and moderating the earth's climate, and removing and diluting some of the pollutants and wastes that we produce.

Indeed, freshwater is one of the earth's most important forms of natural capital. Despite its importance, water is one of our most poorly managed resources. We

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. GOOD NEWS refers to good news about the environmental challenges we face.

waste it and pollute it. We also charge too little for making it available. This encourages still greater waste and pollution of this resource, for which we have no substitute (**Concept 13-1A**).

Access to water is a *global health issue*. The World Health Organization (WHO) estimates that every day, an average of 3,900 children younger than age 5 die from waterborne infectious diseases because they do not have access to safe drinking water.

Water is an *economic issue* because it is vital for reducing poverty and producing food and energy. It is an *issue for women and children* in less-developed countries. Almost half of the world's people do not have water piped to their homes and as a result, poor women and girls often are responsible for finding and carrying daily supplies of water (Figure 13-3) from distant wells and other sources to their homes.

Water is also a *national and global security issue* because of increasing tensions both within and between nations over access to limited water resources that they share.

Water is an *environmental issue* because excessive withdrawal of water from rivers and aquifers results in falling water tables, decreasing river flows (**Core Case Study**), shrinking lakes, and disappearing wetlands. This loss of water in combination with water pollution result in declining water quality, lower fish populations, species extinctions, and degradation of aquatic ecosystem services (see Figure 8-5, p. 172, and Figure 8-15, p. 181).

CORE CASE STUDY

A. Ishokon-UNEP/Peter Arnold, Inc.

Figure 13-3 Many areas of the world suffer from severe and long-lasting shortages of freshwater. This has a major impact on the poor in some areas of India, especially women and children such as this young girl carrying water to her home in a very dry area. According to the United Nations, over 1.2 billion people—about 4 times the entire U.S. population—do not have access to clean water where they live. Each day girls and women in this group typically walk an average of almost 6 kilometers (4 miles) and spend an average of 3 hours collecting water from distant sources.

Most of the Earth's Freshwater Is Not Available to Us

Only a tiny fraction of the planet's enormous water supply—*about 0.024%*—is readily available to us as liquid freshwater in accessible groundwater deposits and in lakes, rivers, and streams. The rest is in the salty oceans (about 97% of the earth's volume of liquid water), in frozen polar ice caps and glaciers, or in deep underground, inaccessible locations.

Fortunately, the world's freshwater supply is continually collected, purified, recycled, and distributed in the earth's *hydrologic cycle*—the movement of water in the seas, in the air, and on land, which is driven by solar energy and gravity (see Figure 3-16, p. 67). This irreplaceable water recycling and purification system wors well, unless we overload it with pollutants or withdraw water from underground and surface water supplies faster than it can be replenished. We can also alter precipitation rates and distribution patterns of water through our influence on projected climate change. In some parts of the world, we are doing all of these things, mostly because we have thought of the earth's water as essentially a free and infinite resource. (See *The Habitable Planet*, Video 8, at **www.learner.org/resources/series209.html**).

On a global basis, we have plenty of freshwater but it is not distributed evenly. Differences in average annual precipitation and economic resources divide the world's continents, countries, and people into water *haves* and *have-nots*. For example, Canada, with only 0.5% of the world's population, has 20% of the world's liquid freshwater, while China, with 19% of the world's people, has only 7% of the supply. Asia has 60% of the population but only 30% of the water supply.

Groundwater and Surface Water Are Critical Resources

Some precipitation seeps into the ground and percolates downward through spaces in soil, gravel, and rock until an impenetrable layer of rock stops it. The water in these spaces is called **groundwater**—one of our most important sources of freshwater and a key component of the earth's natural capital.

The spaces in soil and rock close to the earth's surface hold little moisture. However, below a certain depth, in the **zone of saturation**, these spaces are completely filled with water. The top of this groundwater zone is the **water table**. It falls in dry weather, or when we remove groundwater faster than nature can replenish it, and it rises in wet weather.

Deeper down are geological layers called **aquifers**, underground caverns and porous layers of sand, gravel, or rock through which groundwater flows. Mostly because of gravity, groundwater normally moves from points of high elevation and pressure to points of lower elevation and pressure. Some caverns have rivers of groundwater flowing through them. But the porous layers of sand, gravel, or rock in most aquifers are like large, elongated sponges through which groundwater seeps—typically moving only a meter or so (about 3 feet) per year and rarely more than 0.3 meter (1 foot) per day. Watertight layers of rock or clay below such aquifers keep the water from escaping deeper into the earth.

We use pumps to bring large quantities of this groundwater to the surface for drinking, irrigating crops, and supplying industries. Most aquifers are replenished naturally by precipitation that percolates downward through exposed soil and rock, a process called *natural recharge*. Others are recharged from the side by *lateral recharge* from nearby lakes, rivers, and streams.

According to the U.S. Geological Survey, there is 100 times more freshwater underground than there is in all of the world's rivers and lakes. However, most aquifers recharge extremely slowly. Also, because so much of the earth's landscape has been built on or paved over, water can no longer penetrate the ground to recharge aquifers below many urban areas. In addition, in dry areas of the world, there is little precipitation available to recharge aquifers. Withdrawing water from such aquifers faster than it is replaced is like withdrawing money from a savings bank account faster than you deposit new money.

Nonrenewable aquifers get very little, if any, recharge. They are found deep underground and were formed tens of thousands of years ago. Withdrawing water from these aquifers amounts to *mining* a nonrenewable resource.

Another of our most important resources is **surface water**, the freshwater from precipitation and melted snow that flows across the earth's land surface and into lakes, wetlands, streams, rivers, estuaries, and ultimately into the oceans. Precipitation that does not infiltrate the ground or return to the atmosphere by evaporation is called **surface runoff**. The land from which surface water drains into a particular river, lake, wetland, or other body of water is called its **watershed**, or **drainage basin**. An example is the basin that supplies water to the Colorado River (Figure 13-1).

CORE CASE STUDY

CONNECTIONS

Groundwater and Surface Water

There is usually a connection between surface water and groundwater because eventually, most groundwater naturally flows into rivers, lakes, estuaries, and wetlands. Thus, if we disrupt the hydrologic cycle by removing groundwater faster than it is replenished, nearby streams, lakes, and wetlands can dry up. This process degrades aquatic biodiversity and other ecological services.

We Use Much of the World's Reliable Runoff

According to water scientists (hydrologists), two-thirds of the annual surface runoff into rivers and streams is lost in seasonal floods and is not available for human use. The remaining one-third is **reliable runoff**, which we can generally count on as a source of freshwater from year to year. **GREEN CAREER:** Hydrologist

During the last century, the human population tripled, global water withdrawals increased sevenfold, and per capita withdrawals quadrupled. As a result, we now withdraw about 34% of the world's reliable runoff. This is a global average. Withdrawal rates already severely strain the reliable runoff in some areas. For example, in the arid American Southwest, up to 70% of the reliable runoff is withdrawn for human purposes, mostly for irrigation (**Core Case Study**). Some water experts project that because of a combination of population growth, increased water use per person, and failure to reduce unnecessary water waste, we may be withdrawing up to 90% of the reliable runoff by 2025.

CORE CASE STUDY

Worldwide, we use 70% of the water we withdraw each year from rivers, lakes, and aquifers to irrigate cropland and raise livestock; that figure rises to 90% in arid regions. Industry uses another 20% of the water withdrawn each year, and cities and residences use the remaining 10%. Affluent lifestyles require large amounts of water (Science Focus, at right), much of it unnecessarily wasted.

CASE STUDY

Freshwater Resources in the United States

The United States has more than enough renewable freshwater. But it is unevenly distributed and much of it is contaminated by agricultural and industrial practices. The eastern states usually have ample precipitation, whereas many western and southwestern states have little (Figure 13-4, top, p. 322).

According to a 2009 study by U.S. Geological Survey (USGS), in 2005, groundwater and surface water withdrawn in the United States was used primarily for removing heat from electric power plants (41%), irrigation (37%), public water supplies (13%), and industry and raising livestock (9%). In the eastern United States, most water is used for power plant cooling and manufacturing. In many parts of this area, the most serious water problems are flooding, occasional water shortages as a result of pollution, and **drought**, a prolonged period in which precipitation is at least 70% lower than average and evaporation is higher than normal in a particular area.

In the arid and semiarid areas of the western half of the United States (Figure 13-5, bottom, p. 322), irrigation counts for as much as 85% of water use. Much of

SCIENCE FOCUS

Water Footprints and Virtual Water

Each of us has a **water footprint**, which is a rough measure of the volume of water that we use directly and indirectly to keep ourselves alive and to support our lifestyles.

According to the American Waterworks Association, each day the average American directly uses about 260 liters (69 gallons) of water—enough water to fill about 1.7 typical bathtubs of water (each containing about 151 liters, or 40 gallons, of water). In the United States, this water is used mostly for flushing toilets (27%), washing clothes (22%), taking showers (17%), and running faucets (16%), or is wasted by water leaks (14%). By contrast, the world's poorest people each use less than 19 liters (5 gallons) of water a day, on average.

We use much larger amounts of water indirectly, because water is used to provide us with food and other consumer products. Producing and delivering a typical hamburger, for example, takes about 2,400 liters (630 gallons) of water—most of which is used to grow the grain that is fed to cattle. This water would fill about 16 bathtubs. Similarly, according to the Coca Cola Company, it takes about 500 liters (132 gallons)—roughly 3 bathtubs of water—to make a 2-liter (0.5-gallon) bottle of soda, if you include the water used to grow and harvest ingredients such as sugar cane.

Water that is not directly consumed but is used to produce food and other products is called **virtual water**, and it makes up a large part of our water footprints, especially in more-developed countries. Figure 13-A shows examples of the amounts of virtual water used for producing and delivering products. These values can vary, depending on how much of the supply chain is included, but they give us a rough estimate of the size of our water footprints.

Because of global trade, the virtual water used to produce and transport the wheat in a loaf of bread or the coffee beans used to make a cup of coffee (Figure 13-A) is often withdrawn as groundwater or surface water in another part of the world. For some countries, it makes sense to save real water by importing virtual water through food imports, instead of producing all of their food domestically. Such countries include Egypt and other Middle Eastern nations in dry climates with little water. Five countries—the Netherlands, Jordan, the United Kingdom, Japan, and South Korea—depend on virtual water imports for more than 62% of their water needs.

Large exporters of virtual water—mostly in the form of wheat, corn, soybeans, and other foods—are the European Union, the United States, Brazil, and Australia. Indeed, Brazil's supply of freshwater per person is more than 8 times the U.S. supply per person, 14 times China's supply, and 29 times India's supply. This explains why Brazil is likely to be one of the world's largest exporters of virtual water in the form of crops such as soybeans (see Figure 1-6, p. 10) to countries such as China. However, prolonged severe droughts in parts of Australia, the United States, and the European Union are stressing the abilities of these countries to meet the growing global demand for their food exports. In addition, a fourth of the U.S. corn crop is now being converted to ethanol to "feed" cars instead of people and livestock. If climate change threatens water supplies as projected for some important crop-growing and food-exporting regions, water scarcity will turn into food scarcity as virtual water supplies drop—another example of connections in nature.

Critical Thinking

About how many bathtubs of water were used to provide all of the jeans and cotton shirts that you own? About how many tubs of water were used to provide you with the bread that you typically eat each week?

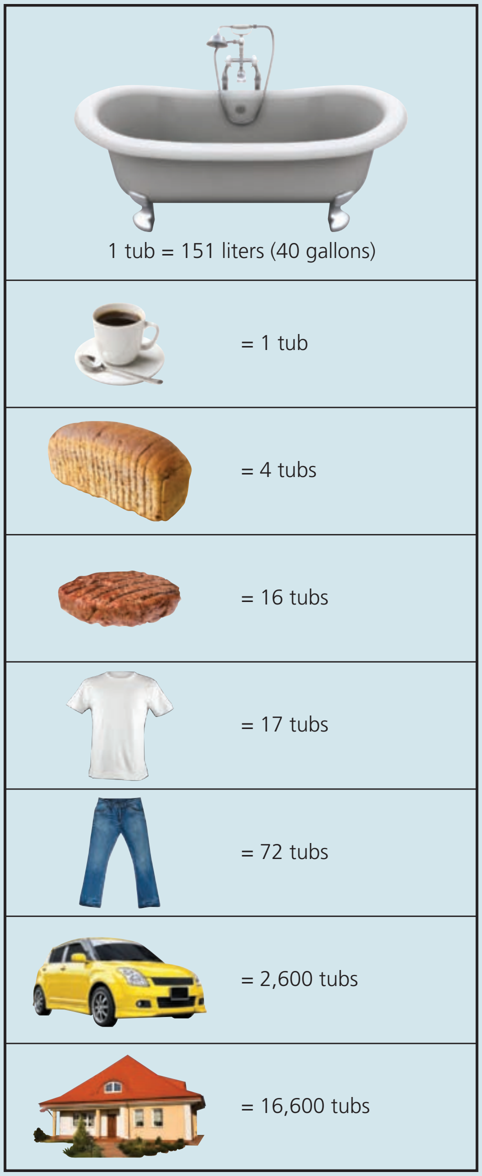
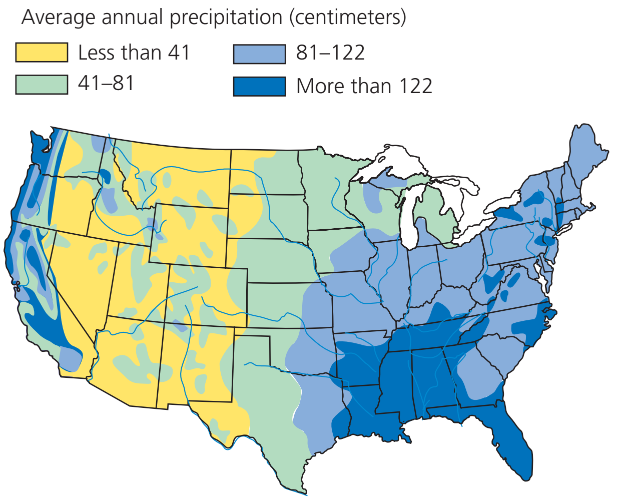


Figure 13-A Producing and delivering a single one of each of the products shown here requires the equivalent of at least one and usually many bathtubs full of water, called *virtual water*. A typical bathtub contains about 151 liters (40 gallons) of water. The average amount of water used to raise a single steer during its typical 3-year life from birth to slaughter and to market by an industrial producer would fill more than 20,000 bathtubs. This includes water used for providing the steer with food and drinking water and water used to clean up its wastes. It is not surprising that about 70% of the world's water is used for irrigation, because it takes about 1,000 metric tons (900 tons) of water to produce 1 metric ton (0.9 ton) of grain. (Data from UNESCO-IHE Institute for Water Education, UN Food and Agriculture Organization, World Water Council, Water Footprint Network, and Coca Cola Company) [Photos from Shutterstock; Credits (top to bottom: Kirsty Pargeter, Aleksandra Nadeina, Alexander Kallina, Kelpfish, Wolfgang Amri, Skip Odonnell, Eky Chan, Rafal Olechowski)]



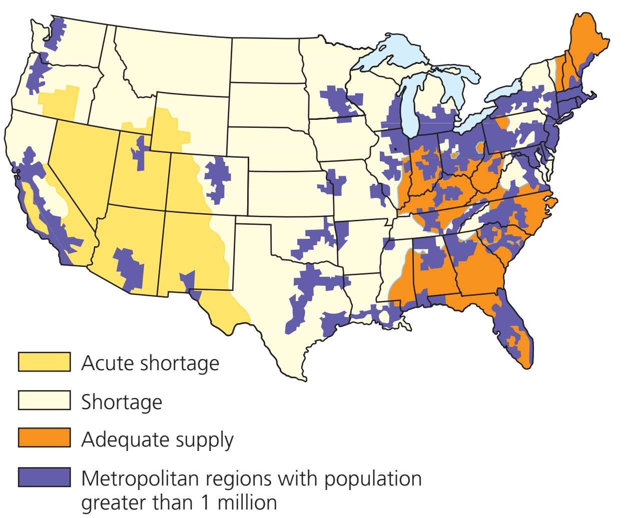


Figure 13-4 The top map shows the average annual precipitation and major rivers in the continental United States. The bottom map shows water-deficit regions in the continental United States and their proximity to metropolitan areas having populations greater than 1 million (shaded areas). **Question:** Why do you think some areas with moderate precipitation still suffer from water shortages? (Data from U.S. Water Resources Council and U.S. Geological Survey)

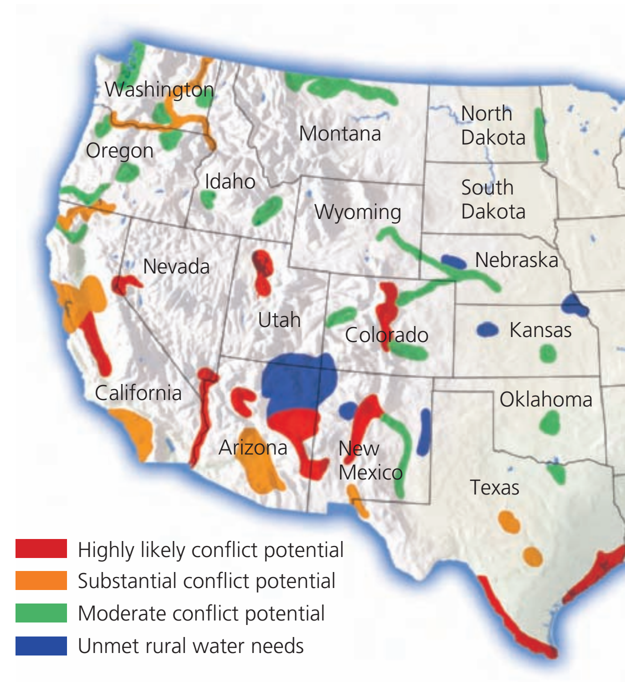


Figure 13-5 This map shows water scarcity hotspots in 17 western states that, by 2025, could face intense conflicts over scarce water needed for urban growth, irrigation, recreation, and wildlife. Some analysts suggest that this is a map of places not to live in the foreseeable future. **Question:** Which, if any, of these areas are found in the Colorado River basin (Figure 13-1)? (Data from U.S. Department of the Interior)

it is unnecessarily wasted and used to grow thirsty crops on arid and semiarid land. The major water problem in much of the western United States is a shortage of runoff caused by low precipitation (Figure 13-4, top), high evaporation, and recurring prolonged drought.

According to the USGS, about one-third of the freshwater withdrawn in the United States comes from groundwater sources, and the other two-thirds comes from rivers, lakes, and reservoirs. Water tables in many water-short areas, especially in the arid and semiarid western half of the lower 48 states, are dropping quickly as farmers and rapidly growing urban areas (Figure 13-5, purple areas, bottom) deplete many aquifers faster than they can be recharged.

In 2007, the USGS projected that areas in at least 36 states are likely to face water shortages by 2013 because of a combination of drought, rising temperatures, population growth, urban sprawl, and increased use and waste of water. The U.S. Department of the Interior mapped out *water hotspots* in 17 western states (Figure 13-5). In these areas, competition for scarce water to support growing urban areas, irrigation, recreation, and wildlife could trigger intense political and legal conflicts between states and between rural and urban areas within states during the next 20 years. Based on 19 global climate models used by the UN Intergovernmental Panel on Climate Change, climate researcher Richard Seager and his colleagues at Columbia University have projected that the southwestern United States and parts of northern Mexico are very likely to have long periods of extreme drought throughout most of the rest of this century.

The Colorado River system (Figure 13-1) will be directly affected by such drought. There are five major problems associated with the use of water from this river (**Core Case Study**). *First*, the Colorado River basin includes some of the driest lands in the United States and Mexico. *Second*, for its size, the river has only a modest flow of water. *Third*, legal pacts signed in 1922 and 1944 between the United States and Mexico allocated more water for human use than the river can supply—even in rare years when there is no drought. In addition, the pacts allocated no water for protecting aquatic and terrestrial wildlife. *Fourth*, since 1960, the river has rarely flowed all the way to the Gulf of California because of its reduced water flow (due to many dams), increased water withdrawals, and a prolonged drought in much of the American Southwest. *Fifth*, the river receives enormous amounts of pollutants from urban areas, farms, animal feedlots, and industries, as it makes its way toward the sea.

According to 2009 study by the U.S. Geological Survey, between 1975 and 2005, the amount of water used in the United States has remained fairly stable despite a 30% rise in population and a significant increase in average resource use per person. This is mainly because of increased use of more efficient irrigation systems and reduced use of one-way cooling for many electric power plants. This is an encouraging trend but the United States still unnecessarily wastes about half of the water it withdraws from groundwater and surface supplies.

Water Shortages Will Grow

The main factors that cause water scarcity in any particular area are a dry climate, drought, too many people using a water supply more quickly than it can be replenished, and wasteful use of water. Figure 13-6 shows the current degree of stress faced by each of the world's major river systems, based on a comparison of the amount of available surface water with the amount used per person.

More than 30 countries—most of them in the Middle East and Africa—now face stress from water scarcity. By 2050, some 60 countries, many of them in Asia, with three-fourths of the world's population, are likely to be suffering from water stress. Per capita water resources in China, the world's most populous country, are less than a third of the global average, and falling. In 2006, the Chinese government reported that two-thirds of China's 600 major cities faced water shortages. Rapid urbanization, economic growth, and drought are expected to put further strains on China's already short water resources. And per capita water resources in India, the world's second most populous country, are about one-sixth the global average. On the other hand, Brazil's per capita water resources are almost 4 times the global average.

Currently, about 30% of the earth's land area—a total area roughly 5 times the size of the United States—experiences severe drought. In 2007, climate researcher David Rind and his colleagues projected that by 2059, as much as 45% of the earth's land surface—more than 7 times the area of the United States—could experience extreme drought, mostly as a result of projected climate change caused by a warmer atmosphere.

Two or more countries share the available water supplies in each of 263 of the world's water basins, which together cover nearly half of the earth's surface and are home to about 40% of the world's people. However, countries in only 158 of those basins have water-sharing agreements. This explains why conflicts among nations over shared water resources are likely to increase as populations grow, as demand for water increases, and as supplies shrink in many parts of the world. **Explore More:** See a Case Study at **www.cengage.com/login** to learn about current and projected conflicts over water supplies in the Middle East.

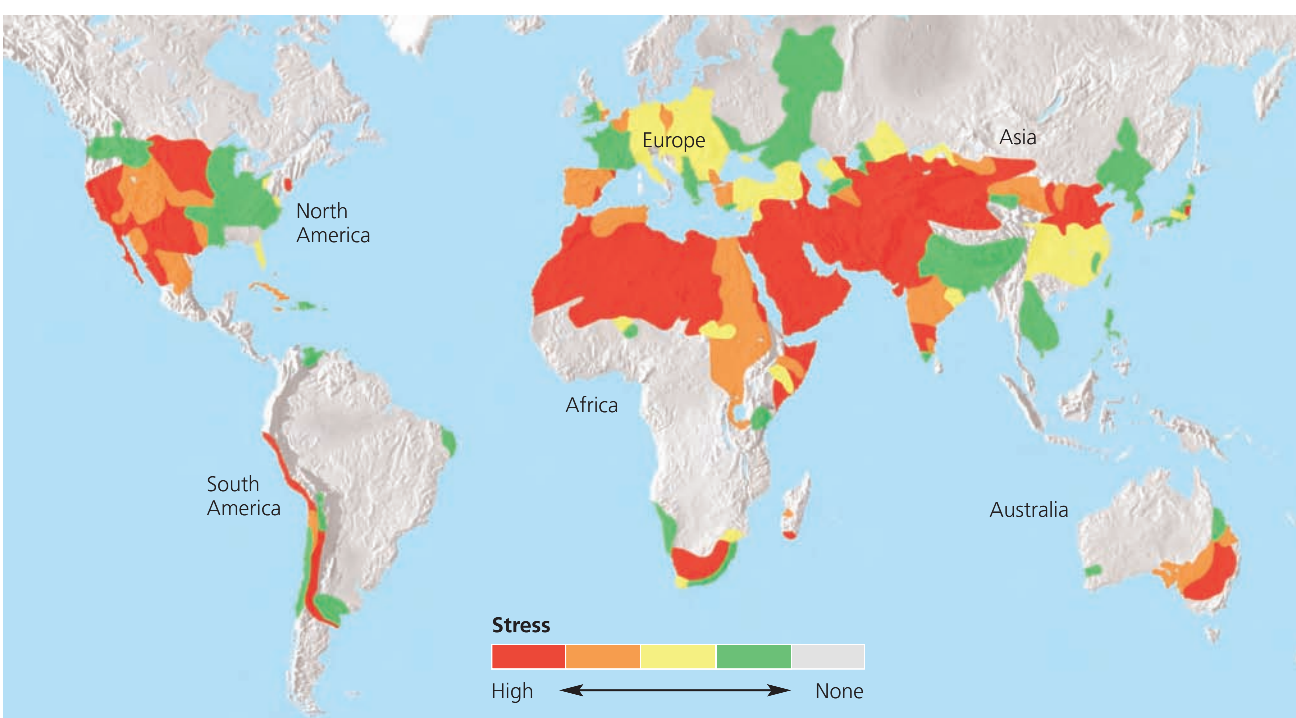


Figure 13-6 **Natural capital degradation:** The world's major river basins differ in their degree of water scarcity stress, the measurement of which is based on a comparison of the amount of water available with the amount used by humans (**Concept 13-1B**). **Questions:** If you live in a water-stressed area, what signs of stress have you noticed? In what ways, if any, has it affected your life? (Data from World Commission on Water Use in the 21st Century)

There are also conflicts over whether water supply resources should be owned and managed by local and national government agencies or by private companies. **Explore More:** See a Case Study at **www.cengage.com/login** for more details on this controversy.

In 2009, the United Nations reported that about 1.2 billion people—one of every six in the world—lacked regular access to enough clean water for drinking, cooking, and washing. The report also noted that by 2025, at least 3 billion of the world's projected 7.9 billion people are likely to lack access to clean water. This amounts to nearly 3 times the current population of China and nearly 10 times the current population of the United States.

If the second projection is correct, there are three likely results: greatly increased incidences of sickness and death from drinking contaminated water; millions of environmental refugees from arid and semiarid regions engaged in a desperate search for water, land, and food; and intense conflicts within and between countries—especially in the water-short Middle East and Asia—over dwindling shared water resources. This helps to explain why many analysts view the likelihood of increasing water shortages in many parts of the world as one of the world's most serious environmental, health, and national security problems.

CONNECTIONS

Water Shortages and Hunger

Some water-short countries are reducing their irrigation water needs by importing grain, thereby freeing up more of their own water supplies for industrial and urban development. The result is a competition for the world's grain, which includes indirect competition for the world's water (virtual water used to grow grain). In this global competition for water and grain, financially strong countries hold the advantage. As a result, grain prices are likely to rise, leading to food shortages and more widespread hunger among the poor.

There Are Several Ways to Increase Freshwater Supplies

So what can we do to deal with the projected shortages of freshwater in many parts of the world? One solution is to provide more water by reducing unnecessary waste of water. Other solutions involve increasing water supplies by withdrawing groundwater; building dams and reservoirs to store runoff in rivers for release as needed (**Core Case Study**); transporting surface water from one area to another; and converting saltwater to freshwater (desalination). The next four sections of this chapter look at the advantages and disadvantages of these options.

CORE CASE STUDY

13-2 Is Extracting Groundwater the Answer?

CONCEPT 13-2 Groundwater used to supply cities and grow food is being pumped from aquifers in some areas faster than it is renewed by precipitation.

Groundwater Is Being Withdrawn Faster Than It Is Replenished in Some Areas

Most aquifers are renewable resources unless the groundwater they contain becomes contaminated or is removed faster than it is replenished by rainfall, as is occurring in many parts of the world. Aquifers provide drinking water for nearly half of the world's people. In the United States, aquifers supply almost all of the drinking water in rural areas, one-fifth of that in urban areas, and 37% of the country's irrigation water. Relying more on groundwater has advantages and disadvantages (Figure 13-7).

Currently, water tables are falling in many areas of the world because the rate of pumping water from nearly all of the world's aquifers (mostly to irrigate crops) is greater than the rate of natural recharge from rainfall and snowmelt (**Concept 13-2**). The world's three largest grain producers—China, India, and the United States—as well as Mexico, Saudi Arabia, Iran, Yemen, Israel, and Pakistan are overpumping many of their aquifers.

Every day, the world withdraws enough water from aquifers to fill a convoy of large tanker trucks stretching 480,000 kilometers (298,000 miles)—more than the distance to the moon. Currently, more than 400 million people, including 175 million in India and 130 million in China, are being fed by grain produced through this unsustainable use of groundwater, according to the World Bank. This number is expected to grow until the water runs out or until governments put caps on aquifer withdrawal rates and stop providing subsidies that encourage overpumping and water waste.

The widespread drilling of inexpensive tube wells by small farmers, especially in India and China, has accelerated aquifer overpumping. As water in aquifers is removed faster than it is renewed, water tables fall. Then farmers drill deeper wells, buy larger pumps, and

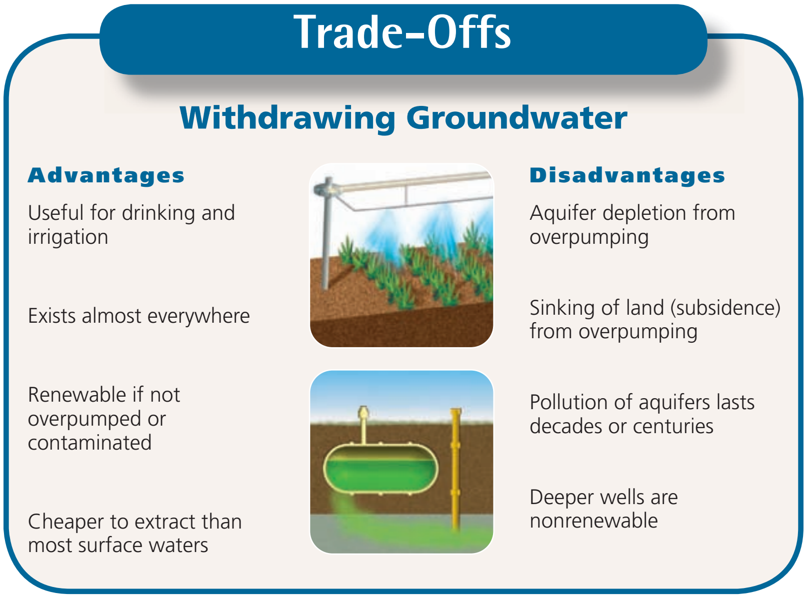


Figure 13-7 Withdrawing groundwater from aquifers has advantages and disadvantages. **Questions:** Which two advantages and which two disadvantages do you think are the most important? Why?

use more energy to pump water to the surface. This process eventually depletes the groundwater in aquifers or at least removes all the water that can be pumped at an affordable cost.

Saudi Arabia is as water-poor as it is oil-rich. It gets about 70% of its drinking water at a high cost by removing salt from seawater, a process called *desalination*. The rest of the country's water is pumped from deep aquifers, which are about as nonrenewable as the country's oil. Much of this water is used to irrigate crops such as wheat grown on desert land (Figure 13-8) and to fill large numbers of fountains and swimming pools, which lose a lot of water through evaporation into the hot, dry desert air. In 2008, Saudi Arabia announced that irrigated wheat production had largely depleted its major deep aquifer and said that it would stop producing wheat by 2016 and import grain (virtual water) to help feed its 30 million people.

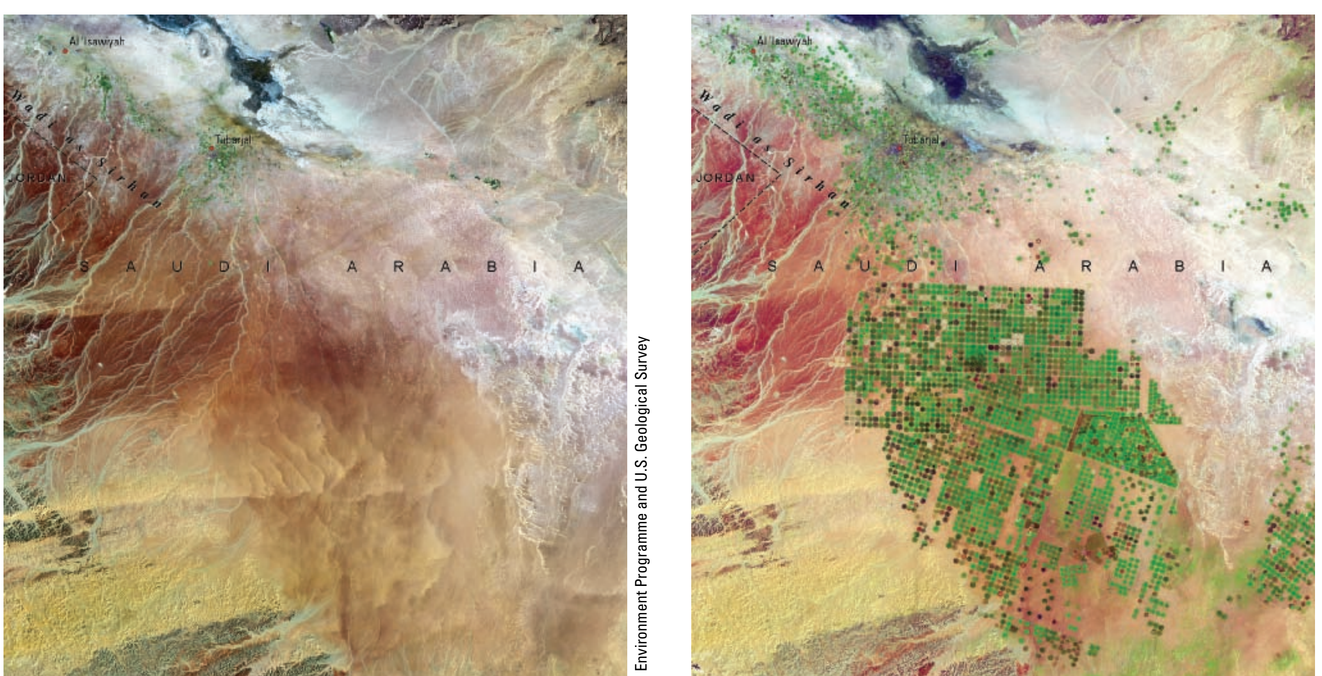
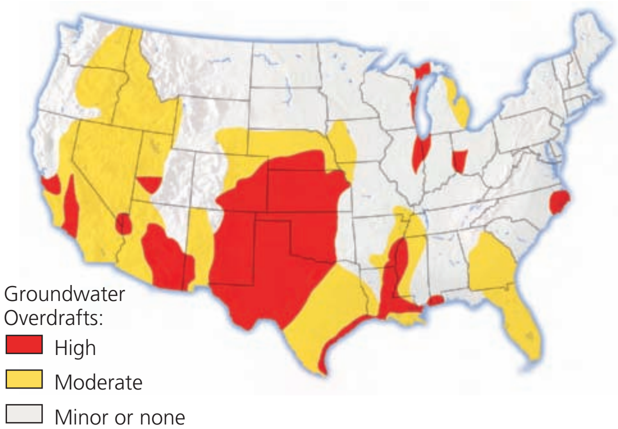


Figure 13-8 **Natural capital degradation:** These satellite photos show farmland irrigated by groundwater pumped from an ancient and nonrenewable aquifer in a vast desert region of Saudi Arabia between 1986 (left) and 2004 (right). Irrigated areas appear as green dots (each representing a circular spray system) and brown dots show areas where wells have gone dry and the land has returned to desert. Hydrologists estimate that because of aquifer depletion, most irrigated agriculture in Saudi Arabia will disappear within the next 5 to 10 years.



CENGAGENOW™ **Active Figure 13-9 Natural capital degradation:** This map shows areas of greatest aquifer depletion from groundwater overdraft in the continental United States. Aquifer depletion is also high in Hawaii and Puerto Rico (not shown on map). *See an animation based on this figure at* CengageNOW. **Questions:** Do you depend on any of these overdrawn aquifers for your drinking water? If so, what is the level of severity of overdraft where you live? (Data from U.S. Water Resources Council and U.S. Geological Survey)


Earth Observatory/NASA

Figure 13-10 These crop fields in the state of Kansas are irrigated by groundwater pumped from the Ogallala. Green circles show irrigated areas and brown, gray, and white circles represent fields that have been recently harvested and plowed under or that have not been planted for a year.

CASE STUDY

Aquifer Depletion in the United States

In the United States, groundwater is being withdrawn from aquifers, on average, four times faster than it is replenished, according to the U.S. Geological Survey (**Concept 13-2**). Figure 13-9 shows the areas of greatest aquifer depletion. One of the most serious overdrafts of groundwater is in the lower half of the Ogallala, the world's largest known aquifer, which lies under eight midwestern states from southern South Dakota to Texas (most of the large red area in the center of Figure 13-9).

The gigantic Ogallala aquifer supplies about one-third of all the groundwater used in the United States and has helped to turn the Great Plains into one of world's most productive irrigated agricultural regions (Figure 13-10). The problem is that the Ogallala is essentially a one-time deposit of liquid natural capital with a very slow rate of recharge.

In parts of the southern half of the Ogallala, groundwater is being pumped out 10–40 times faster than the slow natural recharge rate, which has lowered water tables and increased pumping costs, especially in northern Texas.

Government subsidies designed to increase crop production have encouraged farmers to grow water-thirsty crops in dry areas, which has accelerated depletion of the Ogallala. Serious aquifer depletion is also taking place in California's semiarid Central Valley, which supplies half of the country's fruits and vegetables (the long red area in the California portion of Figure 13-9). In 2009, Nobel Prize–winning physicist and U.S. Secretary of Energy Steven Chu warned that because of projected climate change, "We're looking at a worst case scenario where there's no more agriculture in California."

The Ogallala also helps to support biodiversity. In various places, groundwater from the aquifer flows out of the ground onto land or onto lake bottoms through exit points called *springs*. In some cases, springs feed wetlands, which are vital habitats for many species, especially birds. When the water tables fall, many of these aquatic oases of biodiversity disappear.

THINKING ABOUT
The Ogallala Aquifer

What are three things you would do to promote more sustainable use of the Ogallala aquifer?

Overpumping Aquifers Has Several Harmful Effects

Overpumping of aquifers not only limits future food production, but also increases the gap between the rich and poor in some areas. As water tables drop, farmers must drill deeper wells, buy larger pumps, and use more electricity to run those pumps. Poor farmers cannot afford to do this and end up losing their land and working for richer farmers, or migrating to cities that are already crowded with poor people struggling to survive.

Withdrawing large amounts of groundwater sometimes allows the sand and rock in aquifers to collapse.

This causes the land above the aquifer to *subside* or sink, a phenomenon known as *land subsidence*. Sharply defined, dramatic subsidence is sometimes referred to as *sinkholes*. Once an aquifer becomes compressed by subsidence, recharge is impossible. In addition, land subsidence can damage roadways, water and sewer lines, and building foundations. Areas in the United States suffering from such subsidence include California's San Joaquin Valley (Figure 13-11), Baton Rouge in Louisiana, the Phoenix area in Arizona, and parts of Florida.

Mexico City, built on an old lakebed, has one of the world's worse subsidence problems because of increasing groundwater overdrafts due to rapid population growth and urbanization. Some parts of the city have sunk as much as 10 meters (33 feet). Parts of Beijing, China are also sinking as its water table has fallen 61 meters (200 feet) since 1965.

Groundwater overdrafts near coastal areas, where many of the world's largest cities and industrial areas are found, can pull saltwater into freshwater aquifers. This makes the groundwater undrinkable and unusable for irrigation. This problem is especially serious in coastal areas of the U.S. states of California, Florida, South Carolina, Georgia, Texas, and New Jersey, as well as in areas of Turkey, the Philippines, and Thailand.

If we do not sharply slow the depletion of aquifers, an increasing number of the world's people will have to live on rainwater and suffer from decreased food production. Figure 13-12 lists ways to prevent or slow the problem of aquifer depletion by using this largely renewable resource more sustainably.

Dick Ireland/U.S. Geological Survey, 1977

Figure 13-11 This pole shows subsidence from overpumping of an aquifer for irrigation in California's San Joaquin Central Valley between 1925 and 1977. In 1925, the land surface in this area was near the top of this pole. Since 1977 this problem has gotten worse.

Solutions

Groundwater Depletion

Prevention	**Control**
Waste less water	Raise price of water to discourage waste
Subsidize water conservation	Tax water pumped from wells near surface waters
Limit number of wells	Set and enforce minimum stream flow levels
Do not grow water-intensive crops in dry areas	Divert surface water in wet years to recharge aquifers

Figure 13-12 There are a number of ways to prevent or slow groundwater depletion by using water more sustainably. **Questions:** Which two of these solutions do you think are the most important? Why?

Deep Aquifers Might Be Tapped

With global water shortages looming, scientists are evaluating *deep aquifers* as future water sources. Preliminary results suggest that some of these aquifers hold enough water to support billions of people for centuries. And the quality of water in these aquifers may be much higher than the quality of the water in most rivers and lakes.

GOOD NEWS

There are four major concerns about tapping these ancient deposits of water. *First*, they are nonrenewable and cannot be replenished on a human timescale. *Second*, little is known about the geological and ecological impacts of pumping water from deep aquifers. *Third*, some deep aquifers flow beneath more than one country, and there are no international treaties that govern rights to use them. Without such treaties, water wars could break out. *Fourth*, the costs of tapping deep aquifers are unknown and could be high.

13-3 Is Building More Dams the Answer?

▶ **CONCEPT 13-3 Building dam-and-reservoir systems has greatly increased water supplies in some areas, but has also disrupted ecosystems and displaced people.**

Large Dams and Reservoirs Have Advantages and Disadvantages

A **dam** is a structure built across a river to control the river's flow. Usually, dammed water creates an artificial lake, or **reservoir**, behind the dam (**Core Case Study** and Figure 13-2). The main goals of a dam-and-reservoir system are to capture and store runoff, and release it as needed to control floods, generate electricity (hydroelectricity), and supply water for irrigation and for towns and cities. Reservoirs also provide recreational activities such as swimming, fishing, and boat-

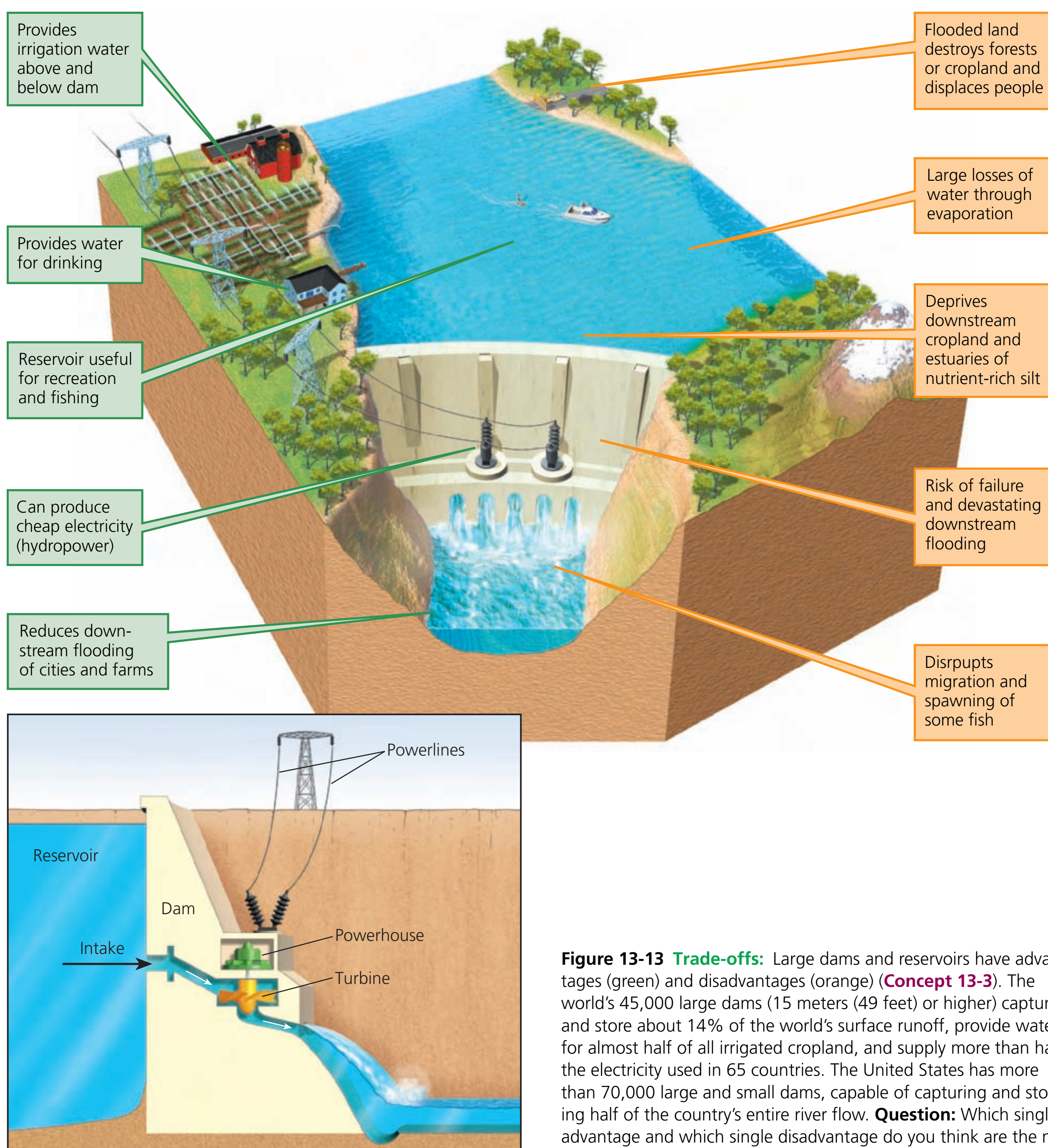


Figure 13-13 Trade-offs: Large dams and reservoirs have advantages (green) and disadvantages (orange) (**Concept 13-3**). The world's 45,000 large dams (15 meters (49 feet) or higher) capture and store about 14% of the world's surface runoff, provide water for almost half of all irrigated cropland, and supply more than half the electricity used in 65 countries. The United States has more than 70,000 large and small dams, capable of capturing and storing half of the country's entire river flow. **Question:** Which single advantage and which single disadvantage do you think are the most important?

ing. Large dams and reservoirs have both benefits and drawbacks (Figure 13-13).

More than 45,000 large dams in the world (22,000 of them in China, including the huge, recently built Three Gorges Dam) have increased the annual reliable runoff available for human use by nearly one-third. As a result, reservoirs now hold 3 to 6 times more water than the total amount flowing in all of the world's natural rivers. **Explore More:** See a Case Study at **www.cengage.com/login** to learn about the pros and cons of China's huge Three Gorges Dam.

On the down side, this engineering approach to river management has displaced 40–80 million people from their homes, flooded an area of mostly productive land totaling roughly the area of the U.S. state of California, and impaired some of the important ecological services that rivers provide (see Figure 8-15, left, p. 181). A 2007 study by the World Wildlife Fund (WWF) estimated that about one out of five of the world's freshwater fish and plant species are either extinct or endangered, primarily because dams and water withdrawals have sharply decreased the flow of many rivers such as the Colorado (**Core Case Study**, Figure 13-1). The study also found that, because of dams, excessive water withdrawals, and in some areas, prolonged severe drought, only 21 of the planet's 177 longest rivers run freely from their sources to the sea (see Figure 8-18, p. 183). Projected climate change will worsen this situation in areas that become hotter and receive less precipitation.

The reservoirs behind dams also eventually fill up with sediments such as mud and silt, typically within 50 years, which makes them useless for storing water or producing electricity. About 85% of U.S. dam-and-reservoir systems will be 50 years old or older by 2020.

Using dams to trap and store river flows and withdrawing large amounts of water from rivers for irrigation and drinking water can cause lakes and inland seas that are fed by these rivers to dry up. An example is Africa's Lake Chad. It is surrounded by the African countries of Chad, Niger, Cameroon, and Nigeria, which have some of the world's fastest growing populations. Because of a combination of rapid population growth, greatly increased and inefficient irrigation, and prolonged drought, the lake has shrunk by 97% since 1963 and may soon disappear completely.

HOW WOULD YOU VOTE?

Do the advantages of large dams outweigh their disadvantages? Cast your vote online at **www.cengage.com/login**.

If climate change occurs as projected during this century, it will intensify shortages of water in many parts of the world. Hundreds of millions of people in China, India, and other parts of Asia depend on river flows fed by melting glaciers in the Himalayas. Many of these glaciers in Asia and in parts of South America are receding as the earth's atmosphere warms. If these mountain glaciers eventually disappear, rivers that are fed by them will dwindle or dry up. This will make it more difficult for farmers who depend on this water to grow enough food for about 1 billion people—more than about 3 times the current U.S. population. In 2009, China announced plans to build 59 reservoirs to collect some of the water now melting from its shrinking glaciers.

A Closer Look at the Overtapped Colorado River Basin

Since 1905, the amount of water flowing to the mouth of the heavily dammed Colorado River (**Core Case Study** and Figure 13-1) has dropped dramatically (Figure 13-14). In most years since 1960, the river has dwindled to a small, sluggish stream by the time it reaches the Gulf of California. This threatens the survival of aquatic species that spawn in the river as well as those that live in its coastal estuary.

In 2008, a number of hydrologists warned that the current rate of withdrawal of water from the Colorado River is not sustainable. Water experts also project that if the climate continues to warm as projected, mountain snows that feed the river will melt faster and earlier, and the melt water will evaporate in greater amounts, making less water available to the river system. In 2009, a study by Balaji Rajagopalan and his colleagues at the University of Colorado in Boulder projected that if such changes cause a 20% drop in the river's flow, there is about a 50% chance that its reservoirs will be depleted by 2057.

Historically, about 80% of the water withdrawn from the Colorado has been used to irrigate crops and raise cattle. That is because the government paid for the

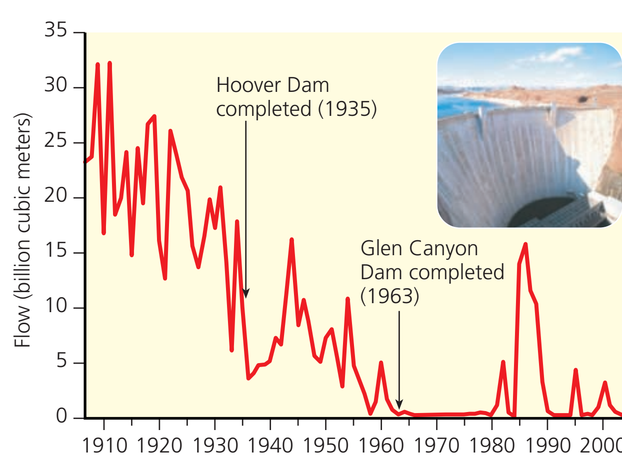


Figure 13-14 The measured flow of the Colorado River at its mouth has dropped sharply since 1905 as a result of multiple dams, water withdrawals for agriculture and urban water supplies, and prolonged drought. Historical records and tree-ring analysis show that about once every century, the southwestern United States suffers from a mega-drought—a decades-long dry period. (Data from U.S. Geological Survey)

dams and reservoirs and has supplied many farmers and ranchers with water at low prices. These government subsidies have led to inefficient use of irrigation water, including the growing of crops such as rice, cotton, and alfalfa that need a lot of water.

Other problems are evaporation, leakage of reservoir water into the ground below, and siltation from some of the large dammed reservoirs on the Colorado River. For example, there are huge losses of river water in the Lake Mead and Lake Powell reservoirs from evaporation and seepage of water into porous rock beds under the reservoirs.

In addition, as the flow of the Colorado River slows in large reservoirs behind dams, it drops much of its load of suspended silt. This deprives the river's coastal delta of much-needed sediment and causes flooding and loss of ecologically important coastal wetlands, as has happened in the area around the U.S. city of New Orleans, Louisiana (Case Study, p. 184). The amount of silt being deposited on the bottoms of the Lake Powell and Lake Mead reservoirs is roughly 20,000 dump truck loads every day. Sometime during this century, these reservoirs will probably be too full of silt to store water for generating hydroelectric power or controlling floods.

If some of the Southwest's largest reservoirs (Figure 13-2) essentially become empty during this century, the region could experience an economic and ecological catastrophe with fierce political and legal battles over who will get how much of the region's greatly diminished water supply. Agricultural production would drop sharply and many people in the region's booming desert cities such as Phoenix, Arizona, and Las Vegas, Nevada (which gets very little rain and relies on Lake Mead behind the Hoover Dam to meet more than 90% of its water needs), likely would have to migrate to other areas.

Withdrawing more groundwater from aquifers is not a solution, because water tables under much of the area served by the Colorado River have been dropping, sometimes drastically, due to aquifer overpumping (Figure 13-9). Such withdrawals threaten the survival of species that spawn in the river, and estuaries that serve as breeding grounds for numerous aquatic species are shrinking.

To deal with the water supply problems in the dry Colorado River basin, water experts call for the seven states using the river to enact and enforce strict water conservation measures and to slow urban population growth and urban development. They also call for eliminating subsidies for agriculture in this region, shifting water-thirsty crops to less arid areas, and prohibiting the use of water to keep golf courses and lawns green in this desert area. They suggest that sharply increasing the historically low price of water from the river is an important way to promote such solutions.

The case of the Colorado River system illustrates the problems faced by people living in arid and semiarid regions with shared river systems. These already serious problems will only get worse as growing populations, economic growth, and possible climate change place increasing stresses on limited supplies of surface water.

THINKING ABOUT
The Colorado River

What are three steps you would take to deal with the problems of the Colorado River system? How would you implement them politically?

13-4 Is Transferring Water from One Place to Another the Answer?

▶ **CONCEPT 13-4** **Transferring water from one place to another has greatly increased water supplies in some areas but has also disrupted ecosystems.**

Water Transfers Can Be Wasteful and Environmentally Harmful

Using a lot of water to produce a particular type of food or other product is not necessarily bad if it is done in an area where water is plentiful and water waste is controlled. For example, growing lettuce requires a lot of water and can be done easily in areas with plenty of rainfall. But when you have lettuce in a salad in the United States, chances are good that it was grown with the use of heavy irrigation in the arid Central Valley of California (Figure 13-15).

Water used to irrigate lettuce and other crops in the Central Valley is transported there through huge aqueducts from the High Sierra Mountains of eastern California. Such water transfers have benefited many people, but they have also wasted a lot of water and they have degraded ecosystems from which the water was taken (**Concept 13-4**) (see the two Case Studies that follow).

Such water waste is part of the reason why many products include large amounts of virtual water (Figure 13-A). One factor contributing to inefficient water use—for example, growing thirsty lettuce in desertlike areas—is that governments (taxpayers) subsidize the

Figure 13-15 This lettuce crop is growing in the Imperial Valley of central California. This and other water-intensive crops are grown in this arid area mostly because of the availability of cheap, government-subsidized irrigation water brought in from northern California, but also because the weather allows for growing crops year round in this valley. **Question:** Have you ever checked to see where your lettuce and other produce that you eat come from?

costs of water transfers and irrigation in some dry regions. Without such subsidies, farmers could not make a living in these areas.

■ **CASE STUDY**

California Transfers Massive Amounts of Water from Water-Rich Areas to Water-Poor Areas

One of the world's largest water transfer projects is the *California Water Project* (Figure 13-16). It uses a maze of giant dams, pumps, and lined canals, or *aqueducts*, to transport water from water-rich northern California to water-poor southern California's heavily populated cities and agricultural regions. This project supplies massive amounts of water to areas that, without such water transfers, would be mostly desert.

For decades, northern and southern Californians have feuded over how the state's water should be allocated under this project. Southern Californians want more water from the north to grow more crops and to support Los Angeles, San Diego, and other growing urban areas. Agriculture consumes three-fourths of the water withdrawn in California, much of it used inefficiently for growing crops in the desertlike conditions of the southern half of the state (Figure 13-15).

Northern Californians counter that sending more water south degrades the Sacramento River, threatens fisheries, and reduces the flushing action that helps clean San Francisco Bay of pollutants. In the case of Mono Lake, on the eastern slope of the High Sierras, transferring water almost destroyed a whole lake ecosystem. The lake—an important feeding stop for migratory water birds—experienced an 11-meter (35-foot) drop in its water level after 1941 when much of the water in streams that feed it was diverted to Los Angeles. These diversions have since been stopped, and the lake is rising again.

Figure 13-16 The California Water Project and the Central Arizona Project transfer huge volumes of water from one watershed to another. The red arrows show the general direction of water flow. **Questions:** What effects might this system have on different areas on this map? How might it affect areas from which the water is taken?

Northern Californians also argue that much of the water sent south is wasted in the transfer process, in urban settings and in inefficient irrigation systems. They point to studies showing that making irrigation just 10% more efficient would provide all the water necessary for domestic and industrial uses in southern California.

According to a 2002 study, projected climate change will make matters worse, sharply reducing the availability of water in California. If the snowpacks in the High Sierras, which store water seasonally as slow-melting packed snow, melt faster because of projected atmospheric warming and receive less precipitation during drought years, there will be less water available for transferring to the south. Some analysts project that during this century, many people living in arid southern California cities, as well as farmers in this area, may have to move elsewhere because of water shortages.

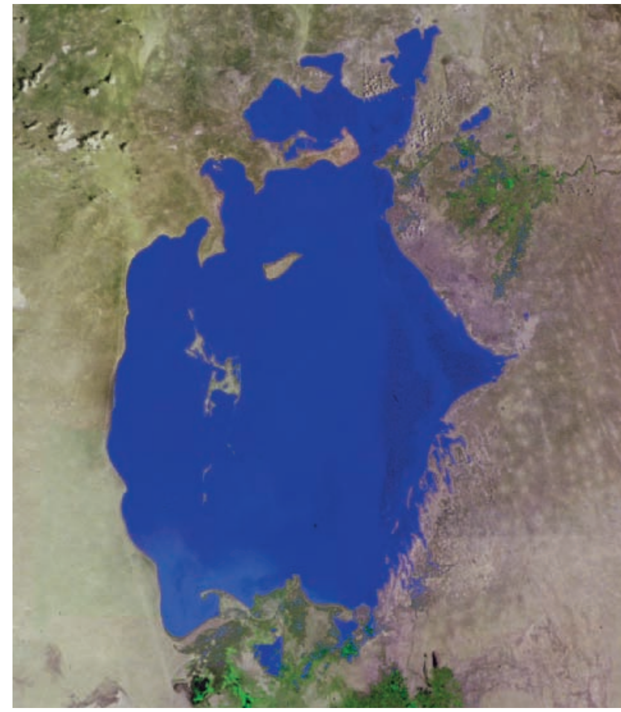
■ **CASE STUDY**

The Aral Sea Disaster: A Striking Example of Unintended Consequences

The shrinking of the Aral Sea (Figure 13-17), once a large inland body of saline water, is the result of a large-scale water transfer project in an area of the former Soviet Union with the driest climate in central Asia. Since 1960, enormous amounts of irrigation water have been diverted from the two rivers that supply water to the Aral Sea. The goal was to create one of the world's largest irrigated areas, mostly for raising cotton and rice. The irrigation canal, the world's longest, stretches more than 1,300 kilometers (800 miles)—roughly the distance between the two U.S. cities of Boston, Massachusetts and Chicago, Illinois.

This large-scale water diversion project, coupled with drought and high evaporation rates due to the area's hot and dry climate, has caused a regional ecological and economic disaster. Since 1961, the sea's salinity has risen sevenfold and the average level of its water has dropped by an amount roughly equal to the height of a six-story building. The Southern Aral Sea lost 90% of its volume of water and split into two major parts, one of which is now gone (Figure 13-17, bottom). Water withdrawal for agriculture has reduced the two rivers feeding the sea to mere trickles.

About 85% of the area's wetlands have been eliminated and about half the local bird and mammal species have disappeared. A huge area of the former Southern Aral Sea lake bottom is now a human-made desert covered with glistening white salt. The sea's greatly increased salt concentration—3 times saltier than ocean water—has caused the presumed local extinction of 26 of the area's 32 native fish species. This has devastated the area's fishing industry, which once provided work for more than 60,000 people. Fishing villages and boats (see Photo 6 in the Detailed Contents) once located on the sea's coastline now sit abandoned in a salt desert.



1976

2009

Figure 13-17 **Natural capital degradation:** The *Aral Sea* was one of the world's largest saline lakes. Since 1960, it has been shrinking and getting saltier because most of the water from the two rivers that replenish it has been diverted to grow cotton and food crops. These satellite photos show the sea in 1976 and in 2009. As the Southern Aral Sea shrank, it split into two lakes and left behind a salty desert, economic ruin, increasing health problems, and severe ecological disruption. By late 2009, the larger eastern part of the once huge Southern Aral Sea was gone (bottom-right part of each photo). The smaller Northern Aral Sea (top of each photo) has also shrunk, but not nearly as much as the Southern Aral Sea has. **Question:** What are three things that you think should be done to help prevent further shrinkage of the Aral Sea?

Winds pick up the sand and salty dust and blow it onto fields as far as 500 kilometers (310 miles) away. As the salt spreads, it pollutes water and kills wildlife, crops, and other vegetation. Aral Sea dust settling on glaciers in the Himalayas is causing them to melt at a faster than normal rate—a prime example of unexpected connections and unintended consequences.

Shrinkage of the Aral Sea has also altered the area's climate. The once-huge sea acted as a thermal buffer that moderated the heat of summer and the extreme cold of winter. Now there is less rain, summers are hotter and drier, winters are colder, and the growing season is shorter. The combination of such climate change and severe salinization has reduced crop yields by 20–50% on almost one-third of the area's cropland.

To raise yields, farmers have used more herbicides, insecticides, and fertilizers, which have percolated downward and accumulated to dangerous levels in the groundwater—the source of most of the region's drinking water. Many of the 45 million people living in the Aral Sea's watershed have experienced increasing health problems—including anemia, respiratory illnesses, liver and kidney disease, eye problems, and various cancers—from a combination of toxic dust, salt, and contaminated water.

GOOD NEWS

Since 1999, the United Nations and the World Bank have spent about $600 million to purify drinking water and upgrade irrigation and drainage systems in the area. This has improved irrigation efficiency and helped flush salts from croplands. The five countries surrounding the lake and its two feeder rivers have worked to improve irrigation efficiency and to partially replace water-thirsty crops with other crops that require less irrigation water.

A dike completed in 2005 has blocked the flow of water from the much smaller Northern Aral Sea into the southern sea. As a result, since 2005, the level of the northern sea has risen by 4 meters (13 feet), its surface area has increased by 13%, and its salinity has decreased by more than two-thirds. However, the much larger southern sea is still shrinking. By late 2009, its eastern lobe was essentially gone, and the European Space Agency projects that the rest of the Southern Aral Sea could dry up completely by 2020.

13-5 Is Converting Salty Seawater to Freshwater the Answer?

CONCEPT 13-5 We can convert salty ocean water to freshwater, but the cost is high, and the resulting salty brine must be disposed of without harming aquatic or terrestrial ecosystems.

Removing Salt from Seawater Is Costly, Kills Marine Organisms, and Produces Briny Wastewater

Desalination involves removing dissolved salts from ocean water or from brackish (slightly salty) water in aquifers or lakes. It is another way to increase supplies of freshwater (**Concept 13-5**).

The two most widely used methods for desalinating water are *distillation* and *reverse osmosis*. Distillation involves heating saltwater until it evaporates (leaving behind salts in solid form) and condenses as freshwater. Reverse osmosis (or *microfiltration*) uses high pressure to force saltwater through a membrane filter with pores small enough to remove the salt.

Today, about 14,450 desalination plants (250 of them in the United States) operate in more than 125 countries, especially in the arid nations of the Middle East, North Africa, the Caribbean, and the Mediterranean. They meet less than 0.3% of the world's demand and 0.4% of the U.S. demand for freshwater. In 2009, Saudi Arabia opened the world's largest desalination plant, which gives it the world's largest capacity for desalinating water.

There are three major problems with the widespread use of desalination. *First* is the high cost, because it takes a lot of increasingly expensive energy to remove salt from seawater. A *second* problem is that pumping large volumes of seawater through pipes and using chemicals to sterilize the water and keep down algae growth kills many marine organisms and also requires large inputs of energy (and thus money) to run the pumps. A *third* problem is that desalination produces huge quantities of salty wastewater that must go somewhere. Dumping it into nearby coastal ocean waters increases the salinity of the ocean water, which threatens food resources and aquatic life in the vicinity. Disposing of it on land could contaminate groundwater and surface water (**Concept 13-5**).

Bottom line: Currently, significant desalination is practical only for water-short, wealthy countries and cities that can afford its high cost. But scientists and engineers are working to develop better and more affordable desalination technologies (Science Focus, p. 334).

RESEARCH FRONTIER

Developing better and more affordable desalination technologies; see **www.cengage.com/login**.

SCIENCE FOCUS

The Search for Improved Desalination Technology

Scientists are working to develop new membranes for reverse osmosis that can separate water from salt more efficiently and with less pressure. According to the World Business Council, since 1995, technological advances have brought the cost of producing freshwater from sea water down by 80%. But this is still not cheap enough to make it useful for most irrigation or to meet much of the world's demand for drinking water.

GOOD NEWS

This may change if scientists can figure out how to use solar energy or other means to desalinate seawater cheaply and how to safely dispose of the salty wastewater left behind. Another possibility is the development of molecular-size nanofilters to desalinate water at a more affordable cost.

A consortium of companies has proposed building ships that carry desalination equipment. The ships would operate over the horizon offshore and transfer the water to shore through seabed pipelines or in food grade shuttle tankers like those used to transport liquids such as wine or orange juice. The ships would have lower fuel costs than land-based desalination plants. Also, by generating their own power using gas turbine engines like those used on jumbo jets fueled by clean-burning biodiesel oil, they would not be affected by onshore power failures. In addition, they would be able to move away from the paths of storms and, because of their distance from shore, they could draw water from depths below where most marine organisms are found. The resulting brine could be returned to the ocean and diluted far away from coastal waters. California officials are evaluating this approach.

Two Australian companies, Energetech and H2AU, have joined forces to build an experimental desalination plant that uses the power generated by ocean waves—an indirect form of solar energy—to drive reverse-osmosis desalination. This approach, based on applying one of the three principles of sustainability, produces no air pollution and conserves energy by using it where it is produced to desalinate water. Thus, costs should be much lower than for other desalination methods. In addition, the plant will be located offshore where the resulting brine can be mixed with ocean water without affecting near-shore ecosystems.

In 2005, General Electric—a major global corporation—began focusing on finding better ways to desalinate water. Because about 40% of the world is going to be short of freshwater in the next 10–20 years, GE sees desalination as one of the world's major growth businesses. **GREEN CAREER:** desalination engineer

Another possibility is to build desalination plants near coastal electric power plants. Since power plants need water for cooling and desalination plants need heat, why not combine the two and use the waste heat from power plants to help desalinate the water that was used for cooling? Scientists estimate that this approach could reduce the cost of today's most efficient desalination process by about 17%.

Critical Thinking

Do you think that improvements in desalination will justify more wasteful uses of water, such as maintaining swimming pools, fountains, and golf courses in desert areas? Explain your reasoning.

13-6 How Can We Use Water More Sustainably?

▶ **CONCEPT 13-6 We can use water more sustainably by cutting water waste, raising water prices, slowing population growth, and protecting aquifers, forests, and other ecosystems that store and release water.**

Reducing Water Waste Has Many Benefits

Cutting the waste of water is almost always quicker and less costly than trying to provide new supplies of water, except in cases where governments subsidize water supply systems, which makes water prices artificially low. Here are three estimates concerning water waste provided by Mohamed El-Ashry of the World Resources Institute:

- About two-thirds of the water used throughout the world is unnecessarily wasted through evaporation, leaks, and other losses.
- In the United States—the world's largest user of water—about half of the water drawn from surface and groundwater supplies is unnecessarily wasted.
- It is economically and technically feasible to reduce water waste to 15%, thereby meeting most of the world's water needs for the foreseeable future.

GOOD NEWS

According to water resource experts, the first major cause of water waste is *water's low cost to users*. Underpricing of water is mostly the result of government subsidies that provide irrigation water, electricity, and diesel fuel used by farmers to pump water from rivers and aquifers at below-market prices. Because these subsidies keep water prices artificially low, users have little or no financial incentive to invest in water-saving technologies. In addition, these subsidies often go to pay for irrigating crops that require lots of water in dry areas (Figure 13-15). According to water resources expert Sandra Postel, "By heavily subsidizing water, governments give out the false message that it is abundant and can . . . be wasted—even as rivers are drying up, aquifers are being depleted, fisheries are collapsing, and species are going extinct."

However, farmers, industries, and others benefiting from government water subsidies argue that the subsidies promote the settlement and farming of arid, unproductive land, stimulate local economies, and help to keep the prices of food, manufactured goods, and electricity low.

THINKING ABOUT
Government Water Subsidies

Should governments provide subsidies to farmers and cities to help keep the price of water low? Explain.

Higher water prices encourage water conservation but make it difficult for low-income farmers and city dwellers to buy enough water to meet their needs. When South Africa raised water prices, it dealt with this problem by establishing *lifeline* rates, which give each household a set amount of free or low-priced water to meet basic needs. When users exceed this amount, they pay higher prices as their water use increases—*a user-pays approach*.

The second major cause of water waste is a *lack of government subsidies for improving the efficiency of water use*. A basic rule of economics is that you get more of what you reward. Withdrawing environmentally harmful subsidies that encourage water waste and providing environmentally beneficial subsidies for more efficient water use would sharply reduce water waste and help to reduce water shortages.

HOW WOULD YOU VOTE?

Should water prices be raised sharply to help reduce water waste? Cast your vote online at **www.cengage.com/login**.

We Can Cut Water Waste in Irrigation

About 60% of the irrigation water applied throughout the world does not reach the targeted crops. Most irrigation systems obtain water from a groundwater well or a surface water source. The water then flows by gravity through unlined ditches in crop fields so the crops can absorb it (Figure 13-18, left). This *flood irrigation* method delivers far more water than is needed for crop growth and typically loses 40% of the water through evaporation, seepage, and runoff. This wasteful method is used on 97% of China's irrigated land.

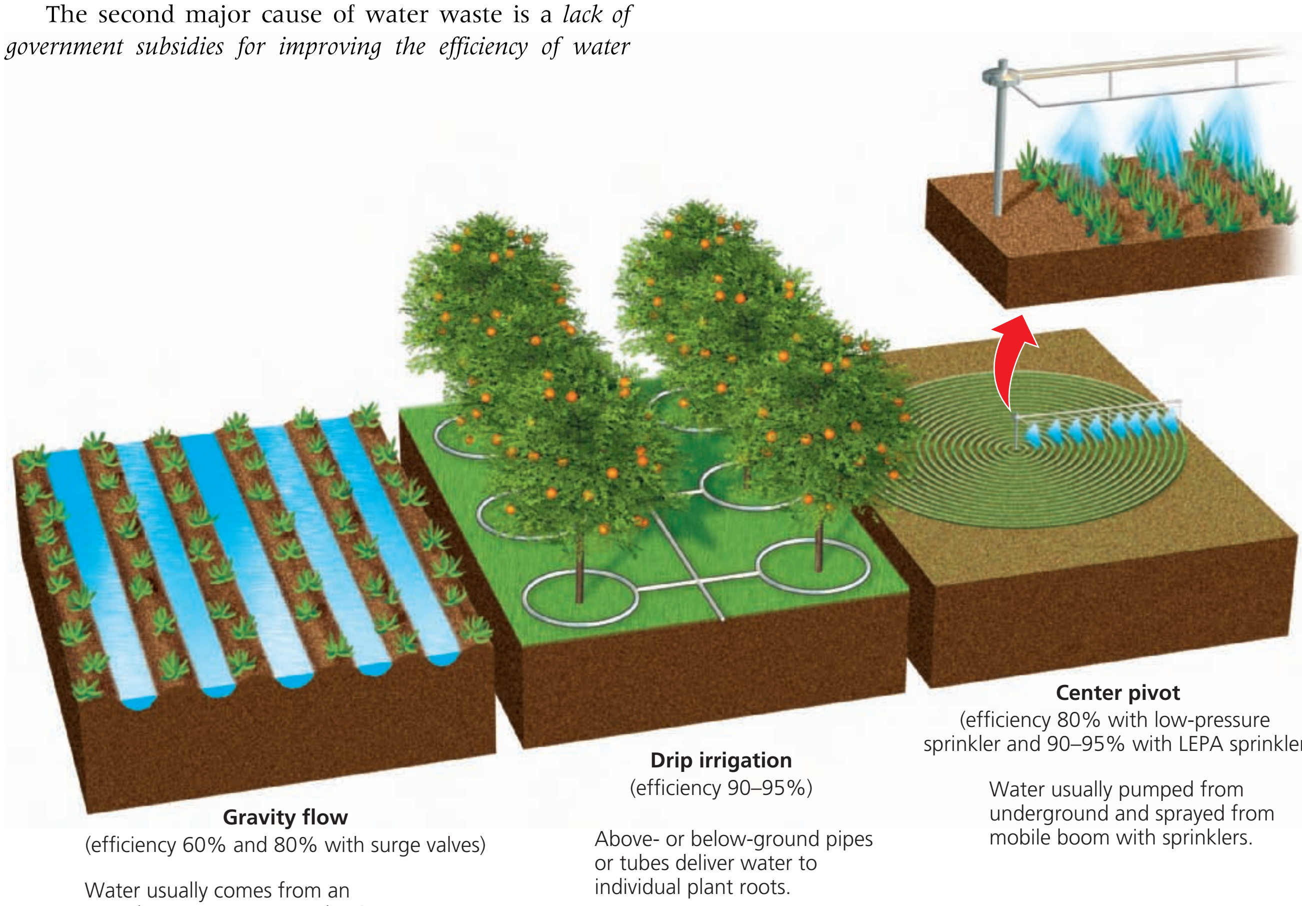


Figure 13-18 Several different systems are used to irrigate crops. The two most efficient systems are the low-energy, precision application (LEPA) center-pivot system and the drip irrigation system. Because of high initial costs, they are not widely used. The development of new, low-cost, drip-irrigation systems may change this situation.

More efficient and environmentally sound irrigation technologies can greatly reduce water demands and water waste on farms by delivering water more precisely to crops—a *more crop per drop* strategy. For example, the *center-pivot, low-pressure sprinkler* (Figure 13-18, right), which uses pumps to spray water on a crop, allows about 80% of the water to reach crops. *Low-energy, precision application sprinklers*, another form of center-pivot irrigation, put 90–95% of the water where crops need it.

Drip, or *trickle irrigation*, also called *microirrigation* (Figure 13-18, center), is the most efficient way to deliver small amounts of water precisely to crops. It consists of a network of perforated plastic tubing installed at or below the ground level. Small pinholes in the tubing deliver drops of water at a slow and steady rate, close to the roots of individual plants. These systems drastically reduce water waste because 90–95% of the water input reaches the crops. By using less water, they also reduce the amount of harmful salt that irrigation water leaves in the soil.

GOOD NEWS

Current drip irrigation systems are costly, but improvements are on the way. The cost of a new type of drip irrigation system developed by the nonprofit International Development Enterprises is one-tenth as much per unit of land area as that of conventional drip systems.

Drip irrigation is used on just over 1% of the world's irrigated crop fields and about 4% of those in the United States. This percentage rises to 13% in the U.S. state of California, 66% in Israel, and 90% in Cyprus. Suppose that water were priced closer to the value of the ecological services it provides and that government subsidies that encourage water waste were reduced or eliminated. Then drip irrigation would probably be used to irrigate most of the world's crops.

RESEARCH FRONTIER

Developing more efficient and affordable irrigation systems; see **www.cengage.com/login**.

The Chinese government is acutely aware of its worsening water supply situation and, in 2009, announced its commitment to converting the country into a water-saving society. It is also experimenting with paying farmers not to irrigate crops in its environmentally degraded and water-short, far-west desert region.

GOOD NEWS

Figure 13-19 lists other ways to reduce water waste in crop irrigation. Since 1950, Israel has used many of these techniques to slash irrigation water waste by 84% while irrigating 44% more land. Israel now treats and reuses 30% of its municipal sewage water for crop production and plans to increase this to 80% by 2025. The government has also gradually eliminated most water subsidies to raise Israel's price of irrigation water, which is now one of the highest in the world.

Solutions

Reducing Irrigation Water Waste

- Line canals bringing water to irrigation ditches
- Irrigate at night to reduce evaporation
- Monitor soil moisture to add water only when necessary
- Grow several crops on each plot of land (polyculture)
- Encourage organic farming
- Avoid growing water-thirsty crops in dry areas
- Irrigate with treated waste water
- Import water-intensive crops and meat

Figure 13-19 There are a number of ways to reduce water waste in irrigation. **Questions:** Which two of these solutions do you think are the best ones? Why?

According to the United Nations, reducing current global withdrawal of water for irrigation by just 10% would save enough water to grow crops and meet the estimated additional water demands of the earth's cities and industries through 2025.

CONNECTIONS

Water Conservation, Energy, and Money

Energy use and water use are closely connected. It takes energy to move water, to treat it, to heat it for use in showering and washing dishes, and then to treat the resulting wastewater. And producing energy uses and pollutes water. Thus, when we save water we also save energy, reduce air and water pollution and greenhouse gas emissions, and we save money.

Less-Developed Countries Use Low-Tech Methods for Irrigation

Many of the world's poor farmers use small-scale and low-cost traditional irrigation technologies. For example, millions of farmers in countries such as Bangladesh where water tables are high use human-powered treadle pumps to bring groundwater up to the earth's surface and into irrigation ditches (Figure 13-20). These wooden devices are cheap (about $25), easy to build from local materials, and operate on leg power. Other farmers in some less-developed countries use buckets, small tanks with holes, or simple plastic tubing systems for drip irrigation.

Rainwater harvesting is another simple and inexpensive way to provide water for drinking and growing crops throughout most of the world. It involves using pipes from rooftops, and channels dug in the ground, to direct rainwater that would otherwise run off the

International Development Enterprises

Figure 13-20 **Solutions:** In areas of Bangladesh and India, where water tables are high, many small-scale farmers use treadle pumps to supply irrigation water to their fields.

land. It can be stored in underground or above-ground storage tanks (cisterns), ponds, and plastic barrels for use during dry spells. This is especially useful in less-developed countries, such as India, where much of the rain comes in a short monsoon season. In southern Australia, over 40% of households use rainwater stored in tanks as their main source of drinking water.

Other strategies used by poor farmers to increase the amount of crop per drop of rainfall include polyculture farming to create more canopy cover and reduce water losses by evaporation; planting deep-root perennial crop varieties (see Figure 12-C, p. 312); controlling weeds; and mulching fields to retain more moisture. Water waste can also be reduced by growing crops hydroponically (see Figure 12-6, p. 282).

We Can Cut Water Waste in Industry and Homes

Producers of chemicals, paper, oil, coal, primary metals, and processed food consume almost 90% of the water used by industry in the United States. Some of these industries recapture, purify, and recycle water to reduce their water use and water treatment costs. For example, more than 95% of the water used to make steel can be recycled. Figure 13-21 lists ways to use water more efficiently in industries, homes, and businesses (**Concept 13-3**).

Another way to reduce water use and waste is to shift away from producing electricity with coal-burning and nuclear power plants that use huge quantities of water for once-through cooling systems. Over the next five decades, they could be replaced by wind farms on land and offshore and by solar cell power plants, as we discuss more in Chapter 16. This would be an application of the solar energy **principle of sustainability** (see back cover).

Flushing toilets with water (most of it clean enough to drink) is the single largest use of domestic water in the United States and accounts for about one-fourth of home water use. Since 1992, U.S. government standards have required that new toilets use no more than 6.1 liters (1.6 gallons) of water per flush. Even then, the water used to flush such a toilet just twice is more than the daily amount of water available to many of the world's poor who live in dry areas.

Architect and designer William McDonough has designed a toilet with a bowl so smooth that nothing sticks to it, including bacteria. Only a light mist is needed to flush it. Low-flow showerheads can also save large amounts of water by cutting the flow of shower in half. Xeros Ltd., a British company, recently developed a washing machine that uses as little as a cup of water for each washing cycle.

According to UN studies, 30–60% of the water supplied in nearly all of the major cities in less-developed countries is lost, mostly through leakage of water mains, pipes, pumps, and valves. Water experts say that fixing these leaks should be a high priority for governments, as it would cost less than building dams or importing water. Even in advanced industrialized countries such as the United States, these losses to leakage average 10–30%. However, leakage losses have been reduced to about 3% in Copenhagen, Denmark, and to 5% in Fukuoka, Japan.

Solutions

Reducing Water Waste

- Redesign manufacturing processes to use less water
- Recycle water in industry
- Landscape yards with plants that require little water
- Use drip irrigation
- Fix water leaks
- Use water meters
- Raise water prices
- Use waterless composting toilets
- Require water conservation in water-short cities
- Use water-saving toilets, showerheads, and front-loading clothes washers
- Collect and reuse household water to irrigate lawns and nonedible plants
- Purify and reuse water for houses, apartments, and office buildings

Figure 13-21 There are a number of ways to reduce water waste in industries, homes, and businesses (**Concept 13-3**). **Questions:** Which three of these solutions do you think are the best ones? Why?

CONNECTIONS

Water Leaks and Water Bills

Any water leak unnecessarily wastes water and raises water bills. Homeowners can detect a silent toilet water leak by adding a few drops of food coloring to the toilet tank and waiting 5 minutes. If the color shows up in the bowl, you have a leak. Be sure to fix leaking faucets. A faucet dripping once per second wastes up to 8,200 liters (3,000 gallons) of water a year—enough to fill about 75 bathtubs. This is money going down the drain.

Many homeowners and businesses in water-short areas are using drip irrigation on their properties GOOD NEWS and copying nature by replacing water-hogging green lawns with a diversity of native plants that need little water (Figure 13-22). Such water-thrifty landscaping reduces water use by 30–85% and sharply reduces needs for labor, fertilizer, and fuel. This example of reconciliation ecology (see Chapter 10, p. 245) also helps to preserve biodiversity, and reduces polluted runoff, air pollution, and yard wastes.

However, many Americans want a green lawn, even if they live in desert area. About 85,500 square kilometers (33,000 square miles) of U.S. land is covered by lawns. The water used on the average American lawn each year would fill up about 540 bathtubs. Despite such water use and waste, people in some communities have passed ordinances that require green lawns and prevent individuals from planting water-conserving vegetation in their yards. But this may change if people who live in water-short areas have to pay much higher water bills.

In a typical house, about 50–75% of the *gray water*—water from bathtubs, showers, sinks, dishwashers, and clothes washers—could be stored in a holding tank and then reused to irrigate lawns and nonedible plants, to flush toilets, and to wash cars. Israel reuses 70% of its wastewater to irrigate nonfood crops. In Singapore, all sewage water is treated at reclamation plants for reuse by industry. U.S. cities such as Las Vegas, Nevada, and Los Angeles, California, are also beginning to recycle some of their wastewater. These efforts mimic the way nature purifies water by recycling it, following the chemical cycling **principle of sustainability**. SUSTAINABILITY

The fact that water usually comes at a low cost is also a major cause of excessive water use and waste in homes and industries. Many water utility and irrigation authorities charge a flat fee for water use and some charge less for the largest users of water. About one-fifth of all U.S. public water systems do not have water meters and charge a single low rate for almost unlimited water use. Also, many apartment dwellers have little incentive to conserve because water use charges are included in their rent. When the U.S. city of Boulder, Colorado, introduced water meters, water use per person dropped by 40%.

©Paul Senyszyn/iStockphoto

Figure 13-22 This yard in Encinitas, a city in a dry area of southern California (USA), uses a diversity of plants that are native to the arid environment and require little watering.

CONNECTIONS

Smart Cards and Water Conservation

In Brazil, an electronic device called a *water manager* allows customers to obtain water on a pay-as-you-go basis. People buy *smart cards* (like long-distance phone cards), each of which contains a certain number of water credits. When they punch in the card's code on their water manager device, the water company automatically supplies them with a specified amount of water. Brazilian officials say this approach saves electrical power, encourages water conservation, and typically reduces household water bills by 40%.

We Can Use Less Water to Remove Wastes

Currently, we use large amounts of freshwater clean enough to drink to flush away industrial, animal, and household wastes. According to the FAO, if current trends in population and resource use continue growing, within 40 years, we will need the world's entire reliable flow of river water just to dilute and transport the wastes we produce. We could save much of this water by using systems that mimic the way nature deals with wastes by recycling them.

For example, sewage treatment plants take human waste, which contains valuable plant nutrients, and dump most of it into rivers, lakes, and oceans. This overloads aquatic systems with such nutrients. We could apply nature's chemical cycling **principle of sustainability** and use the nutrient-rich sludge produced by waste treatment plants as a soil fertilizer, instead of wasting freshwater to transport it. To make this feasible, we would have to ban the discharge of toxic industrial chemicals into sewage treatment plants. Otherwise, the nutrient-rich sludge from sewage treatment plants would be too toxic to apply to cropland soils.

Another way to recycle our wastes is to rely more on waterless composting toilets. These devices convert human fecal matter to a small amount of dry and odorless soil-like humus material that can be removed from a composting chamber every year or so and returned to the soil as fertilizer. One of the authors (Miller) used a composting toilet for over a decade, while living and working deep in the woods in an experimental home and office.

We Need to Use Water More Sustainably

Figure 13-23 lists some strategies that scientists have suggested for using water more sustainably (**Concept 13-6**).

Each of us can help to bring about such a "blue revolution" and reduce our water footprints by using and wasting less water (Figure 13-24). As with other problems, the solution starts with thinking globally and acting locally.

Solutions

Sustainable Water Use

- Waste less water and subsidize water conservation
- Do not deplete aquifers
- Preserve water quality
- Protect forests, wetlands, mountain glaciers, watersheds, and other natural systems that store and release water
- Get agreements among regions and countries sharing surface water resources
- Raise water prices
- Slow population growth

Figure 13-23 A variety of methods can help us to use the earth's water resources more sustainably (**Concept 13-6**). **Questions:** Which two of these solutions do you think are the most important? Why?

What Can You Do?

Water Use and Waste

- Use water-saving toilets, showerheads, and faucet aerators
- Shower instead of taking baths, and take short showers
- Repair water leaks
- Turn off sink faucets while brushing teeth, shaving, or washing
- Wash only full loads of clothes or use the lowest possible water-level setting for smaller loads
- Use recycled (gray) water for watering lawns and houseplants and for washing cars
- Wash a car from a bucket of soapy water, and use the hose for rinsing only
- If you use a commercial car wash, try to find one that recycles its water
- Replace your lawn with native plants that need little if any watering
- Water lawns and yards only in the early morning or evening
- Use drip irrigation and mulch for gardens and flowerbeds

Figure 13-24 **Individuals matter:** You can reduce your use and waste of water. See www.h2ouse.org for a number of tips, provided by the Environmental Protection Agency and the California Urban Water Conservation Council, that you can use anywhere for saving water. **Questions:** Which of these steps have you taken? Which of them would you like to take?

13-7 How Can We Reduce the Threat of Flooding?

▶ **CONCEPT 13-7 We can lessen the threat of flooding by protecting more wetlands and natural vegetation in watersheds, and by not building in areas subject to frequent flooding.**

Some Areas Get Too Much Water from Flooding

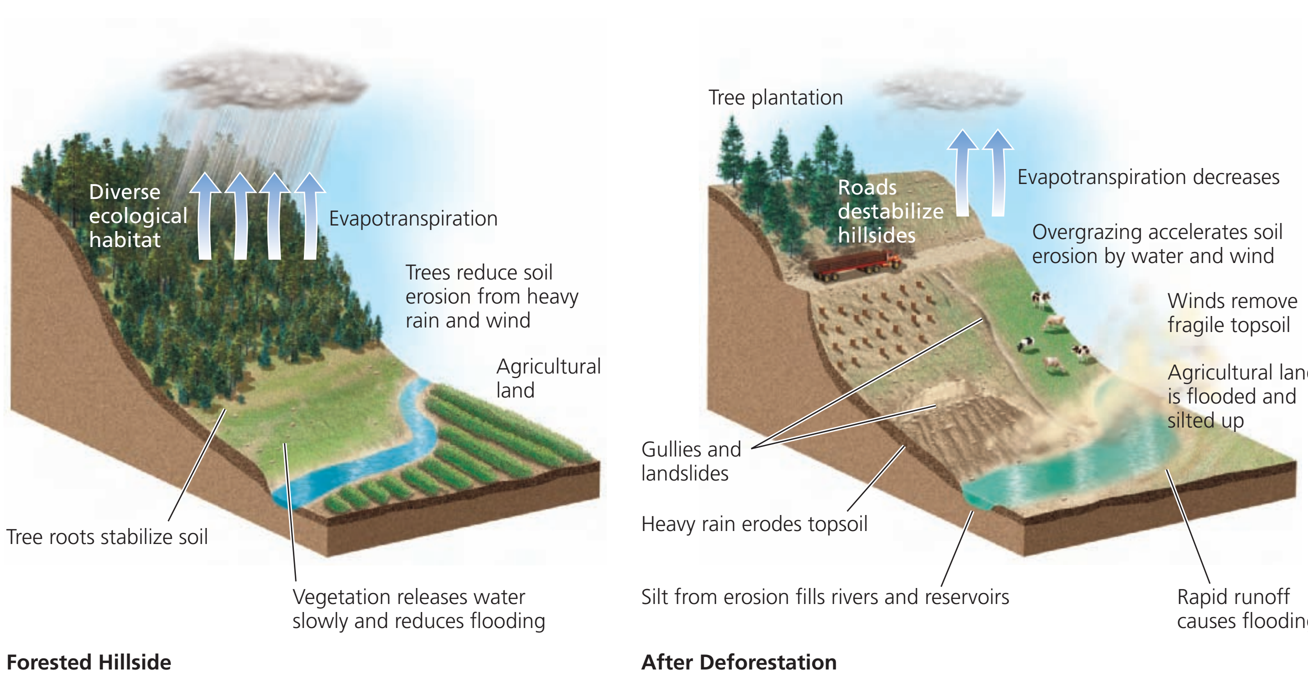
Some areas have too little water, but others sometimes have too much because of natural flooding by streams, caused mostly by heavy rain or rapidly melting snow. Other areas flood because they receive most of their water as heavy downpours during certain times of the year. A flood happens when water in a stream overflows its normal channel and spills into an adjacent area, called a **floodplain**. These areas, which usually include highly productive wetlands, help to provide natural flood and erosion control, maintain high water quality, and recharge groundwater.

People settle on floodplains to take advantage of their many assets, including fertile soil, ample water for irrigation, availability of nearby rivers for transportation and recreation, and flat land suitable for crops, buildings, highways, and railroads. To reduce the threat of flooding for people who live on floodplains, rivers have been narrowed and straightened (*channelized*), surrounded by protective levees and walls, and dammed to create reservoirs that store and release water as needed (Figure 13-2). However, in the long run, such measures can lead to greatly increased flood damage when heavy snow melt or prolonged rains overwhelm them.

CORE CASE STUDY

Floods actually provide several benefits. They have created some of the world's most productive farmland by depositing nutrient-rich silt on floodplains. They also recharge groundwater and help to refill wetlands, thereby supporting biodiversity and aquatic ecological services.

But floods also kill thousands of people each year and cost tens of billions of dollars in property damage (see the Case Study that follows). Floods are usually considered natural disasters, but since the 1960s, human activities have contributed to a sharp rise in flood deaths and damages, meaning that such disasters are partly human-made. One such human activity is the *removal of water-absorbing vegetation*, especially on hillsides (Figure 13-25).



CENGAGENOW™ **Active Figure 13-25 Natural capital degradation:** These diagrams show a hillside before and after deforestation. Once a hillside has been deforested for timber, fuelwood, livestock grazing, or unsustainable farming, water from precipitation rushes down the denuded slopes, erodes precious topsoil, and can increase flooding and pollution in local streams. Such deforestation can also increase landslides and mudflows. A 3,000-year-old Chinese proverb says, "To protect your rivers, protect your mountains." *See an animation based on this figure at* CengageNOW. **Question:** How might a drought in this area make these effects even worse?

Z.Yi-UNEP/Peter Arnold, Inc.

Figure 13-26 Deforestation of hills and mountains in China's Yangtze River Basin contributed to increased flooding, topsoil erosion, and the flow of eroded sediment into the Yangtze River. Because of these harmful effects, China stopped the deforestation and established a massive tree-planting program to reforest the degraded land.

CONNECTIONS

Deforestation and Flooding in China

In 1998, severe flooding in China's Yangtze River watershed, home to 400 million people, killed at least 15 million people and caused massive economic losses. Scientists identified the causes as heavy rainfall, rapid snowmelt, and deforestation (Figure 13-26) that had removed 85% of the watershed's tree cover. Chinese officials banned tree cutting in the watershed and accelerated tree replanting with the long-term goal of restoring some of the area's natural, ecological flood-control services.

Draining and building on wetlands, which naturally absorb floodwaters, is a second human activity that increases the severity of flooding. When Hurricane Katrina struck the Gulf Coast of the United States in August 2005 and flooded the city of New Orleans, Louisiana (see Figure 8-19, p. 185) and surrounding areas, the damage was intensified because of the degradation or removal of coastal wetlands that had historically helped to buffer this low-lying land against storm surges.

Another human-related factor that will increase flooding is a rise in sea levels during this century from projected climate change caused mostly by human activities that warm the atmosphere (as discussed in Chapter 19). Reports in 2007 by the Organization for Economic Cooperation and Development (OECD) and the Intergovernmental Panel on Climate Change (IPCC) projected that, by the 2070s, as many as 150 million people—an amount equal to almost half of the current U.S. population—living in many of the world's largest coastal cities are likely to be at risk from such coastal flooding. According to IPCC scientists, climate change projected for this century means that, in general, wet areas will get wetter and suffer from increased flooding, and dry areas will get drier and suffer from longer droughts.

■ CASE STUDY

Living Dangerously on Floodplains in Bangladesh

Bangladesh is one of the world's most densely populated countries. In 2009, it had 162 million people, packed into an area roughly the size of the U.S. state of Wisconsin (which has a population of less than 6 million). And the country's population is projected to increase to 222 million by 2050. Bangladesh is a very flat country, with nearly one-fifth of its area sitting less than 1.0 meter (3.2 feet) above sea level, and it is one of the world's poorest countries.

The people of Bangladesh depend on moderate annual flooding during the summer monsoon season to grow rice and help maintain soil fertility in the delta basin. The annual floods also deposit eroded Himalayan soil on the country's crop fields. Bangladeshis have adapted to moderate flooding. Most of the houses have flat thatch roofs on which families can take refuge with their belongings in case of rising waters. The roofs can be detached from the walls, if necessary, and floated like rafts. After the waters have subsided, the roof can be reattached to the walls of the house. But great floods can overwhelm such defenses.

In the past, great floods occurred every 50 years or so. But between 1987 and 2007 there were five severe floods, which covered a third of the country with water.

Bangladesh's flooding problems begin in the Himalayan watershed, where rapid population growth, deforestation, overgrazing, and unsustainable farming on steep and easily erodible slopes have increased flows of water during monsoon season. Monsoon rains now run more quickly off the denuded Himalayan foothills, carrying vital topsoil with them (Figure 13-25, right).

This increased runoff of soil, combined with heavier-than-normal monsoon rains, has led to more severe flooding along Himalayan rivers as well as downstream in Bangladesh's delta areas. In 1998, a disastrous flood covered two-thirds of Bangladesh's land area, in some places for 2 months. The flood drowned at least 2,000 people and left 30 million people—roughly equal to the entire population of Tokyo, Japan, the world's most populous city—homeless. It also destroyed more than one-fourth of the country's crops, which caused thousands of people to die of starvation. In 2002, another flood left 5 million people homeless and flooded large areas of rice fields. Yet another major flood occurred in 2004.

Living on Bangladesh's coastal floodplain at sea level means coping with storm surges, cyclones, and tsunamis. As many as 1 million people drowned as a result of a tropical cyclone in 1970. Another cyclone in 2003 killed more than a million people and left tens of millions homeless.

Many of the coastal mangrove forests in Bangladesh and elsewhere (see Figure 8-10, p. 175) have been cleared for fuelwood, farming, and aquaculture ponds created for raising shrimp. The result: more severe flooding, because these coastal wetlands had partially sheltered Bangladesh's low-lying coastal areas from storm surges, cyclones, and tsunamis. Damages and deaths from cyclones in areas of Bangladesh still protected by mangrove forests have been much lower than in areas where the forests have been cleared.

A projected rise in sea level and an increase in storm intensity during this century, mostly because of projected climate change caused by atmospheric warming, will likely be a major threat to Bangladeshis who live on the delta adjacent to the Bay of Bengal. This could force millions of people to become environmental refugees with no place to go in this already densely populated country.

Bangladesh is one of the few less-developed nations that is preparing and implementing plans to adapt to sea levels rises projected as a result of climate change. This includes using varieties of rice and other crops that can better tolerate flooding, saltwater, and drought; shifting to new crops such as maize; developing small vegetable gardens in bare patches between houses that can help reduce dependence on rice; building small ponds that can collect monsoon rainwater to use for irrigating vegetable gardens during dry periods; and creating a network of earthen embankments that can help protect against high tides and moderate storm surges when cyclones strike.

We Can Reduce Flood Risks

Figure 13-27 lists some ways to reduce flooding risks (**Concept 13-7**). To improve flood control, we can rely less on engineering devices such as dams and levees and more on nature's systems such as wetlands and water- and topsoil-retaining vegetation in watersheds.

Channelizing streams is a way to reduce upstream flooding. But it also eliminates aquatic habitats, reduces groundwater discharge, and results in a faster flow, which can increase downstream flooding and sediment deposition. In addition, channelization encourages human settlement in floodplains, which increases the risk of damages and deaths from major floods.

Levees or floodwalls along the banks of streams contain and speed up stream flow, but they also increase the water's capacity for doing damage downstream. They also do not protect against unusually high and powerful floodwaters such as those that occurred in 1993 when two-thirds of the levees built along the Mississippi River in the United States were damaged or destroyed. Dams

Solutions

Reducing Flood Damage

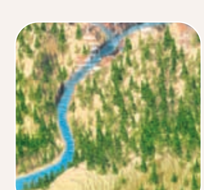
Prevention

Preserve forests on watersheds

Preserve and restore wetlands in floodplains

Tax development on floodplains

Use floodplains primarily for recharging aquifers, sustainable agriculture and forestry



Control

Straighten and deepen streams (channelization)

Build levees or floodwalls along streams

Build dams

Figure 13-27 These are some methods for reducing the harmful effects of flooding (**Concept 13-4**). **Questions:** Which two of these solutions do you think are the most important? Why?

can reduce the threat of flooding by storing water in a reservoir and releasing it gradually, but they also have a number of disadvantages (Figure 13-13). An important way to reduce flooding is to *preserve existing wetlands* and *restore degraded wetlands* to take advantage of the natural flood control they provide in floodplains. We can also sharply reduce emissions of greenhouse gases that contribute to projected atmospheric warming and the resulting climate change, which will likely raise sea levels and flood many of the world's coastal areas during this century.

On a personal level, we can use the precautionary principle (see Chapter 9, p. 213) and *think carefully about where we choose to live*. Many poor people live in flood-prone areas because they have nowhere else to go. Most people, however, can choose not to live in areas especially subject to flooding or to water shortages.

Here are this chapter's *three big ideas*:

- One of the world's major environmental problems is the growing shortage of freshwater in many parts of the world.
- We can increase water supplies in water-short areas in a number of ways, but the most important way is to reduce overall water use and waste by using water more sustainably.
- We can use water more sustainably by cutting water waste, raising water prices, slowing population growth, and protecting aquifers, forests, and other ecosystems that store and release water.

REVISITING The Colorado River and Sustainability

CORE CASE STUDY

SUSTAINABILITY

The **Core Case Study** that opens this chapter discusses the problems that have resulted from a large number of U.S. states sharing a river's limited water resource in a water-short region. Such problems are representative of those faced by many other arid regions of the world, especially areas where the population is growing rapidly and water resources are dwindling for various reasons.

Generally, the water resource strategies used in the 20th century have worked against the earth's natural chemical cycles and processes. Large dams, river diversions, levees, and other big engineering schemes have helped to provide much of the world with electricity, food, drinking water, and flood control. But they have also degraded the aquatic natural capital needed for long-term economic and ecological sustainability by seriously disrupting rivers, streams, wetlands, aquifers, and other aquatic systems.

The three **principles of sustainability** (see back cover) can guide us in using water more sustainably during this century. Scientists hope to use solar energy to desalinate water and increase supplies. Recycling more water will also help us to reduce water waste. Preserving biodiversity by avoiding disruption of aquatic systems and their adjacent terrestrial systems is a key factor in maintaining water supplies and water quality.

This *blue revolution*, built mostly around cutting unnecessary water waste, will provide numerous economic and ecological benefits. There is no time to lose in implementing it.

There is a water crisis today. But the crisis is not about having too little water to meet our needs. It is a crisis of mismanaging water so badly that billions of people—and the environment—suffer badly.

WORLD WATER VISION REPORT

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 318. Discuss the importance of the Colorado River basin in the United States and how human activities are stressing this system (**Core Case Study**). CORE CASE STUDY
2. Explain why access to water is a health issue, an economic issue, a women's and children's issue, a national and global security issue, and an environmental issue. Describe how water is recycled by the hydrologic cycle and how human activities have overloaded and altered this cycle. What percentage of the earth's freshwater is available to us?
3. Define **groundwater**, **zone of saturation**, **water table**, and **aquifer**. Distinguish among **surface water**, **surface runoff**, and **reliable runoff**. What is a **watershed** or **drainage basin**? Define **drought**. What percentage of the world's reliable runoff are we using and what percentage are we likely to be using by 2025? How is most of the world's water used? Describe the availability and use of freshwater resources in the United States. Explain why much of the area in 36 states is likely to suffer from water shortages throughout most of this century. What are five major problems resulting from the way people are using water from the Colorado River basin?
4. How many countries face water scarcity today and how many may face water scarcity by 2050? What percentage of the earth's land suffers from severe drought today and

how might this change by 2059? How many people in the world lack regular access to clean water today and how high might this number grow by 2025? Define and give an example of a **water footprint**. What is **virtual water**? Why do many analysts view the likelihood of greatly increasing water shortages as one of the world's most serious environmental problems? Describe the connection between water shortages, grain imports, food prices, and malnutrition.

5. What are the advantages and disadvantages of withdrawing groundwater? Describe the problem of groundwater depletion in the world and in the United States, especially in the Ogallala aquifer. Describe the problems of land subsidence and contamination of freshwater aquifers near coastal areas resulting from the overdrawing of water from aquifers. Describe ways to prevent or slow groundwater depletion, including the possible use of *deep aquifers*.

6. What is a **dam**? What is a **reservoir**? What are the advantages and disadvantages of using large dams and reservoirs? Describe what has happened to water flows in the Colorado River since 1960, other problems that are likely to further decrease its supply of water, and the likely consequences of such changes (**Core Case Study**). List three possible solutions to this problem. CORE CASE STUDY

7. Describe the California Water Project and the controversy over this huge water transfer program. Describe the environmental disaster caused by the Aral Sea water transfer project. Define **desalination** and distinguish between distillation and reverse osmosis as methods for desalinating water. What are three major limitations on the widespread use of desalination? What are scientists doing to try to deal with these problems?

8. What percentage of available freshwater is unnecessarily wasted in the world and in the United States? What are two major causes of water waste? Describe four irrigation methods and list ways to reduce water waste in irrigation in more- and less-developed countries. List four ways to reduce water waste in industry and homes, and three ways to use less water to remove wastes. List four ways to use water more sustainably and four ways in which you can reduce your use and waste of water.

9. What is a **floodplain** and why do people like to live on floodplains? What are the benefits and drawbacks of floods? List three human activities that increase the risk of flooding. Describe the increased flooding risks that many people in Bangladesh face and what they are doing about it. List three ways to reduce the risks of flooding.

10. What are this chapter's *three big ideas*? Describe the relationships between water resource problems in the Colorado River basin (**Core Case Study**) and the three **principles of sustainability**. CORE CASE STUDY SUSTAINABILITY

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. What do you believe are the three most important priorities for dealing with the water resource problems of the Colorado River basin, as discussed in the **Core Case Study** that opens this chapter? Explain your choices. CORE CASE STUDY

2. List three ways in which human activities are affecting the water cycle. How might these changes to the cycle affect your lifestyle? How might your lifestyle be contributing to these effects?

3. What role does population growth play in water supply problems? Relate this to water supply problems of the Colorado River basin (**Core Case Study**). CORE CASE STUDY

4. Explain why you are for or against **(a)** raising the price of water while providing lower lifeline rates for the poor and lower-middle class, **(b)** withdrawing government subsidies that provide farmers with water at low cost, and **(c)** providing government subsidies to farmers for improving irrigation efficiency.

5. Calculate how many liters (and gallons) of water are wasted in 1 month by a toilet that leaks 2 drops of water per second. (1 liter of water equals about 3,500 drops and 1 liter equals 0.265 gallon.) How many bathtubs (containing about 151 liters or 40 gallons of water) could this wasted water fill?

6. List the three most important ways in which you could reduce your unnecessary waste of water. Which, if any, of these things do you do?

7. List three ways in which human activities increase the harmful effects of flooding. What is the best way to prevent each of these human impacts? Do you think they should be prevented? Why or why not?

8. List three ways in which you could apply **Concept 13-6** (p. 334) in order to make your lifestyle more environmentally sustainable.

9. Congratulations! You are in charge of the world. What are three actions you would take to **(a)** provide an adequate, safe drinking water supply for the poor and for other people in less-developed countries, **(b)** sharply reduce groundwater depletion, **(c)** sharply reduce water waste in irrigation, and **(d)** sharply reduce water waste in homes and businesses?

10. List two questions that you would like to have answered as a result of reading this chapter.

ECOLOGICAL FOOTPRINT ANALYSIS

In 2005, the population of the U.S. state of Florida consumed 24.5 billion liters (6.5 billion gallons) of freshwater daily. It is projected that in 2025, the daily consumption will increase to 32.1 billion liters (8.5 billion gallons) per day. Between 2005 and 2025, the population of Florida is projected to increase from 17.5 million to 25.9 million.

1. Based on total freshwater use:
   - **a.** Calculate the per capita consumption of water per day in Florida in 2005 and the projected per capita consumption per day for 2025.
   - **b.** Calculate the per capita consumption of water for the year in Florida in 2005 and the projected per capita consumption per year for 2025.
2. In 2005, how did Florida's *average water footprint* (consumption per person per year), based only on water used within the state, compare with the average U.S. water footprint of approximately 249,000 liters (66,000 gallons) per person per year, and with the global average water footprint of 123,770 liters (32,800 gallons) per person per year?

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14 Geology and Nonrenewable Mineral Resources

CORE CASE STUDY The Real Cost of Gold

Mineral resources extracted from the earth's crust are processed into an amazing variety of products that can make our lives easier and provide us with economic benefits and jobs. But a number of harmful environmental effects are caused by extracting minerals from the ground and converting them to such products.

For example, many newlyweds would be surprised to know that mining enough gold to make their wedding rings produced roughly enough mining waste to equal the total weight of more than three mid-size cars. This waste is usually left piled near the mine site and can pollute the air and nearby surface water.

In Australia and North America, mining companies level entire mountains of rock containing only small concentrations of gold. To extract the gold, miners spray a solution of highly toxic cyanide salts (which react with gold) onto huge piles of crushed rock. The solution then drains off the rocks, pulling some gold with it, into settling ponds (Figure 14-1). After the solution is recirculated in this process a number of times, the gold is removed from the ponds.

This cyanide is extremely toxic to birds and mammals drawn to these ponds in search of water. The ponds can also leak or overflow, which poses threats to underground drinking water supplies and to fish and other forms of life in nearby lakes and streams. Special liners in the settling ponds can prevent leaks, but some have failed. According to the U.S. Environmental Protection Agency, all such liners will eventually leak.

In 2000, snow and heavy rains washed out an earthen dam on one end of a cyanide leach pond at a gold mine in Romania. The dam's collapse released large amounts of water laced with cyanide and toxic metals into the Tisza and Danube Rivers, which flow through parts of Romania, Hungary, and Yugoslavia. Several hundred thousand people living along these rivers were told not to fish in them or to drink or withdraw water from the rivers or from wells adjacent to them. Businesses located near the rivers were shut down. Thousands of fish and other aquatic animals and plants were killed. This accident and a similar one that occurred in January 2001 could have been prevented if the mining company had installed a stronger containment dam and a backup settling pond to prevent leakage into nearby surface water.

In 2009, the world's top five gold producing countries were, in order, China, South Africa, the United States, Australia, and Peru. These countries vary in how they deal with the environmental impacts of gold mining.

In this chapter, we will look at the earth's dynamic geologic processes, the valuable minerals such as gold that some of these processes produce, and the potential supplies of these resources. We will also study the environmental effects of using these resources. Finally, we will consider how we might obtain and use mineral resources more sustainably.

Creatas/SuperStock

Figure 14-1 This gold mine in the Black Hills of the U.S. state of South Dakota has disturbed a large area of land. This site also contains cyanide leach piles and settling ponds that are highly toxic to wildlife in the immediate area.

Key Questions and Concepts

14-1 **What are the earth's major geological processes and hazards?**

CONCEPT 14-1 Dynamic processes move matter within the earth and on its surface, and can cause volcanic eruptions, earthquakes, tsunamis, erosion, and landslides.

14-2 **How are the earth's rocks recycled?**

CONCEPT 14-2 The three major types of rock found in the earth's crust—sedimentary, igneous, and metamorphic—are recycled very slowly by the processes of erosion, melting, and metamorphism.

14-3 **What are mineral resources and what are the environmental effects of using them?**

CONCEPT 14-3 We can make some minerals in the earth's crust into useful products, but extracting and using these resources can disturb the land, erode soils, produce large amounts of solid waste, and pollute the air, water, and soil.

14-4 **How long will supplies of nonrenewable mineral resources last?**

CONCEPT 14-4A All nonrenewable mineral resources exist in finite amounts, and as we get closer to depleting any mineral resource, the environmental impacts of extracting it generally become more harmful.

CONCEPT 14-4B Raising the price of a scarce mineral resource can lead to an increase in its supply, but there are environmental limits to this effect.

14-5 **How can we use mineral resources more sustainably?**

CONCEPT 14-5 We can try to find substitutes for scarce resources, reduce resource waste, and recycle and reuse minerals.

Note: Supplements 2 (p. S3), 4 (p. S11), 8 (p. S30), and 9 (p. S57) can be used with this chapter.

Civilization exists by geological consent, subject to change without notice.

WILL DURANT

14-1 What Are the Earth's Major Geological Processes and Hazards?

▶ **CONCEPT 14-1 Dynamic processes move matter within the earth and on its surface, and can cause volcanic eruptions, earthquakes, tsunamis, erosion, and landslides.**

The Earth Is a Dynamic Planet

Geology, one of the subjects of this chapter, is the science devoted to the study of dynamic processes taking place on the earth's surface and in its interior. As the primitive earth cooled over eons, its interior separated into three major concentric zones: the *core*, the *mantle*, and the *crust* (see Figure 3-2, p. 56).

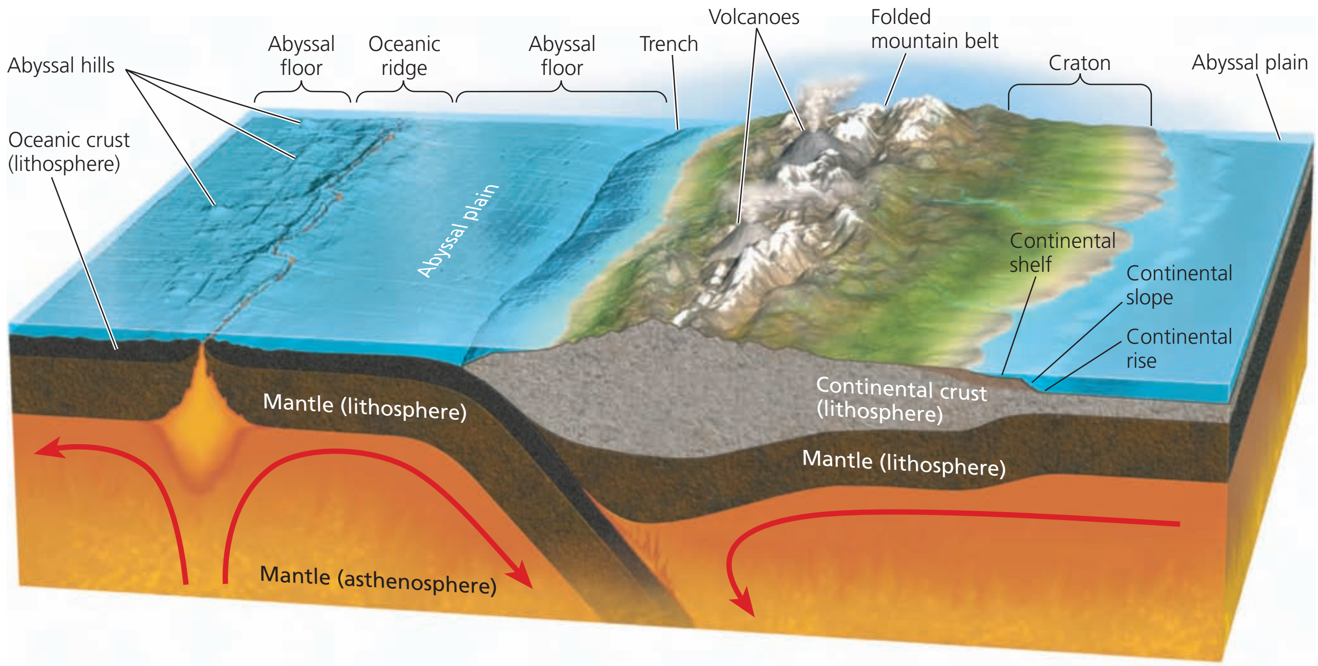
The **core** is the earth's innermost zone. It is extremely hot and has a solid inner part, surrounded by a liquid core of molten or semisolid material. Surrounding the core is a thick zone called the **mantle**. Most of the mantle is solid rock, but under its rigid outermost part is the **asthenosphere**—a zone of hot, partly melted rock that flows and can be deformed like soft plastic.

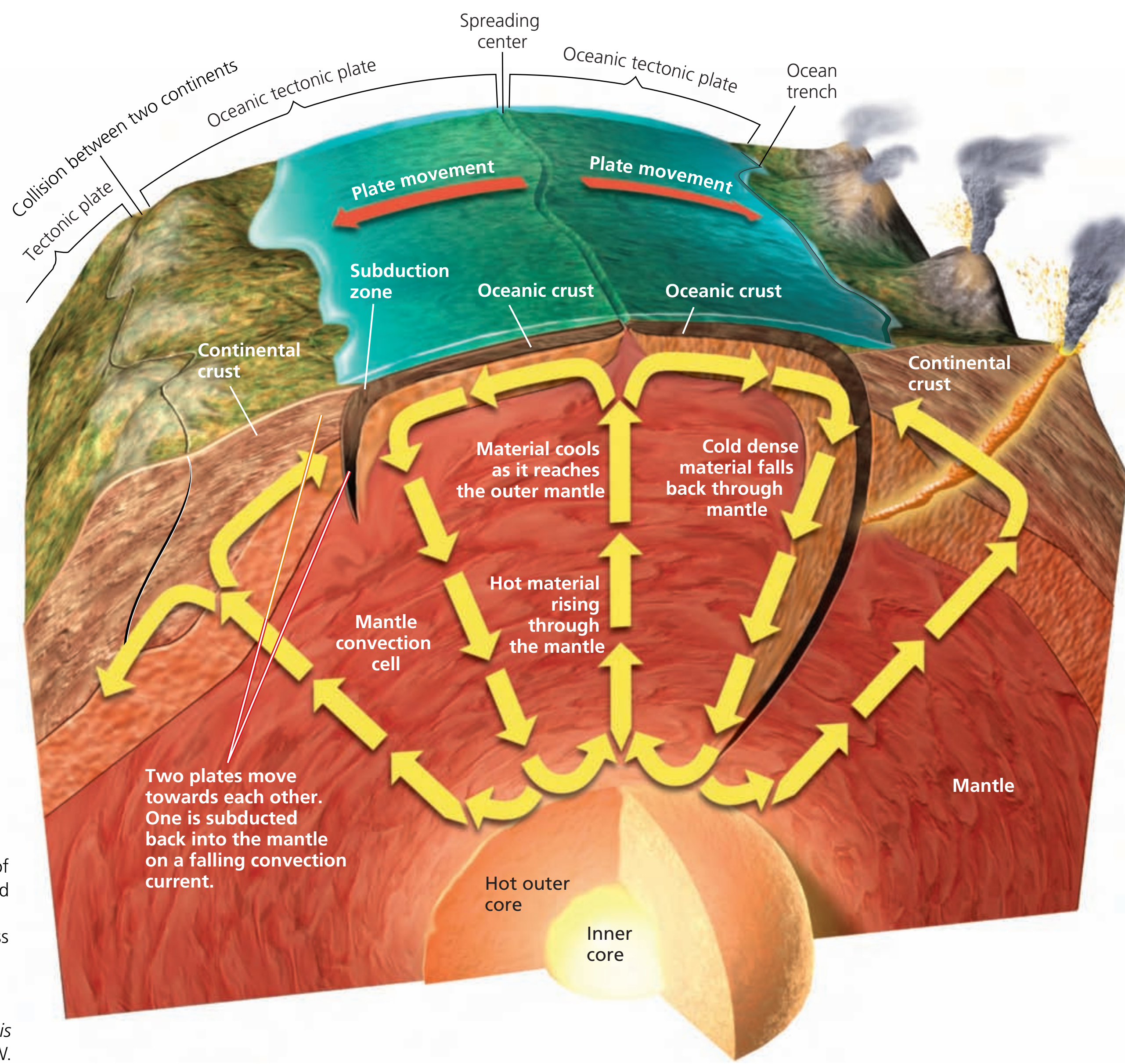
The outermost and thinnest zone of the earth is the **crust**. It consists of the *continental crust*, which underlies the continents (including the continental shelves extending into the oceans), and the *oceanic crust*, which underlies the ocean basins and makes up 71% of the earth's crust (Figure 14-2, p. 348). The combination of the crust and the rigid, outermost part of the mantle (above the asthenosphere) is called the **lithosphere**.

The Earth Beneath Your Feet Is Moving

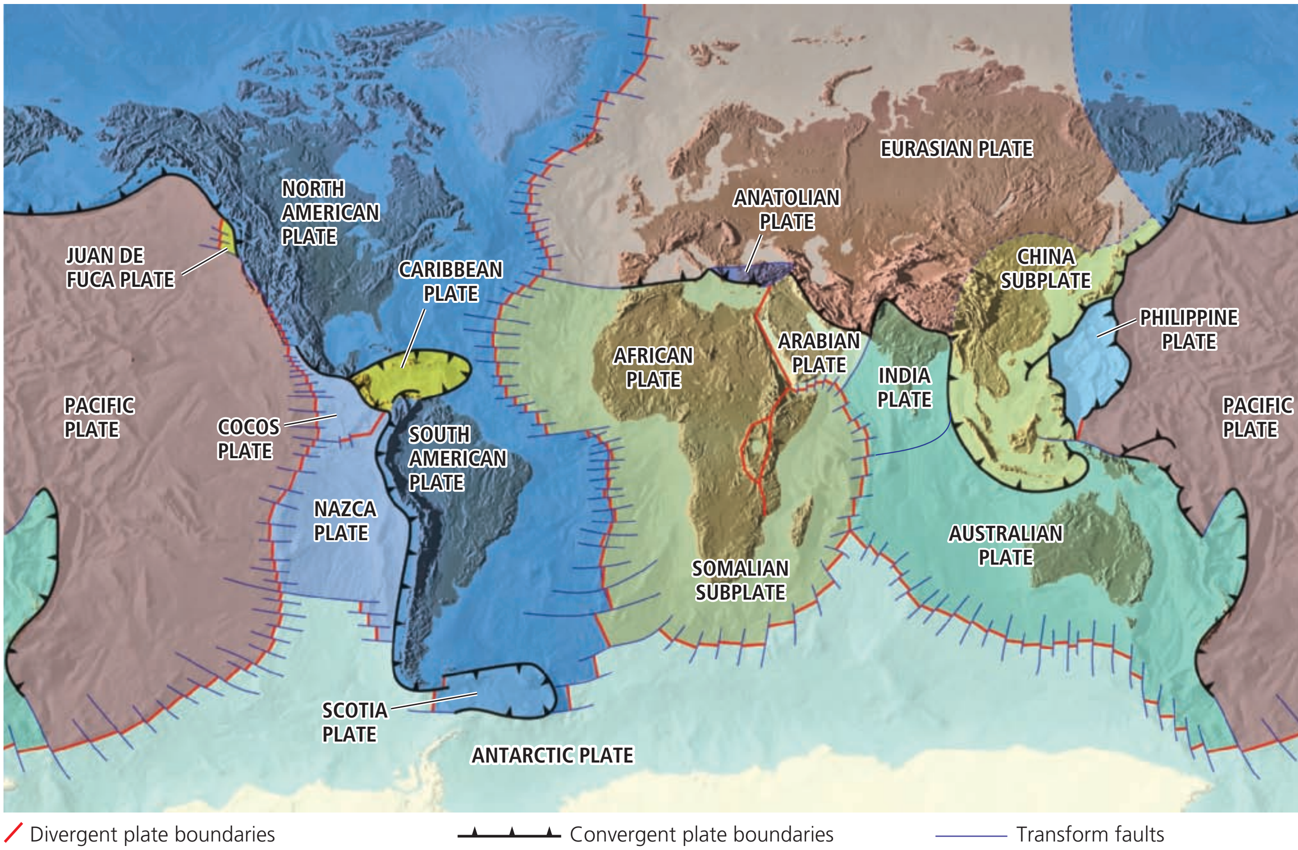
We tend to think of the earth's crust, mantle, and core as fairly static. In reality, *convection cells* or *currents* move large volumes of rock and heat in loops within the mantle like gigantic conveyer belts (Figure 14-3, p. 348 and **Concept 14-1**). Geologists believe that the flows of energy and heated material in these convection cells caused the lithosphere to break up into a dozen or so huge rigid plates, called **tectonic plates**, which move extremely slowly atop the asthenosphere (Figure 14-3, p. 348, and Figure 14-4, p. 349).

Figure 14-2
The earth's crust and upper mantle have certain major features. The *lithosphere*, composed of the crust and outermost mantle, is rigid and brittle. The *asthenosphere*, a zone in the mantle, can be deformed by heat and pressure.





CENGAGENOW™
Active Figure 14-3
The earth's crust is made up of a mosaic of huge rigid plates, called *tectonic plates*, which move very slowly across the asthenosphere in response to forces in the mantle. *See an animation based on this figure at* CengageNOW.



CENGAGENOW™ **Active Figure 14-4** This map shows the earth's major tectonic plates. *See an animation based on this figure at* CengageNOW. **Question:** Which plate are you riding on?

These gigantic, thick plates are somewhat like the world's largest and slowest-moving surfboards on which we ride without noticing their movement. Their typical speed is about the rate at which fingernails grow. Throughout the earth's history, continents have split apart and joined as their underlying tectonic plates drifted atop the earth's asthenosphere (see Figure 4-8, p. 89).

Much of the geologic activity at the earth's surface takes place at the boundaries between tectonic plates as they separate, collide, or slide past one another. The tremendous forces produced at these plate boundaries can cause mountains to form, earthquakes to shake parts of the crust, and volcanoes to erupt.

When an oceanic plate collides with a continental plate, the continental plate usually rides up over the denser oceanic plate and pushes it down into the mantle (Figure 14-3) in a process called *subduction*. The area where this collision and subduction takes place is called a *subduction zone*. Over time, the subducted plate melts and then rises again toward the earth's surface as molten rock, or *magma*.

When oceanic plates move apart from one another, magma flows up through the resulting cracks. This creates *oceanic ridges* (Figure 14-2), some of which have higher peaks and deeper canyons than the earth's continents have. On the other hand, when two oceanic plates collide, a *trench* ordinarily forms at the boundary between the two plates as the denser plate is subducted under the less dense one. When two continental plates collide, they push up mountain ranges such as the Himalayas along the collision boundary.

Tectonic plates can also slide and grind past one another along a fracture (fault) in the lithosphere—a type of boundary called a *transform fault*. Most transform faults are located on the ocean floor but a few are found on land. For example, the North American Plate and the Pacific Plate slide past each other along California's San Andreas fault (Figure 14-5, p. 350).

Some Parts of the Earth's Surface Build Up and Some Wear Down

Internal geologic processes, generated by heat from the earth's interior, typically build up the earth's surface by pushing up the continental and oceanic crusts, forming mountains and volcanoes (Figures 14-2 and 14-3). By contrast, *external geologic processes*, driven directly or indirectly by energy from the sun (mostly in the form of flowing water and wind) and influenced by gravity, tend to wear down the earth's surface and move matter from one place to another (**Concept 14-1**).

One major external geologic process is **weathering**, the physical, chemical, and biological processes that break down rocks into smaller particles that help to build

Kevin Schafer/Peter Arnold, Inc.

Figure 14-5 This is the San Andreas Fault as it crosses part of the Carrizo plain between San Francisco and Los Angeles, California (USA). This fault, which runs almost the full length of California, is responsible for earthquakes of various magnitudes. **Question:** Is there a transform fault near where you live?

soil. The physical processes of weathering involve wind, water, and temperature changes. In chemical weathering, rainwater or groundwater, made acidic by reacting with carbon dioxide in the atmosphere, slowly dissolve rocks. An example of biological weathering occurs when lichens gradually wear down rock into smaller particles.

Another major external process is *erosion*, discussed in Chapter 12 (pp. 289–290). In this process—a result of weathering—material is dissolved, loosened, or worn away from one part of the earth's surface and deposited elsewhere. Flowing streams and rain cause most erosion (see Figure 12-11, p. 289, and Figure 12-12, p. 290). Wind also blows particles of soil from one area to another (see Figure 12-13, p. 290).

Slowly flowing bodies of ice called *glaciers* (see Figure 3-18, p. 68) cause slow-motion erosion by scraping the land as they move across it. During the last ice age, which ended about 10,000 years ago, ice sheets called *continental glaciers* covered vast areas of North America, Europe, and Asia. The Great Lakes, the world's largest mass of freshwater, formed during this period as retreating glaciers gouged out huge basins. As the climate warmed and the glaciers melted (see Figure 4-9, p. 89), water filled these basins.

Volcanoes Release Molten Rock from the Earth's Interior

An active **volcano** occurs where magma reaches the earth's surface through a central vent or a long crack, called a *fissure* (Figure 14-6). Many volcanoes form along the boundaries of the earth's tectonic plates (Figure 14-4) when one plate slides under or moves away from another plate. Magma that reaches the earth's surface is called *lava*. Volcanic activity can release large chunks of lava rock, glowing hot ash, liquid lava, and gases (including water vapor, carbon dioxide, and sulfur dioxide) into the environment (**Concept 14-1**).

The second largest volcanic eruption during the 20th century occurred in 1991 when Mount Pinatubo exploded on the island of Luzon in the Philippines. It killed several hundred people, despite the evacuation of more than 200,000 of the island's residents. Buildings covered with wet ash collapsed and the volcano ejected enough material into the atmosphere to reduce incoming solar energy and cool the earth's average temperature by about 0.5 C° (1 F°) for 15 months.

While volcanic eruptions can be destructive, they do provide some benefits. They can result in the formation of majestic mountains and lakes such as Crater Lake (Figure 8-17, left, p. 182), and the weathering of lava contributes to fertile soils.

GOOD NEWS

We can reduce the loss of human life and some of the property damage caused by volcanic eruptions in several ways. For example, we use historical records and geologic measurements to identify high-risk areas, so that people can choose to avoid living in those areas. We also use monitoring devices that warn us when volcanoes are likely to erupt, and we have developed evacuation plans for areas prone to volcanic activity.

Earthquakes Are Geological Rock-and-Roll Events

Forces inside the earth's mantle and near its surface push, stress, and deform rocks. At some point the stress can cause the rocks to suddenly shift or break and produce a transform fault, or fracture in the earth's crust (Figure 14-5). When a fault forms, or when there is abrupt movement on an existing fault, energy that has accumulated over time is released in the form of vibrations, called *seismic waves*, which move in all directions through the surrounding rock. This internal geological process is called an **earthquake** (Figure 14-7 and **Concept 14-1**). Most earthquakes occur at the boundaries of tectonic plates (Figure 14-4) when colliding plates create tremendous pressures in the earth's crust or when plates slide past one another at transform faults.

The place where an earthquake begins, often far below the earth's surface is called the *focus* (Figure 14-7). The earthquake's *epicenter* is located on the earth's surface directly above the focus. The energy of the earth's

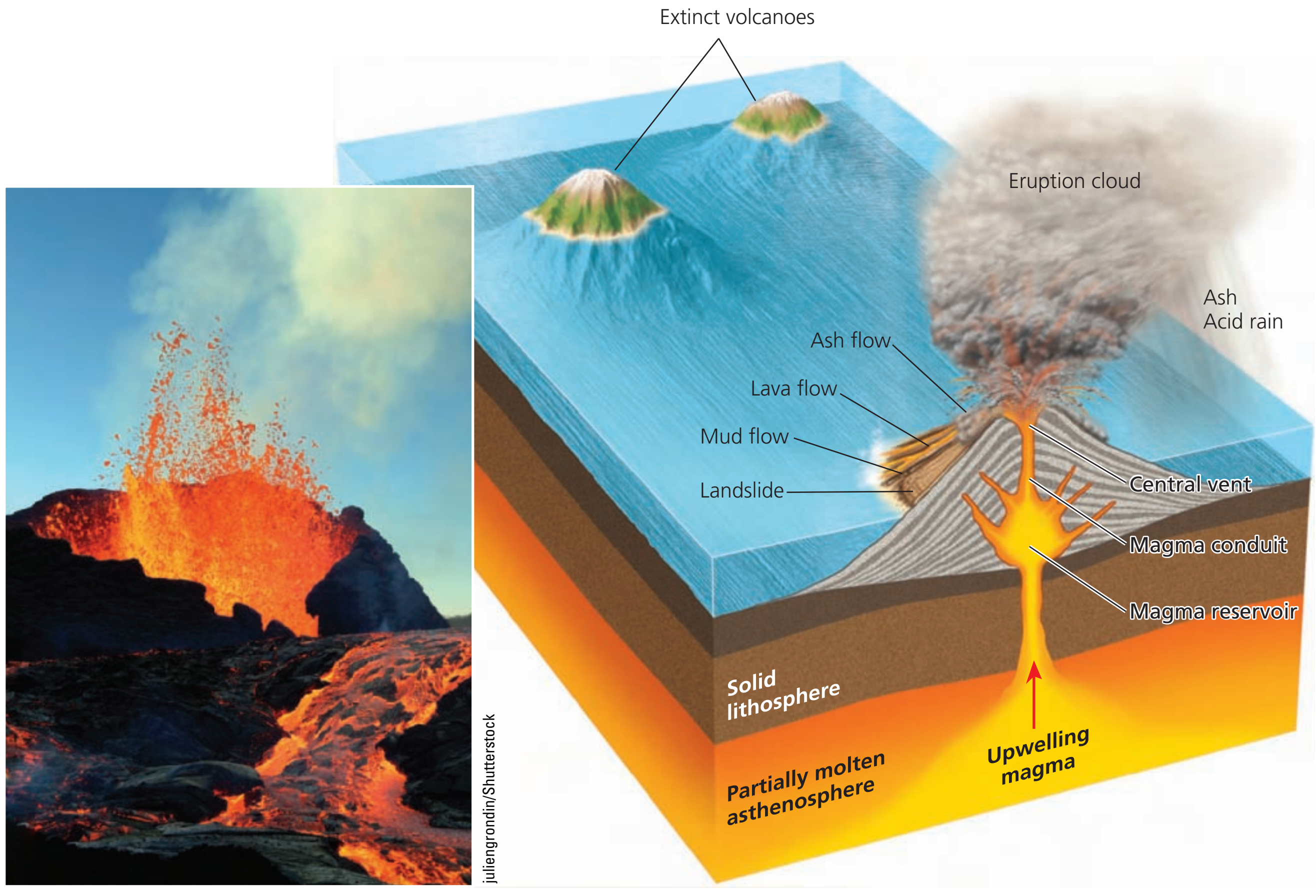


Figure 14-6 A *volcano* is created when magma in the partially molten asthenosphere rises in a plume through the lithosphere to erupt on the surface as lava (photo inset), which builds into a cone. Sometimes, internal pressure is high enough to cause lava, ash, and gases to be ejected into the atmosphere or to flow over land, causing considerable damage. Some volcanoes that have erupted and then become inactive have formed islands or chains of islands.

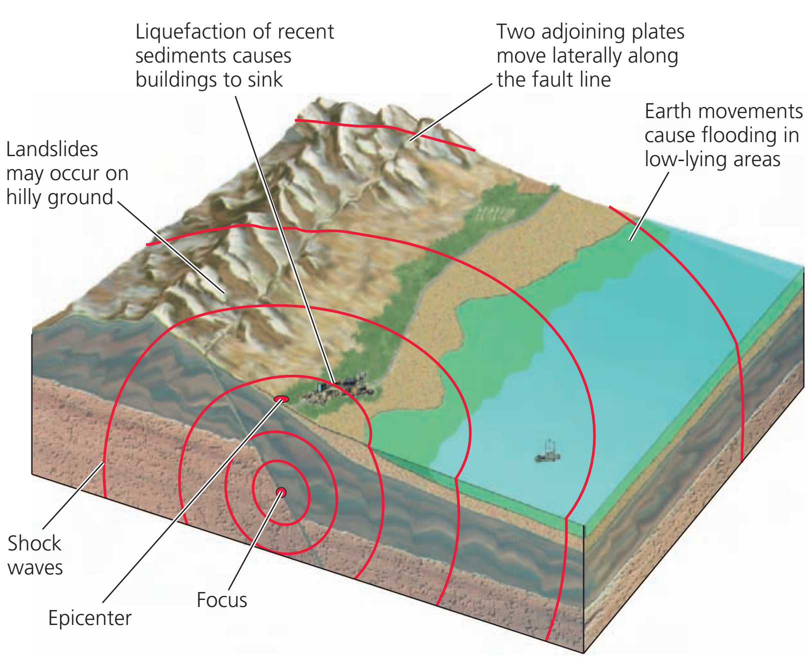


Figure 14-7 An *earthquake* (left), one of nature's most powerful events, has certain major features and effects. In 2010, a major 7.0 earthquake in Haiti (right) killed at least 72,000 people and devastated this already very poor country.

tremendous internal stress is released in the form of *seismic* (shock) *waves,* which move upward and outward from the earthquake's *focus* like ripples in a pool of water.

Scientists measure the severity of an earthquake by the *magnitude* of its seismic waves. The magnitude is a measure of ground motion (shaking) caused by the earthquake, as indicated by the *amplitude,* or size of the seismic waves when they reach a recording instrument, called a *seismograph*.

Scientists use the *Richter scale*, on which each unit has an amplitude 10 times greater than the next smaller unit. Thus, a magnitude 5.0 earthquake would result in 10 times more ground shaking than a magnitude 4.0 earthquake and the amount of ground movement from a magnitude 7.0 quake is 100 times greater than that of a magnitude 5.0 quake. Seismologists rate earthquakes as *insignificant* (less than 4.0 on the Richter scale), *minor* (4.0–4.9), *damaging* (5.0–5.9), *destructive* (6.0–6.9), *major* (7.0–7.9), and *great* (over 8.0). The largest recorded earthquake occurred in Chile on May 22, 1960 and measured 9.5 on the Richter scale. Each year, scientists record the magnitude of more than 1 million earthquakes, most of which are too small to feel.

The *primary effects of earthquakes* include shaking and sometimes a permanent vertical or horizontal displacement of the ground. These effects may have serious consequences for people and for buildings, bridges, freeway overpasses, dams, and pipelines. A major earthquake is a very large rock-and-roll geological event.

GOOD NEWS

One way to reduce the loss of life and property damage from earthquakes is to examine historical records and make geologic measurements to locate active fault zones. We can then map high-risk areas and establish building codes that regulate the placement and design of buildings in such areas. Then people can evaluate the risk and factor it into their decisions about where to live. Also, engineers know how to make homes, large buildings, bridges, and freeways more earthquake resistant. (See Figure 16, p. S48, in Supplement 8 for a map of earthquake risk in various areas of the United States and Figure 17, p. S48, in Supplement 8 for a map of such areas throughout the world.)

Earthquakes on the Ocean Floor Can Cause Huge Waves Called Tsunamis

A **tsunami** is a series of large waves generated when part of the ocean floor suddenly rises or drops (Figure 14-8). Most large tsunamis are caused when certain types of faults in the ocean floor move up or down as a result of a large underwater earthquake, a landslide caused by such an earthquake, or in some cases, by a volcanic eruption (**Concept 14-1**). Such earthquakes often occur offshore in subduction zones where an oceanic tectonic plate slips under a continental plate (Figure 14-3).

Tsunamis are often called *tidal waves*, although they have nothing to do with tides. They can travel far across the ocean at the speed of a jet plane. In deep water the waves are very far apart—sometimes hundreds of kilometers—and their crests are not very high. As a tsunami approaches a coast with its shallower waters, it slows

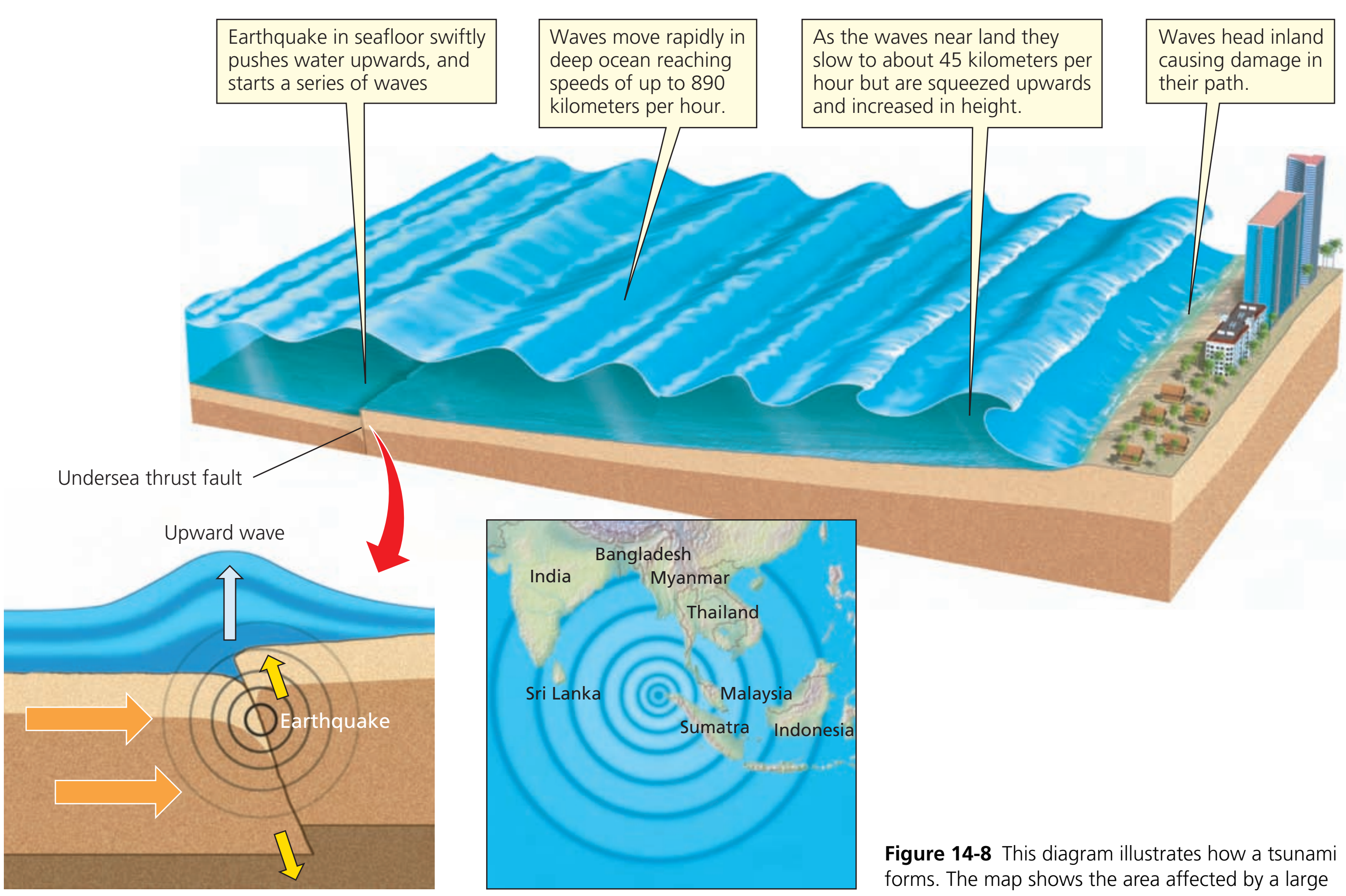


Figure 14-8 This diagram illustrates how a tsunami forms. The map shows the area affected by a large tsunami in December 2004.

Figure 14-9 In December 2004, a great earthquake with a magnitude of 9.15 on the seafloor of the Indian Ocean generated a tsunami that killed 168,000 people in Indonesia, as well as tens of thousands more in other countries bordering the Indian Ocean. These photos show the Banda Aceh Shore near Gleebruk in Indonesia on June 23, 2004 before the tsunami (left), and on December 28, 2004 after it was stuck by the tsunami (right).

down, its wave crests squeeze closer together, and their heights grow rapidly. It can hit a coast as a series of towering walls of water that can level buildings.

We can detect tsunamis through a network of ocean buoys or pressure recorders located on the ocean floor that provide some degree of early warning. These data are relayed to tsunami emergency warning centers. But there are far too few of these recorders and emergency warning centers to adequately monitor earthquake activity that might generate tsunamis.

Between 1900 and late 2000, tsunamis killed an estimated 278,000 people in regions of the Pacific Ocean. The largest loss of life occurred in December 2004 when a great underwater earthquake in the Indian Ocean with a magnitude of 9.15 caused a tsunami that generated waves as high as 31 meters (100 feet)—about the height of a four-story building. It killed about 228,000 people and devastated many coastal areas of Indonesia (Figure 14-9), Thailand, Sri Lanka, South India, and even eastern Africa. No buoys or gauges were in place to provide an early warning of this tsunami.

CONNECTIONS

Coral Reefs, Mangrove Forests, and Tsunami Damage

Coral reefs and mangrove forests slow the waves that roll over them, reducing their force before they hit nearby shorelines. Satellite observations and ground studies done in February 2005 by the UN Environment Programme pointed out the role that healthy coral reefs (see Figure 8-1, p. 168) and mangrove forests (see Figure 8-10, p. 175) played in reducing the force of the 2004 tsunami's huge waves and the resulting death toll and destruction in some areas. In areas where mangrove forests had been removed, the damage and death toll were much higher than in areas where mangrove forests remained.

14-2 How Are the Earth's Rocks Recycled?

▶ **CONCEPT 14-2 The three major types of rock found in the earth's crust—sedimentary, igneous, and metamorphic—are recycled very slowly by the processes of erosion, melting, and metamorphism.**

There Are Three Major Types of Rocks

The earth's crust consists mostly of rocks and minerals. A **mineral** is an element or inorganic compound that occurs naturally in the earth's crust as a *crystalline solid,* or one that has a regularly repeating internal arrangement of its atoms. A few minerals consist of a single element such as gold and mercury (see Figure 2-4, p. 38). But most of the more than 2,000 identified minerals occur as inorganic compounds formed by various combinations of elements. Examples include salt (sodium chloride or NaCl, Figure 2, p. S12, in Supplement 4) and quartz (silicon dioxide or SiO_2).

Rock is a solid combination of one or more minerals found in the earth's crust. Some kinds of rock such as limestone (calcium carbonate, or $CaCO_3$) and quartzite (silicon dioxide, or SiO_2) contain only one mineral. But most rocks consist of two or more minerals. For example, granite is a mixture of mica, feldspar, and quartz crystals.

Based on the way it forms, rock is placed in three broad classes: sedimentary, igneous, or metamorphic (**Concept 14-2**). **Sedimentary rock** is made of *sediments*—dead plant and animal remains and tiny particles of weathered and eroded rocks. These sediments are transported by water, wind, or gravity to downstream, downwind, downhill, or underwater sites. There they are deposited in layers that accumulate over time. Eventually, the increasing weight and pressure on the underlying sedimentary layers convert them into rock. Examples include *sandstone* and *shale* (formed from pressure created by deposited layers made mostly of sand), *dolomite* and *limestone* (formed from the compacted shells, skeletons, and other remains of dead aquatic organisms), and *lignite* and *bituminous coal* (derived from compacted plant remains).

Igneous rock forms below or on the earth's surface when magma wells up from the earth's upper mantle or deep crust (Figure 14-6) and then cools and hardens. Examples include *granite* (formed underground) and *lava rock* (formed aboveground). Igneous rocks form the bulk of the earth's crust but are usually covered by sedimentary rocks.

Metamorphic rock forms when a preexisting rock is subjected to high temperatures (which may cause it to melt partially), high pressures, chemically active fluids, or a combination of these agents. These forces may transform a rock by reshaping its internal crystalline structure and its physical properties and appearance. Examples include *slate* (formed when shale and mudstone are heated) and *marble* (produced when limestone is exposed to heat and pressure).

Earth's Rocks Are Recycled Very Slowly

The interaction of physical and chemical processes that change rocks from one type to another is called the **rock cycle** (Figure 14-10). Over millions of years, this important form of natural capital recycles the earth's

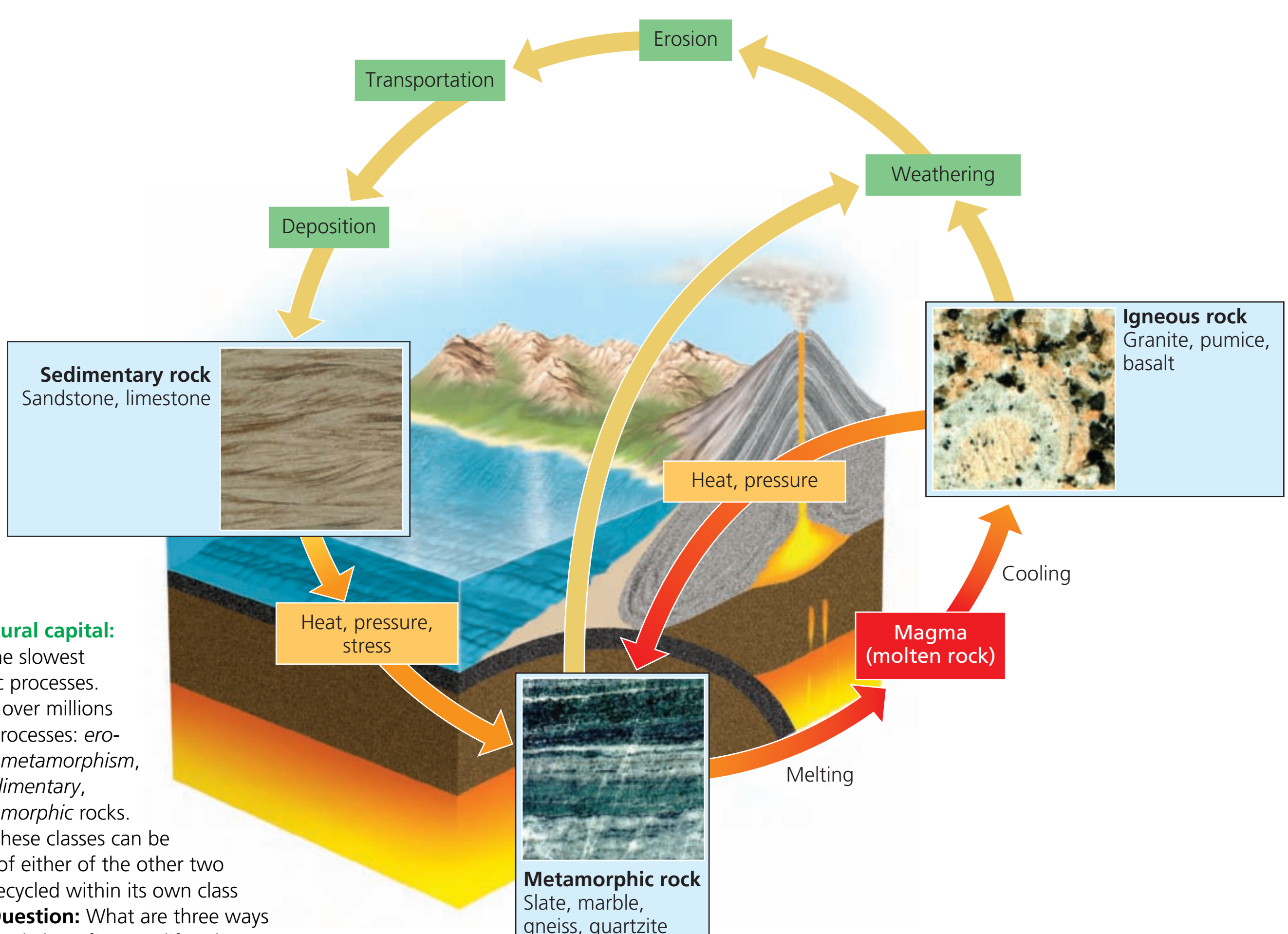


Figure 14-10 **Natural capital:** The *rock cycle* is the slowest of the earth's cyclic processes. Rocks are recycled over millions of years by three processes: *erosion*, *melting*, and *metamorphism*, which produce *sedimentary*, *igneous*, and *metamorphic* rocks. Rock from any of these classes can be converted to rock of either of the other two classes or can be recycled within its own class (**Concept 14-2**). **Question:** What are three ways in which the rock cycle benefits your lifestyle?

three types of rock and it is the slowest of the earth's cyclic processes (**Concept 14-2**). In this process, rocks are broken down, melted, fused together into new forms by heat and pressure, cooled, and sometimes recrystallized within the earth's mantle and crust.

The rock cycle also plays a major role in forming concentrated deposits of mineral resources. Some of these minerals, such as iron and salt, are crucial to our very life processes. In fact, without the earth's incredibly slow rock cycle, you would not exist.

14-3 What Are Mineral Resources and What Are the Environmental Effects of Using Them?

CONCEPT 14-3 We can make some minerals in the earth's crust into useful products, but extracting and using these resources can disturb the land, erode soils, produce large amounts of solid waste, and pollute the air, water, and soil.

We Use a Variety of Nonrenewable Mineral Resources

A **mineral resource** is a concentration of naturally occurring material from the earth's crust that we can extract and process into raw materials and useful products at an affordable cost (**Concept 14-3**). We know how to find and extract more than 100 minerals from the earth's crust. Two major types of minerals are *metallic minerals* (such as aluminum and gold), and *nonmetallic minerals* (such as sand and limestone). Because minerals and rocks take so long to form, they are classified as *nonrenewable resources*.

An **ore** is rock that contains a large enough concentration of a particular mineral—often a metal—to make it profitable for mining and processing. A **high-grade ore** contains a large concentration of the desired mineral, whereas a **low-grade ore** contains a smaller concentration.

Nonrenewable metal and nonmetal mineral resources have a variety of uses. *Aluminum* (Al) is used for packaging and beverage cans, and as a structural material in motor vehicles, aircraft, and buildings. *Iron* (Fe) is used to make steel, an essential material used in buildings and motor vehicles. Steel is a mixture (alloy) of iron and other elements that are added to give it certain physical properties. *Manganese* (Mn), *cobalt* (Co), and *chromium* (Cr) are widely used in important steel alloys. *Copper* (Cu), a good conductor of electricity, is used for electrical and communications wiring. *Gold* (Au) (**Core Case Study**) is used in electrical equipment, tooth fillings, jewelry, coins, and some medical implants.

The most widely used nonmetallic minerals are sand and gravel. *Sand*, which is mostly silicon dioxide (SiO_2), is used to make glass, bricks, and concrete for the construction of roads and buildings. *Gravel* is used for roadbeds and to make concrete. Another common nonmetallic mineral is *limestone* (mostly calcium carbonate, or $CaCO_3$), which is crushed to make concrete and cement. *Phosphate salts* are mined and used in inorganic fertilizers and in some detergents.

Most published estimates of the supply of a given mineral resource refer to its **reserves**: identified resources from which we can extract the mineral profitably at current prices. Reserves increase when we find new, profitable deposits and when higher prices or improved mining technologies make it profitable to extract deposits that previously were considered too expensive to remove.

Some Environmental Impacts of Mineral Use

We can use metals to produce many useful products. But mining, processing, using, and disposing of, or recycling metals—what is known as the *life cycle of a metal*

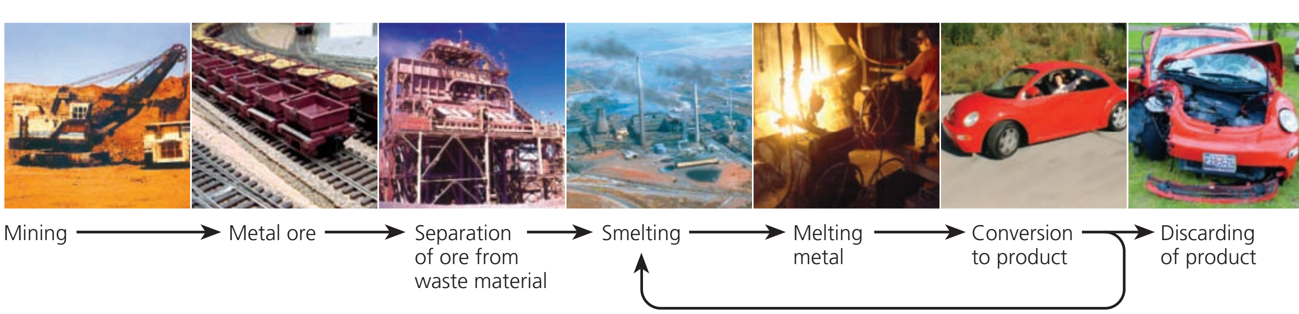


Figure 14-11 Each metal resource that we use has a *life cycle*. Each step in this process uses large amounts of energy and water, and produces some pollution and waste.

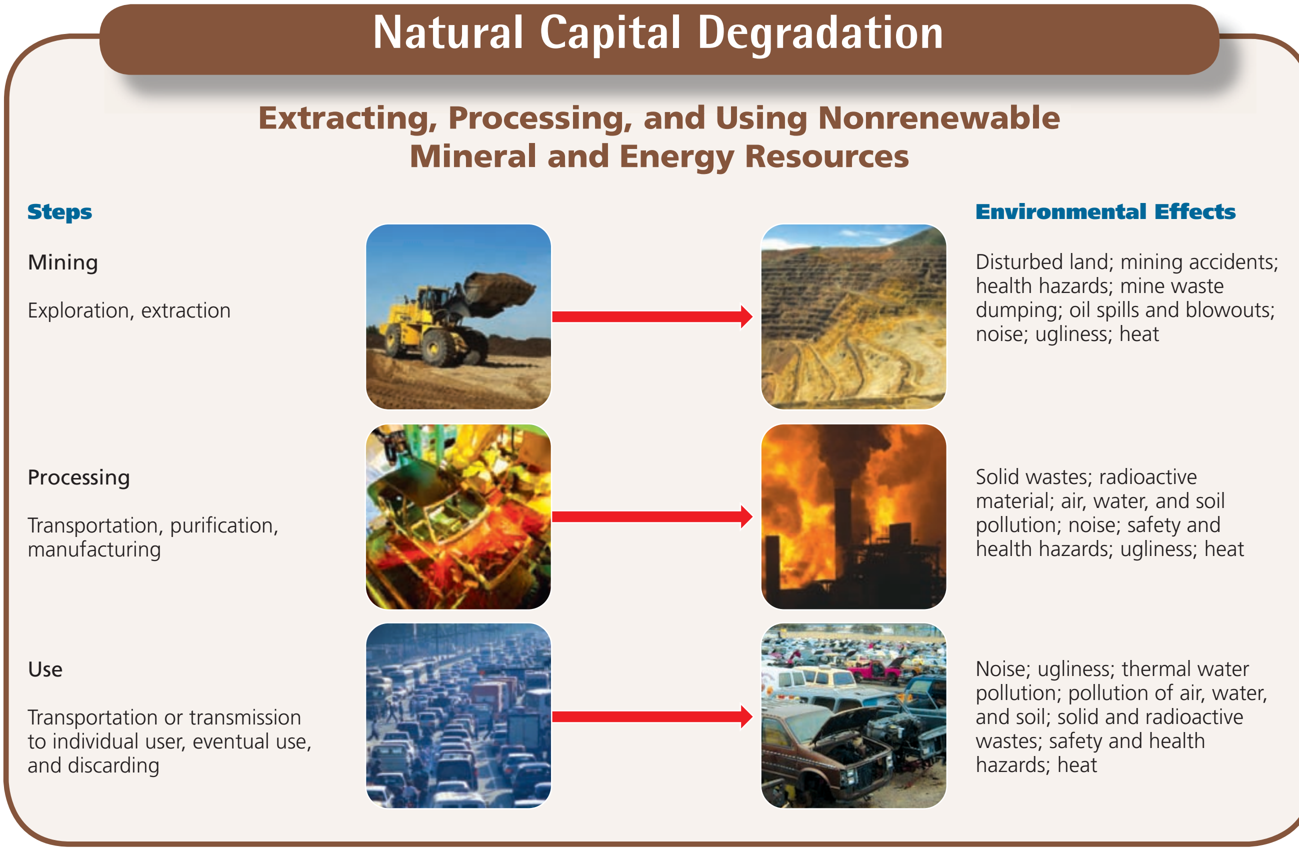


Figure 14-12 The extraction, processing, and use of any nonrenewable mineral or energy resource all contribute to a number of harmful environmental effects (**Concept 14-3**). Further, providing the energy required to carry out each step causes additional pollution and environmental degradation. **Questions:** What are three mineral resources that you used today? Which of these harmful environmental effects might have resulted from obtaining and using these resources?

(Figure 14-11)—takes enormous amounts of energy and water and can disturb the land, erode soil, produce solid waste and greenhouse gases, and pollute the air, water, and soil (Figure 14-12) (**Concept 14-3**). Some environmental scientists and resource experts warn that the greatest danger from continually increasing our consumption of nonrenewable mineral resources may be the environmental damage caused by their extraction, processing, and conversion to products. At some point, the costs of these harmful environmental effects can exceed the value of the minerals.

The environmental impacts from mining an ore are affected by its percentage of metal content, or *grade*. The more accessible and higher-grade ores are usually exploited first. As they become depleted, mining lower-grade ores takes more money, energy, water, and other materials, and increases land disruption, mining waste, and pollution.

THINKING ABOUT
Low-Grade Ores

Use the second law of thermodynamics (see Chapter 2, p. 47) to explain why mining lower-grade ores requires more energy and materials and increases land disruption, mining waste, and pollution.

There Are Several Ways to Remove Mineral Deposits

After mineral deposits are located, several different mining techniques can be used to remove them. The location and type of the mineral resource determines the technique used to remove it.

Shallow mineral deposits are removed by **surface mining**, in which materials lying over a deposit are removed to expose the resource for processing. There are many different types of surface mining, but they generally begin with removal of all vegetation, including forests, from a site. Then the **overburden**, or soil and rock overlying a useful mineral deposit, is removed. It is usually deposited in piles of waste material called **spoils**. When ore deposits that contain metals such as gold (**Core Case Study**) are dredged from streams, the unused materials or *tailings* are usually left on the land. Surface mining is used to extract about 90% of the nonfuel mineral and rock resources and 60% of the coal used in the United States.

The type of surface mining used depends on two factors: the resource being sought and the local topography. In **open-pit mining** (Figure 14-13), machines dig very large holes and remove metal ores (such as

BenC/Shutterstock

Figure 14-13 **Natural capital degradation:** This *open-pit* copper mine, which is located near the U.S. city of Bisbee, Arizona, has been abandoned since the mid-1970s. **Question:** Should governments require mining companies to fill in and restore such sites once their ore is depleted? Explain.

iron, copper, and gold ores), as well as sand, gravel, and stone (such as limestone and marble).

Strip mining is useful and economical for extracting mineral deposits that lie in large horizontal beds close to the earth's surface. In **area strip mining**, used where the terrain is fairly flat, a gigantic earthmover strips away the overburden, and a power shovel—which can be as tall as a 20-story building—removes the mineral deposit (Figure 14-14). The resulting trench is filled with overburden, and a new cut is made parallel to the previous one. This process is repeated over the entire site.

Contour strip mining (Figure 14-15, p. 358) is used mostly to mine coal on hilly or mountainous terrain. Gigantic power shovels and bulldozers cut a series of terraces into the side of a hill. Then, huge earthmovers remove the overburden, a power shovel extracts the coal, and the overburden from each new terrace is dumped onto the one below. Unless the land is restored, a wall of dirt called a *highwall* is left in front of a highly erodible bank of soil and rock.

Another surface mining method is **mountaintop removal**. In the Appalachian Mountains of the United States, where this form of mining is commonly used, explosives, earth movers, large power shovels, and other machines with huge buckets, called *draglines*, are used to remove the top of a mountain and expose seams of coal, which are then removed.

Deep deposits of minerals are removed by **subsurface mining**, in which underground mineral resources are removed through tunnels and shafts. This method is used to remove coal and metal ores that are too deep to be extracted by surface mining. Miners dig a deep, vertical shaft, blast open subsurface tunnels and chambers to reach the deposit, and use machinery to remove the resource and transport it to the surface.

Mining Has Harmful Environmental Effects

Mining can do long-term harm to the environment in a number of ways. One type of damage is *scarring and disruption of the land surface* (Figures 14-1 and 14-13 through 14-17). CORE CASE STUDY

U.S. Fish and Wildlife Service

Figure 14-14 This heavy piece of equipment with a large bucket is removing material from an area-strip-mining operation in the U.S. state of Wyoming.

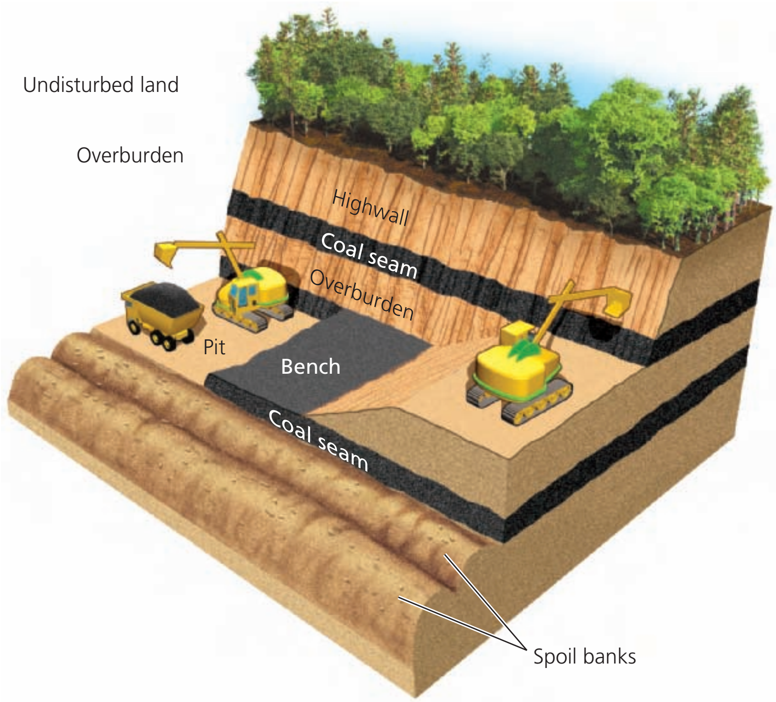


Figure 14-15 **Natural capital degradation:** *Contour strip mining* is used in hilly or mountainous terrain to extract minerals such as coal.

For example, area strip mining often leaves a series of spoils banks (Figure 14-16). Spoils are very susceptible to chemical weathering and erosion by water and wind. Regrowth of vegetation on these banks is quite slow, because they have no topsoil, and thus returning a site to its previous condition before it was strip-mined requires the long process of primary ecological succession (see Figure 5-19, p. 119).

In mountaintop removal (Figure 14-17), enormous machines plow great volumes of waste rock and dirt into valleys below the mountaintops. This destroys forests, buries mountain streams, and increases flood hazards. Wastewater and toxic sludge, produced when the coal is processed, are often stored behind dams in these valleys, which can overflow or collapse and release toxic substances such as arsenic and mercury.

In nearby communities, people live with daily blasting until the mountaintop is blown away, and on most days, it is hard for them to avoid breathing coal dust. These communities can be damaged economically, as well as environmentally by mountaintop removal. Large-scale daily blasting can also disrupt groundwater springs and wells that people depend on for water.

In the United States, more than 500 mountaintops in West Virginia and other Appalachian states have been removed to extract coal. The resulting spoils have buried about 1,900 kilometers (1,200 miles) of streams, according to the U. S. Environmental Protection Agency (EPA). In 2010, the EPA issued regulations that will make it more difficult for coal companies to start up new mountaintop removal projects that will likely cause a certain level of water pollution. This could curtail mountaintop removal if the ruling stays in place. You can tour some of the obliterated landscapes of the Appalachian Mountains by visiting the website Appalachian Voices at **http://www.appvoices.org/**.

GOOD NEWS

Surface mining in tropical forests and other tropical areas destroys or degrades vital biodiversity when forests are cleared and when rivers are polluted with mining wastes. Since 1980, millions of miners have streamed into these areas in search of gold (**Core Case Study**). These small-scale miners use destruc-

CORE CASE STUDY

pmphoto/Shutterstock

Figure 14-16 **Natural capital degradation:** Area strip mining of coal in Germany created these spoils banks. A coal-burning power plant is in the background. **Question:** Should governments require mining companies to restore such sites as fully as possible? Explain.

Jim Wark/Peter Arnold, Inc.

Figure 14-17 **Natural capital degradation:** This is a mountaintop coal mining operation in the U.S. state of West Virginia, where coal is the state rock. The large amount of debris that results from this method is deposited in the valleys and streams below. Mountaintop removal for coal is also occurring in the U.S. states of Virginia, Tennessee, Kentucky, and Pennsylvania. See other sites at **http://www.appvoices.org/**. **Question:** Are you for or against mountaintop coal mining? Explain.

tive techniques to dig large pits and dredge sediments from rivers. Some use hydraulic mining—a technique that was outlawed in the United States—in which water cannons wash entire hillsides into collection boxes for gold removal (see Photo 7 in the Detailed Contents).

CONNECTIONS

Mercury Poisoning and Tropical Gold Mining

Mercury is a highly toxic metal that interferes with the human nervous system and brain functions, and it can build up to high levels in the human body. Mercury is used illegally and rampantly in Asia, Africa, and Latin America where tens of thousands of small-scale gold miners use it to separate gold from stream sediments. As many as 3 grams of mercury escape to the environment for every 1 gram of gold produced in this way. It is the second-worst human-related source of mercury pollution in the world after the burning of coal. Fish populations in one area of Borneo have subsequently dropped by 70% and miners and villagers in areas of mercury pollution suffer from deadly mercury poisoning.

Surface mining sites can be cleaned up and restored (Figure 14-18, p. 360), but it is costly. The U.S. Department of the Interior (DOI) estimates that at least 500,000 surface-mined sites dot the U.S. landscape, mostly in the West. The DOI also estimates that cleaning up these sites could cost taxpayers as much as $70 billion. Worldwide, cleaning up abandoned mining sites would cost trillions of dollars.

Subsurface mining disturbs less than one-tenth as much land as surface mining disturbs, and it usually produces less waste material. However, it creates hazards such as cave-ins, explosions, and fires. Miners often get diseases such as black lung, caused by prolonged inhalation of coal dust in subsurface mines. Another problem is *subsidence*—the collapse of land above some underground mines. It can damage houses, crack sewer lines, break gas mains, and disrupt groundwater systems.

Mining operations also produce large amounts of solid waste—three-fourths of all U.S. solid waste—and

INDIVIDUALS MATTER

Maria Gunnoe

In 2009, West Virginia environmental activist Maria Gunnoe, a former waitress and mother of two teenagers, won a Goldman Environmental Prize for her effort to fight against mountaintop removal coal mining.

This award—considered the "Nobel Prize for the Environment"—recognizes grassroots environmental leaders from around the world and their extraordinary efforts to protect the natural world and human rights. Each recipient receives a cash prize of $150,000.

In 2000, work had begun on a mountaintop removal coal mine on a ridge above her house in West Virginia. Since then, the project has flooded her property seven times, covered her yard with toxic coal sludge, contaminated her well and groundwater, and forced her family to use bottled water for drinking, cooking, and bathing. The coal company called the damages "an act of God."

This experience turned her into a fearless community organizer and advocate for environmental justice in the Appalachian coalfields. She has persisted in her campaign against mountaintop-removal coal mining, despite receiving not only many warnings from people urging her to leave her ancestral land, but even death threats. Now, she speaks all over the nation and is recognized as an inspiring leader in her fight against some of the country's wealthiest and most politically powerful coal companies.

A. S. Zain/Shutterstock

Figure 14-18 This mining site in Indonesia has been ecologically restored, but such restoration is rare.

cause major water and air pollution. For example, *acid mine drainage* occurs when rainwater that seeps through a mine or a spoils pile carries sulfuric acid (H_2SO_4, produced when aerobic bacteria act on iron sulfide minerals in spoils) to nearby streams and groundwater. (See *The Habitable Planet*, Video 6 at **www.learner.org/resources/series209.html**.)

In addition, huge quantities of water used to process ore often contain pollutants such as sulfuric acid, mercury, and arsenic. Runoff of this water contaminates freshwater supplies and fish used for food, and it can destroy some forms of aquatic life. According to the EPA, mining has polluted about 40% of western watersheds in the United States.

Mining operations also emit toxic chemicals into the atmosphere. In the United States, the mining industry produces more toxic emissions than any other industry—typically accounting for almost half of all such emissions.

Removing Metals from Ores Has Harmful Environmental Effects

Ore extracted by mining typically has two components: the *ore mineral*, containing the desired metal, and waste material, or *gangue*. Removing the waste material from ores produces piles of waste, called *tailings*. Particles of toxic metals in the tailings can be blown by the wind or leached by rainfall and can contaminate surface water and groundwater.

After removal of the waste material, heat or chemical solvents are used to extract metals from the ores. Heating ores to release metals is called **smelting** (Figure 14-11). Without effective pollution control equipment, smelters emit enormous quantities of air pollutants, including sulfur dioxide and suspended toxic particles, which damage vegetation and acidify soils in the surrounding area. Smelters also release greenhouse gases, cause water pollution, and produce liquid and solid hazardous wastes that require safe disposal.

An example of using chemicals to remove metals from their ores is the use of highly toxic solutions of cyanide salts to extract gold from its ore (**Core Case Study**) [CORE CASE STUDY]. After extracting the gold from a mine, some mining companies have deliberately declared bankruptcy. This has allowed them to walk away from cleaning up their mining operations, leaving behind large amounts of cyanide-laden water in leaking holding ponds.

14-4 How Long Will Supplies of Nonrenewable Mineral Resources Last?

▶ **CONCEPT 14-4A All nonrenewable mineral resources exist in finite amounts, and as we get closer to depleting any mineral resource, the environmental impacts of extracting it generally become more harmful.**

▶ **CONCEPT 14-4B Raising the price of a scarce mineral resource can lead to an increase in its supply, but there are environmental limits to this effect.**

Mineral Resources Are Distributed Unevenly

The earth's crust contains fairly abundant deposits of nonrenewable mineral resources such as iron and aluminum. But deposits of important mineral resources such as manganese, chromium, cobalt, and platinum are relatively scarce. The earth's geologic processes have not distributed deposits of nonrenewable mineral resources evenly among countries.

Massive exports can deplete the supply of a country's nonrenewable minerals. During the 1950s, for example, South Korea exported large amounts of its iron and copper. Since the 1960s, the country has not had enough of these metals to support its rapid economic growth and now must import them.

Five nations—the United States, Canada, Russia, South Africa, and Australia—supply most of the world's nonrenewable mineral resources. South Africa is the world's largest producer of chromium and platinum. Three countries—the United States, Germany, and Russia—with only 8% of the world's population, consume about 75% of the most widely used metals. But China is rapidly increasing its use of key metals such as copper, aluminum, zinc, and lead and consumes twice as much steel as the U.S., Europe, and Japan combined.

Since 1900, and especially since 1950, there has been a sharp rise in the total and per capita use of nonrenewable mineral resources in the United States. As a result, the United States has depleted some of its once-rich deposits of metals such as lead, aluminum, and iron. Currently, the United States imports all of its supplies of 20 key nonrenewable mineral resources and more than 90% of its supplies of 4 other key minerals.

Most U.S. imports of nonrenewable metal resources come from reliable and politically stable countries. But experts are especially concerned about four *strategic metal resources*—manganese, cobalt, chromium, and platinum—which are essential for the country's economy and military strength. The United States has little or no reserves of these metals.

Other strategic minerals are metals such as tungsten, titanium, and niobium. Titanium, for example, is very important for making armor plating, aircraft, and high-end weapons, while tungsten is widely used as electrodes in electronic devices, rocket engine nozzles, and steel alloys used in turbine blades. According to the U.S. Geological Survey, China has 57% of the world's estimated tungsten reserves, Canada has 12%, and the United States only 4%. Some strategic metals are extremely important for rapidly developing technologies such as solar cells, computer chips, fuel cells, batteries and motors for hybrid-electric and all-electric cars, and generators in wind turbines.

Supplies of Nonrenewable Mineral Resources Can Be Economically Depleted

The future supply of nonrenewable minerals depends on two factors: the actual or potential supply of the mineral and the rate at which we use it. We have never completely run out of any mineral, but a mineral becomes *economically depleted* when it costs more than it is worth to find, extract, transport, and process the remaining deposits (**Concept 14-4A**). At that point, there are five choices: *recycle or reuse existing supplies*, *waste less*, *use less*, *find a substitute*, or *do without*.

Depletion time is the time it takes to use up a certain proportion—usually 80%—of the reserves of a mineral at a given rate of use. When experts disagree about depletion times, it is often because they are using different assumptions about supplies and rates of use (Figure 14-19).

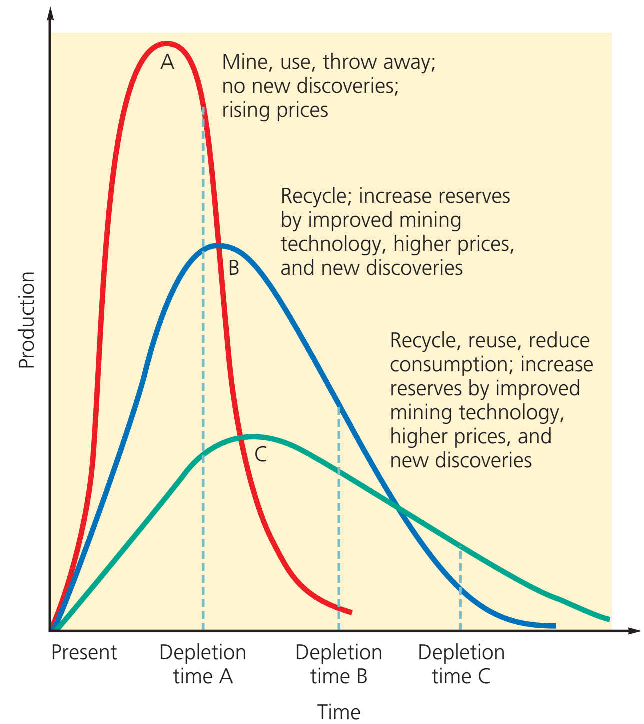


Figure 14-19 **Natural capital depletion:** Each of these *depletion curves* for a nonrenewable resource (such as aluminum or copper) is based on a different set of assumptions. Dashed vertical lines represent the times at which 80% depletion occurs.

The shortest depletion-time estimate assumes no recycling or reuse and no increase in reserves (curve A, Figure 14-19). A longer depletion-time estimate assumes that recycling will stretch existing reserves and that better mining technology, higher prices, or new discoveries will increase reserves (curve B). The longest depletion-time estimate (curve C) makes the same assumptions as A and B, but also includes reuse and reduced consumption to further expand reserves. Finding a substitute for a resource leads to a new set of depletion curves for the new resource.

According to a 2006 study by Thomas Graedel of Yale University, if all nations wanted to extract metal resources from the earth's crust at the same rate as more-developed nations do today, there might not be enough metal resources to meet the demand, even with extensive recycling.

Market Prices Affect Supplies of Nonrenewable Minerals

Geologic processes determine the quantity and location of a mineral resource in the earth's crust. Economics determines what part of the known supply is extracted and used. An increase in the price of a scarce mineral resource can lead to increased supplies and can encourage more efficient use, but there are limits to this effect (**Concept 14-4B**).

According to standard economic theory, in a competitive market system, a plentiful mineral resource is cheap when its supply exceeds demand. When a resource becomes scarce, its price rises. This can encourage exploration for new deposits, stimulate development of better mining technology, and make it profitable to mine lower-grade ores. It can also encourage a search for substitutes and promote resource conservation.

According to some economists, however, this price effect may no longer apply very well in most of the more-developed countries. Governments in such countries often use subsidies, taxes, regulations, and import tariffs to control the supply, demand, and prices of key minerals to such an extent that a truly competitive market does not exist.

Most mineral prices are kept artificially low because governments subsidize the development of their domestic mineral resources to help promote economic growth and national security. In the United States, for instance, mining companies get various types of government subsidies (see Case Study at right), including *depletion allowances*—permission to deduct from their taxes their costs of developing and extracting mineral resources. These allowances amount to 5–22% of their gross income gained from selling the minerals.

Most consumers are unaware that the real costs of consumer products made from mineral resources are higher than their market prices. This is because consumers are paying the taxes that provide government subsidies and tax breaks for mining companies and that help to pay for the control of harmful environmental and health effects caused by mineral extraction, processing, and use (Figure 14-12). If these hidden extra costs were included in the market prices of such goods, some economists say these harmful effects would be sharply reduced, recycling and reuse would increase dramatically, and many minerals would be replaced with less harmful substitutes.

Mining company representatives insist that they need taxpayer subsidies and low taxes to keep the prices of minerals low for consumers. They also claim that, without the subsidies, their companies might move their operations to other countries where they could avoid such taxes as well as mining and pollution control regulations.

Other economic factors that affect supplies of mineral resources are scarce investment capital and high financial risk. Typically, if geologists identify 10,000 possible deposits of a given resource, only 1,000 sites are worth exploring; only 100 justify drilling, trenching, or tunneling; and only 1 becomes a productive mine or well. When investment capital is short, mining companies are less inclined to invest with such slim chances of recovering their investments. Thus, mineral supplies do not grow.

CASE STUDY

An Outdated Mining Subsidy: The U.S. General Mining Law of 1872

Some people have become wealthy by using the little-known U.S. General Mining Law of 1872. It was designed to encourage mineral exploration and the mining of *hard rock minerals*—such as gold (**Core Case Study**), silver, copper, and uranium—on public lands and to help develop the western territories.

CORE CASE STUDY

Under this law, a person or corporation can file a mining claim or assume legal ownership of parcels of land on essentially all U.S. public land except national parks and wilderness. To file a claim, you say you believe the land contains valuable hard rock minerals and you promise to spend $500 to improve it for mineral development. You must then pay $120 per year for each 8-hectare (20-acre) parcel of land used to maintain the claim, whether or not a mine is in operation.

Until 1995, when a freeze on such land transfers was declared by Congress, one could pay the federal government $6–12 per hectare ($2.50–5.00 an acre) for such land owned jointly by all U.S. citizens. One could then lease the land to someone else, build on it, sell it, or use it for essentially any purpose. People have constructed golf courses, hunting lodges, hotels, and housing subdivisions on public land that they bought from taxpayers at 1872 prices. According to a 2004 study by the Environmental Working Group, public lands containing an estimated $285 billion worth of publicly owned mineral resources have been transferred to private companies under this law.

According to the Bureau of Land Management, mining companies remove at least $4 billion worth of hard rock minerals per year from U.S. public land—equal to an average of $183,000 an hour. These companies pay taxpayers royalties amounting to only 2.3% of the value of the minerals, compared to royalties of 13.2% paid for oil, natural gas, and coal, and 14% for grazing rights on public lands.

After removing valuable minerals, some mining companies have walked away from their mining operations, leaving behind a toxic mess. A glaring example is the Summitville gold mine site near Alamosa, Colorado (Figure 14-20). A Canadian company used the 1872 mining law to buy the land from the federal government in 1984 at a bargain price. It then spent $1 million developing the site, removed $98 million worth of gold, and abandoned the polluted site.

In 1992, the mining law was modified to require mining companies to post bonds to cover 100% of the estimated cleanup costs in case they go bankrupt. However, because such bonds were not required in the past, the U.S. Department of the Interior estimates that cleaning up degraded land and streams on more than

Figure 14-20 **Natural capital degradation:** This Summitville gold mining site near Alamosa, Colorado, became a toxic waste site after the Canadian company that owned it declared bankruptcy and abandoned it, rather than cleaning up the acids and toxic metals that leaked from the site into the nearby Alamosa River. Cleanup by the EPA will cost U.S. taxpayers about $120 million.

500,000 abandoned hard rock mining sites will cost U.S. taxpayers $32–72 billion. In 2009, the EPA was ordered by a federal court to develop a new rule guaranteeing that hard rock miners will pay all cleanup costs.

Mining companies point out that they must invest large sums (often $100 million or more) to locate and develop an ore site before they make any profits from mining hard rock minerals. They argue that government-subsidized land costs allow them to provide high-paying jobs to miners, supply vital resources for industry, and keep mineral-based products affordable. But critics argue that the money taxpayers give up as subsidies to mining companies offsets the lower prices they pay for these products.

Critics of this very old law call for permanently banning such sales of public lands, although some do support 20-year leases of designated public land for hard rock mining. Critics also call for much stricter environmental controls and cleanup restrictions on hard rock mining. They want the government to set up a fund to clean up abandoned mining sites that is paid for by higher royalties from hard rock mining companies. They would require mining companies to pay a royalty of 8–12% on the *gross* (not net) *income* they earn from a given site, based on the wholesale value of all minerals removed from public land—similar to the rates paid by oil, natural gas, and coal companies. Critics have tried for three decades to get Congress to make such reforms.

Is Mining Lower-Grade Ores the Answer?

Some analysts contend that we can increase supplies of some minerals by extracting lower grades of ore. They point to the development of new earth-moving equipment, improved techniques for removing impurities from ores, and other technological advances in mineral extraction and processing. Such advancements have made it possible to extract some lower-grade ores and even to reduce their costs. For example, in 1900, the average copper ore mined in the United States was about 5% copper by weight. Today, that ratio is 0.5%, yet copper costs less (when adjusted for inflation).

However, several factors can limit the mining of lower-grade ores (**Concept 14-4B**). One is the increased cost of mining and processing larger volumes of ore, as the second law of thermodynamics would dictate (see Chapter 2, p. 47). Another is the increasing shortages of freshwater needed to mine and process some minerals, especially in arid and semiarid areas such as much of the western United States (see Figures 13-4 and 13-5). A third limiting factor is the environmental impacts of the increased land disruption, waste material, and pollution produced during the mining and processing of ores (Figure 14-12).

One way to improve mining technology and reduce its environmental impact is to use microorganisms that can breakdown rock material and

GOOD NEWS

extract minerals in a process called *in-place*, or *in situ*, (pronounced "in SY-too") *mining*. If naturally occurring bacteria cannot be found to extract a particular metal, genetic engineering techniques could be used to produce such bacteria. Using this biological approach, sometimes called *biomining*, miners remove desired metals from ores through wells bored into the deposits. It leaves the surrounding environment undisturbed and reduces the air pollution associated with the smelting of metal ores. It also reduces water pollution from releases of hazardous chemicals such as those resulting from the use of cyanide (Figure 14-1) and mercury in gold mining (**Core Case Study**).

CORE CASE STUDY

RESEARCH FRONTIER

Developing biomining and other new methods for extracting more minerals from ores; see **www.cengage.com/login**.

On the down side, microbiological ore processing is slow. It can take decades to remove the same amount of material that conventional methods can remove within months or years. However, genetic engineers are looking for ways to modify bacteria that could speed up the process. So far, biomining methods are economically feasible only with low-grade ores for which conventional techniques are too expensive.

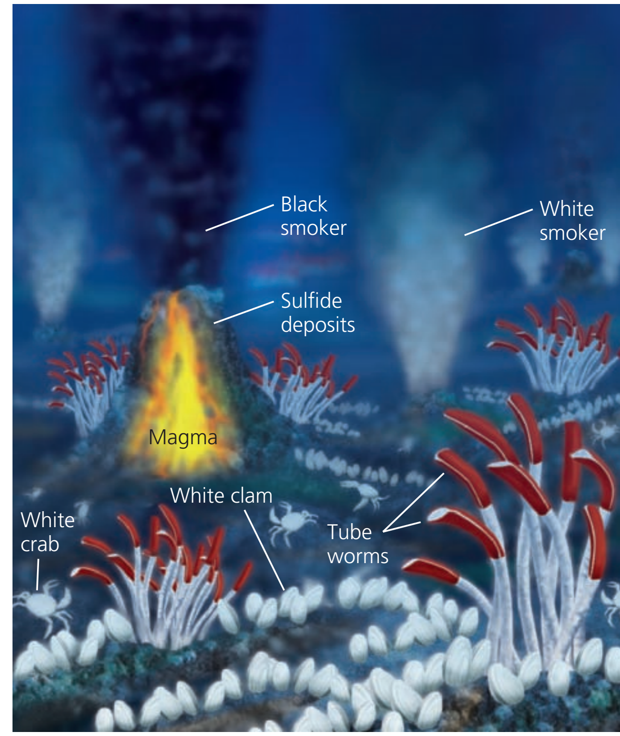


Figure 14-21 **Natural capital:** *Hydrothermal deposits* form when mineral-rich superheated water shoots out of vents in solidified magma on the ocean floor near some tectonic plate boundaries. As this water mixes with cold seawater, black particles of metal sulfides precipitate out and build up as chimney-like mineral deposits around the vents. A variety of rare and exotic forms of life—including giant clams, six-foot tubeworms, and eyeless shrimp—exist in the dark depths around these black smokers. These life-forms are supported by bacteria that produce food through chemosynthesis from sulfur compounds discharged by the vents.

Can We Get More Minerals from the Ocean?

Some ocean mineral resources are dissolved in seawater. However, most of the chemical elements found in seawater occur in such low concentrations that recovering these mineral resources takes more energy and money than they are worth. Currently, only magnesium, bromine, and sodium chloride are abundant enough to be extracted profitably. On the other hand, deposits of minerals, mostly in sediments along the shallow continental shelf and adjacent shorelines, are significant sources of sand, gravel, phosphates, sulfur, tin, copper, iron, tungsten, silver, titanium, platinum, and diamonds.

THINKING ABOUT
Extracting Minerals from Seawater

Use the second law of thermodynamics (see Chapter 2, p. 47) to explain why it costs too much to extract most dissolved minerals from seawater.

Another potential source of some minerals is hydrothermal ore deposits that form when superheated, mineral-rich water shoots out of vents in volcanic regions of the ocean floor. As the hot water comes into contact with cold seawater, black particles of various metal sulfides precipitate out and accumulate as chimney-like structures, called *black smokers*, near the hot water vents (Figure 14-21). These deposits are especially rich in minerals such as copper, lead, zinc, silver, and gold. Currently, it costs too much to mine these vent systems.

Still another possible source of metals from the ocean floor is *manganese nodules* that cover large areas of the Pacific Ocean floor and smaller areas of the Atlantic and Indian Ocean floors. These potato-size globs take millions of years to form as the metals that make them up slowly separate from their suspension in seawater and sea floor sediments and join together chemically. In the future, they could be sucked up by giant vacuum pipes or scooped up by other underwater mining machines.

So far, these ocean floor resources have not been developed because of high costs and squabbles over who owns them and how any profits gained from extracting them should be distributed among competing nations. Also, some marine scientists have serious concerns about the effects of ocean floor mining on aquatic life.

14-5 How Can We Use Mineral Resources More Sustainably?

▶ **CONCEPT 14-5 We can try to find substitutes for scarce resources, reduce resource waste, and recycle and reuse minerals.**

We Can Find Substitutes for Some Scarce Mineral Resources

Some analysts believe that even if supplies of key minerals become too expensive or too scarce due to unsustainable use, human ingenuity will find substitutes (**Concept 14-5**). They point to the current *materials revolution* in which silicon and other materials, particularly ceramics and plastics, are being used as replacements for metals. They also point out the possibilities of finding new substitutes for scarce minerals through nanotechnology (Science Focus, below).

RESEARCH FRONTIERS

Materials science, engineering, and nanotechnology; see **www.cengage.com/login**.

For example, fiber-optic glass cables that transmit pulses of light are replacing copper and aluminum wires in telephone cables. In the future, nanowires may eventually replace the fiber-optic glass cables. High-strength plastics and composite materials, strengthened by lightweight carbon and glass fibers, are beginning to transform the automobile and aerospace industries. They cost

SCIENCE FOCUS

The Nanotechnology Revolution

Nanotechnology, or *tiny tech*, uses science and engineering to manipulate and create materials out of atoms and molecules at the ultra-small scale of less than 100 nanometers. A nanometer equals one billionth of a meter. It is one hundred-thousandth the width of a human hair, and the period at the end of this sentence is about 1 million nanometers in diameter. At the nanoscale level, conventional materials have unconventional and unexpected properties (discussed in more detail on page S16 in Supplement 4).

Scientists plan to use atoms of abundant substances such as carbon, silicon, silver, titanium, and boron as building blocks to create everything from medicines and solar cells to automobile bodies. Nanomaterials are currently used in more than 800 consumer products and the number is growing rapidly. Such products include stain-resistant and wrinkle-free coatings on clothes, odor-eating socks, self-cleaning coatings on sunglasses and windshields, sunscreens, deep-penetrating skin care products, and food containers that release nanosilver ions to kill bacteria, molds, and fungi. **GREEN CAREER:** environmental nanotechnology

Nanotechnologists envision innovations such as a supercomputer the size of a sugar cube that could store all the information now found in the U.S. Library of Congress; biocomposite particles smaller than a human cell that would make our bones and tendons super strong; nanovessels filled with medicines and delivered to cells anywhere in the body; and nanomolecules specifically designed to seek out and kill cancer cells.

We could also use nanoparticles to remove industrial pollutants in contaminated air, soil, and groundwater, and we might be able to purify water and desalinate water at an affordable cost with nanofilters. We could also use the technology to turn garbage into breakfast by mimicking how nature turns wastes into plant nutrients, thus following the chemical cycling **principle of sustainability**. The list could go on.

So what is the catch? Ideally, this bottom-up manufacturing process would occur with little environmental harm, with no depletion of nonrenewable resources, and with many potential environmental benefits. But there are concerns over some possible unintended and harmful health effects on humans, because a few studies have raised red flags.

As particles get smaller, they become more reactive and potentially more toxic to humans and other animals. Laboratory studies show that nanoparticles can move across the placenta from mother to fetus and from the nasal passage to the brain. They might also penetrate deeply into the lungs, be absorbed into the bloodstream, and penetrate cell membranes. A British animal study found that certain carbon nanotubes could damage lungs in the same way that asbestos does. A study done in Singapore showed that nanosilver particles severely disrupted development in zebra fish embryos. In addition, scientists note that such damage in humans could take years or decades to become apparent.

Many analysts say we need to take two steps before unleashing nanotechnology more broadly. *First*, carefully investigate its potential risks. *Second*, develop guidelines and regulations for controlling its growing applications until we know more about the potentially harmful effects of this new technology. So far, governments have done little to evaluate and regulate such risks. In 2009, an expert panel of the U.S. National Academy of Sciences said that the federal government was not doing enough to evaluate the potential health and environmental risks from engineered nanomaterials.

Critical Thinking

How might the development of nanotechnology affect gold mining (**Core Case Study**)?

less to produce than metals, do not need painting and therefore would involve less pollution, can be molded into any shape, and help to increase fuel efficiency by greatly reducing the weight of motor vehicles.

But substitution is not a cure-all. For example, platinum is currently unrivaled as a catalyst, used in industrial processes to speed up chemical reactions, and chromium is an essential ingredient of stainless steel. We can try to find substitutes for such scarce resources, but this may not always be possible.

We Can Recycle and Reuse Valuable Metals

A more sustainable way to use nonrenewable mineral resources (especially valuable or scarce metals such as gold, iron, copper, and platinum) is to recycle or reuse them. For example, recycling aluminum beverage cans (Figure 14-22) and scrap aluminum produces 95% less air pollution and 97% less water pollution, and uses 95% less energy than mining and processing aluminum ore. Cleaning up and reusing items instead of melting and reprocessing them has an even lower environmental impact.

GOOD NEWS

THINKING ABOUT
Metal Recycling and Nanotechnology

How might the development of a nanotechnology revolution (Science Focus, p. 365) over the next 20 years affect the recycling of metal mineral resources?

Huquette Roe/Shutterstock

Figure 14-22 These compacted bales of aluminum cans are ready for recycling. About 54% of the aluminum cans used in the United States are recycled.

Solutions

Sustainable Use of Nonrenewable Minerals

- Do not waste mineral resources.
- Recycle and reuse 60–80% of mineral resources.
- Include the harmful environmental costs of mining and processing minerals in the prices of items.
- Reduce mining subsidies.
- Increase subsidies for recycling, reuse, and finding substitutes.
- Redesign manufacturing processes to use less mineral resources and to produce less pollution and waste (cleaner production).
- Use mineral resource wastes of one manufacturing process as raw materials for other processes.
- Slow population growth.

Figure 14-23 We can use nonrenewable mineral resources more sustainably (**Concept 14-5**). **Questions:** Which two of these solutions do you think are the most important? Why?

We Can Use Mineral Resources More Sustainably

Some analysts say we have been asking the wrong question. Instead of asking how we can increase supplies of nonrenewable minerals, we should be asking, *how can we decrease our use and waste of such resources?* (See the Case Study that follows.) Answering this second question could provide important technologies for using mineral resources more sustainably (**Concept 14-5**). Figure 14-23 and the following Case Study describe some of these strategies.

THINKING ABOUT
Gold Mining

CORE CASE STUDY

How would you apply the solutions in Figure 14-23 to decreasing the need to mine gold (**Core Case Study**) and to reducing the harmful environmental effects of gold mining?

CASE STUDY
Pollution Prevention Pays

GOOD NEWS

In 1975, the U.S.-based Minnesota Mining and Manufacturing Company (3M), which makes 60,000 different products in 100 manufacturing plants, began a Pollution Prevention Pays (3P) program. It redesigned its equipment and processes, used fewer hazardous raw materials, identified toxic chemical outputs (and recycled or sold them as raw materials to other companies), and began making more nonpolluting products.

Between 1975 and 2008, the 3M Pollution Prevention Pays program prevented more than 1.4 million metric tons (1.5 million tons) of pollutants from reaching the environment—roughly equal to the weight of more than 100 empty jumbo jet airliners. The company has also saved more than $1.2 billion in waste disposal and material costs. This is an excellent example of why pollution prevention pays.

Since 1990, a growing number of companies have adopted similar pollution and waste prevention programs that have led to *cleaner production*. (See the Guest Essay by Peter Montague on cleaner production on the website for this chapter.)

Here are this chapter's *three big ideas*:

- Dynamic forces that move matter within the earth and on its surface recycle the earth's rocks, form deposits of mineral resources, and cause volcanic eruptions, earthquakes, and tsunamis.
- The available supply of a mineral resource depends on how much of it is in the earth's crust, how fast we use it, mining technology, market prices, and the harmful environmental effects of removing and using it.
- We can use mineral resources more sustainably by trying to find substitutes for scarce resources, reducing resource waste, and reusing and recycling nonrenewable minerals.

REVISITING Gold Mining and Sustainability

CORE CASE STUDY

SUSTAINABILITY

In this chapter, we began with a discussion of the harmful effects of gold mining (**Core Case Study**). We also discussed a number of possibilities for extracting and using gold and other nonrenewable mineral resources in less harmful, more sustainable ways.

Technological developments can help us to expand supplies of mineral resources and to use them more sustainably. For example, if we develop it safely, we could use nanotechnology (Science Focus, p. 365) to make new materials that could replace scarce mineral resources. Another promising technology is biomining—the use of microbes to extract mineral resources without disturbing the land or polluting air and water as much as conventional mining operations do. We could make increasing use of solar energy to generate electricity we need for powering such processes—an application of the solar energy **principle of sustainability**.

We can also use mineral resources more sustainably by reusing and recycling them, and by reducing unnecessary resource use and waste—applying the recycling **principle of sustainability**. Industries can mimic nature by using a diversity of ways to reduce the unnecessary waste of resources and to prevent pollution, thus applying the diversity **principle of sustainability**. By applying these three principles to the use of mineral resources, we would reduce the harmful environmental effects of mining and processing minerals, thereby helping to sustain nature's ability to rely on the same principles of sustainability.

Mineral resources are the building blocks on which modern society depends. Knowledge of their physical nature and origins, the web they weave between all aspects of human society and the physical earth, can lay the foundations for a sustainable society.

ANN DORR

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 347. Describe some harmful environmental effects of gold mining (**Core Case Study**).

CORE CASE STUDY

2. Define **geology**. Define and distinguish among the **core**, **mantle**, **crust**, **asthenosphere**, and **lithosphere**. Define **tectonic plates** and explain how they were likely formed. Distinguish between a subduction zone and a transform fault. What is **weathering** and why is it important? Define **volcano** and describe the nature and effects of a volcanic eruption. Define **earthquake** and describe its nature and effects. What is a **tsunami** and what are its effects?
3. Define **mineral**, **rock**, **sedimentary rock**, **igneous rock**, and **metamorphic rock** and give an example of each. Define and explain the importance of the **rock cycle**.
4. Define **mineral resource** and list two major types of such resources. Describe three uses of rock as a resource. Define **ore** and distinguish between a **high-grade ore** and a **low-grade ore**. What are **reserves**? Describe the life cycle of a metal resource. Describe three major harmful environmental effects of extracting, processing, and using nonrenewable mineral resources.

5. What is **surface mining**? Define **overburden, spoils** and **open-pit mining**. Define **strip mining** and distinguish among **area strip mining, contour strip mining,** and **mountaintop removal mining**. What is **subsurface mining**? Describe three harmful environmental effects of mining. What is **smelting** and what are its major harmful environmental effects?

6. What five nations supply most of the world's nonrenewable mineral resources? How dependent is the United States on other countries for important nonrenewable mineral resources, including strategic metals? Define **depletion time** and describe three types of depletion curves for a mineral resource.

7. Describe the conventional view of the relationship between the supply of a mineral resource and its market price. What are five effects of a mineral becoming scarce? Discuss the pros and cons of the U.S. General Mining Law of 1872.

8. Describe the opportunities and limitations of increasing mineral supplies by mining lower-grade ores. What are the advantages and disadvantages of biomining? Describe the opportunities and limitations of getting more minerals from the ocean.

9. Describe the opportunities and limitations of finding substitutes for scarce mineral resources. How could nanotechnology affect the search for substitutes, and how might it affect the mining industry? What are some possible problems that could arise from the growing use of nanotechnology? Describe the benefits of recycling and reusing valuable metals. List five ways to use nonrenewable mineral resources more sustainably. Describe 3M Company's Pollution Prevention Pays program.

10. What are the three big ideas of this chapter? Describe how we can apply the three **principles of sustainability** in order to obtain and use nonrenewable mineral resources in a more sustainable way.

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. List three ways in which you could apply **Concept 14-5** to making your lifestyle more environmentally sustainable.

2. List three ways in which decreasing the need to mine gold and reducing its harmful environmental effects (**Core Case Study**) could benefit you.

3. What do you think would happen if the earth's tectonic plates stopped moving? Explain.

4. You are an igneous rock. Write a report on what you experience as you move through the rock cycle (Figure 14-10). Repeat this exercise, assuming you are a sedimentary rock and then a metamorphic rock.

5. Use the second law of thermodynamics (see Chapter 2, p. 47) to analyze the scientific and economic feasibility of each of the following processes:
   a. Extracting most of the minerals that are dissolved in seawater
   b. Mining increasingly lower-grade deposits of minerals
   c. Using inexhaustible solar energy to mine minerals
   d. Continuing to mine, use, and recycle minerals at increasing rates

6. Explain why you support or oppose each of the following proposals concerning extraction of hard rock minerals on public land in the United States (see Case Study, p. 362): **(a)** halting the practice of granting title to public land for actual or claimed hard rock mineral deposits; **(b)** requiring mining companies to pay a royalty of 8–12% on the gross income they earn from hard rock minerals that they extract from public lands; and **(c)** making hard rock mining companies legally responsible for restoring the land and cleaning up the environmental damage caused by their activities.

7. Suppose you were told that mining deep ocean mineral resources would mean severely degrading ocean-bottom habitats and life-forms such as giant tube worms and giant clams. Do you think that this information should prevent or put an end to such ocean-bottom mining? Explain.

8. List three ways in which a nanotechnology revolution (Science Focus, p. 365) could benefit you and three ways in which it could harm you.

9. Congratulations! You are in charge of the world. What are the three most important features of your policy for developing and sustaining the world's nonrenewable mineral resources?

10. List two questions that you would like to have answered as a result of reading this chapter.

DATA ANALYSIS

Uranium (U) is a mineral resource obtained from uranium ore in various types of rock at different concentrations. It is used as a fuel in the reactors of nuclear power plants. A high-grade ore has 2% U and a low-grade ore has 0.1% U. The estimated worldwide recoverable resources of uranium weigh 4,743,000 metric tons. The United States has about 7% of the world's uranium resources, which amounts to about 332,000 metric tons.

1. Given that current worldwide usage of uranium is about 66,500 metric tons per year, how long will the world's present recoverable uranium resources last?
2. Assume U.S. usage is about 25% of world usage. If the United States were to rely only on its domestic uranium resources, how long would they last, assuming a 100% recovery rate (meaning that 100% of the resource can be used)?
3. Assume that most U.S. ore bodies contain high-grade ore (2% U) and that the recovery rates of uranium from the ore (accounting for losses in mining, extraction, and refining) average 65%. How many metric tons of ore will have to be mined to meet U.S. needs?

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengagebrain.com/shop/ISBN/0538735341** and choose Chapter 14 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

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15 Nonrenewable Energy

CORE CASE STUDY A Brief History of Human Energy Use

Everything runs on energy. Some sources of energy, such as oil, coal, and natural gas—also called *fossil fuels*—as well as uranium used to fuel nuclear power plants, are *nonrenewable* because they take millions of years to form in the earth's crust. Other energy resources such as the sun, wind, flowing water, wood, and heat from the earth's interior are *renewable* because they can be replenished by nature within hours or decades.

Human use of energy has grown dramatically throughout history, but especially since European countries began the industrial revolution about 275 years ago. At that time, wood harvested from forests was burned to provide most of the energy used for heating buildings and running steam engines. By 1850, Europeans were harvesting firewood faster than nature could replace it, and thus they depleted many of the forests that surrounded their rapidly industrializing cities.

European nations, and later the United States, survived this early energy crisis by learning how to mine and burn coal in homes and in industrial plants. In 1859, raw petroleum was pumped out of the ground from the first oil well in Titusville, Pennsylvania (USA) and later, we invented ways to convert it to fuels such as gasoline and heating oil. We also learned how to burn natural gas, usually found underground over oil deposits. Then we began burning coal in large, central power plants to produce electricity. In 1885, Carl Benz invented the internal combustion engine that ran on gasoline to power cars and other vehicles. By 1900, we were getting 40% of our total energy use from oil (mostly from gasoline derived from oil), and in the 1950s, we learned how to produce electricity in nuclear power plants.

Today, we continue to live in a fossil fuel era, as most of the energy used in the world and the United States comes from oil, coal, and natural gas resources (Figure 15-1). These energy resources, like all energy resources, each have advantages and disadvantages that we examine in this chapter. In the next chapter, we look at the advantages and disadvantages of a variety of renewable energy resources.

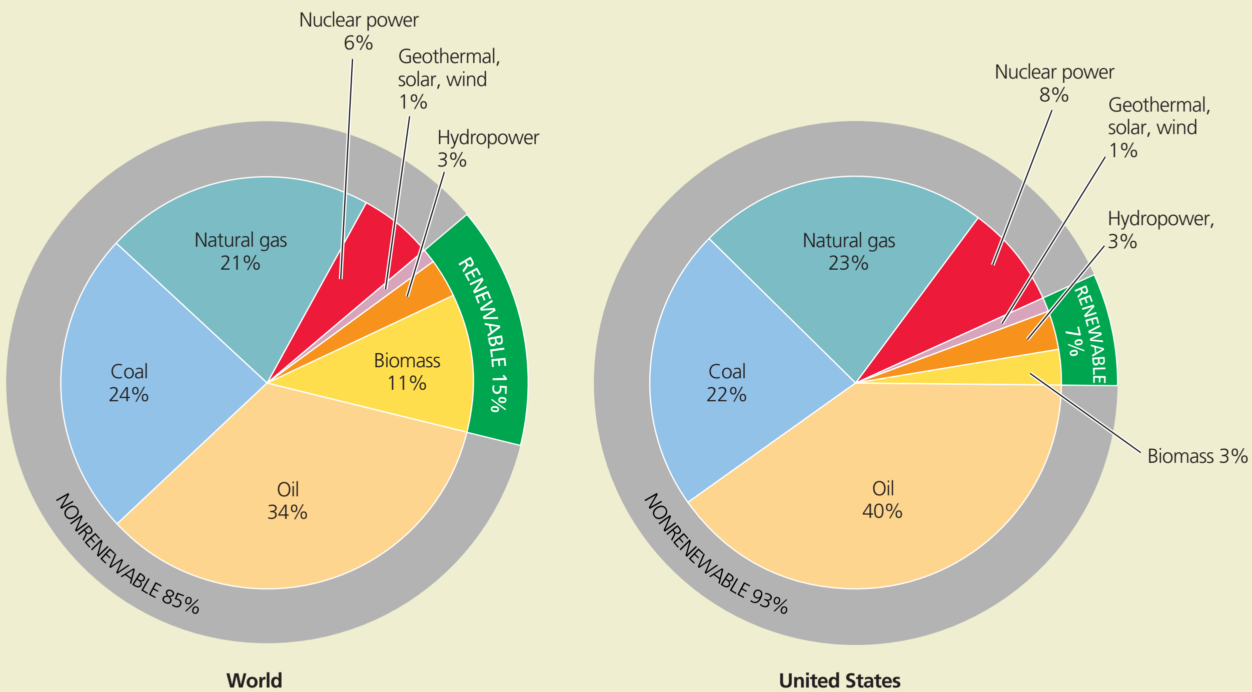

Figure 15-1 We get most of our energy by burning carbon-containing fossil fuels (see Figure 2-14, p. 46). This figure shows energy use by source throughout the world (left) and in the United States (right) in 2008. Note that oil is the most widely use form of commercial energy and that about 79% of the energy used in the world (85% of the energy used the United States) comes from burning nonrenewable fossil fuels. (These figures also include rough estimates of energy from biomass that is collected and used by individuals without being sold in the marketplace.) **Question:** Why do you think the world as a whole relies more on renewable energy than the United States does? (Data from U.S. Department of Energy, British Petroleum, Worldwatch Institute, and International Energy Agency)

Key Questions and Concepts

15-1 What is net energy and why is it important?

CONCEPT 15-1 Net energy is the amount of high-quality energy available from an energy resource minus the amount of energy needed to make it available.

15-2 What are the advantages and disadvantages of using oil?

CONCEPT 15-2A Conventional oil is currently abundant, has a high net energy yield, and is relatively inexpensive, but using it causes air and water pollution and releases greenhouse gases to the atmosphere.

CONCEPT 15-2B Heavy oils from tar sand and oil shale exist in potentially large supplies but have low net energy yields and higher environmental impacts than conventional oil has.

15-3 What are the advantages and disadvantages of using natural gas?

CONCEPT 15-3 Conventional natural gas is more plentiful than oil, has a high net energy yield and a fairly low cost, and has the lowest environmental impact of all fossil fuels.

15-4 What are the advantages and disadvantages of using coal?

CONCEPT 15-4A Conventional coal is plentiful and has a high net energy yield and low cost, but it has a very high environmental impact.

CONCEPT 15-4B Gaseous and liquid fuels produced from coal could be plentiful, but they have lower net energy yields and higher environmental impacts than conventional coal has.

15-5 What are the advantages and disadvantages of using nuclear energy?

CONCEPT 15-5 Nuclear power has a low environmental impact and a very low accident risk, but its use has been limited by a low net energy yield, high costs, fear of accidents, long-lived radioactive wastes, and the potential for spreading nuclear weapons technology.

Note: Supplements 2 (p. S3), 8 (p. S30), and 9 (p. S57) can be used with this chapter.

Typical citizens of advanced industrialized nations each consume as much energy in 6 months as typical citizens in less developed countries consume during their entire life.

MAURICE STRONG

15-1 What Is Net Energy and Why Is It Important?

▶ **CONCEPT 15-1 Net energy is the amount of high-quality energy available from an energy resource minus the amount of energy needed to make it available.**

Basic Science: Net Energy Is the Only Energy That Really Counts

We start our discussion of energy alternatives with basic science based on the two laws of thermodynamics (see Chapter 2, p. 47) that govern all physical and chemical changes involved in the use of fossil fuels and other energy alternatives.

Because of the first law of thermodynamics, it takes high-quality energy to get high-quality energy. For example, before oil becomes useful to us, it must be found, pumped up from beneath the ground (Figure 15-2, left, p. 372) or ocean floor (Figure 15-2, right), transferred to a refinery, converted to useful fuels, and delivered to consumers. Each of these steps uses high-quality energy, mostly obtained by burning fossil fuels such as oil and coal. The second law of thermodynamics tells us that some of the high-quality energy used in each step is automatically wasted and degraded to lower-quality energy. No matter how hard we try or how clever we are, we cannot violate the two scientific laws of thermodynamics.

The usable amount of *high-quality energy* available from a given quantity of an energy resource is its **net energy**. That is the total amount of useful energy available from an energy resource minus the energy needed to make it available to consumers (**Concept 15-1**). It is calculated by estimating the total amount of energy available from the resource over its projected lifetime and then subtracting the estimated amount of energy

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. GOOD NEWS refers to good news about the environmental challenges we face.

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Figure 15-2 We can pump oil up from underground reservoirs on land (left) and under the sea bottom (right). Today, high-tech equipment can tap into an oil deposit on land and at sea to a depth of almost 11 kilometers (7 miles). But this requires a huge amount of high-quality energy and can cost billions of dollars per well. For example, the well that tapped into BP's Thunder Horse oil field in the Gulf of Mexico at water depths of up to 1.8 kilometers (1.1 miles) took almost 20 years to complete and cost more than $5 billion. And as we saw in 2010 with the explosion of a BP deep-sea oil-drilling rig such as that shown here, there is a lot of room for improvement in deep-sea drilling technology.

used, *automatically wasted* because of the second law of thermodynamics, and *unnecessarily wasted* in finding, extracting, processing, and transporting the useful energy to consumers.

Net energy is like the net profit earned by a business after it deducts its expenses. If a business has $1 million in sales and $900,000 in expenses, its net profit is $100,000. This is the only figure that really counts to anyone who owns or plans to invest in such a business on a long-term basis.

Similarly, suppose that it takes about 9 units of energy to produce 10 units of energy by growing and processing corn to produce ethanol fuel for cars. Then the net useful energy yield is only 1 unit of energy. We can express net energy as the ratio of energy produced to the energy used to produce it. In this example, the *net energy ratio* would be 10/9, or approximately 1.1. As the ratio increases, its net energy yield also rises. When the ratio is less than 1, there is a net energy loss. Figure 15-3 shows estimated net energy ratios for various types of space heating, high-temperature heat for industrial processes, and transportation.

Currently, most conventional oil has a high net energy ratio because for many years, much of it has come from large concentrated deposits of light crude oil found not too deep underground or under the ocean floor in fairly shallow water. As these sources become depleted, oil producers have to use more energy and money to develop more dispersed and often smaller deposits that are found deeper underground or under the sea bottom (Figure 15-2). As this occurs, the net energy ratio of conventional oil declines and extraction costs rise sharply in accordance with the two laws of thermodynamics, which we cannot violate.

Energy Resources With Low or Negative Net Energy Yields Need Help to Compete in the Marketplace

Here is a general rule that we can use to help evaluate the economic usefulness of an energy resource based on its net energy yield. *Any energy resource with a low or negative net energy yield cannot compete in the open marketplace with other energy alternatives with higher net energy yields unless it is subsidized by the government (taxpayers) or by some other outside source of funding.* Relying on such energy resources is like investing in a business that has a very low profit margin or that always loses money unless the government or some outside benefactor props it up.

For example, electricity produced by nuclear power has a low net energy yield because large amounts of energy are needed for each step in the *nuclear power fuel cycle*: to extract and process uranium ore, convert it into nuclear fuel, build and operate nuclear power plants, safely store the resulting highly radioactive wastes for thousands of years, dismantle each highly radioactive plant after its useful life (typically 40–60 years), and safely store its radioactive parts for thousands of years. The low net energy yield for this fuel cycle (not just for

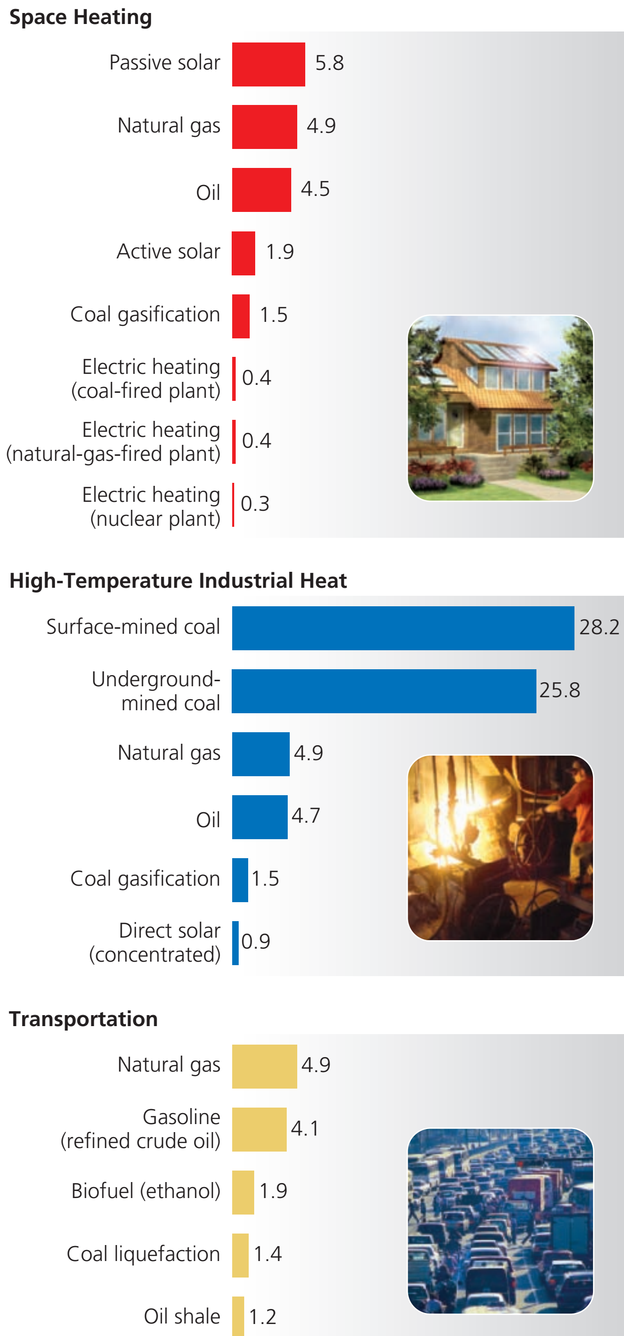


Figure 15-3 **Science:** *Net energy ratios* for various energy systems over their estimated lifetimes differ widely: the higher the net energy ratio, the greater the net energy available (**Concept 15-1**). **Question:** Based on these data, which two resources in each category should we be using? (Data from U.S. Department of Energy; U.S. Department of Agriculture; Colorado Energy Research Institute, *Net Energy Analysis*, 1976; and Howard T. Odum and Elisabeth C. Odum, *Energy Basis for Man and Nature*, 3rd ed., New York: McGraw-Hill, 1981)

the operations of the nuclear plant itself) is one reason why many governments throughout the world must heavily subsidize nuclear power to make it available to consumers.

Reducing Energy Waste Improves Net Energy Yields and Can Save Money

One component of a net energy ratio is the amount of energy from an energy resource that is wasted because of the energy lost automatically due to the second law of thermodynamics. We have no control over this factor, except to try to use energy resources with net energy yields that are as high as possible (Figure 15-3).

But another component of any net energy ratio is the energy that is unnecessarily wasted in making useful energy available for use. We can control this factor by reducing such unnecessary waste and thus raising the net energy yield of a resource. To go back to our business analogy, by reducing waste and improving efficiency you can make a business with a low profit margin more profitable.

Here is a mixture of bad and great news. The *bad news* is that about 84% of all commercial energy used in the United States is wasted. In other words, only about 16% of the dollars that Americans pay for energy actually provides them with high-quality energy. (Even more energy is wasted in China and many of the world's other countries, but here, we use the United States as an example.)

Roughly 41% of all commercial energy is automatically wasted because of the second law of thermodynamics. This means that Americans unnecessarily waste about 43% (the rest of the total wasted 84%). They do this by driving gas-guzzling motor vehicles instead of gas-sipping vehicles that get at least 15 kilometers per liter (35 miles per gallon). The United States also uses very inefficient coal-burning and nuclear power plants to produce about two-thirds of its electricity. In addition, most Americans live and work in poorly designed, underinsulated, and leaky buildings equipped with inefficient lighting, furnaces, air conditioners, and other appliances.

The *great news* is that we know how to reduce most of this unnecessary energy waste. By doing this, Americans could save money, sharply reduce their emissions of carbon dioxide and other air pollutants, and decrease their expensive dependence on imported oil (about 52% of the oil they used in 2009). Indeed, cutting energy waste is the fastest, cheapest, and most environmentally beneficial source of energy. This still largely untapped energy resource will provide more energy in less time than we could obtain by drilling for oil, burning more coal, and building new nuclear power plants. In the next chapter we discuss how to tap into this abundant source of energy and why this has not been done.

15-2 What Are the Advantages and Disadvantages of Using Oil?

▶ **CONCEPT 15-2A Conventional oil is currently abundant, has a high net energy yield, and is relatively inexpensive, but using it causes air and water pollution and releases greenhouse gases to the atmosphere.**

▶ **CONCEPT 15-2B Heavy oils from tar sand and oil shale exist in potentially large supplies but have low net energy yields and higher environmental impacts than conventional oil has.**

We Depend Heavily on Oil

Oil supplies about one-third of the world's commercial energy and 40% of that used in the United States (Figure 15-1). (See Figure 1, p. S3, in Supplement 2 for a graph of global oil consumption between 1950 and 2009.) Thus, oil is the lifeblood of most of the world's economies and modern lifestyles and is the world's largest business. We use oil to grow most of our food, transport people and goods, and make most of the things we use every day—from plastics to asphalt on roads.

CORE CASE STUDY

Petroleum, or **crude oil** (oil as it comes out of the ground), is a black, gooey liquid (see Figure 2-14, left, p. 46) consisting of hundreds of different combustible hydrocarbons along with small amounts of sulfur, oxygen, and nitrogen impurities. This *conventional oil*, also known as *light or sweet crude oil*, makes up about 30% of the world's estimated supply of oil. The other 70% is *unconventional heavy oil* with the consistency of molasses. Some of it is thick oil left behind in wells and some is extracted from deposits of tar sands and oil shale rock. It takes considerable energy and money to extract this heavy oil, which reduces its net energy yield.

Deposits of conventional crude oil and natural gas often are trapped together under domes deep within the earth's crust on land or under the seafloor. The crude oil is dispersed in pores and cracks in underground rock formations, somewhat like water saturating a sponge. To extract the oil, developers drill a well vertically or horizontally into the deposit beneath the ground or sea bottom. Then oil, drawn by gravity out of the rock pores flows into the bottom of the well and is pumped to the surface. It takes energy and money to find and drill an oil well, and to pump oil from the well (Figure 15-2)—all of which reduces the net energy yield of the resulting oil.

After years of pumping, usually a decade or so, the pressure in a well drops and its rate of conventional crude oil production starts to decline. This point in time is referred to as **peak production** for the well. The same thing can happen to a large oil field when the overall rate of production from its numerous wells begins to decline. *Global peak production* is the point in time when we reach the maximum overall rate of conventional crude oil production for the whole world. Once we pass this point, the rate of global production of conventional oil begins to decline. Then, if we continue using conventional oil faster than we can produce it, its price rises. There is disagreement over whether we have reached or will soon reach the global peak production of conventional crude oil.

After it is extracted, conventional crude oil is transported to a *refinery* by pipeline, truck, or ship (oil tanker). There it is heated to separate it into components with different boiling points (Figure 15-4) in a complex process called *refining*. This process, like all other steps in the cycle of oil production and use, decreases the net energy yield of oil.

Some of the products of crude oil distillation, called **petrochemicals**, are used as raw materials in industrial organic chemicals, cleaning fluids, pesticides, plastics, synthetic fibers, paints, medicines, and many other products. Producing a desktop computer, for example, typically requires about ten times its weight in fossil fuels, mostly oil. Despite their many benefits, petrochemicals also add to our growing ecological footprints in various ways that we discuss in later chapters.

THINKING ABOUT
Petrochemicals

Look at your clothing and the room you are sitting in, and try to identify the items that were made from petrochemicals. What are three important ways in which your lifestyle would be different without oil?

How Long Might Supplies of Conventional Crude Oil Last?

World oil consumption has been growing rapidly since 1950 (see Figure 1, p. S3, in Supplement 2) and conventional crude oil is now the single largest source of commercial energy in the world and in the United States (Figure 15-1). In 2009, the world used the equivalent of almost 31 billion barrels of oil, with each barrel containing 159 liters (42 gallons) of oil. *Laid end to end, the number of barrels of conventional crude oil used in 2009 would stretch to about 34 million kilometers (21 million miles)—long enough to reach to the moon and back 44 times!* And oil use is expected to increase by 37% by 2030.

CORE CASE STUDY

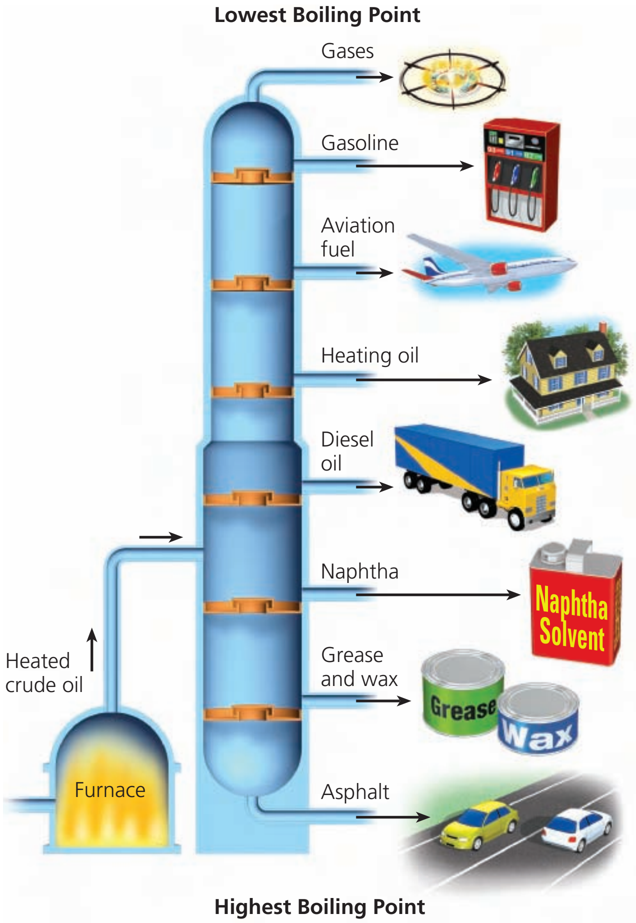


Figure 15-4 **Science:** When crude oil is refined, many of its components are removed at various levels, depending on their boiling points, of a giant distillation column (left) that can be as tall as a nine-story building. The most volatile components with the lowest boiling points are removed at the top of the column. The photo above shows an oil refinery in the U.S. state of Texas.

The world's three largest consumers of oil in 2009 were the United States (using 23% of all oil produced), China (8%), and Japan (6%). Within a few years, China is expected to become the world's largest consumer of oil.

Proven oil reserves are identified deposits from which conventional crude oil can be extracted profitably at current prices with current technology. Other deposits of potentially recoverable oil are classified as **unproven reserves**. They consist of *probable reserves* with a 50% chance of recovery and *possible reserves* with a 10% to 40% chance of recovery. Since the world currently is so dependent on oil, the oil industry is the world's largest business. As a result, control of proven and unproven oil reserves is the single greatest source of global economic and political power.

The world is not about to run out of conventional oil in the near future. Geologists project that proven and unproven global reserves of conventional crude oil will be 80% depleted sometime between 2050 and 2100, depending on consumption rates. The remaining 20% will likely be too costly to remove (see Figure 9, p. S61, in Supplement 9 for a brief history of the Age of Oil). If supplies of conventional oil decrease and the demand for oil increases as projected in coming decades, oil prices will rise as long as the demand remains higher than the available supply. (We explore supply and demand and their effects on prices further in Chapter 23.)

We have four options: look for more oil, use less oil, waste less oil, or use other energy resources. Many analysts think that we have no time to lose and should vigorously pursue all four options.

OPEC Controls Most of the World's Crude Oil Supplies

The 13 countries that make up the Organization of Petroleum Exporting Countries (OPEC) have about 60% of the world's proven crude oil reserves and thus are likely to control most of the world's oil supplies for many decades. Today, OPEC's members are Algeria, Angola, Ecuador, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela. In 2009, OPEC produced about 39% of the world's oil.

Saudi Arabia has the largest portion of the world's conventional proven crude oil reserves (20%). Other countries with large proven reserves are, in order, Iran, Iraq, Kuwait, the United Arab Emirates, Venezuela, and Russia. The United States and China, the world's two largest users of oil, respectively, have only about 1.5% and 1% of the world's proven crude oil reserves. About 85% of all proven conventional crude oil reserves are in the hands of government-owned companies. Private companies such as ExxonMobil and BP control only about 7% of all proven conventional oil reserves and thus have little control over oil supplies and prices.

A serious problem for oil supplies worldwide is that since 1984, production of conventional crude oil from existing proven reserves has exceeded new oil discoveries. Since 2005, global crude oil production has generally leveled off. Of the world's 64 major oil fields, 54 are now in decline.

Some analysts say that there is a lot of oil still to be found. But they are talking mostly about small, dispersed, and harder-to-extract deposits of conventional crude oil, deposits of heavy oil that must be extracted from existing oil wells, and unconventional oil-like materials from tar sands and oil shales. These resources are much more expensive to develop than most of today's conventional crude oil deposits and they have much lower net energy yields. Using them also results in a much higher environmental impact.

For example, there has been quite a lot of information in the popular press and on certain Internet sites about the Bakken oil formation, which lies under parts of Montana, South Dakota, North Dakota, and Canada (see Figure 18, p. S49, in Supplement 8). Some writers have argued that this oil source holds great promise for bolstering oil supplies. But in 2008, the U.S. Geological Survey projected that over the next 20 years, only about 10% of the estimated conventional and unconventional oil in unproven reserves in the Bakken formation could be recovered and only with a low net energy yield and high environmental costs. This new oil would meet current U.S. oil needs for the equivalent of only about one year.

Based on data from the U.S. Department of Energy (DOE) and the U.S. Geological Survey, if global oil consumption continues to grow at about 2% per year, then:

- Saudi Arabia, with the world's largest proven conventional crude oil reserves, could supply the world's entire oil needs for only about 7 years.
- the remaining estimated proven reserves under Alaska's North Slope would meet current world demand for only 6 months or U.S. demand for less than 3 years.
- the estimated unproven reserves in Alaska's Arctic National Wildlife Refuge (ANWR) (see Figure 18, p. S49 in Supplement 8) would meet the current world demand for only 1–5 months and U.S. demand for 7–24 months (Figure 15-5).
- If one day the Chinese use as much oil per person as Americans do today, they will need the equivalent of seven more Saudi Arabian supplies to meet their demand.

We need to keep in mind three things when evaluating future oil supplies:

1. Potential reserves are not proven reserves. Just because there is oil in the ground does not mean that it is economically and environmentally feasible to extract it.
2. We must use the scientific concept of *net energy yield* to help evaluate the real potential of any oil deposit, especially for unproven reserves.
3. We need to take into account the very high and growing rate at which oil is being used worldwide—currently about 31 billion barrels of oil a year.

Bottom line: *To keep using conventional oil at the projected increasing rate of consumption, we must discover proven reserves of conventional oil equivalent to the current Saudi Arabian supply every 5 years*. Most oil geologists say this

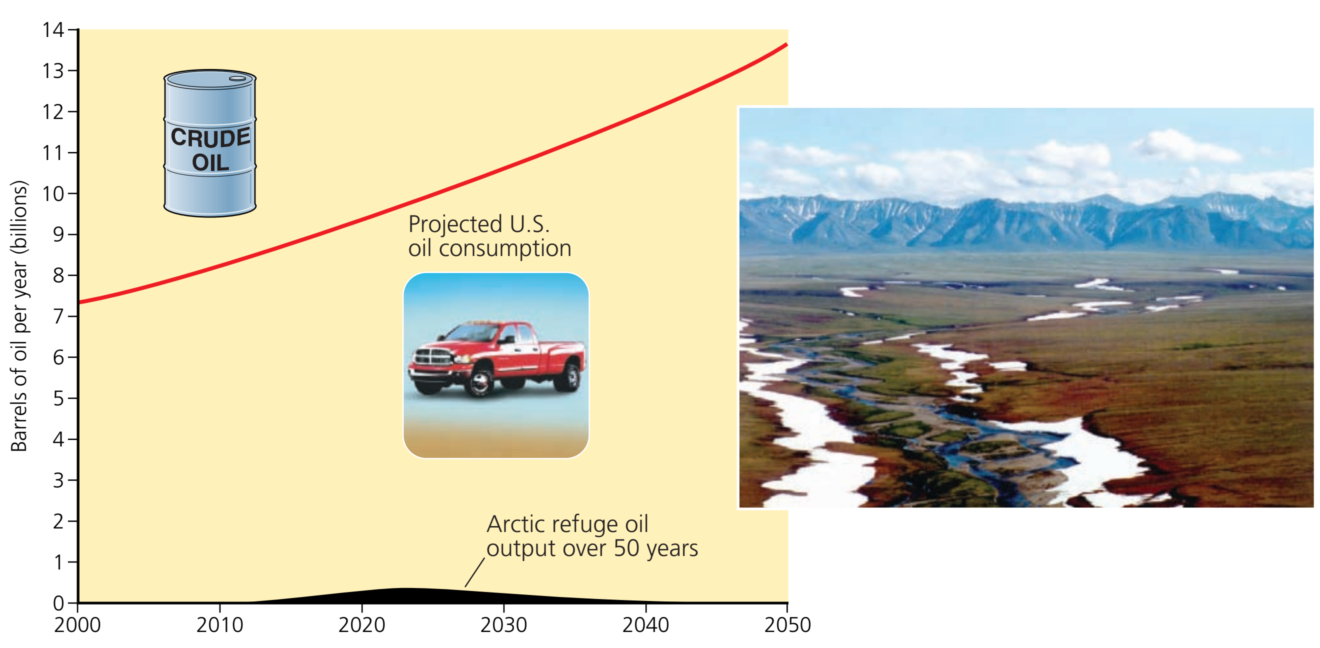


Figure 15-5 The amount of crude oil that *might* be found in the Arctic National Wildlife Refuge (right), if developed and extracted over 50 years, is only a tiny fraction of projected U.S. oil consumption. In 2008, the DOE projected that developing this oil supply would take 10–20 years and would lower gasoline prices at the pump by 6 cents per gallon at most. (Data from U.S. Department of Energy, U.S. Geological Survey, and Natural Resources Defense Council)

is highly unlikely. **Explore More:** See a Case Study at **www.cengage.com/login** to learn more about how long global supplies of conventional oil might last.

The United States Uses Much More Oil Than It Produces

The United States gets about 85% of its commercial energy from fossil fuels, with 40% coming from crude oil (see Figure 6, p. S59, in Supplement 9). The United States produces about 9% of the world's crude oil (see Figure 18, p. S49, in Supplement 8), but it uses 23% of the world's production. The basic problem is that the United States *has only about 1.5% of the world's proven crude oil reserves*, much of it in environmentally sensitive areas.

Since 1984, crude oil use in the United States has exceeded new domestic discoveries, and U.S. production carries a high cost, compared to production costs in the Middle East. This helps to explain why in 2009 the United States imported about 52% of its crude oil (compared to 24% in 1970) at a cost of about $200 billion. In 2009, the largest sources of U.S. imported oil were, in order, Canada, Mexico, Saudi Arabia, Venezuela, and Nigeria. The U.S. Department of Energy estimates that if current trends continue, the United States will import 70% of its oil by 2025.

CONNECTIONS

Oil Consumption, Terrorism, and National Security

According to a 2005 report by the Institute for the Analysis of Global Security, almost one-fourth of the world's crude oil is controlled by states that sponsor or condone terrorism. The report points out that buying oil from such countries helps fund terrorism. According to a 2006 poll of 100 U.S. foreign policy experts in *Foreign Policy* magazine, *the highest priority in fighting terrorism must be to sharply reduce America's dependence on foreign oil*. A 2009 report drawn up by a military advisory board of retired U.S. generals and admirals also called for greatly reducing America's reliance on foreign oil because it poses a serious national security risk.

The U.S. Energy Information Agency, as well as a number of independent geologists, estimate that if the United States opens up all of its public lands and coastal regions to oil exploration, it will find an amount of crude oil that would probably meet no more than about 1% of the country's current annual need. And this oil would be developed only at very high production costs, low net energy yields, and high environmental impacts as was made clear by the 2010 BP oil well blowout in the Gulf of Mexico. In addition, the total amount of oil that BP expected to produce from that ill-fated well in the gulf would have provided only about 5 days worth of oil for the United States. In other words, according to these energy analysts, *the United States cannot even come close to meeting its huge and growing demand for crude oil and gasoline by increasing domestic supplies*.

Using Crude Oil Has Advantages and Disadvantages

Figure 15-6 lists the advantages and disadvantages of using crude oil as an energy resource. The extraction, processing, and burning of nonrenewable oil and other fossil fuels have severe environmental impacts (see Figure 14-12, p. 356), including land disruption, greenhouse gas emissions and other forms of air pollution, water pollution (Figure 15-7), and loss of biodiversity.

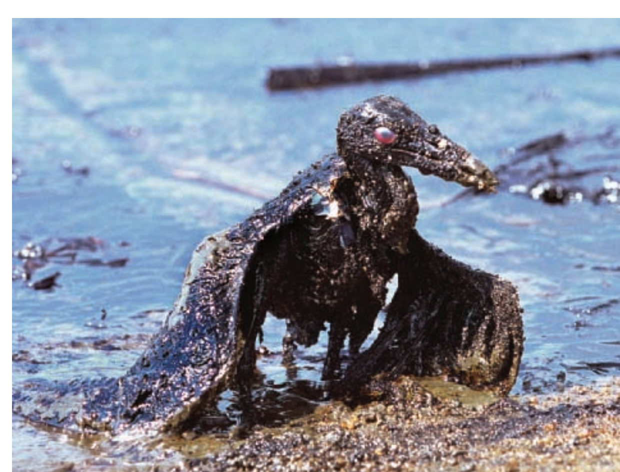
A critical and growing problem is that burning oil or any carbon-containing fossil fuel releases the greenhouse gas CO_2 into the atmosphere. According to most

Trade-Offs

Conventional Oil

Advantages	Disadvantages
Ample supply for several decades	Water pollution from oil spills and leaks
High net energy yield but decreasing	Environmental costs not included in market price
Low land disruption	Releases CO_2 and other air pollutants when burned
Efficient distribution system	Vulnerable to international supply interruptions

Figure 15-6 Using crude oil as an energy resource has advantages and disadvantages (**Concept 15-2A**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?



D. Rodriques-UNEP/Peter Arnold

Figure 15-7 This bird was covered with oil from an oil spill in Brazilian waters. If volunteers had not removed the oil, it would have destroyed this bird's natural buoyancy and heat insulation, causing it to drown or die from exposure because of a loss of body heat.

of the world's top climate scientists, this will warm the atmosphere and contribute to projected climate change during this century. Currently, burning oil, mostly as gasoline and diesel fuel for transportation, accounts for about 43% of global CO_2 emissions, which have been increasing rapidly (see the graph in Figure 14, p. S63, in Supplement 9).

Another problem with relying on oil is that its once high net energy yield is declining as oil producers are forced to turn to oil that is buried deep underground and deep under the ocean floor far offshore. This is expensive and reduces the net energy yield of such oil.

HOW WOULD YOU VOTE?

Do the advantages of relying on conventional crude oil as the world's major energy resource outweigh its disadvantages? Cast your vote online at **www.cengage.com/login**.

CASE STUDY

Heavy Oil from Tar Sand

Tar sand, or **oil sand**, is a mixture of clay, sand, water, and a combustible organic material called *bitumen*—a thick, sticky, tarlike heavy oil with a high sulfur content.

Northeastern Alberta in Canada has three-fourths of the world's tar sand resources in sandy soil under a huge area of remote boreal forest (see Figure 7-13, bottom photo, p. 160) roughly equal to the area of the U.S. state of North Carolina. Other deposits are in Venezuela, Colombia, Nigeria, Russia, and the U.S. state of Utah.

The amount of heavy oil potentially available from bitumen in Canada's tar sands is roughly equal to seven times the total conventional oil reserves of Saudi Arabia. If we include known unconventional heavy oil reserves that can be extracted from tar sands and converted into synthetic crude oil, Canada has the world's second largest oil reserves (13%) after Saudi Arabia with 20%.

The big drawback is that developing this resource has major harmful impacts on the land (Figure 15-8), air, water, wildlife, and climate. About 20% of Alberta's tar sand is close enough to the surface to be strip mined. Before the mining takes place, the overlying boreal forest is clear-cut, wetlands are drained, and some rivers and streams are diverted. Next the overburden of sandy soil, rocks, peat, and clay is stripped away to expose the tar sand deposits. Then five-story-high electric power shovels dig up the tar sand and load it into three-story-high trucks, which carry it to an upgrading plant. There the oil sand is mixed with hot water and steam to extract the bitumen, which is heated by natural gas in huge cookers and converted into a low-sulfur, synthetic, heavy crude oil suitable for refining.

To extract this heavy oil, more earth is being removed in Canada's Athabasca Valley than anywhere else in the world. The project also produces huge amounts of air pollution that fill the mining region's air with dust, steam, smoke, gas fumes, and a tarry stench (Figure 15-8). According to a 2009 study by CERA, an energy consulting group, the process also releases 3 to 5 times more greenhouse gases per barrel of the heavy synthetic crude oil than is released in the extraction and production of conventional crude oil.

In addition, the process uses large amounts of water and creates lake-size tailing ponds of polluted and essentially indestructible toxic sludge and wastewater. Each year, many migrating birds die trying to get water and food from the ponds. Also, the dikes of compacted sand surrounding the tailings ponds have the potential to leak and release large volumes of toxic sludge onto nearby land and into the Athabasca River.

Figure 15-8 Producing heavy oil from Canada's Alberta tar sands project involves strip-mining areas large enough to be seen from outer space, draining wetlands, and diverting rivers. It also produces huge amounts of air and water pollution and has been called the world's most environmentally destructive project. For oil from the sands to be profitable, oil must sell for $70–90 a barrel.

AP Photo/Jeff McIntosh

This method of producing oil takes a great deal of energy—mostly through burning natural gas and using diesel fuel to run the massive machinery—and therefore has a low net energy yield. In other words, producing heavy oil from tar sands is one of the least efficient, dirtiest, and most environmentally harmful ways to produce energy. Despite these extremely harmful environmental effects, in 2009, the United States imported about 19% of its oil from Canada, about half of it produced from tar sands. By 2030, the United States may get as much as 36% of its imported oil from Canadian tar sands.

THINKING ABOUT
Use of Oil from Tar Sands in the United States

Should the United States increase imports of synthetic crude oil produced from tar sands in Canada? Explain. What are the alternatives?

Will Heavy Oil from Oil Shale Be a Useful Resource?

Oily rocks are another potential supply of heavy oil. Such rocks, called *oil shales* (Figure 15-9, left), contain a solid combustible mixture of hydrocarbons called *kerogen*. It is extracted from crushed oil shales after they are heated in a large container—a process that yields a distillate called **shale oil** (Figure 15-9, right). Before the thick shale oil can be sent by pipeline to a refinery, it must be heated to increase its flow rate and processed to remove sulfur, nitrogen, and other impurities.

About 72% of the world's estimated oil shale reserves are buried deep in rock formations located primarily in government-owned land in the U.S. states of Colorado, Wyoming, and Utah in an area known as the Green River formation and in the nearby Bakken oil formation (see Figure 18, p. S49, in Supplement 8). The U.S. Bureau of Land Management estimates that these deposits contain an amount of potentially recoverable heavy oil equal to almost 4 times the size of Saudi Arabia's conventional oil reserves and 11 times the size of Alberta's tar sand reserves. Estimated potential global supplies of shale oil are about 240 times larger than estimated global supplies of conventional crude oil.

So why should we ever worry about running out of oil? The problem is that most of these oil shale deposits are locked up in rock and ore of such low grade that it takes considerable energy and money to mine and convert the kerogen to shale oil. Thus, its net energy is low, even lower than that of heavy oil produced from tar sands. Such a low net energy yield means that this energy resource cannot compete in the open marketplace unless the U.S. government (taxpayers) provides it with large subsidies and tax breaks.

It also takes a lot of water to produce shale oil—about 5 barrels of water for each barrel of shale oil. The massive U.S. deposits are mostly in arid areas of the West, where water is in short supply (see Figure 13-4, bottom, p. 322) and likely to become even scarcer because of current and projected prolonged drought for this area. Most of this water would have to come from the already overtapped Colorado River system (see Chapter 13 Core Case Study, p. 317). Furthermore, digging up and processing shale oil has a much higher environmental impact than does producing crude oil, and it releases 27–52% more CO_2 into the atmosphere per unit of energy produced.

Figure 15-10 lists the advantages and disadvantages of using tar sands and oil shales as energy resources.

THINKING ABOUT
Heavy Oils

Do the advantages of relying on heavy oil from tar sands and oil shales outweigh its disadvantages? Explain.

U.S. Department of Energy

Figure 15-9 Shale oil (right) can be extracted from oil shale rock (left). However, producing shale oil requires large amounts of water and has a low net energy yield and a very high environmental impact.

Trade-Offs

Heavy Oils from Oil Shale and Tar Sand

Advantages	Disadvantages
Large potential supplies	Low net energy yield
Easily transported within and between countries	Releases CO_2 and other air pollutants when produced and burned
Efficient distribution system in place	Severe land disruption and high water use

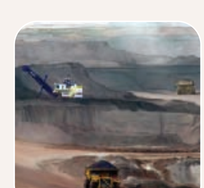


Figure 15-10 Using heavy oil from tar sands and oil shales as an energy resource has advantages and disadvantages (**Concept 15-2B**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

15-3 What Are the Advantages and Disadvantages of Using Natural Gas?

▶ **CONCEPT 15-3 Conventional natural gas is more plentiful than oil, has a high net energy yield and a fairly low cost, and has the lowest environmental impact of all fossil fuels.**

Natural Gas Is a Useful and Clean-Burning Fossil Fuel

Natural gas is a mixture of gases of which 50–90% is methane (CH_4). It also contains smaller amounts of heavier gaseous hydrocarbons such as propane (C_3H_8) and butane (C_4H_{10}), and small amounts of highly toxic hydrogen sulfide (H_2S). It is a versatile fuel with a high net energy yield (Figure 15-3) that can be burned to heat space and water, to produce electricity, and to propel vehicles. BROAD, a major Chinese company, uses it to power its specially designed air conditioners of large buildings.

Conventional natural gas lies above most reservoirs of crude oil. But that found in deep-sea and remote land areas where natural gas pipelines have not been built is usually burned off (Figure 15-11) because it costs too much to build pipelines to distribute it.

When a natural gas field is tapped, propane and butane gases are liquefied under high pressure and removed as **liquefied petroleum gas (LPG)**. LPG is stored in pressurized tanks for use mostly in rural areas not served by natural gas pipelines. The rest of the gas (mostly methane) is purified and pumped into pressurized pipelines for distribution across land areas. The global use of natural gas has been increasing steadily since 1950 (see Figure 7, p. S60, in Supplement 9).

Glovatskiy/Shutterstock

Figure 15-11 Natural gas found above a deep sea oil well deposit or in a remote land area is usually burned off (flared) because no pipeline is available to collect and transmit the gas to users. This practice wastes this energy resource and adds climate-changing CO_2, soot, and other air pollutants to the atmosphere. **Question:** Can you think of an alternative to burning off this gas?

Russia—the Saudi Arabia of natural gas—has about 25% of the world's proven natural gas reserves, followed by Iran (15%) and Qatar (14%). The United States has only 3.4% of the world's proven natural gas reserves (see Figure 18, p. S49, in Supplement 8) but uses about 22% of the world's annual production (see Figure 6, p. S59, in Supplement 9).

Burning natural gas releases the greenhouse gas carbon dioxide and several other air pollutants into the atmosphere. However, it releases much less CO_2 per unit of energy than do coal, crude oil, synthetic crude oil from tar sands and oil shales, and the nuclear power fuel cycle. Thus, some see natural gas as an important fuel for making the transition from oil and coal to renewable solar and wind power during this century (as we discuss further in Chapter 16).

Natural gas can be converted to **liquefied natural gas (LNG)** at a high pressure and at the very low temperature of about –162 °C (–260 °F). This highly flammable liquid can be transported overseas in refrigerated tanker ships. After arriving at its destination, it is heated and converted back to the gaseous state to be distributed by pipeline.

Japan imports large amounts of LNG from Russia, and the United States plans to become the world's largest importer of LNG by 2025. Some analysts warn that this could make the United States too dependent on countries that have not been consistently stable and friendly, such as Russia and Iran, for supplies of LNG. In addition, LNG has a low net energy yield, as more than a third of its energy content is used to liquefy it, process it, ship it to users, and reconvert it to natural gas.

GOOD NEWS

The long-term global outlook for conventional natural gas supplies is better than that for crude oil. At current consumption rates, known reserves of conventional natural gas should last the world 62–125 years and the United States 82–118 years.

Figure 15-12 lists the advantages and disadvantages of using conventional natural gas as an energy resource.

Is Unconventional Natural Gas the Answer?

There are also several sources of *unconventional natural gas*. One is *coal bed methane gas* found in coal beds near the earth's surface across parts of the United States

Trade-Offs

Conventional Natural Gas

Advantages	Disadvantages
Ample supplies	Low net energy yield for LNG
High net energy yield	Releases CO_2 and other air pollutants when burned
Emits less CO_2 and other pollutants than other fossil fuels	Difficult and costly to transport from one country to another

Figure 15-12 Using conventional natural gas as an energy resource has advantages and disadvantages (**Concept 15-3**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why? Do you think that the advantages of using conventional natural gas outweigh its disadvantages?

and Canada (see Figure 19, p. S50, in Supplement 8). Another is natural gas trapped in underground shale (limestone) beds that are found in many parts of the United States and that could meet U.S. natural gas needs for up to 100 years. However, the environmental impacts of producing natural gas from these two sources—scarring of land, large water use, and potential pollution of drinking water from aquifers—may limit its use. Residents of the United States who rely on aquifers for their drinking water have little protection from pollution of their water supplies from these two unconventional sources of natural gas because the 2005 Energy Policy Act excluded natural gas companies from regulation under U.S. water pollution control laws.

Another unconventional source is *methane hydrate* (Figure 15-13)—methane trapped in icy, cage-like structures of water molecules. It is buried in some areas of tundra under arctic permafrost, in places such as Alaska and Siberia. It is also found lying on the ocean floor in several areas of the world. So far, it costs too much to get natural gas from methane hydrates, and the release of methane (a potent greenhouse gas) to the atmosphere during removal and processing would speed up atmospheric warming and the resulting climate change.

J. Pinkston and L. Stern / U.S. Geological Survey

Figure 15-13 Gas hydrates are crystalline solids that can be burned as shown here. They form naturally from the reaction of various gases (commonly methane) with water at low temperatures and under high pressures. Natural gas hydrates form extensively in permafrost and in sediments just under the sea floors around all of the world's continents. Methane hydrates, shown here, are a potentially good fuel.

15-4 What Are the Advantages and Disadvantages of Using Coal?

▶ **CONCEPT 15-4A Conventional coal is plentiful and has a high net energy yield and low cost, but it has a very high environmental impact.**

▶ **CONCEPT 15-4B Gaseous and liquid fuels produced from coal could be plentiful, but they have lower net energy yields and higher environmental impacts than conventional coal has.**

Coal Is a Plentiful but Dirty Fuel

Coal (see Figure 2-14, center, p. 46) is a solid fossil fuel that was formed in several stages from of the remains of land plants that were buried 300–400 million years ago and then exposed to intense heat and pressure over those millions of years (Figure 15-14, p. 382).

For a long time, coal has been widely used to provide heat and electricity (**Core Case Study**). It is currently burned in power plants (Figure 15-15, p. 381) to generate about 42% of the world's electricity, 46% of the electricity used in the United States, and 70% of that in China. It is also burned in industrial plants to make steel, cement, and other products.

CORE CASE STUDY

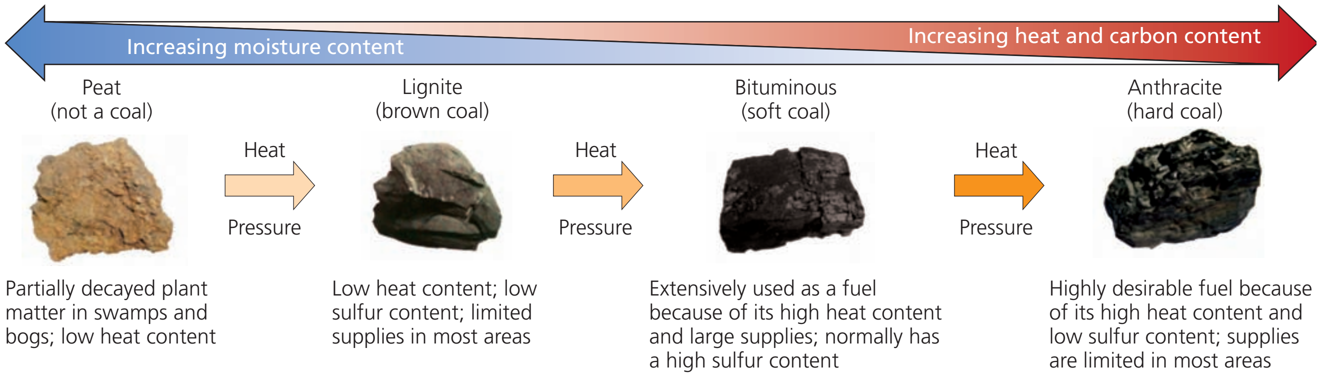


Figure 15-14 Over millions of years, several different types of coal have formed. Peat is a soil material made of moist, partially decomposed organic matter and is not classified as a coal, although it too is used as a fuel. The different major types of coal vary in the amounts of heat, carbon dioxide, and sulfur dioxide released per unit of mass when they are burned.

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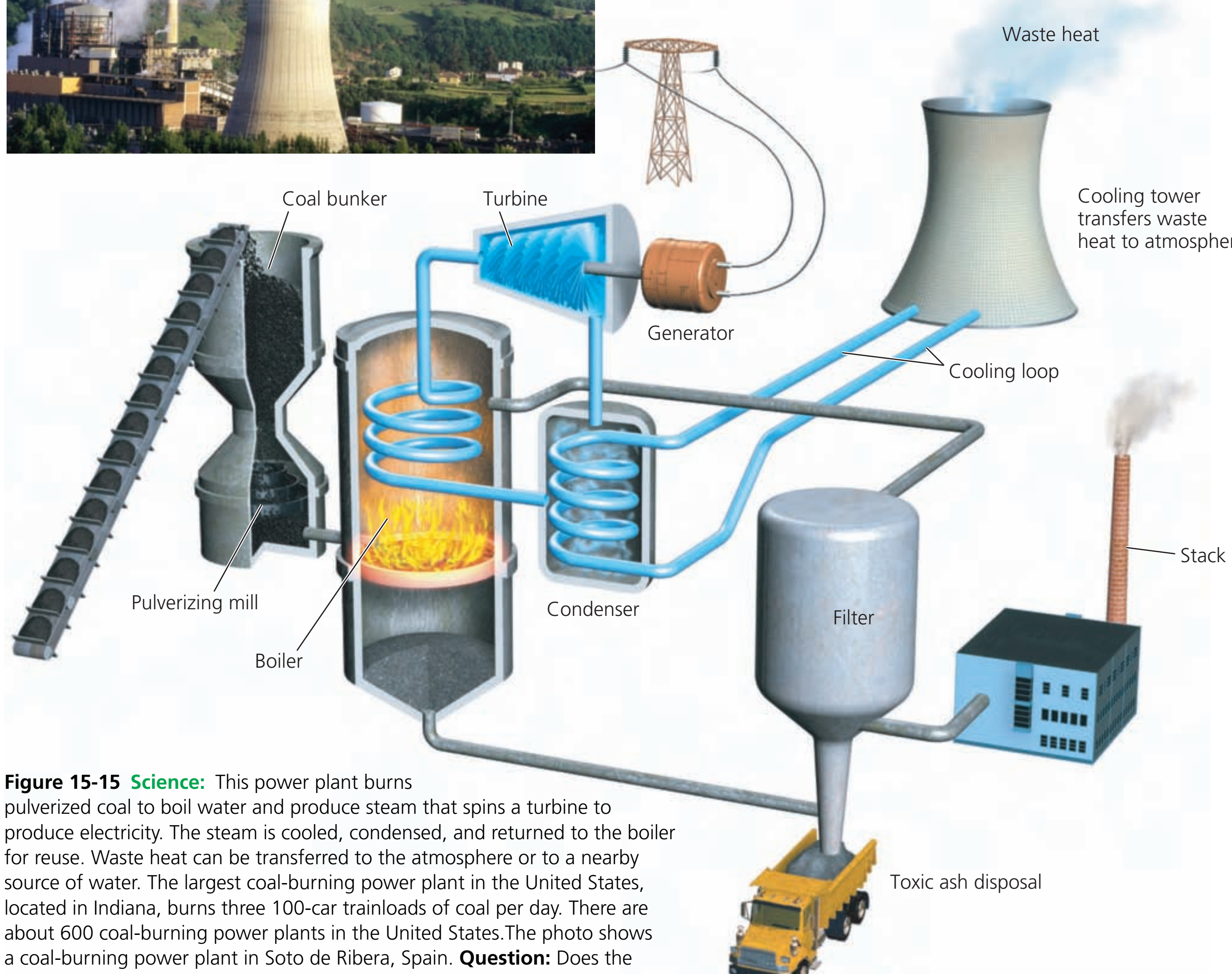


Figure 15-15 **Science:** This power plant burns pulverized coal to boil water and produce steam that spins a turbine to produce electricity. The steam is cooled, condensed, and returned to the boiler for reuse. Waste heat can be transferred to the atmosphere or to a nearby source of water. The largest coal-burning power plant in the United States, located in Indiana, burns three 100-car trainloads of coal per day. There are about 600 coal-burning power plants in the United States.The photo shows a coal-burning power plant in Soto de Ribera, Spain. **Question:** Does the electricity that you use come from a coal-burning power plant?

In order, the three largest coal-burning countries are China, the United States, and India.

Coal is the world's most abundant fossil fuel, and the world has depended on it as a major energy resource for several hundred years (**Core Case Study**). See Figure 7, p. S60, in Supplement 9 for a graph of global coal use between 1950 and 2009.

CORE CASE STUDY

According to the U.S. Geological Survey, identified and unidentified global supplies of coal could last for 214–1,125 years, depending on how rapidly they are used. Five countries have 76% of the world's proven coal reserves. The United States is the Saudi Arabia of coal, with 28% of the world's proven coal reserves (see Figure 19, p. S50, in Supplement 8 for a map of major U.S. coal deposits), followed by Russia (with 18%), China (14%), Australia (9%), and India (7%).

The U.S. Geological Survey estimates that identified U.S. coal reserves should last about 250 years at the current consumption rate. But a 2007 study by the U.S. National Academy of Sciences puts that estimate at about 100 years (see Figure 6, p. S59, in Supplement 9 for a graph of U.S. coal use between 1980 and 2009, with projections to 2030).

The problem is that coal is by far the dirtiest of all fossil fuels. Before it is even burned, the processes of making it available severely degrade land (see Figures 14-14 through 14-17, pp. 357–359) and pollute water and air. When coal is burned without expensive pollution control devices, it severely pollutes the air (Figure 15-16). Coal is mostly carbon but contains small amounts of sulfur, which is released into the air as sulfur dioxide (SO_2) when the coal burns. Burning coal also releases large amounts of black carbon particulates (soot) and much smaller, fine particles of pollutants. The fine particles can get past our bodies' natural defenses that help to keep our lungs clean. According to a 2004 study by the Clean Air Task Force, fine-particle pollution in the United States, mostly from coal-burning power plants, prematurely kills more than 24,000 people a year, or an average of nearly 66 people every day.

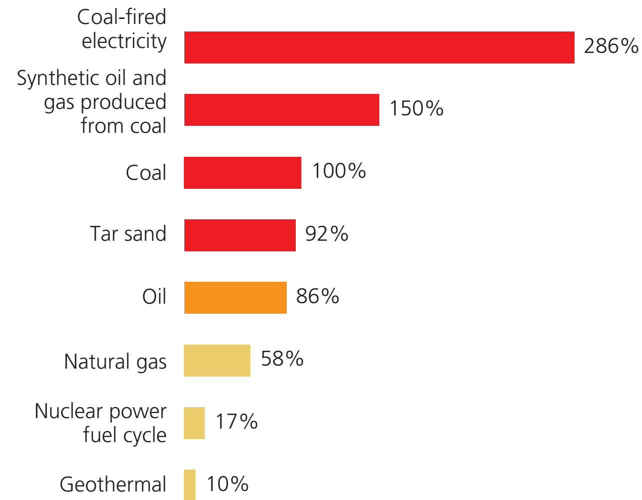


Figure 15-17 CO_2 emissions, expressed as percentages of emissions released by burning coal directly, vary with different energy resources. **Question:** Which produces more CO_2 emissions per kilogram, burning coal to heat a house or heating with electricity generated by coal? (Data from U.S. Department of Energy)

Coal-burning power and industrial plants are among the largest emitters of the greenhouse gas CO_2 (Figure 15-17). According to a 2007 study by the Center for Global Development, coal-burning power plants account for 25% of all human-generated CO_2 emissions in the world, and 40% of such emissions in the United States.

Another problem with burning coal is that it emits trace amounts of radioactive materials as well as toxic and indestructible mercury into the atmosphere. Indeed, a coal-burning power plant releases about 100 times more radioactivity into the atmosphere than does a nuclear power plant with the same energy output. Finally, burning coal produces a highly toxic ash that must be safely stored, essentially forever (see the Case Study on p. 384).

The use of coal is growing, especially in China, which has relied on coal to help fuel its rapid economic growth. Currently, China uses three times as much coal as the United States uses. In 2009, on average, China was building the equivalent of one large coal-fired power plant every week—most of them without modern air pollution control equipment. China has become the world's leading emitter of CO_2 and of sulfur dioxide, which contributes to acid rain and serious human health problems. According to a World Bank report, China has 20 of the world's 30 most polluted cities, with outdoor and indoor air pollution—most of it from burning coal—causing 650,000 to 700,000 deaths a year there.

Deb Kushal/Peter Arnold, Inc.

Figure 15-16 This coal-burning industrial plant in India produces large amounts of air pollution because is has inadequate air pollution controls.

Trade-Offs

Coal

Advantages

Ample supplies in many countries

High net energy yield

Low cost when environmental costs are not included

Disadvantages

Severe land disturbance and water pollution

Fine particle and toxic mercury emissions threaten human health

Emits large amounts of CO_2 and other air pollutants when produced and burned

Figure 15-18 Using coal as an energy resource has advantages and disadvantages (**Concept 15-4A**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why? Do you think that the advantages of using coal as an energy resource outweigh its disadvantages?

The primary reason that coal is a relatively cheap way to produce electricity is that most of its harmful environmental and health costs are not included in the market price of electricity from coal-burning power plants. In 2008, the U.S. Energy Administration and the Worldwatch Institute estimated that when the harmful costs of using coal are included, burning coal becomes the second most expensive way to produce electricity after solar cells. However, this estimate does not include the additional costs of regulating coal ash (see the Case Study that follows). Figure 15-18 lists the advantages and disadvantages of using coal as an energy resource (**Concept 15-4A**).

■ **CASE STUDY**

The Problem of Coal Ash

Some energy analysts say that we should never commit ourselves to using an energy resource that requires us to store any resulting harmful wastes essentially forever. Coal fails this test, because burning it and removing pollutants from the resulting emissions produces an ash that contains highly toxic and indestructible chemicals such as arsenic, cadmium, chromium, lead, mercury, and radioactive radium. Each year, the amount of hazardous ash produced by coal-fired power plants in the United States would fill a train with enough rail cars to stretch three-and-one-half times the distance between New York City and Los Angeles, California.

Burning coal always produces ash as a waste. One type of ash is what is left over after the coal has burned. Another form of ash containing highly toxic chemicals is created because of U.S. government regulations that require the removal of various harmful air pollutants from the smokestack emissions of coal-burning power and industrial plants. These harmful chemicals become part of the hazardous coal ash that can contaminate water and soil.

Some of the ash from coal-burning plants is sold and recycled into cement and concrete, used as a base for paving roads, or converted into wallboard (drywall) for use in homes and offices. Since 2001, the EPA and the U.S. Department of Agriculture have been encouraging U.S. farmers to use dry coal ash as a fertilizer. Officials say that the fertilizer contains only tiny amounts of toxic metals removed from the exhaust of coal-burning power pants. But there are no federal limits on the amounts of such toxic metals in coal-ash fertilizer.

In the United States, about 57% of the ash is either buried (sometimes in active or abandoned mines where it can contaminate groundwater) or made into a wet slurry that is stored in holding ponds. From the ponds, these indestructible toxic wastes can slowly leach into groundwater or break through their earthen dams and severely pollute nearby rivers, groundwater, and towns.

Wet storage of this waste is cheap and the U.S. government has not been inspecting or regulating the more than 500 wet coal ash storage ponds located near power plants in 32 states. After studying this problem for almost three decades, the EPA in 2010 proposed treating coal ash as either a strictly-regulated hazardous waste or a weakly-regulated nonhazardous waste.

The hazards of unregulated wet-slurry storage of coal ash became clear on December 22, 2008, when a rupture occurred in a wall of a coal ash storage pond not far from Knoxville, Tennessee. The resulting spill flooded an area larger than the combined areas of 300 football fields with toxic sludge that destroyed or damaged 40 homes and other buildings. It also tainted waterways and soil with arsenic and other toxic chemicals, killed fish, and disrupted the lives of the people in a nearby rural community. Cleanup will cost an estimated $1.2 billion.

In 2007, the EPA determined that toxic metals and other harmful chemicals in coal ash waste ponds have contaminated groundwater used by 63 communities in 26 U.S states. In 2009, the EPA also estimated that there are 44 coal ash waste ponds in several states that are highly hazardous (see Figure 28, p. S56, in Supplement 8). Another 2009 study by the Environmental Integrity Project (EIP) put the number of such ponds at 100. In 2002, an EPA study (released in 2009) revealed that people who drank water contaminated by coal ash slurry over a long period of time had a 1 in 50 chance of getting cancers of the lung and bladder.

The EIP made two major recommendations. *First,* the government should inspect, monitor, and regulate all types of existing and planned coal ash storage sites on an emergency basis. *Second,* the government should phase out all wet storage of toxic coal ash and classify coal ash as a hazardous waste. Then the waste should be stored dry in lined landfills designed to contain contaminants, or it should be recycled into products that will not release its harmful chemicals into the environment.

For nearly three decades, coal and electric utility companies have successfully opposed such regulations. They argue correctly that forcing them to include these harmful environmental and health costs in the price of coal-generated electricity would make it considerably more expensive. This could threaten their profits and investments because it would make coal less competitive with other cleaner and increasingly cheaper energy alternatives such as natural gas and wind power.

The Clean Coal and Anti-Coal Campaigns

For decades, economically and politically powerful U.S. coal companies and coal-burning utilities have understandably fought to preserve their profits by opposing measures such as stricter air pollution standards for coal-burning plants and classification of coal ash as a hazardous waste. For over two decades, these companies have also led the fight against efforts to classify climate-changing CO_2 as a pollutant, which would threaten their long-term economic survival.

Beginning in 2008, the U.S. coal industry along with many coal-burning electric utility companies and the Union Pacific railroad, which transports coal, funded a highly effective $40 million publicity campaign to promote the misleading idea of *clean coal*. We can burn coal more cleanly. But critics point out that there is no such thing as clean coal. One critic has argued that the possibility of developing clean coal is no more likely than that of making a healthy cigarette.

In fact, the American Lung Association estimates that burning coal to produce electricity prematurely kills an estimated 24,000 Americans a year. Mining the coal usually involves disrupting the land and polluting water and air. Even with stricter air pollution controls, burning coal will always involve some emissions of CO_2 and other air pollutants, and it will always create indestructible toxic coal ash removed from smokestack emissions.

According to climate scientist James Hansen, head of the NASA Goddard Center, "Coal is the single greatest threat to civilization and all life on the planet." More than 230 new coal-burning power plants have been proposed in the United States since 2000. Citizen activist groups in a growing anti-coal movement have stopped 127 of these proposals from going forward. They are working to stop the building of any new coal-burning power plants and to phase out the 600 exisiting plants over the next few decades.

HOW WOULD YOU VOTE?

Should using coal to produce electricity be phased out over the next few decades? Cast your vote online at **www.cengage.com/login**.

We Can Convert Coal into Gaseous and Liquid Fuels

We can convert solid coal into **synthetic natural gas** (**SNG**) by a process called *coal gasification*, which removes sulfur and most other impurities from coal. We can also convert coal into liquid fuels such as methanol and synthetic gasoline through a process called *coal liquefaction*. Such fuels are called *synfuels*, and when they are burned, they produce less air pollution then does burning coal directly. But using these fuels requires mining and using much more coal than would burning the coal directly.

One approach being evaluated in Great Britain and Australia is to forget about mining coal. The idea is to burn coal seams underground, tap the resulting gases (mostly CH_4 and CO_2), burn the CH_4 in gas turbines to produce electricity, and capture the CO_2 and store it underground. Evaluating whether this approach is economically and environmentally feasible could take about two decades.

Compared to burning coal directly, producing synfuels requires mining 50% more coal. Producing and burning synfuels could also add 50% more carbon dioxide to the atmosphere (Figure 15-17). As a result, synfuels have a lower net energy yield and cost more to produce per unit of energy than conventional coal. Also, it takes large amounts of water to produce synfuels. In other words, greatly increased use of these synfuels would worsen two of the world's major environmental problems: projected climate change caused largely by CO_2 emissions and increasing water shortages in many parts of the world (see Figure 13-5, p. 322 and Figure 13-6, p. 323).

Figure 15-19 lists the advantages and disadvantages of using liquid and gaseous synfuels produced from coal (**Concept 15-4B**).

Trade-Offs

Synthetic Fuels

Advantages	Disadvantages
Large potential supply in many countries	Low to moderate net energy yield
Vehicle fuel	Requires mining 50% more coal with increased land disturbance, water pollution and water use
Lower air pollution than coal	Higher CO_2 emissions than coal

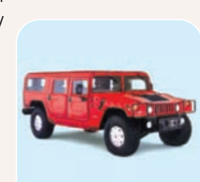


Figure 15-19 The use of synthetic natural gas (SNG) and liquid synfuels produced from coal has advantages and disadvantages (**Concept 15-4B**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why? Do you think that the advantages of using synfuels produced from coal as an energy source outweigh the disadvantages?

15-5 What Are the Advantages and Disadvantages of Using Nuclear Energy?

▶ **CONCEPT 15-5 Nuclear power has a low environmental impact and a very low accident risk, but its use has been limited by a low net energy yield, high costs, fear of accidents, long-lived radioactive wastes, and the potential for spreading nuclear weapons technology.**

How Does a Nuclear Fission Reactor Work?

Nuclear power is a source of energy that we learned how to use fairly recently, primarily for generating electricity (**Core Case Study**). To evaluate the advantages and disadvantages of nuclear power, we must know how a nuclear power plant and its accompanying nuclear fuel cycle work. A nuclear power plant is a highly complex and costly system designed to perform a relatively simple task: to boil water and produce steam that spins a turbine and generates electricity.

What makes it complex and costly is the use of a controlled nuclear fission reaction (see Figure 2-9, center, p. 43) to provide the heat. The fission reaction takes place in a *reactor*. The most common reactors, called *light-water reactors* (LWRs, see Figure 15-20), produce 85% of the world's nuclear-generated electricity (100% in the United States).

Just in the process of generating electricity, LWRs are highly inefficient, losing about 75% of the high-quality energy available in their nuclear fuel as waste heat to the environment. Before that point, 9% of the energy content of the fuel has already been lost as heat when the uranium fuel is mined, upgraded, and transported to the plant. At least another 8% is lost in dealing with the radioactive wastes produced by a plant, bringing the net energy loss to about 92%. If we add the enormous amount of energy needed to dismantle a plant at the end of its life and store its highly radioactive materials for thousands of years, some scientists estimate that using nuclear power will eventually require more energy than it will ever produce. Thus, the entire nuclear fuel cycle has a low and possibly negative net energy yield and must therefore be heavily subsidized by governments to compete in the open marketplace against other energy alternatives with higher net energy yields.

The fuel for a reactor is made from uranium ore mined from the earth's crust. After it is mined, the ore must be enriched to increase the concentration of its fissionable uranium-235 by 1% to 5%. The enriched uranium-235 is processed into small pellets of uranium dioxide. Each pellet, about the size of an eraser on a pencil, contains the energy equivalent of about a ton of coal. Large numbers of the pellets are packed into closed pipes, called *fuel rods*, which are then grouped together in *fuel assemblies*, to be placed in the core of a reactor.

Control rods are moved in and out of the reactor core to absorb neutrons, thereby regulating the rate of fission and amount of power produced. A *coolant,* usually water, circulates through the reactor's core to remove heat, and this keeps the fuel rods and other reactor components from melting and releasing massive amounts of radioactivity into the environment. A modern LWR includes an emergency core cooling system as a backup to help prevent such meltdowns.

A *containment shell* with thick, steel-reinforced concrete walls surrounds the reactor core. It is designed to keep radioactive materials from escaping into the environment, in case there is an internal explosion or a melting of the reactor's core. It also protects the core from some external threats such as tornadoes and plane crashes. This gives you an idea of why these plants cost so much to build—about $14 billion for a typical plant today—and why this cost is rising rapidly. The cost of a single nuclear plant is nearly 3 times as much as the national government of Costa Rica spent on everything in 2009.

What Is the Nuclear Fuel Cycle?

A nuclear power plant is only one part of the *nuclear fuel cycle* (Figure 15-21, p. 388), which also includes the mining of uranium, processing and enriching the uranium to make fuel, using it in a reactor, and safely storing the resulting highly radioactive wastes, in the form of depleted or spent fuel rods, for thousands of years until their radioactivity falls to safe levels. The cycle also includes dismantling the highly radioactive reactors at the end of their useful lives and safely storing their radioactive components for thousands of years.

Each step in the nuclear fuel cycle adds to the cost of nuclear power and reduces its net energy yield (**Concept 15-1**). Proponents of nuclear power tend to focus on the low CO_2 emissions and multiple safety features of the reactors. But in evaluating the safety, economic feasibility, net energy yield, and overall environmental impact of nuclear power, energy experts and economists caution us to look at the entire nuclear fuel cycle, not just the power plant itself.

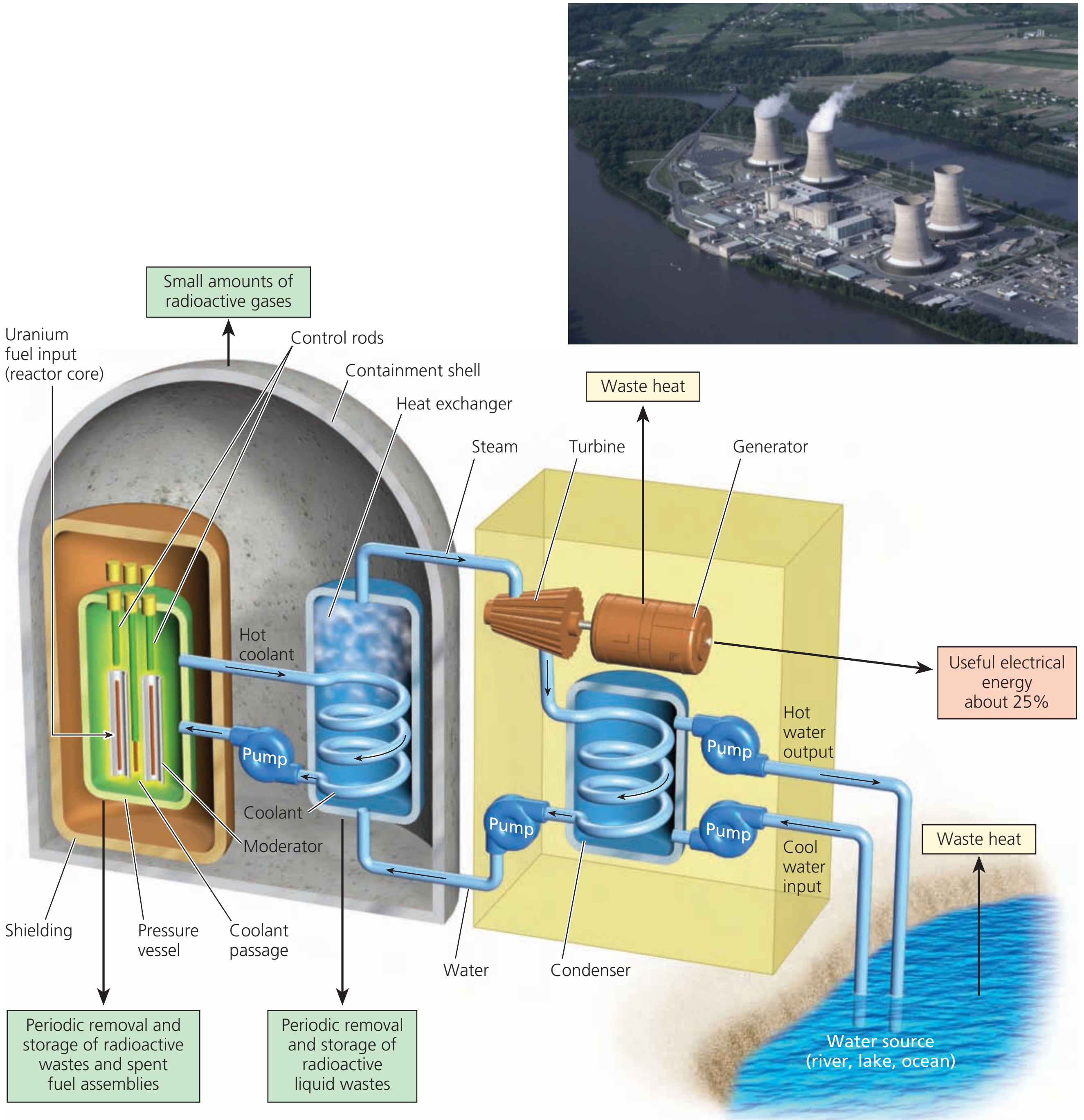


Figure 15-20 **Science:** This water-cooled nuclear power plant, with a pressurized water reactor, pumps water under high pressure into its core where nuclear fission takes place. It produces huge quantities of heat that is used to convert the water to steam, which spins a turbine that generates electricity. Some nuclear plants withdraw the water they use from a nearby source such as a river and return the heated water to that source, as shown here. Other nuclear plants transfer the waste heat from the intensely hot water to the atmosphere by using one or more gigantic cooling towers, as shown in the inset photo of the Three Mile Island nuclear power plant near Harrisburg, Pennsylvania (USA). There, a serious accident in 1979 almost caused a meltdown of the plant's reactor. **Question:** How do you think the heated water returned to a body of water affects that aquatic ecosystem?

What Happened to Nuclear Power?

In the 1950s, researchers predicted that by the year 2000, at least 1,800 nuclear power plants would supply 21% of the world's commercial energy (25% in the United States) and most of the world's electricity.

After almost 60 years of development, enormous government subsidies, and a huge investment, these goals have not been met. In 2010, 436 commercial nuclear reactors in 31 countries produced only 6% of the world's commercial energy and 14% of its electricity. Nuclear power is now the world's slowest-growing form of commercial energy.

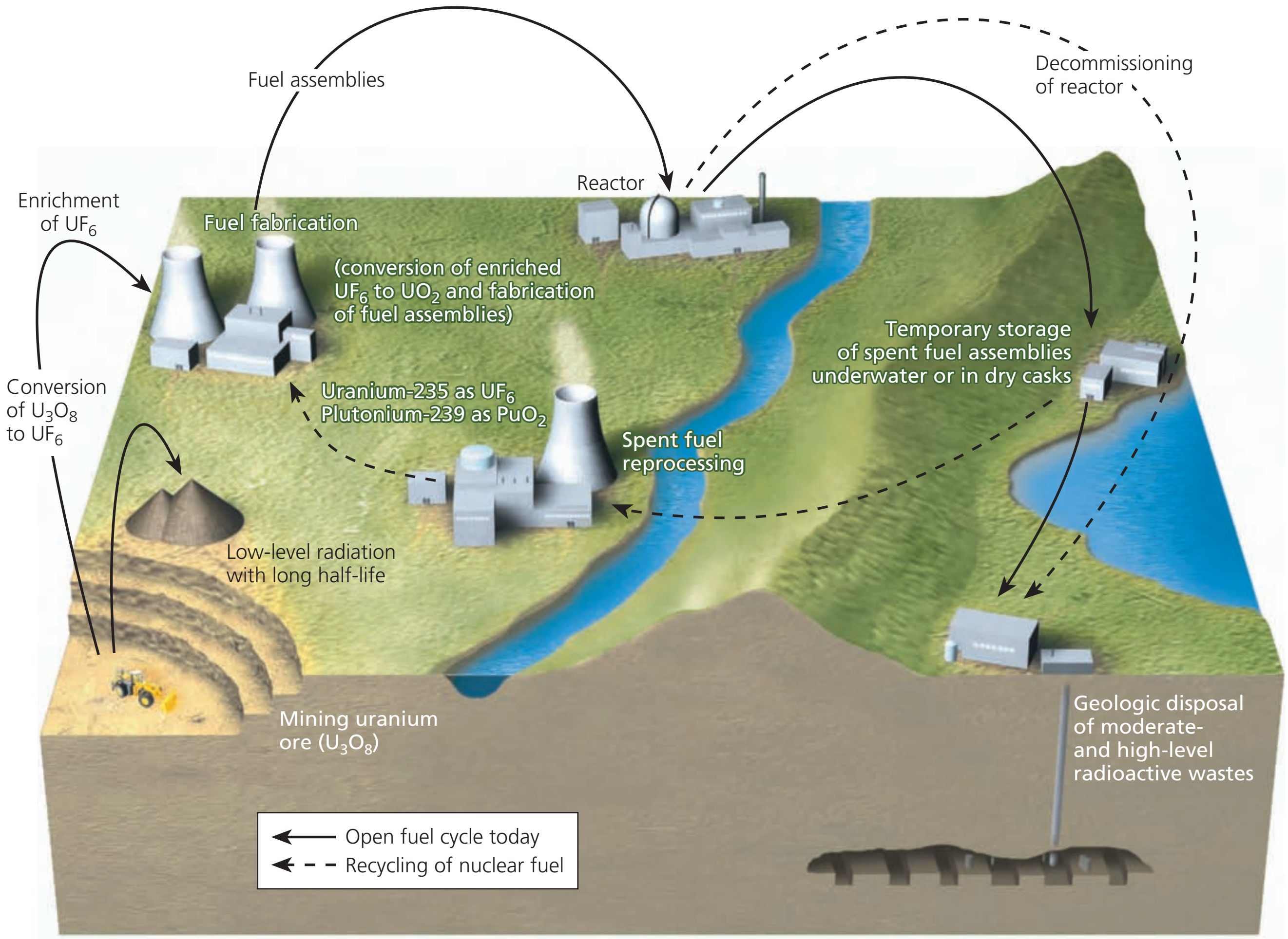


Figure 15-21 **Science:** Using nuclear power to produce electricity involves a sequence of steps and technologies that together are called the *nuclear fuel cycle.* As long as a reactor is operating safely, the power plant itself has a fairly low environmental impact and a very low risk of an accident. But considering the entire nuclear fuel cycle, the financial costs are high and the environmental impact and other risks increase. Radioactive wastes must be stored safely for thousands of years, several points in the cycle are vulnerable to terrorist attack, and the technology used in the cycle can also be used to produce uranium in a form that can be used in nuclear weapons (**Concept 15-5**). All in all, an amount of energy equal to about 92% of the energy content of the nuclear fuel is wasted in the nuclear fuel cycle. As a result, electricity produced by this fuel cycle has such a low net energy yield that it cannot compete in the open marketplace with energy alternatives that have higher net energy yields, unless it is supported by huge government subsidies. **Question:** Do you think the market price of nuclear-generated electricity should include all the costs of the nuclear fuel cycle or should governments (taxpayers) continue to subsidize nuclear power? Explain.

The graph in Figure 10, p. S62, in Supplement 9 shows the global trend in electricity production by nuclear power plants between 1960 and 2009. In 2009, 104 licensed commercial nuclear power reactors in 31 states generated about 8% of the country's overall energy and 19% of its electricity (see Figure 21, p. S51, in Supplement 8 for a map of the locations of these plants). This percentage is expected to decline over the next several decades as existing reactors wear out and are retired faster than new ones are built.

The U.S. government has provided huge subsidies, tax breaks, and loan guarantees to the nuclear power industry. It also provides accident insurance guarantees, because insurance companies have refused to fully insure any nuclear reactor. Without these taxpayer-subsidized payments, this industry would not exist in the United States or anywhere else, as would be expected because of the low net energy yield of the nuclear fuel cycle. In addition, after almost 60 years of discussion and research, there is no scientific or political consensus on how to safely store the resulting highly radioactive wastes for thousands of years.

Another obstacle has been public concerns about the safety of nuclear reactors. Because of the multiple built-in safety features, the risk of exposure to radioactivity from nuclear power plants in the United States and most other more-developed countries is extremely low. However, explosions and partial or complete meltdowns are possible, as we learned in 1986 from the serious accident at the Chernobyl nuclear plant in Ukraine (see the Case Study that follows). **Explore More:** See a Case Study at **www.cengage.com/login** to learn about the near meltdown of the reactor core at the Three Mile Island nuclear plant in the U.S. state of Pennsylvania in 1986 (see photo in Figure 15-20).

CASE STUDY

Chernobyl: The World's Worst Nuclear Power Plant Accident

Chernobyl is known around the globe as the site of the world's most serious nuclear power plant accident. On April 26, 1986, two simultaneous explosions in one of the four operating reactors in this nuclear power plant in Ukraine (then part of the Soviet Union) blew the massive roof off the reactor building. The reactor partially melted down and its graphite components caught fire and burned for 10 days. The initial explosion and the prolonged fires released a radioactive cloud that spread over much of Belarus, Russia, Ukraine, and Europe, and it eventually encircled the planet.

According to UN studies, the Chernobyl disaster was caused by a poor reactor design (not the type used in the United States or in most other parts of the world) and by human error, and it had serious consequences. By 2005, some 56 people had died prematurely from exposure to radiation released by the accident. The number of long-term premature deaths from the accident, primarily from exposure to radiation, range from 9,000 by World Health Organization estimates, to 212,000 as estimated by the Russian Academy of Medical Sciences, to nearly 1 million according to a 2010 study by Alexey Yablokov and two other Russian scientists, published by the New York Academy of Sciences.

After the accident, some 350,000 people had to abandon their homes because of contamination by radioactive fallout. In addition to fear about long-term health effects such as cancers, many of these victims continue to suffer from stress and depression. In parts of Ukraine, people still cannot drink the water or eat locally produced food. There are also higher rates of thyroid cancer, leukemia, and immune system abnormalities in children exposed to Chernobyl's radioactive fallout.

Chernobyl taught us that a major nuclear accident anywhere can have harmful effects that reverberate throughout much of the world.

CENGAGENOW™ Watch how winds carried radioactive fallout around the world after the Chernobyl meltdown at CengageNOW.

The Conventional Nuclear Power Fuel Cycle Has Advantages and Disadvantages

Figure 15-22 lists the major advantages and disadvantages of producing electricity by using the nuclear power fuel cycle (**Concept 15-5**). With the exception of cost, using nuclear power to produce electricity has some important advantages over coal-burning power plants (Figure 15-23).

France depends on nuclear power for more of its electricity than any other country in the world. **Explore More:** See a Case Study at **www.cengage.com/login** to learn about the benefits and problems of nuclear power as it is used in France.

Let's look more closely at some of the challenges involved in using nuclear power.

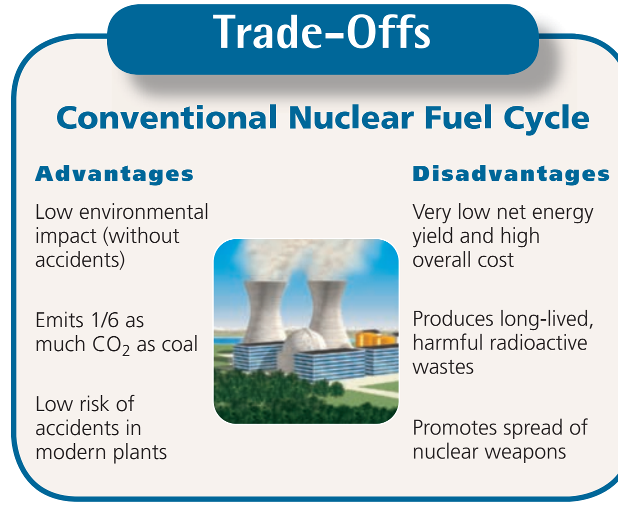


Figure 15-22 Using the nuclear power fuel cycle (Figure 15-21) to produce electricity has advantages and disadvantages (**Concept 15-5**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why? Do you think that the advantages of using the conventional nuclear power fuel cycle to produce electricity outweigh its disadvantages? Explain.

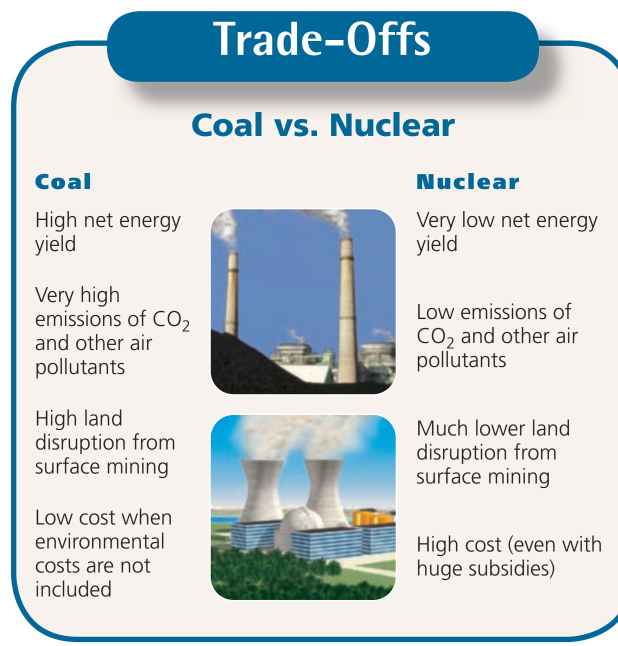


Figure 15-23 The risks of using nuclear power, compared with the risks of using coal-burning plants to produce electricity. A 1,000-megawatt nuclear plant is refueled once a year, whereas a coal plant of the same size requires 80 rail cars of coal a day. **Question:** If you had to choose, would you rather live near a coal-fired power plant or a nuclear power plant? Explain.

Storing Spent Radioactive Fuel Rods Presents Risks

After about 3 or 4 years, the high-grade uranium fuel in a nuclear reactor becomes spent, or useless, and must be replaced. On a regular basis, reactors are shut down for a short period to refuel them. This involves replacing about a third of the reactor's fuel rods that contain the spent fuel. After they are removed, the intensely hot and highly radioactive spent fuel rod assemblies are stored outside of the nuclear reactor building in *water-filled pools* (Figure 15-24, left). After several years of cooling, they can be transferred to *dry casks* made of heat-resistant metal alloys and concrete (Figure 15-24, right). These intensely radioactive materials must be stored safely for many thousands of years.

A 2005 study by the U.S. National Academy of Sciences warned that the intensely radioactive waste storage pools and dry casks at 68 nuclear power plants in 31 U.S. states are especially vulnerable to sabotage or terrorist attack. These pools and casks are usually located outside of reactor buildings and thus are not protected nearly as well as the reactor core is from accidents or acts of terrorism.

A 2002 study by the Institute for Resource and Security Studies and the Federation of American Scientists found that in the United States, about 161 million people—53% of the population—live within 121 kilometers (75 miles) of an aboveground spent-fuel storage site, most of which are at existing nuclear power plants. For some time, critics have been calling for the immediate construction of much more secure structures to protect spent-fuel storage pools and dry casks either at nuclear power plant facilities or at regional storage sites. However, critics say that because this would add to the already very high cost of electricity produced by the nuclear fuel cycle, very little has been done to improve the safety and security of these sites.

The long-term goal is to find a way to store these dangerous radioactive wastes safely at a central site. But after 25 years of research and testing and over $8 billion of U.S. government (taxpayer) subsidy payments, no scientifically and politically acceptable site for such storage has been found. Meanwhile these deadly wastes are building up.

THINKING ABOUT
Nuclear Power Plant Security

Do you favor providing much better protection for pools and dry casks used to store highly radioactive spent nuclear fuel rods, even if this raises the cost of electricity? How much more (expressed as a percentage) would you be willing to pay for electricity to ensure that this was done?

CONNECTIONS
Nuclear Power Plants and the Spread of Nuclear Weapons

The United States and 14 other countries have been selling commercial and experimental nuclear reactors and uranium fuel enrichment and purification technology in the international marketplace for decades. Much of this information and equipment can be used to produce bomb-grade material for use in nuclear weapons. This is one reason that 60 countries—1 of every 3 in the world—now have nuclear weapons or have the knowledge and ability to produce bomb-grade material. Energy expert John Holdren, pointed out that, with the exception of the United States, Great Britain, and the former Soviet Union, every country that has nuclear weapons or the knowledge to develop them has gained most of such information by using civilian nuclear power technology.

U.S. Department of Energy/Nuclear Regulatory Commission

U.S. Department of Energy/Nuclear Regulatory Commission

Figure 15-24 **Science:** After 3 or 4 years in a reactor, spent fuel rods are removed and stored in a deep pool of water contained in a steel-lined concrete basin (left) for cooling. After about 5 years of cooling, the fuel rods can be stored upright on concrete pads (right) in sealed dry-storage casks made of heat-resistant metal alloys and concrete. **Questions:** Would you be willing to live within a block or two of these casks or have them transported through the area where you live in the event that they were transferred to a long-term storage site? Explain. What are the alternatives?

Dealing with Radioactive Wastes Produced by Nuclear Power Is a Difficult Problem

Each part of the nuclear power fuel cycle produces radioactive wastes. *High-level radioactive wastes* consist mainly of spent fuel rods and assemblies from commercial nuclear power plants, the waste materials from dismantled plants, and assorted wastes from the production of nuclear weapons. They must be stored safely for at least 10,000 years and, by some estimates, up to 240,000 years if long-lived plutonium-235 is not removed from the wastes.

For example, according to a Nevada state agency report, 10 years after being removed from a reactor, a spent-fuel rod assembly would still emit enough radiation to kill a person standing 1 meter (39 inches) away in less than 3 minutes. Even if all the nuclear power plants in the world were shut down tomorrow, we would still have to find and pay for a way to protect ourselves and hundreds to several thousands of generations to come from the intensely radioactive wastes that have already been produced. This underscores the principle that we should be very careful about committing ourselves to any technology that produces harmful wastes that must be safely stored, essentially forever.

As previously mentioned, most highly radioactive fuel rods are stored temporarily in pools and dry casks (Figure 15-24) near the reactor sites. The long-term goal has been to find ways to store these wastes safely for thousands of years. Most scientists and engineers agree in principle that deep burial in a geologically acceptable underground repository is the safest and cheapest way to store these and other high-level radioactive wastes. However, after almost 60 years of research and evaluation, no country has built and tested such a repository. Some scientists contend that it is not possible to demonstrate that this or any method will work for thousands of years. They consider the problem of what to do with nuclear wastes as a *wicked problem*—scientific shorthand for an essentially unsolvable scientific problem.

Spent fuel rods could also be processed to remove radioactive plutonium, as is done with some of the other radioactive wastes we produce. This reduces the storage time for these wastes from up to 240,000 to about 10,000 years. But this is costly and produces plutonium that other countries or terrorists could use to make nuclear weapons. This is the main reason for why, after spending billions of dollars, the United States abandoned this fuel recycling approach in 1977.

Some analysts have suggested shooting our intensely radioactive wastes into space or into the sun. But the costs of such an effort would be extremely high and a launch accident—such as the 1986 explosion of the space shuttle Challenger—could disperse high-level radioactive wastes over large areas of the earth's surface.

CASE STUDY

High-Level Radioactive Wastes in the United States

In 1987, the DOE announced plans to build a repository for underground storage of high-level radioactive wastes from commercial nuclear reactors on federal land in the Yucca Mountain desert region, about 160 kilometers (100 miles) northwest of Las Vegas, Nevada. By 2008, the U.S. government had spent more than $10.4 billion on evaluation and preliminary development of the site with $2 billion of these costs paid by the nuclear industry and $8.4 billion paid by taxpayers. In 2008, the total cost of the repository was projected to be $96 billion, which would have added even more to the high cost of the nuclear power fuel cycle.

Critics charged that the selection of the earthquake-prone Yucca Mountain site was based more on political convenience than on scientific suitability. Some scientists argued that the site should never be allowed to open, mostly because rock fractures and tiny cracks are likely to allow water to flow through the site. The build-up of hydrogen gas produced from the breakdown of this water by the intense heat of the stored waste materials would likely cause an explosion. In 1998, Jerry Szymanski, once the DOE's top geologist at Yucca Mountain and later an outspoken opponent of the site plan, said that if water flooded the site, it could cause an explosion so large that "Chernobyl would be small potatoes."

In 2009, the president of the United States agreed with such criticisms and requested that the U.S. Congress cut off funding for the Yucca Mountain project while other, shorter-term alternatives are evaluated. Meanwhile, large amounts of U.S. nuclear waste sit in pools and dry casks (Figure 15-24), mostly near reactors at scattered sites around the country, and these volumes of waste continue to grow (see Figure 21, p. S51, in Supplement 8 for a map of the U.S. commercial reactor sites).

What Should We Do with Worn-out Nuclear Power Plants?

When a coal-burning power plant or a wind farm reaches the end of its useful life, it can be simply torn down. But this cannot be done with a worn-out nuclear plant, which contains highly radioactive materials that must be stored safely for thousands of years.

Scientists have proposed three ways to retire worn-out nuclear power plants. One strategy is to dismantle the plant after it is decommissioned (closed) and to store its radioactive parts in a secure repository, which so far no country has built and tested. A second approach is to install a physical barrier around the plant and set up full-time security for 30–100 years, until the plant can be dismantled after its radioactivity has reached safer levels. These levels would still be high enough to require safe storage of leftover parts for thousands of years.

A third option is to enclose the entire plant in a concrete and steel-reinforced tomb, called a containment structure. This is what was done with the Chernobyl reactor after it exploded, but within a few years, the containment structure began to crumble, due to the corrosive nature of the radiation inside the damaged reactor, and to leak radioactive wastes. The structure is being rebuilt at great cost and is unlikely to last even several hundred years. Regardless of the method chosen, the high costs of retiring nuclear plants adds to the total costs of the nuclear power fuel cycle and reduces its already low net energy yield. It shows again the scientific and economic problems that occur from adopting a technology that produces highly dangerous wastes that essentially must be stored forever.

Companies operating nuclear power plants in the United States have been required to set aside money to help fund the tear-down and storage of worn-out plants. However, by 2009, several companies had fallen behind in setting aside such funds. Many existing plants will have to be retired over the next couple of decades, and someone will have to pay for dealing with them. Some analysts fear that taxpayers will end up footing the bill and thus will have to provide another expensive subsidy for the U.S. nuclear power industry.

Despite nuclear industry hopes for reviving nuclear power, 285 of today's 436 commercial nuclear reactors will reach the end of their useful lives by 2025, unless governments renew their operating licenses for another 20 years (as has happened for half of the 104 reactors operating in the United States). In 2010, only 47 new reactors were under construction, not even close to the number needed just to replace the reactors that will have to be decommissioned. Another 133 reactors are planned but even if they are completed after a decade or two, they will not replace the 285 aging reactors that must be retired. Also, private investment capital for building new reactors is scarce because of the very high costs and risks involved. These facts explain why many energy officials expect the importance of nuclear power to decline over the next several decades.

Critics also point out that increased use of nuclear power in the United States will make the country even more dependent on imports of uranium needed to fuel the plants. Currently, about 95% of the uranium used to fuel U.S. nuclear plants is imported, mostly from Russia.

Nuclear power advocates also contend that increased use of nuclear power will greatly reduce or eliminate CO_2 emissions and, in turn, reduce the projected threat of climate change caused by atmospheric warming. Critics point out that the nuclear power industry has mounted a misleading but effective public relations campaign to convince the public that nuclear power does not involve emissions of CO_2 and other greenhouse gases.

Scientists point out that this argument is only partially correct. While they are operating, nuclear plants do not emit CO_2, although large amounts are emitted during their construction, which can take 10 years or longer. In addition, every other step in the nuclear power fuel cycle (Figure 15-22), and especially in the manufacturing of many tons of construction cement, involves CO_2 emissions. Such emissions are much lower than those from coal-burning power plants (Figure 15-17) but they still contribute to projected atmospheric warming and climate change. Also, according to a 2004 study by German scientists, CO_2 emissions per kilowatt-hour of electricity from the entire nuclear fuel cycle are much higher than the numbers in Figure 15-17 indicate.

In 2007, the Oxford Research Group, an independent organization dedicated to promoting global security, said that in order for nuclear power to play an effective role in slowing projected atmospheric warming, the nuclear industry would have to build a new reactor somewhere in the world every week for the next 70 years. By comparison, the intergovernmental Nuclear Energy Agency estimated that one new plant would have to be built each month. The current rate of reactor construction is nowhere near either of these estimates. In addition, a new and very costly repository like the now-abandoned Yucca Mountain site in the United States would have to be built every few years to store the amount of highly radioactive nuclear waste that would result from building the number of nuclear reactors needed to slow projected climate change.

Can Nuclear Power Lessen Dependence on Imported Oil and Help Reduce Projected Global Warming?

Some proponents of nuclear power in the United States claim it will help reduce the U.S. dependence on imported crude oil. Other analysts argue that it will not do so because oil-burning power plants provide only about 2% of the electricity produced in the United States (and in most other countries that use nuclear power).

Are New-Generation Nuclear Reactors the Answer?

Partly to address economic and safety concerns, the politically powerful U.S. nuclear industry has persuaded Congress to provide more large government subsidies and taxpayer-guaranteed loans to help it build more conventional plants and hundreds of smaller, new-generation plants. The industry claims these smaller plants will be safer and can be built quickly (in 3–6 years).

These *advanced light-water reactors (ALWRs)* have built-in *passive safety features* designed to make explosions and releases of radioactive emissions almost impossible. Some scientists call for replacing today's uranium-based reactors with new ones based on the element thorium. They argue that such reactors would be much cheaper and safer, and would cut nuclear wastes in half and reduce the spread of nuclear weapons technology. But decades of research must be done to test such claims.

Also, most new-generation reactors will probably run at higher temperatures to improve their energy efficiency. This could shorten the life of reactor components, increase already high costs, and raise safety concerns. In 2009, Great Britain's chief of Health and Safety said that he could not recommend plans for building nuclear plants using the new French and U.S. designs because of significant safety issues that need to be resolved. However, since 2000, the nuclear power industry has mounted a major public relations campaign to distract the public from the problems related to nuclear power. Between 2000 and 2010, the U.S. nuclear industry spent $645 million lobbying Congress and the White House to get them to support further development of nuclear power.

To be environmentally and economically acceptable, some analysts believe that any new-generation nuclear technology must meet the five criteria listed in Figure 15-25. **Explore More:** See a Science Focus at **www.cengage.com/login** to learn more about new second-generation nuclear reactors.

HOW WOULD YOU VOTE? ✓

Should using nuclear power to produce electricity be phased out over the next few decades? Cast your vote online at **www.cengage.com/login**.

Will Nuclear Fusion Save Us?

Nuclear fusion is a nuclear change at the atomic level in which the nuclei of two isotopes of a light element such as hydrogen are forced together at extremely high temperatures until they fuse to form a heavier nucleus, releasing energy in the process (see Figure 2-9, bottom, p. 43). Some scientists hope that controlled nuclear fusion will provide an almost limitless source of energy.

With nuclear fusion, there would be no risk of a meltdown or of a release of large amounts of radioactive materials from a terrorist attack, and little risk of the additional spread of nuclear weapons, because bomb-grade materials are not required for fusion energy. Fusion power might also be used to destroy toxic wastes and to supply electricity for desalinating water and for decomposing water to produce hydrogen fuel.

This sounds great. So what is holding up fusion energy? In the United States, after more than 50 years of research and a $25 billion investment of mostly government funds, controlled nuclear fusion is still in the laboratory stage. None of the approaches tested so far has produced more energy than they use.

Solutions

- Reactors must be built so that a runaway chain reaction is impossible.
- The reactor fuel and methods of fuel enrichment and fuel reprocessing must be such that they cannot be used to make nuclear weapons.
- Spent fuel and dismantled structures must be easy to dispose of without burdening future generations with harmful radioactive waste.
- Taking its entire fuel cycle into account, it must generate a net energy yield high enough so that it does not need government subsidies, tax breaks, or loan guarantees to compete in the open marketplace.
- Its entire fuel cycle must generate fewer greenhouse gas emissions than other energy alternatives.

Figure 15-25 Some critics of nuclear power say that any new generation of nuclear power plants should meet all of these five criteria. So far, no existing or proposed reactors even come close to doing so.

The United States, China, Russia, Japan, South Korea, and the European Union have agreed to spend at least $25 billion in a joint effort to build a large-scale experimental nuclear fusion reactor by 2018. If everything goes well, the reactor is supposed to produce enough electricity to run the air conditioners in a small city for a few minutes.

Unless there is some unexpected scientific breakthrough, some skeptics will continue to quip that "nuclear fusion is the power of the future and always will be." Some analysts urge us to use the solar energy **principle of subtainability** and rely mostly on the direct solar and wind energy that is produced by the sun—a gigantic nuclear fusion reactor that is safely located about 150 million kilometers (93 million miles) away.

Experts Disagree about the Future of Nuclear Power

Proponents of nuclear power argue that governments should continue funding research, development, and pilot-plant testing of potentially safer and cheaper fission reactors, along with nuclear fusion. In the United States, energy research and development in general received a little over $135 billion in government funds between 1949 and 2005, according to a 2006 Congressional Research Service report. Of that amount, more than half went to nuclear energy (fission and fusion).

Others would support expansion of nuclear power only when the five criteria listed in Figure 15-25 are met. And some would phase out government subsidies, tax breaks, and insurance and loan guarantees for nuclear power.

According to World Bank economists, conventional and proposed new-generation nuclear power plants will not compete in today's energy market unless they are shielded from open-market competition by government subsidies and tax breaks. This is because the technology is extremely expensive and its net energy yield is very low. To critics such as energy expert Amory Lovins, electricity from nuclear power, touted in the 1950s as being "too cheap to meter," has now become "too expensive to matter." The nuclear power industry downplays such claims by focusing on nuclear plants instead of on the entire nuclear fuel cycle.

This need for huge government subsidies explains why most nuclear power development takes place in countries such as France, China, Russia, and Japan where governments fund and control its development. Such centralized control allows governments to heavily subsidize nuclear power without close public scrutiny. Also, some governments like nuclear power because it can provide them with the technology for producing bomb-grade uranium and plutonium for use in nuclear weapons.

THINKING ABOUT
Government Subsidies for Nuclear Power

Do you think the benefits of nuclear power justify high government subsidies for the nuclear industry? Explain.

Here are this chapter's *three big ideas:*

- A key factor to consider in evaluating the usefulness of any energy resource is its net energy yield.
- Conventional oil, natural gas, and coal are plentiful and have moderate to high net energy yields, but using any fossil fuel, especially coal, has a high environmental impact.
- Nuclear power has a low environmental impact and a very low accident risk, but high costs, a low net energy yield, long-lived radioactive wastes, and the potential for spreading nuclear weapons technology have limited its use.

REVISITING The History of Energy Use and Sustainability

CORE CASE STUDY SUSTAINABILITY

In the **Core Case Study** that opens this chapter, we noted that over the past several hundred years, humans have, more than once, shifted from one primary set of energy resources to another. Two examples are the shift from wood to coal and the more recent shift from coal to a mix of all three fossil fuels and nuclear power.

The guiding scientific principle underlying all energy use is that the long-term usefulness of any energy resource depends on it *net energy yield*. This means that any energy resource with a low net energy yield cannot compete in the open marketplace with other energy resources that have higher net energy yields unless it is subsidized. This principle—based on the two laws of thermodynamics, which we have never been able to violate—is highly important to us for environmental, economic, and political reasons.

Conventional oil, natural gas, and coal have moderate to high net energy yields that will decrease as we use up their easily accessible supplies. Using these energy resources and others derived from them involves high environmental impacts, although these impacts may vary. For example, while using coal involves very high greenhouse gas emissions, use of natural gas involves lower emissions.

We also use nuclear power to produce electricity. As we evaluate the net energy yield and environmental impacts of nuclear power, it is important to consider the whole *nuclear power fuel cycle*—from mining the uranium fuel to dismantling and storing the worn-out reactor parts. Considering the whole fuel cycle, nuclear power's environmental impacts are fairly high, and its net energy yield is so low that it is economically unsustainable and must be propped up by various subsidies. Most of the public is not aware of this economic drawback.

The three **principles of sustainability** can help us to find a more sustainable mix of energy resources, as we will explore further in the next chapter. We cannot recycle high-quality energy because of the second law of thermodynamics (see Chapter 2, p. 47). But by reusing and recycling more of the materials we use in industry, homes, and transportation, as nature does through chemical cycling, we can cut our need for energy, thereby raising net energy yields further. Also, by using a diversity of renewable energy resources, just as nature relies on biodiversity, we can further reduce the environmental impacts of our use of energy.

Civilization as we know it will not survive unless we can find a way to live without fossil fuels.

DAVID GOLDSTEIB

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 371. Describe our history of energy use over the last three hundred years. What is **net energy** and why is it important for evaluating energy resources? Explain why the nuclear fuel cycle has a low net energy yield and thus must be subsidized to compete in the open marketplace.

2. What is **crude oil (petroleum)** and how is it extracted from the earth and refined? What percentages of the commercial energy used in the world and in the United States are provided by crude oil? What is the **peak production** for an oil well and for the world? What is a **petrochemical** and why are such chemicals important? What are **proven oil reserves**? Describe the two types of **unproven reserves**. Discuss the question of how long global and U.S. supplies of conventional crude oil might last. What are the major advantages and disadvantages of using conventional crude oil?

3. What is **tar sand**, or **oil sand**, and how is it extracted and converted to heavy oil? What are some environmental problems related to the use of this energy resource? What is **shale oil** and how is it produced? What are the major advantages and disadvantages of using heavy oils produced from tar sand and shale oil as energy resources?

4. Define **natural gas**, **liquefied petroleum gas (LPG)**, and **liquefied natural gas (LNG)**. What three countries have most of the world's natural gas reserves? What are the major advantages and disadvantages of using conventional natural gas as an energy resource? What are three sources of unconventional natural gas and what major problems are related to the use of these resources?

5. What is **coal** and how is it formed? How does a coal-burning power plant work? What three countries have the largest proven reserves of coal? Describe the use of coal in China. Describe the problem of coal ash waste. Explain why there is no such thing as clean coal. What are the major advantages and disadvantages of using coal as an energy resource?

6. What is **synthetic natural gas (SNG)**? What are the major advantages and disadvantages of using liquid and gaseous synfuels produced from coal?

7. How does a nuclear fission reactor work and what are its major safety features? Describe the nuclear fuel cycle. Describe some consequences of the Chernobyl nuclear power plant accident. What are the major advantages and disadvantages of relying on the nuclear fuel cycle as a way to produce electricity? Compare the advantages and disadvantages of using the nuclear fuel cycle and coal to produce electricity.

8. How do nuclear plant operators store highly radioactive spent fuel rods? Why are spent fuel rods vulnerable to terrorist acts? What is the connection between commercial nuclear power plants and the spread of nuclear weapons? How can we deal with the highly radioactive wastes produced by the nuclear fuel cycle? What can we do with worn-out nuclear power plants? Discuss whether using nuclear power can reduce U.S. dependence on imported oil. What role is nuclear power likely to play in slowing projected global climate disruption caused in part by emissions of carbon dioxide? What role might new-generation nuclear power plants play?

9. What is **nuclear fusion** and what is its potential as an energy resource? Describe what happened to conventional nuclear power and its possible role in the future.

10. What are this chapter's *three big ideas*? Describe how the three **principles of sustainability** could be applied to our future energy resource choices.

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. In the past, we have made shifts in our reliance on energy resources (**Core Case Study**). Do you believe that over the next 50 years, we need to shift to a new mix of more sustainable and less environmentally harmful renewable energy resources, or that we should continue depending mostly on nonrenewable fossil fuels and nuclear power? Explain. How might such a shift affect your lifestyle and that of any children and grandchildren that you might have?

2. Should governments give a high priority to considering net energy yields when deciding what energy resources to support? What are other factors that should be considered? Explain your thinking.

3. To continue using oil at the current rate, we must discover and add to global oil reserves the equivalent of two new Saudi Arabian supplies every 10 years. Do you think this is possible? If not, what effects might the failure to find such supplies have on your life and on the lives of any children and grandchildren that you might have?

4. List three actions you can take to reduce your dependence on oil and gasoline in order to slow depletion of the world's oil. Which of these things do you already do or plan to do?

5. Explain why you are for or against increasing oil imports to the United States or to the country in which you live. If you favor reducing dependence on oil imports, what do you think are the three best ways to do this?

6. Some people in China point out that the United States and European nations fueled their economic growth during the industrial revolution by burning coal, with little effort to control the resulting air pollution. They then sought cleaner energy sources later when they became more affluent. China says it is being asked to clean up from the effects of coal burning before it becomes affluent enough to do so, without greatly slowing its economic growth. How would you deal with this dilemma? Since China's outdoor air pollution has implications for the entire world, what role, if any, should the

more-developed nations play in helping China to reduce its dependence on coal and to rely more on sustainable energy resources?

7. Explain why you agree or disagree with the following proposals made by various energy analysts as ways to solve U.S. energy problems: **(a)** find and develop more domestic supplies of crude oil; **(b)** place a heavy federal tax on gasoline and imported oil to help reduce the waste and consumption of crude oil resources and to encourage use of other alternatives; **(c)** increase dependence on coal; **(d)** phase out use of coal by 2050; **(e)** increase dependence on nuclear power; **(f)** phase out all nuclear power plants by 2030.

8. Explain why you agree or disagree with each of the following proposals made by the U.S. nuclear power industry: **(a)** provide up to $350 billion in government subsidies and loan guarantees to build a large number of better-designed nuclear fission power plants, in order to reduce dependence on imported oil and slow projected climate change; **(b)** prevent the public from participating in hearings on the licensing of new nuclear power plants and on safety issues at the nation's nuclear reactors; **(c)** allow electric utility companies to begin charging consumers for some of the costs of proposed new nuclear power plants before they are built; **(d)** greatly increase federal subsidies for developing nuclear fusion.

9. Congratulations! You are in charge of the world. What roles would nonrenewable fossil fuels, the nuclear fuel cycle, and nuclear fusion play in your energy policy? Explain.

10. List two questions that you would like to have answered as a result of reading this chapter.

ECOLOGICAL FOOTPRINT ANALYSIS

In 2008, the average fuel economy of new cars, light trucks, and SUVs in the United States was 11.4 kilometers per liter (kpl) or 26.6 miles per gallon (mpg), and the average motor vehicle in the United States was driven 19,300 kilometers (12,000 miles). There were about 250 million motor vehicles in the United States in 2008. The U.S. Environmental Protection Agency estimates that 2.3 kilograms of CO_2 are released when 1 liter of gasoline is burned (19.4 pounds of CO_2 are released when 1 gallon is burned). Use these data to calculate the *gasoline consumption* and *carbon footprints* of individual motor vehicles with different fuel efficiencies and for all of the motor vehicles in the United States by answering the following questions.

1. Suppose a car has an average fuel efficiency of 8.5 kpl (20 mpg) and is driven 19,300 kilometers (12,000 miles) a year. **(a)** How many liters (and gallons) of gasoline does this vehicle consume in a year? **(b)** If gasoline costs 80 cents per liter ($3.00 per gallon), how much will the owner spend on fuel in a year? **(c)** How many liters (and gallons) and of gasoline would be consumed by a U.S. fleet of 250 million such vehicles in a year? (1 liter = 0.265 gallons and 1 kilometer = 0.621 miles)

2. Recalculate the values in Question 1, assuming that a car has an average fuel efficiency of 19.6 kpl (46 mpg).

3. Determine the number of metric tons of CO_2 emitted annually by **(a)** the car described in Question 1 with a low fuel efficiency, **(b)** a fleet of 250 million vehicles with this same fuel efficiency, **(c)** the car described in Question 2 with a high fuel efficiency, and **(d)** a fleet of 250 million vehicles with this same high fuel efficiency. These calculations provide a rough estimate of the carbon footprints for individual cars and for the entire U.S. fleet with low and high efficiency cars. (1 kilogram = 2.20 pounds; 1 metric ton = 1,000 kilograms = 2,200 pounds = 1.1 tons; 1 ton = 2,000 pounds).

4. If the average fuel efficiency of the U.S. fleet increased from 8.5 kpl (20 mpg) to 19.6 kpl (46 mpg), by what percentage would this reduce the CO_2 emissions from the entire fleet per year? You can think of this as the percentage reduction in the carbon footprint of the U.S. motor vehicle fleet.

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengagebrain.com/shop/ISBN/0538735341** and choose Chapter 15 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

For students with access to premium online resources, log on to **www.cengage.com/login**.

Find the latest news and research, (including videos and podcasts), at the GLOBAL ENVIRONMENT WATCH. Visit **www.CengageBrain.com** for more information.

Energy Efficiency and Renewable Energy

16

CORE CASE STUDY

Amory Lovins and the Rocky Mountain Institute

In 1984, energy analyst Amory B. Lovins completed construction of a large, solar-heated, solar-powered, superinsulated, partially earth-sheltered home and office in Snowmass, Colorado (USA) (Figure 16-1), an area with extremely cold winters. The building serves as headquarters for the Rocky Mountain Institute (RMI)—a nonprofit, non-partisan, group of scientists and analysts who do research and consulting on energy, resource efficiency, and renewable energy alternatives as well as on finding ways to work toward a more just, prosperous, and life-sustaining world.

This office–home has no conventional heating system. Instead, it makes use of energy from the sun, heavy roof insulation, thick stone walls, energy-efficient windows, and a waste-heat recovery system. Solar energy provides 99% of its hot water, 95% of its daytime lighting, and 90% of its household electricity. The building's heating bill in this very cold climate is less than $50 a year. Such savings are accomplished through the use of energy-efficient lights, refrigerators, computers, and other electrical devices and solar cells, which generate electricity when exposed to sunlight. The savings from these energy-efficiency investments repaid their costs in only 10 months.

GOOD NEWS

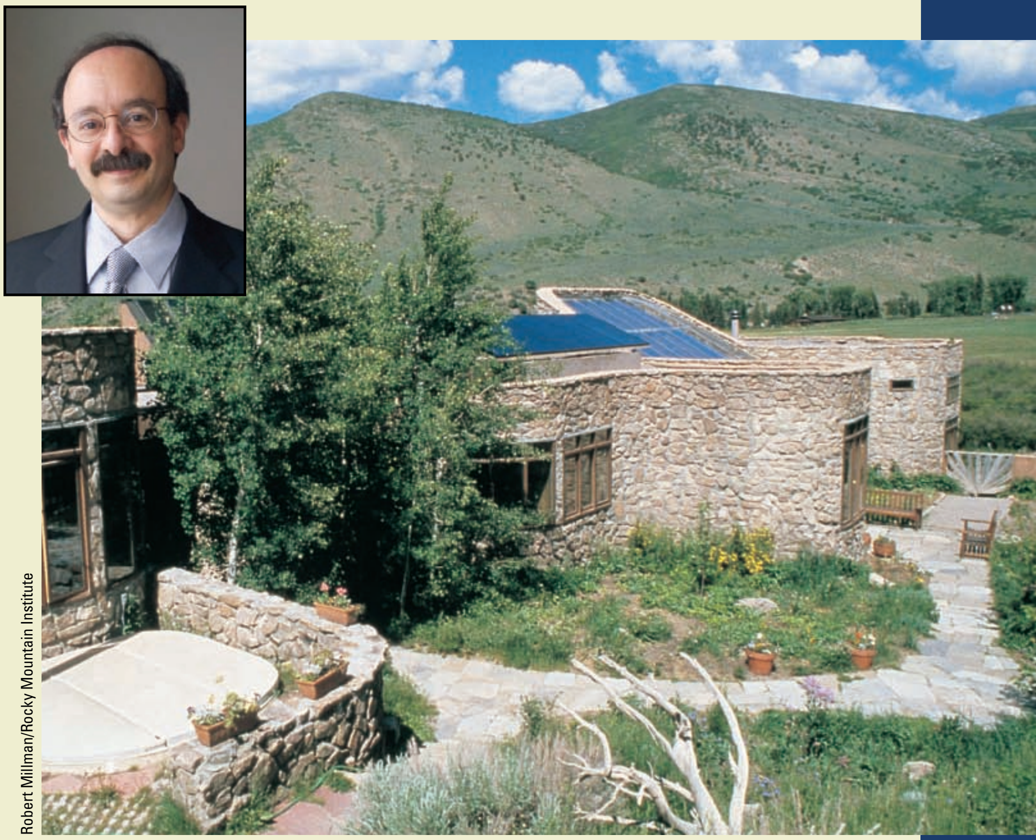
The RMI building is designed to work with nature. It was sited to collect as much sunlight as possible. It contains a central greenhouse that holds a variety of plants, humidifies the building, and helps to heat it and purify its air. Heat from the sun is stored for days in the structure's massive walls and floors. In other words, this building is a shining example of how to apply the solar energy **principle of sustainability**.

SUSTAINABILITY

The work of RMI goes far beyond the walls of this building. Lovins and his staff have consulted with more than 80 major corporations and governments in more than 50 countries, as well as state governments and the U.S. military to help them save energy and money.

In the 1970s, Lovins envisioned humanity making a transition to a more energy-efficient world fueled mostly by an array of renewable energy resources. Since then, he has dedicated his life to showing how such a shift could be made. He is now helping to lead the world into an energy future that is based on cutting energy waste to the bone and getting at least half of our energy from a variety of low- or no-carbon renewable-energy resources. In addition, he has walked his talk by designing, building, and living in his office and home shown in Figure 16-1.

In 2008, Lovins was honored as one of America's Best Leaders by U.S. News Media Group and the Harvard Kennedy School. In this chapter, we will examine the exciting and challenging energy future that he envisioned over three decades ago.



Robert Millman/Rocky Mountain Institute

Figure 16-1 This building houses part of the Rocky Mountain Institute in Snowmass, Colorado (USA), and serves as the home for the Institute's cofounder, Amory B. Lovins (inset photo), who now serves as chairman and chief scientist. The building serves as an outstanding example of energy-efficient passive solar design. For his many contributions to improving energy and resource efficiency and finding alternative solutions to energy problems over the past three decades, Lovins has won essentially every global environmental award. He has also published 29 books and several hundred papers, and still finds time to compose poetry and music, and to play the piano.

Key Questions and Concepts

16-1 Why is energy efficiency an important energy resource?

CONCEPT 16-1 Improving energy efficiency can save the world at least a third of the energy it uses, and it can save the United States up to 43% of the energy it uses.

16-2 How can we cut energy waste?

CONCEPT 16-2 We have a variety of technologies for sharply increasing the energy efficiency of industrial operations, motor vehicles, appliances, and buildings.

16-3 What are the advantages and disadvantages of using solar energy?

CONCEPT 16-3 Passive and active solar heating systems can heat water and buildings effectively, and the costs of using direct sunlight to produce high-temperature heat and electricity are coming down.

16-4 What are the advantages and disadvantages of using hydropower?

CONCEPT 16-4 We can use water flowing over dams, tidal flows, and ocean waves to generate electricity, but environmental concerns and limited availability of suitable sites may limit our use of these energy resources.

16-5 What are the advantages and disadvantages using wind power?

CONCEPT 16-5 When we include the environmental costs of using energy resources in the market prices of energy, wind power is the least expensive and least polluting way to produce electricity.

16-6 What are the advantages and disadvantages of using biomass as an energy resource?

CONCEPT 16-6A Solid biomass is a renewable resource for much of the world's population, but burning it faster than it is replenished produces a net gain in atmospheric greenhouse gases, and creating biomass plantations can degrade soil and biodiversity.

CONCEPT 16-6B We can use liquid biofuels derived from biomass in place of gasoline and diesel fuels, but creating biofuel plantations can degrade soil and biodiversity, and increase food prices and greenhouse gas emissions.

16-7 What are the advantages and disadvantages of using geothermal energy?

CONCEPT 16-7 Geothermal energy has great potential for supplying many areas with heat and electricity, and it has a generally low environmental impact, but the sites where it can be used economically are limited.

16-8 What are the advantages and disadvantages of using hydrogen as an energy resource?

CONCEPT 16-8 Hydrogen fuel holds great promise for powering cars and generating electricity, but for it to be environmentally beneficial, we would have to produce it without using fossil fuels.

16-9 How can we make the transition to a more sustainable energy future?

CONCEPT 16-9 We can make the transition to a more sustainable energy future by greatly improving energy efficiency, using a mix of renewable energy resources, and including the environmental costs of energy resources in their market prices.

Note: Supplements 2 (p. S3), 6 (p. S20), 8 (p. S30), and 9 (p. S57) can be used with this chapter.

Just as the 19th century belonged to coal and the 20th century to oil, the 21st century will belong to the sun, the wind, and energy from within the earth.

LESTER R. BROWN

16-1 Why Is Energy Efficiency an Important Energy Resource?

▶ **CONCEPT 16-1 Improving energy efficiency can save the world at least a third of the energy it uses, and it can save the United States up to 43% of the energy it uses.**

We Waste Huge Amounts of Energy

Many analysts urge us to make much greater use of a strategy not usually thought of as a source of energy—a decrease in our energy use based primarily on reducing unnecessary waste of energy. This largely untapped source of energy is abundant, clean, cheap, and readily available. In using it, we could save money by lowering our utility and gasoline bills, improve military and economic security by reducing or eliminating dependence

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. GOOD NEWS refers to good news about the environmental challenges we face.

on foreign oil, and sharply reduce our greenhouse gas emissions, which contribute to projected climate disruption.

The best way to do reduce our unnecessary waste of energy is to improve **energy efficiency**: the measure of how much work we can get from each unit of energy we use. Each unit of energy saved eliminates the need to produce that energy, and it saves us money. As Amory Lovins (Figure 16-1) puts it, improving energy efficiency means "doing more and better with less energy and money, but with more brains and technology." CORE CASE STUDY

The United States has improved its energy-efficiency since 1980. But Japan, Germany, and France are two to three times more energy efficient than the United States is. For that reason, we use the United States as a prime example of how we can improve energy efficiency and save money. Many other countries, including China and India, can make similar improvements.

For example, you may be surprised to learn that roughly 84% of all commercial energy used in the United States is wasted (Figure 16-2). About 41% of this energy is unavoidably lost because of the degradation of energy quality imposed by the second law of thermodynamics (see Chapter 2, p. 47). The other 43% is wasted unnecessarily, mostly due to the inefficiency of incandescent lightbulbs, furnaces, industrial motors, most motor vehicles, coal and nuclear power plants, and numerous other energy-consuming devices.

Another reason for this waste is that many people live and work in leaky, poorly insulated, and badly designed buildings that require excessive heating in the winter and cooling in the summer—a fact that has been demonstrated clearly by Amory Lovins and his colleagues at the Rocky Mountain Institute (**Core Case Study**). Unnecessary energy waste costs the United States an average of about $570,000 per minute, according to Lovins (see his Guest Essay at CengageNOW™). How much does this cost the United States in a year? CORE CASE STUDY

For years, many Americans have been wasting a lot of money buying larger, gas-guzzling vehicles and building larger houses that require more and more energy to heat and cool. Many live in ever-expanding suburban areas that surround most cities, and they must depend on their cars for getting around. Roughly three of every four Americans commute to work, mostly in energy-inefficient vehicles, and only 5% rely on more energy-efficient mass transit.

The energy that is used to heat and cool homes and other buildings, to provide us with light, and to propel motor vehicles is not free. Thus, saving energy saves us money and also reduces our environmental impact (Figure 16-3). If enough people reduce energy use and waste, then pollution will also be GOOD NEWS

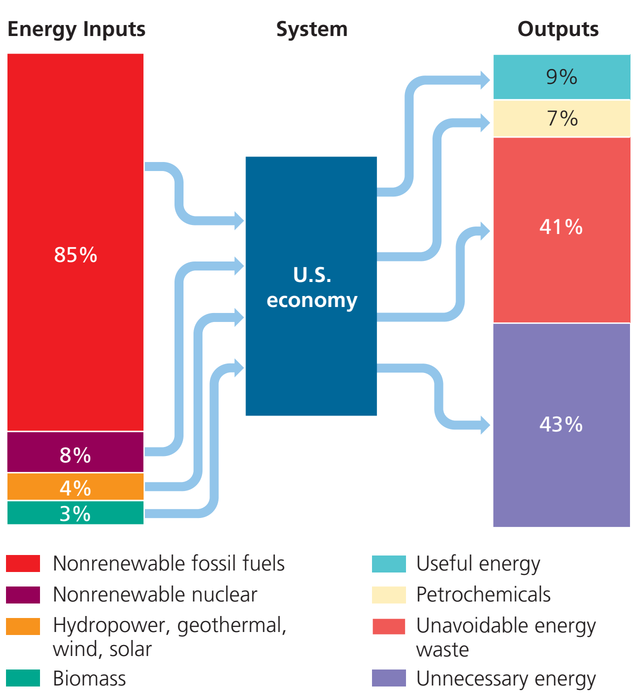


Figure 16-2 This diagram shows how commercial energy flows through the U.S. economy. Only 16% of all commercial energy used in the United States ends up performing useful tasks; the rest of the energy is unavoidably wasted because of the second law of thermodynamics (41%) or is wasted unnecessarily (43%). **Question:** What are two examples of unnecessary energy waste? (Data from U.S. Department of Energy)

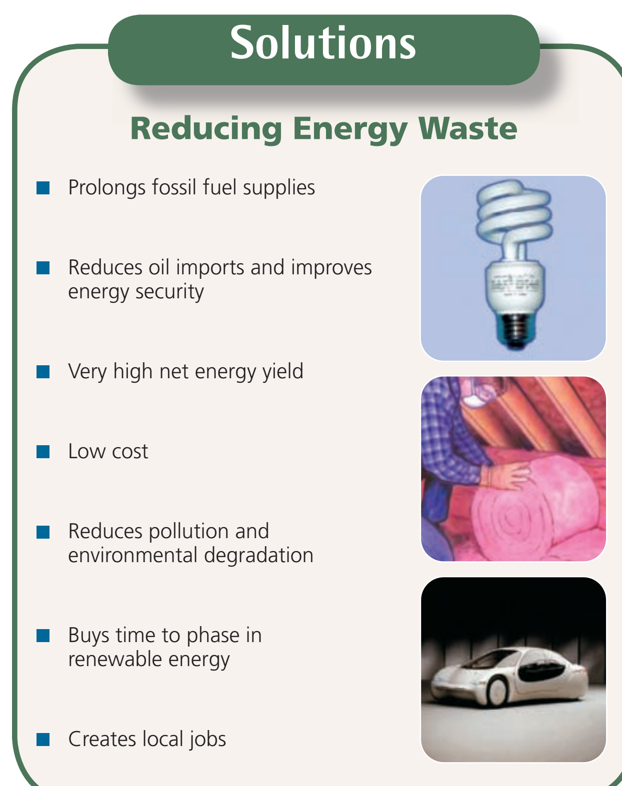


Figure 16-3 Reducing unnecessary energy waste and thereby improving energy efficiency provides several benefits. Amory Lovins estimates that in the United States "we could save at least half the oil and gas and three-fourths of the electricity we use at a cost of only about an eighth of what we're now paying for these forms of energy." **Questions:** Which two of these benefits do you think are the most important? Why?

reduced. This could save us even more money by lowering health care and insurance costs and taxes used for pollution control and cleanup.

We waste large amounts of energy and money by relying heavily on four widely used devices:

- The *incandescent lightbulb* (see Figure 2-16, right, p. 48), which uses only 5–10% of the electricity it draws to produce light, while the other 90–95% is wasted as heat. It is really a *heat bulb* and is gradually being replaced by more energy-efficient compact fluorescent bulbs (see Figure 2-16, left) and even more efficient light-emitting diodes (LEDs).
- The *internal combustion engine* (see Figure 2-16, right), which propels most motor vehicles and wastes about 80% of the energy in its fuel.
- A nuclear *power plant* (see Figure 15-20, p. 387), which produces electricity for space heating or water heating. It wastes about 75% of the energy in its nuclear fuel and probably closer to 92% when we include the additional energy used in the nuclear fuel cycle (see Figure 15-21, p. 388).
- A *coal-fired power plant* (see Figure 15-15, p. 382), which wastes about 66% of the energy that is released by burning coal to produce electricity, and probably 75–80% if we include the energy used to dig up the coal and transport it to the plant, and to transport and store the toxic ash byproduct.

Some energy efficiency experts consider these technologies to be energy-wasting dinosaurs, and they call for us to use our scientific and engineering brainpower to replace them with more energy-efficient and less environmentally harmful alternatives over the next few decades.

16-2 How Can We Cut Energy Waste?

CONCEPT 16-2 We have a variety of technologies for sharply increasing the energy efficiency of industrial operations, motor vehicles, appliances, and buildings.

We Can Save Energy and Money in Industry and Utilities

Industry accounts for about 30% of the world's energy consumption and 33% of U.S. energy consumption, mostly for production of metals, chemicals, petrochemicals, cement, and paper. There are many ways for industries to cut energy waste (**Concept 16-2**).

GOOD NEWS

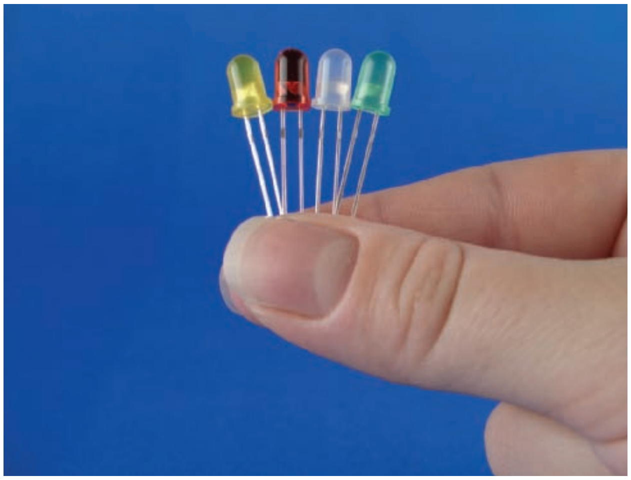
Some industries save energy and money by using **cogeneration**, which involves using a **combined heat and power (CHP)** system. In such a system, two useful forms of energy (such as steam and electricity) are produced from the same fuel source. For example, the steam produced in generating electricity in a CHP system can be used to heat the power plant or other nearby buildings, rather than released into the environment and wasted. The energy efficiency of these systems is 75–90% (compared to 30–40% for coal-fired boilers and nuclear power plants), and they emit one-third as much CO_2 per unit of energy produced as do conventional coal-fired boilers. Denmark leads the world by getting 82% of its electricity from CHP systems. The United States gets only 8% of its electricity from CHP. China does better by getting 13% of its electricity and 60% of its urban central heating from CHP.

Another way to save energy and money in industry is to *replace energy-wasting electric motors*, which use one-fourth of the electricity produced in the United States and 65% of the electricity used in U.S. industry. Most of these motors are inefficient because they run only at full speed with their output throttled to match the task—somewhat like keeping one foot on the gas pedal of your car and the other on the brake pedal to control its speed. Replacing them with variable speed motors, which run at the minimum rate needed for each job, saves energy and reduces the environmental impact of electric motor use.

Recycling materials such as steel and other metals is a third way for industry to save energy and money. For example, producing steel from recycled scrap iron uses 75% less energy than producing steel from virgin iron ore and emits 40% less CO_2. Switching three-fourths of the world's steel production to such furnaces would cut energy use in the global steel industry by almost 40% and sharply reduce its CO_2 emissions.

A fourth way for industry to save energy is to *switch from low-efficiency incandescent lighting* to higher-efficiency fluorescent lighting (see Figure 2-16, left, p. 48) and light-emitting diodes (LEDs) (Figure 16-4). A compact fluorescent bulb uses one-fourth as much electricity as an incandescent bulb, typically lasts ten times as long, and saves at least $30 in replacement costs during its lifetime. Even better, LEDs use about one-seventh of the electricity required by an incandescent bulb and can last about 100 times longer.

A growing number of major corporations are now boasting about the money they save by wasting less energy. For example, the CEO of Dow Chemical Company, which operates 165 manufacturing plants in 37 countries, estimates that between 1996 and 2006, energy efficiency improvements cost Dow about $1 billion, but resulted in savings of about $8.6 billion.



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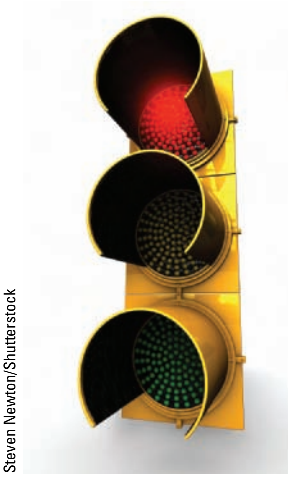


Steven Newton/Shutterstock

Figure 16-4 These small, light-emitting diodes (LEDs) come in different colors (left) and contain no toxic elements. They are being used for industrial and household lighting, and also in Christmas tree lights, traffic lights (right), street lights, and hotel conference and dining room lighting. LEDs last so long (about 100,000 hours) that users can install them and forget about them. LED bulbs are expensive but prices are projected to drop because of newer designs and mass production. Shifting to energy-efficient fluorescent lighting in homes, office buildings, stores, and factories and to LEDs in all traffic lights would save enough energy to close more than 700 of the world's coal-burning electric power plants.

There is also a great deal of energy waste in the generation and transmission of electricity to industries and communities (see Case Study below). Part of the reason is that utility companies have historically encouraged electricity use instead of efficiency. According to Amory Lovins (Figure 16-1), the best way to improve energy efficiency in utilities would be for state utility commissions to reward utilities for cutting our bills by helping us to save energy, instead of rewarding them for selling us more electricity.

CORE CASE STUDY

The utility commissions in six U.S. states have adopted this approach and nine more states may soon follow. In 2009, the American Council for an Energy Efficient Economy estimated that making this efficiency focus a national policy would eliminate the need for building 450 new coal-fired or nuclear power plants by 2050. The state of California has had great success in using such a "save-a-watt" approach and in encouraging energy efficiency in a number of other ways. **Explore More:** See a Case Study at **www.cengage.com/login** to learn about California's efforts to improve energy efficiency.

CASE STUDY

Saving Energy and Money with a Smarter Electrical Grid

Grid systems of high-voltage transmission lines carry electricity from power plants, wind turbines, and other electricity producers to users. Many energy experts place top priority on converting and expanding the outdated U.S. electrical grid system into what they call a *smart grid*. This more energy-efficient, digitally controlled, ultra-high-voltage grid with superefficient transmission lines would be responsive to local and regional changes in demand and supply (see Figure 20, p. S51, in Supplement 8 for a map of the proposed new grid in the United States).

China plans to build an efficient and reliable ultra-high voltage (UHV) electricity grid network by 2020 and to become the global leader in manufacturing and selling such technology and equipment. In 2009 alone, it committed $45 billion to this vital project.

A smarter electrical grid involves a two-way flow of energy and information between producers and users of electricity. Such a system would use smart meters to monitor the amount of electricity used and the patterns of use for each customer. It would then use this information to deliver electricity as efficiently as possible.

Smart meters would also show consumers how much energy they are using by the minute and for each appliance. This information would help them to reduce their power consumption and power bills. Smart appliances such as clothes washers and dryers could be programmed to perform their tasks during off-peak hours when electricity is cheaper. A smart grid could allow individuals to run their air conditioners remotely so that they could leave them off when they are not at home and turn them on before they return. With such a system, customers who use solar cells, wind turbines, or other devices to generate some of their own electricity could cut their bills by selling their excess electricity to utility companies.

According to the U.S. Department of Energy (DOE), building such a grid would cost the United States from $200 billion to $800 billion, but would pay for itself in a few years by saving the U.S. economy more than $100 billion a year.

We Can Save Energy and Money in Transportation

There is a lot of room for reducing energy waste in transportation, which accounts for about 28% of the energy consumption and two-thirds of the oil consumption in the United States. One reason for this waste is that U.S. government fuel efficiency standards for motor vehicles have been generally low for many years. Between 1973 and 1985, average fuel efficiency for new vehicles sold in the United States rose sharply because of government-mandated *corporate average fuel economy (CAFE)* standards. However, since 1985, the average fuel efficiency for new

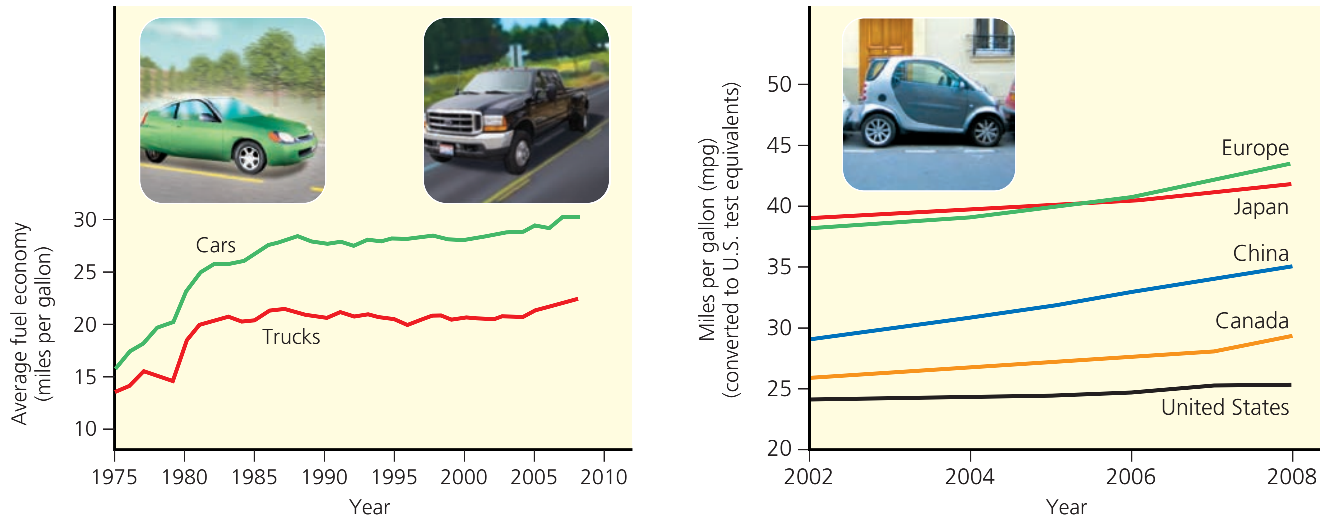


Figure 16-5 This diagram shows changes in the average fuel economy of new vehicles sold in the United States, 1975–2008 (left) and the fuel economy standards in other countries, 2002–2008 (right). (Data from U.S. Environmental Protection Agency, National Highway Traffic Safety Administration, and International Council on Clean Transportation)

vehicles decreased to about 9 kilometers per liter (kpl), or 21 miles per gallon (mpg) (Figure 16-5, left).

This occurred mostly because there was no increase in the CAFE standards until 2008 and because mileage standards for popular trucks and SUVs are not as high as are those for cars. Indeed, a 2008 study by the University of Michigan Transportation Institute showed that the average fuel efficiency of U.S cars has improved by only about 1.3 kpl (3 mpg) since 1908, back in the days of the Ford Model T.

Fuel economy standards for new vehicles in Europe, Japan, China, and Canada are much higher than are those in the United States (Figure 16-5, right). A 2008 law raised U.S. CAFE standards to 15 kpl (35 mpg), to be attained by 2016. However, this future standard will still be much lower than current standards in China and many other countries. Energy experts such as Joseph Romm call for the government to require all new cars sold in the United States to get more than 43 kpl (100 mpg) by 2040.

Partly because of low CAFE standards, in 2010, more than half of all U.S. consumers owned SUVs, pickup trucks, minivans, and other large, inefficient vehicles. One reason for this is that many Americans want to have vehicles that are big and powerful. Another reason is that most U.S. consumers do not realize that gasoline costs them much more than the price they pay at the pump. According to a 2005 study by the International Center for Technology Assessment, the hidden costs of gasoline for U.S. consumers were about $3.18 per liter ($12 per gallon).

These hidden costs include government *subsidies* (payments intended to help businesses survive and thrive) and tax breaks for oil companies, car manufacturers, and road builders; costs of pollution control and cleanup; costs of military protection of oil supplies in the Middle East (not including the two Iraq wars); time wasted idling in traffic jams; and costs of illness from air and water pollution in the form of higher medical bills and health insurance premiums. Consumers pay for these hidden costs, but not at the gas pump.

One way to include more of the real cost of gasoline in its market price is through gasoline taxes, which are widely used in Europe but are politically unpopular in the United States. To help deal with such opposition, some economists and other analysts call for reducing payroll and income taxes to balance increases in gas taxes, thereby relieving consumers of any additional financial burden. So far, oil and car companies have been able to prevent such a solution by influencing elected representatives to keep gasoline taxes low, thereby keeping the true costs of gasoline hidden from consumers.

THINKING ABOUT
The Real Cost of Gasoline

Do you think that the estimated hidden costs of gasoline should be included in its price at the pump? Explain. Would you favor much higher gasoline taxes if payroll taxes were eliminated or sharply reduced? Explain.

Another way for governments to encourage higher efficiency in transportation is to give consumers tax breaks or other economic incentives to encourage them to buy more fuel-efficient vehicles. Energy expert Amory Lovins (**Core Case Study**) has proposed a *fee-bate* program in which buyers of fuel-inefficient vehicles would pay a high fee, and the resulting revenues would be given to buyers of efficient vehicles as rebates. For example, the fee on a gas-guzzling, $57,000 Hummer H2, which averages about 5 kpl (12 mpg), might be $10,000. The government would then give that amount as a rebate to the buyer of a hybrid

CORE CASE STUDY

or other fuel-efficient car that averages 20 kpl (46 mpg) or more.

Within a short time, such a program—endorsed by the U.S. National Academy of Sciences—would greatly increase sales of gas-sipping vehicles. It would also focus carmakers on producing and making their profits from such vehicles, and it would cost the government (taxpayers) nothing. So far, the U.S. Congress has not implemented such a program.

Other ways to save energy in transportation include shifting from diesel-powered to electrified rail systems, building accessible mass transit systems within cities, constructing high-speed rail lines between cities as is done in Japan, China, and much of Europe, and carrying more freight by train instead of by truck.

Another method is to encourage bicycle use by building bike lanes along highways and city streets. Amory Lovins estimates that the United States could cut its oil imports by half if each American driver biked to work just one day a week. To reduce car use, greenhouse gas emissions, and parking congestion, the University of New England in Maine and Ripon College in Wisconsin give free, high-quality bikes to new students who agree to leave their cars at home.

More Energy Efficient Vehicles Are on the Way

There is growing interest in developing modern, super-efficient, ultralight, and ultrastrong cars that could get up to 130 kilometers per liter (300 miles per gallon) using existing technology—a concept that Amory Lovins (Figure 16-1) invented in 1991. (See Amory Lovins's Guest Essay at CengageNOW).

GOOD NEWS

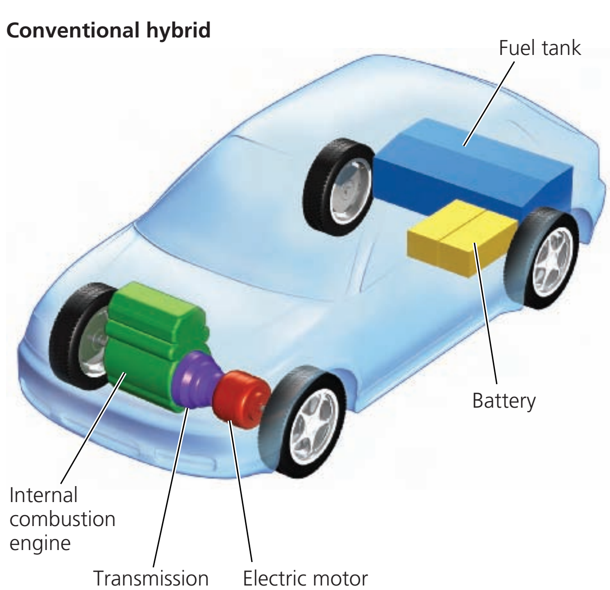
CORE CASE STUDY

One of these vehicles is the energy-efficient, gasoline–electric *hybrid car* (Figure 16-6, left). A primitive form of it was patented in 1909 by Belgium inventor Henri Pieper. Today's version has a small, traditional gasoline-powered engine and a battery-powered electric motor used to provide the energy needed for acceleration and hill climbing. The most efficient models of these cars, such as the Toyota Prius, get a combined city/highway mileage of up to 21 kpl (50 mpg) and emit about 65% less CO_2 per kilometer driven than a comparable conventional car emits.

The next step will probably be the *plug-in hybrid electric vehicle*—a hybrid with a second and more powerful battery that can be plugged into an electrical outlet and recharged (Figure 16-6, right). By running primarily on electricity, plug-in hybrids could easily get the equivalent of at least 43 kpl (100 mpg) for ordinary driving and up to 430 kpl (1,000 mpg), if used only for trips of less than 32 kilometers (40 miles) before recharging.

American manufacturers plan to have a variety of plug-in hybrids available by 2012. However, a Chinese car company (BYD) is already mass-producing and selling the world's first plug-in hybrid, called the Build Your Dreams (BYD) car. It can reach a speed of 100 kilometers per hour (60 miles per hour) and can travel 190 kilometers (120 miles) between battery charges. General Motors plans to introduce the Volt plug-in hybrid in 2011, at a cost of around $40,000. It will travel 64 kilometers (40 miles) on a fully charged battery.

The Chinese company BYD is selling its cars in China and plans to start selling them in Europe for around $22,000. The company, with 5,000 auto engineers and 5,000 battery engineers, aims to become the top-selling carmaker in China by 2015. Using the BYDs widely could help China to reduce urban pollution and greenhouse gas emissions, provide a large number of jobs, and greatly reduce its dependence on oil imported from the Middle East. Another option for drivers is the Indian-made Reva, the world's most successful plug-in



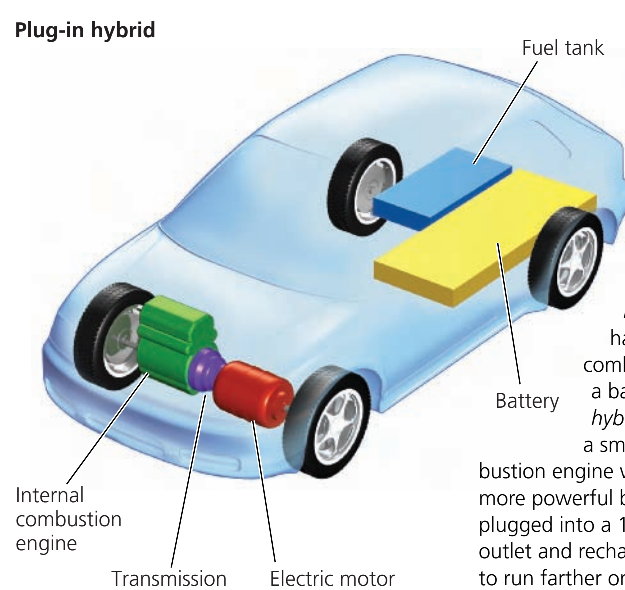


Figure 16-6 **Solutions:** A conventional gasoline–electric *hybrid* vehicle (left) has a small internal combustion engine and a battery. A *plug-in hybrid* vehicle (right) has a smaller internal combustion engine with a second and more powerful battery that can be plugged into a 110-volt or 220-volt outlet and recharged. This allows it to run farther on electricity alone.

hybrid electric vehicle, which is used in a number of European cities and costs around $14,500.

Some analysts project that plug-in hybrids could dominate the motor vehicle market by 2020, partly because most urban and suburban drivers travel less than 64 kilometers (40 miles) a day, and running a car on electricity costs about one-fifth as much per kilometer as running it on gasoline. In addition to this, electricity is less vulnerable to large price hikes than gasoline is. The key is to develop a durable, dependable, safe, and affordable battery (Science Focus below). Another important factor will be to have a network of recharging stations in many convenient locations within and between communities and in home garages.

According to a 2006 DOE study, replacing most of the current U.S. vehicle fleet of 220 million vehicles with highly efficient plug-in hybrid vehicles over 2 decades, would cut U.S. oil consumption by 70–90%, eliminate the need for oil imports, save consumers money, and reduce CO_2 emissions by 27%. If the batteries in these cars were recharged mostly by electricity generated by renewable resources such as wind, U.S. emissions of CO_2 would drop by 80–90%, which would help to slow projected climate change. **GREEN CAREER:** plug-in hybrid car and bus technology

GOOD NEWS

Another option is an *energy-efficient diesel car*, which accounts for 45% of new passenger car sales in Europe. Diesel cars emit more nitrogen oxides and particulates than comparable conventional and hybrid vehicles. However, new diesel engines have very low emissions, are quiet, and are about 30% more fuel efficient than comparable internal combustion engines. Running these vehicles on a fuel called *biodiesel*, discussed later in this chapter, would reduce their air pollution emissions and increase energy efficiency. For SUVs and for most trucks and trains, because of their heavier weights, diesel is a better fuel than gasoline or electricity.

An electric vehicle that uses a *fuel cell* may be the next stage in the development of superefficient cars. Fuel cells are at least twice as efficient as internal combustion engines, have no moving parts, require little maintenance, and use hydrogen gas as fuel to produce electricity. This would essentially eliminate emissions of CO_2 and other air pollutants if the hydrogen was produced from noncarbon or low-carbon renewable sources of electricity such as wind turbines and solar cells. But such cars are unlikely to be widely available until 2020 or later and will probably be very expensive because they have a negative net energy yield. **GREEN CAREER:** fuel-cell technology

The fuel efficiency for all types of cars could nearly double if car bodies were to be made of *ultralight* and *ultrastrong* composite materials such as fiberglass and the carbon-fiber composites (Figure 16-7) used in bicycle helmets and in some racing cars.

RESEARCH FRONTIER

Developing better and more affordable hybrid and fuel cell vehicles; see **www.cengage.com/login**.

SCIENCE FOCUS

The Search for Better Batteries

Thomas Edison invented the first rechargeable, nickel-based battery in 1890. Since then, scientists have created the rechargeable lead-acid batteries used in most cars, the nickel-cadmium batteries used in toys and until recently in laptop computers, and the nickel-metal-hydride batteries that power the Prius and other hybrid vehicles. New battery technology is difficult to develop because it is based on chemical reactions that are governed by the laws of thermodynamics.

The major obstacle standing in the way of mass-market, plug-in, hybrid electric vehicles is the difficulty in making an affordable battery that can store enough energy to power a vehicle over long distances without overheating. One promising type of battery is a *lithium-ion battery*, commonly used in laptop computers and cell phones. These batteries are light and can pack a lot of energy into a small space.

But there are two problems with current lithium-ion batteries. *First*, they have an occasional tendency to overheat, release oxygen, and in rare cases burst into flames. *Second*, they cost twice as much as the nickel-metal-hydride batteries currently used in hybrid cars.

In 2009, researchers at the Massachusetts Institute of Technology (MIT) developed a new type of lithium battery that charges more rapidly, is less likely to heat up to dangerous levels, and is cheaper than the batteries used to power today's hybrid vehicles. One battery manufacturer is using nanotechnology (see Chapter 14, Science Focus, p. 365) to make electrodes out of a nanophosphate material that will lengthen battery life and will not heat up and release flammable oxygen.

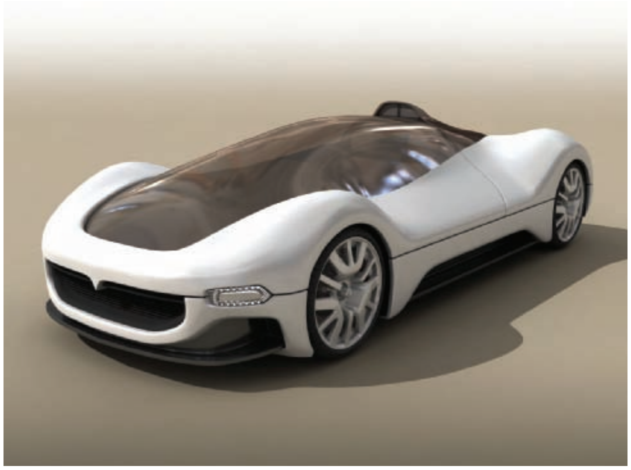
In the quest for lightweight, inexpensive batteries, Anela Belcher, a materials scientist and bioengineer at MIT, is working on an entirely new type of battery. She has genetically engineered a virus that can coat itself with electricity-conducting materials to form a miniscule nanowire. She is trying to find ways to link these tiny wires up to form the components of a battery far more compact and powerful than any yet developed. Such viral batteries would essentially grow themselves without producing the often-toxic wastes now produced in the manufacturing of other types of batteries. **GREEN CAREER:** battery engineer

Another approach is to power a car with an *ultracapacitor*, a battery-like device that stores and releases energy very quickly. If it works and is affordable, this device would make batteries obsolete.

U.S. battery makers are far behind those of Japan, China, and South Korea in developing and producing batteries for cars and other uses. Some analysts warn that in a future that depends on electric vehicles, the United States may end up substituting dependence on batteries built in Asia (mostly South Korea and China) for dependence on imported oil—much of it from the Middle East.

Critical Thinking

Would you buy a plug-in hybrid vehicle? Why or why not?



AND Inc./Shutterstock

Figure 16-7 The body on this concept car, made of carbon-fiber composite, is much safer and stronger than a traditional car body and the car gets better mileage because of its greatly reduced weight. Such car bodies are expensive but further research and mass production could bring their prices down.

We Can Design Buildings That Save Energy and Money

According to a 2007 UN study, better architecture and energy savings in buildings could save 30–40% of the energy used globally. For example, orienting a building to face the sun so it can get more of its heat from solar energy can save up to 20% of heating costs and as much as 75% of such costs when the building is well insulated and airtight (Figure 16-1). This is a simple application of the solar energy **principle of sustainability** (see back cover).

The 24-story Georgia Power Company building in the U.S. city of Atlanta, Georgia, uses 60% less energy than conventional office buildings of the same size. The largest surface of this building faces south to capture as much solar energy as possible. Each floor extends out over the one below it. This blocks out the higher summer sun on each floor to reduce air conditioning costs but allows the lower winter sun to help light and heat each floor during the day. In the building's offices, energy-efficient compact fluorescent lights focus on work areas instead of illuminating entire rooms. Such *green buildings* have been widely used in Europe for almost 2 decades, especially in Germany and the Netherlands, and are beginning to catch on in the United States.

Green architecture, based on energy-efficient and money-saving designs, makes use of natural lighting, passive solar heating, solar cells, solar hot water heaters, recycled wastewater, and energy-efficient appliances and lighting. Some also use *living roofs*, or *green roofs*, covered with soil and vegetation (Figure 16-8 and Photo 10 in the Detailed Contents). Others use white or light-colored roofs that help reduce cooling costs by reflecting incoming solar radiation especially in hotter climates—a strategy for working with nature that people have used for centuries.

Superinsulation is very important in energy-efficient design. As the Rocky Mountain Institute's headquarters (Figure 16-1) demonstrates, a house can be so heavily insulated and airtight that heat from direct sunlight, appliances, and human bodies can warm it with little or no need for a backup heating system, even in extremely cold climates. Superinsulated houses in Sweden use 90% less energy for heating and cooling than typical American homes of the same size use. Such houses can be ventilated with little energy loss to bring in fresh air. Another example of a superinsulated houses is one with thick walls of straw bales that are covered on the inside and outside with adobe (see Photos 8 and 9 in the Detailed Contents). (See the Guest Essay about straw bale construction and solar energy houses by Nancy Wicks at CengageNOW.)

Green building certification standards now exist in 21 countries, thanks to the efforts of the World Green Building Council. Since 1999, the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) program has awarded silver, gold, and platinum standard certificates to nearly 9,000 U.S. buildings that meet certain standards. Between 1999 and 2009, these buildings saved $1.6 billion in electricity costs. **GREEN CAREERS:** environmental design and green architecture

We Can Save Money and Energy in Existing Buildings

There are many ways to save energy and money in existing buildings. A good first step is to have an expert make an *energy survey* of a house or building

City of Chicago—Mark Farina

Figure 16-8 City Hall in Chicago, Illinois (USA), has a *green* or *living roof*—an important part of the city's efforts to become a more sustainable green city. Such a roof can save energy used to heat and cool the building. It absorbs heat from the summer sun, which would otherwise go into the building, and it helps to insulate the structure and retain heat in the winter. In addition, it absorbs precipitation, which would normally become part of the city's storm water runoff and add to pollution of its waterways.

to suggest ways to improve energy efficiency and save money. Such a survey might result in some or all of the following recommendations:

- *Insulate the building and plug leaks.* About one-third of the heated air in typical U.S. homes and buildings escapes through holes, cracks, and closed, single-pane windows (Figure 16-9). During hot weather, these windows and cracks let heat in, increasing the use of air conditioning. Adding insulation to walls and attics, plugging air leaks, and sealing heating and cooling ducts are three of the quickest, cheapest, and best ways to save money and energy in any building.
- *Use energy-efficient windows.* Replacing energy-wasting single-pane windows with energy-efficient double-pane windows or highly efficient *superwindows* that have the insulating effect of a window with 3 to 20 panes can cut expensive heat losses from a house or other building by two-thirds, lessen cooling costs in the summer, and reduce heating system CO_2 emissions.
- *Stop other heating and cooling losses.* Leaky heating and cooling ducts in attics and unheated basements allow 20–30% of a home's heating and cooling energy to escape and draw unwanted moisture and heat into the home. Careful sealing of duct joints can reduce this loss and save money. Also, using white or light-colored roofing or living roofs (Figure 16-8) can cut electricity use for air conditioning and reduce CO_2 emissions in warmer climates. Engineers are working on roofs that can change colors—being white and reflecting solar energy in hot weather and turning dark in order to absorb solar energy during cold weather.
- *Heat houses more efficiently.* In order, the most energy-efficient ways to improve efficiency and save money for heating a space are to use: superinsulation (which would include plugging leaks); a geothermal heat pump that transfers heat stored in the earth to a home (discussed later in this chapter); passive solar heating (Figure 16-1); a high-efficiency, conventional heat pump (in warm climates only); small, cogenerating microturbines fueled by natural gas; and a high-efficiency (92–98%) natural gas furnace. The most wasteful and expensive way to heat a space is to use electric resistance heating with electricity produced by a coal-fired or nuclear power plant (Figure 15-3, p. 373).

  CORE CASE STUDY
- *Heat water more efficiently.* One approach is to use a roof-mounted solar hot water heater. These are widely used in China, Israel, and a number of other countries. Another option is a *tankless instant water heater* fired by natural gas or LPG. (Using electricity for this purpose is not efficient.) These suitcase-size devices, widely used in many parts of Europe, heat water instantly as it flows through a small burner chamber, providing hot water only when it is needed. They cost up to 60% less to operate than a standard electric unit costs. And they work. One of the authors (Miller) used them along with passive and active solar hot water heaters in an office and living space for 12 years.
- *Use energy-efficient appliances.* According to the EPA, if all U.S. households used the most efficient frost-free refrigerator available, 18 large coal or nuclear power plants could close. Microwave ovens use 25–50% less electricity than electric stoves do for

VANSCAN® Continuous Mobile Thermogram by Daedalus Enterprises, Inc.

Figure 16-9 This *thermogram*, or infrared photo, shows heat losses (red, white, and orange) around the windows, doors, roofs, and foundations of houses and stores in Plymouth, Michigan (USA). Many homes and buildings in the United States and other countries are so full of leaks that their heat loss in cold weather and heat gain in hot weather are equivalent to what would be lost through a large, window-sized hole in a wall of the house. **Question:** How do you think the place where you live would compare to these buildings in terms of heat loss and the resulting waste of money spent on heating and cooling bills?

cooking and 20% less than convection ovens use. Clothes dryers with moisture sensors cut energy use by 15%. Refrigerators with a freezer on the bottom cut electricity use and operating costs in half, compared to models with the freezer on top. Front-loading clothes washers use 55% less energy and 30% less water than top-loading models use and cut operating costs in half. Plasma televisions use about 20% more energy than LCD sets of the same size. Keeping TVs, computers, and other appliances on standby can require up to 5% of all residential electricity used. Consumers can reduce this energy use and save money by plugging such electronic devices into a smart power strip that cuts off power when it detects that the device has been turned off.

- *Use energy-efficient lighting.* The best compact fluorescent lightbulbs (CFLs, see Figure 2-16, left, p. 48) produce light of the same brightness and quality as that of incandescent bulbs. They are four times more efficient and last up to ten times longer than incandescent bulbs, which waste 90–95% of their energy input. According to the DOE, replacing 30 incandescent bulbs with CFLs can save a consumer more than $1,000 in electricity costs over the life of the bulbs. Australia, Canada, Brazil, China, and the European Union plan to phase out sales of incandescent bulbs over the next 5–10 years. Over the next 2 decades, most bulbs may be replaced by even more efficient, pea-sized LEDs (Figure 16-4) if LED prices come down. They last 60 times longer than incandescent bulbs and 10 times longer than CFLs. According to a 2008 study by professors E. Fred Shubert and Jong Kyu Kim at Renssalaer Polytechnic Institute, replacing all of the world's lightbulbs with LEDs for a decade would reduce CO_2 emissions and save enough electricity to close 280 coal-fired power plants.

Figure 16-10 summarizes ways in which you can save energy in the place where you live.

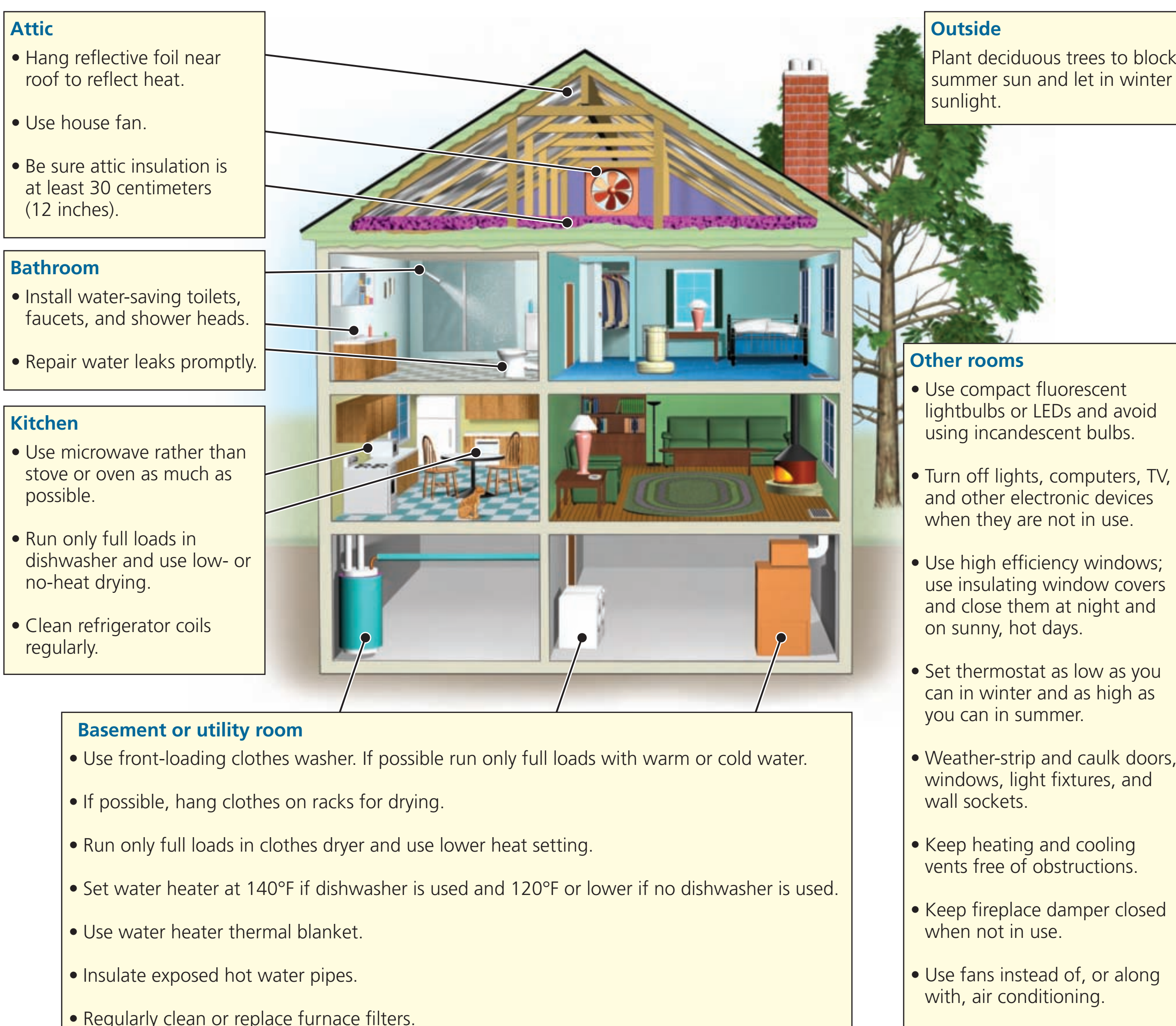


Figure 16-10 **Individuals matter:** You can save energy where you live. **Question:** Which of these things do you do?

CONNECTIONS

Using Compact Fluorescent Bulbs Reduces Mercury Pollution

GOOD NEWS

The typical compact fluorescent lightbulb (CFL) contains a small amount of toxic mercury—roughly the amount that would fit on the tip of a ballpoint pen—and newer bulbs will have only half this amount. The mercury cannot be released to the environment unless the bulb gets broken. The total amount of mercury in all of the country's CFLs is a tiny fraction of the amount of mercury released every year by coal-fired power plants that produce the electricity that lights many energy-wasting incandescent bulbs. While the mercury in CFLs can be recycled (see **www.epa.gov/bulbreycling**), the mercury continuously spewed into the atmosphere by coal-burning power plants cannot be retrieved. Instead, it pollutes air and water, and some of it can end up in our lungs and in our food, especially in fish. Thus, shifting to CFLs helps to reduce the amount of mercury released into the atmosphere.

Why Are We Still Wasting So Much Energy and Money?

Cutting energy waste will not solve our energy problems, but it is an important first step. Considering its impressive array of benefits (Figure 16-3), why is there so little emphasis on improving energy efficiency?

One reason is that fossil fuels, nuclear power, and other widely used energy resources are artificially cheap, primarily because of the government subsidies and tax breaks they receive and because their market prices do not include the harmful environmental and health costs of their production and use. Without such market price feedback, people are more likely to waste energy and less likely to invest in improving energy efficiency.

Another reason is that there are few government tax breaks, rebates, low-interest and long-term loans, and other economic incentives for consumers and businesses to invest in improving energy efficiency. And the U.S. federal government has done a poor job of encouraging fuel efficiency in motor vehicles (Figure 16-5) and educating the public about the environmental and economic advantages of cutting energy waste.

Also, people tend to resist change even when it saves them money. Pilot studies have shown that many people begin saving energy when they use devices that continuously display household or vehicle energy consumption and when their utility bills show comparisons of their energy use with that of similar households. With such feedback, people in some neighborhoods compete to see who can get the lowest heating and electricity bills.

We Can Use Renewable Energy to Provide Heat and Electricity

One of nature's three **principles of sustainability** (see back cover) is to *rely mostly on solar energy*—by far the earth's most abundant and virtually unlimited source of energy. We can get renewable solar energy directly from the sun or indirectly from wind and moving water, as well as from wood and other forms of biomass, none of which would exist without direct solar energy. Another form of renewable energy is geothermal energy from the earth's interior.

SUSTAINABILITY

Studies show that with increased and consistent government subsidies, tax breaks, and funding for research and development, renewable energy could provide 20% of the world's electricity by 2025 and 50% by 2050. Denmark already gets 20% of its electricity from wind and has plans to increase this to 50% by 2030. Brazil gets 45% of its automotive fuel from ethanol made from sugarcane residue, and could phase out its use of gasoline within a decade. Costa Rica gets more than 95% of its electric power from renewable hydroelectric, wind, and geothermal energy. Studies show that with a crash program, the United States could get 20% of its energy and at least 25% of its electricity from renewable sources by 2020.

GOOD NEWS

China is rapidly becoming the world's leader in producing renewable energy and in making and selling wind turbines and solar cells to other countries. By 2009, China had created 1.2 billion jobs in its rapidly growing renewable energy industries and was adding new jobs at a rate of 100,000 per year. China plans to get 15% of its energy from renewable sources by 2020 and 33% by 2050. If China reaches these goals it will reduce its dependence on coal and lower its emissions of CO_2 and other air pollutants.

Making a major shift toward a variety of locally available renewable energy resources over the next few decades would result in more decentralized and energy-efficient national economies that are less vulnerable to supply cutoffs and natural disasters. It would also improve economic and national security for the United States, China, and many other countries by reducing their dependence on imported crude oil and liquefied natural gas. And it would greatly reduce air and water pollution, slow projected climate disruption, create large numbers of jobs, and save consumers money.

If renewable energy is so great, why does it provide only 8% of the world's energy and 7% of the energy used in the United States? There are three major reasons. *First*, since 1950, government tax breaks, subsidies, and funding for research and development of renewable energy resources have been much lower than those for fossil fuels (especially oil) and nuclear power, although subsidies and tax breaks for renewables have increased in recent years.

Second, although subsidies and tax breaks for fossil fuels and nuclear power have essentially been guaranteed for many decades, those for renewable energy in the United States have to be renewed by Congress every few years. This makes it risky for companies to invest in renewable energy.

Third, the prices we pay for nonrenewable fossil fuels and nuclear power do not include the harmful environmental and human health costs of producing and using them. This helps to shield them from free-market competition with renewable sources of energy. And it does not provide consumers with the price information they need to make better financial choices.

Energy analysts such as Amory Lovins (Figure 16-1) say that if these economic handicaps— CORE CASE STUDY *unbalanced and intermittent subsidies* and *inaccurate pricing*—were eliminated, many forms of renewable energy would be cheaper than fossil fuels and nuclear energy, and would quickly take over the energy marketplace.

Throughout the rest of this chapter, we evaluate these renewable energy options.

16-3 What Are the Advantages and Disadvantages of Using Solar Energy?

CONCEPT 16-3 **Passive and active solar heating systems can heat water and buildings effectively, and the costs of using direct sunlight to produce high-temperature heat and electricity are coming down.**

We Can Heat Buildings and Water with Solar Energy

We can provide some homes and other buildings with most of the heat they need by using **passive solar heating systems** (Figures 16-1, 16-11, left, CORE CASE STUDY and 16-12, p. 410). Such a system absorbs and stores heat from the sun directly within a well-insulated structure. Walls and floors of concrete, adobe, brick, or stone, and water tanks can be used to store much of the collected solar energy as heat and to release it slowly throughout the day and night. A small backup heating system such as a vented natural gas or propane heater can be used, if necessary (see the Guest Essay by Nancy Wicks at CengageNOW).

Using passive solar energy is not new. For thousands of years, people have intuitively followed this basic principle of sustainability. They have oriented their dwellings to take advantage of the sun's heat and light, built thick stone walls that collect and store heat during the day and gradually release it at night, and used light colors on their roofs and walls in hot climates to reflect more sunlight and keep their houses cool. Now some of us are rediscovering this ancient earth wisdom.

An **active solar heating system** (Figure 16-11, right) captures energy from the sun by pumping a heat-absorbing fluid (such as water or an antifreeze solution) through special collectors, usually mounted on a roof or on special racks to face the sun. Some of the collected heat can be used directly. The rest can be stored in a

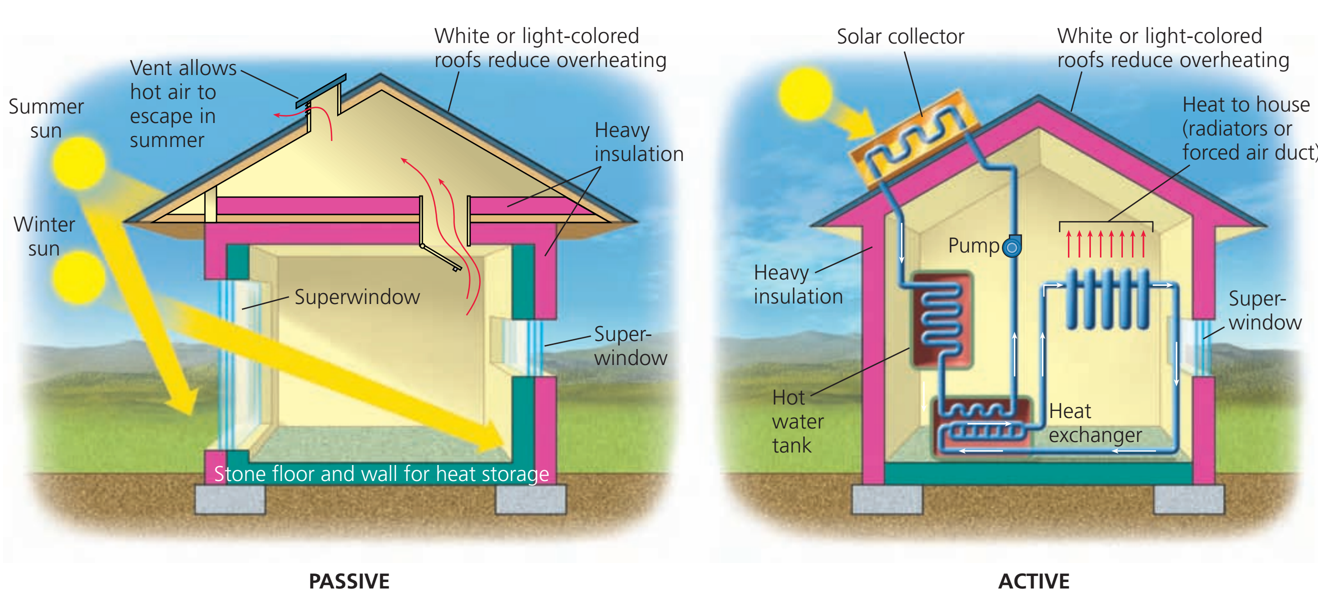


Figure 16-11 **Solutions:** Homes can be heated with passive or active solar systems.

Steven Sargent/National Renewable Energy Laboratory

Alan Ford/National Renewable Energy Laboratory

Figure 16-12 This passive solar home (left) in Golden, Colorado (USA), collects and stores incoming solar energy which provides much of its heat in a climate with cold winters. Such homes also have the best available insulation in their walls and ceilings, and energy-efficient windows to slow the loss of stored solar energy. Notice the solar hot water heating panels in the yard. Some passive solar houses like this one (see photo on right) in Dublin, New Hampshire (USA), have attached sunrooms that collect incoming solar energy.

large insulated container, filled with gravel, water, clay, or a heat-absorbing chemical, for release as needed. Active solar collectors (Figure 16-12, center) are also used to heat water in many homes.

With systems that cost the equivalent of as little as \$200, about one in ten houses and apartment buildings in China (Figure 16-13) currently use the sun to provide hot water. By 2030, half of all households in China may get their hot water in this way—an excellent example of applying the solar energy **principle of sustainability** (see back cover). Once the fairly low initial cost is paid, the hot water is essentially free. Such systems are also widely used in Germany, Japan, Greece, Austria, and Turkey. In Spain and Israel, all new buildings must have rooftop systems for heating water and space. Soon millions of households in less-developed countries such as India and Brazil could be using this simple and inexpensive way to heat water.

National Renewable Energy Laboratory

Figure 16-13 Rooftop solar hot water heaters, such as those shown here on apartment buildings in the Chinese city of Kunming in the province of Yunnan, are now required on all new buildings in China, and their use is growing rapidly in urban and rural areas.

Figure 16-14 lists the major advantages and disadvantages of using passive or active solar heating systems. They can be used to heat new homes in areas with adequate sunlight. (See the maps in Figure 22, p. S52, and Figure 23, p. S53, in Supplement 8.) But solar energy cannot be used to heat existing homes and buildings that are not oriented to receive sunlight or that are blocked from sunlight by other buildings or trees.

We Can Cool Buildings Naturally

Direct solar energy actually works against us when we want to keep a building cool, but we can use indirect solar energy (mainly wind) and other natural services to help cool buildings. For example, we can open windows to take advantage of breezes and use fans to keep the air moving. A living roof (Figure 16-8) can also make a huge difference in keeping a building cool. When there is no breeze, superinsulation and high-efficiency win-

Trade-Offs

Passive or Active Solar Heating

Advantages	Disadvantages
Net energy is moderate (active) to high (passive)	Need access to sun 60% of time during daylight
Very low emissions of CO_2 and other air pollutants	Sun can be blocked by trees and other structures
Very low land disturbance	High installation and maintenance costs for active systems
Moderate cost (passive)	Need backup system for cloudy days

Figure 16-14 Heating a house with a passive or active solar energy system has advantages and disadvantages (**Concept 16-3**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

dows help to keep hot air outside. Here are some other ways to keep cool:

- Block the high summer sun with window overhangs, awnings, or shades.
- In warm climates, use a light-colored roof to reflect as much as 90% of the sun's heat (compared to only 10–15% for a dark-colored roof).
- Use geothermal heat pumps for cooling (and for heating in winter).

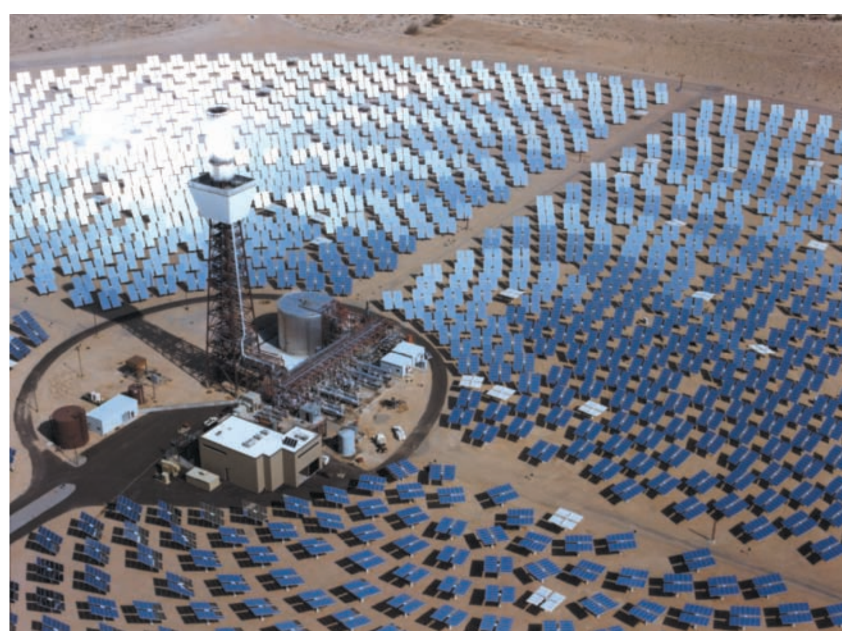
We Can Concentrate Sunlight to Produce High-Temperature Heat and Electricity

Solar thermal systems use different methods to collect and concentrate solar energy in order to boil water and produce steam for generating electricity (Figure 16-15). These systems are used mostly in desert areas with ample sunlight (see the maps in Figure 22, p. S52, and Figure 23, p. S53, in Supplement 8).

A 2009 study by environmental and industry groups estimated that solar thermal power plants could meet up to 25% of the world's projected electricity needs by 2050. These plants would not emit CO_2 into the atmosphere, and building and maintaining them

GOOD NEWS

National Renewable Energy Laboratory



Sandia National Laboratories/National Renewable Energy Laboratory

Figure 16-15 *Solar thermal power:* In this desert solar power plant (left) near Kramer Junction, California (USA), curved (parabolic) solar collectors concentrate solar energy and use it to produce electricity. The concentrated solar energy heats a fluid-filled pipe that runs through the center of each trough. The concentrated heat in the fluid is used to produce steam that powers a turbine that generates electricity. Such plants also exist in desert areas of southern Spain, Australia, and Israel. In another approach (right), an array of computer-controlled mirrors tracks the sun and focuses reflected sunlight on a central receiver, sometimes called a *power tower*. This tower near Daggett, California (USA), can collect enough heat to boil water and produce steam for generating electricity. Excess heat in both systems can be released to the atmosphere by cooling towers. The heat can also be used to melt a certain kind of salt stored in a large insulated container. The heat stored in this *molten salt system* can then be released as needed to produce electricity at night. Such plants also exist in desert areas of southern Spain and North Africa. Because a power tower heats water to higher temperatures, it can have a higher net energy ratio than a parabolic trough system has.

would create thousands of jobs. Researchers at the German Aerospace Center estimate that coupling an array of solar thermal power plants in North Africa with a new high-voltage electricity transmission system could meet all of Europe's electricity needs.

In addition, scientists estimate that, by using a global high-voltage smart electrical distribution system (Case Study, p. 401) along with solar thermal power plants built in less than 1% of the world's deserts—an area roughly the size of Austria or the U.S. state of South Carolina—we could meet all of the world's electricity needs. One drawback is that solar thermal systems have a low net energy yield of only about 3%. Researchers are working to raise it to at least 20%, which will make this approach economically feasible on a large scale.

Water is the factor that may limit the production of electricity from solar thermal power plants. There are two problems. *First*, these power plants require large volumes of cooling water for condensing the steam back to water for reuse and for washing off the surfaces of mirrors and parabolic troughs (Figure 16-15). *Second*, thermal power plants are built in sunny, arid deserts where water is scarce.

In a *wet cooling* system, some of the water must be replenished constantly because it evaporates and is released into the atmosphere by giant cooling towers (see Figure 15-15, p. 382). An alternative that requires much less water is *dry cooling*, which uses fans and heat exchangers to transfer the excess heat to the atmosphere. But running these machines takes energy, which lowers the net energy yield of the whole system and raises the cost of electricity. The U.S state of California has banned the use of wet cooling systems for solar thermal power plants in its water-short desert areas.

Today's solar thermal power plants (without a molten salt storage system) can produce electricity when the sun is out at a much lower cost than that of nuclear power plants, taking into account the nuclear fuel cycle (Figure 15-21, p. 388), and at about the same cost as that of a coal-burning power plant. Adding a molten salt storage system allows these plants to produce power around the clock. Such storage systems make the electricity much more expensive, but experts expect these costs to drop with improved technology and mass production (**Concept 16-3**).

Figure 16-16 summarizes the major advantages and disadvantages of concentrating solar energy to produce high-temperature heat or electricity.

We can use concentrated solar energy on a smaller scale, as well. In some sunny rural areas, people use inexpensive *solar cookers* to focus and concentrate sunlight for cooking food and sterilizing water (Figure 16-17). In 2009, inventor Jon Boehner received a $75,000 prize for developing a $6 solar cooker made from a cardboard box. Solar cookers can replace wood and charcoal fires, which helps to reduce deforestation by decreasing the need for firewood.

Trade-Offs

Solar Energy for High-Temperature Heat and Electricity

Advantages	Disadvantages
Moderate environmental impact	Low net energy and high costs
No direct emissions of CO_2 and other air pollutants	Needs backup or storage system on cloudy days
Lower costs with natural gas turbine backup	High water use for cooling

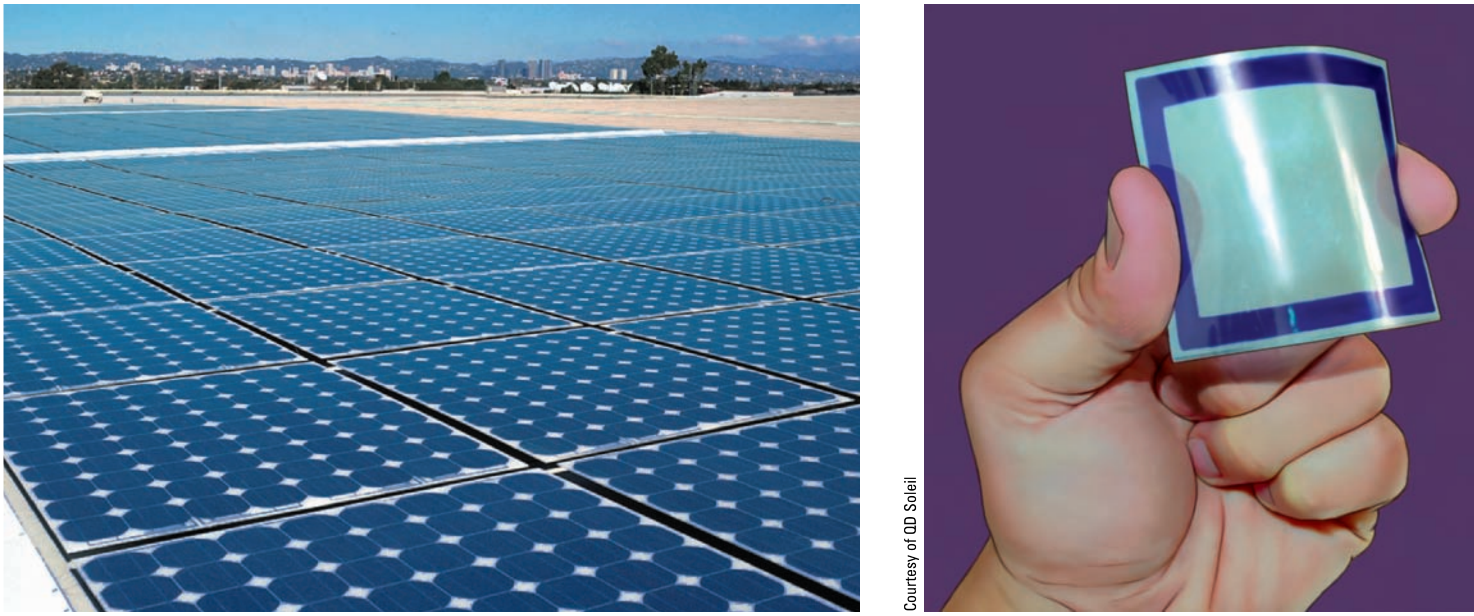
Figure 16-16 Using solar energy to generate high-temperature heat and electricity has advantages and disadvantages (**Concept 16-3**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why? Do you think that the advantages of using these technologies outweigh their disadvantages?

We Can Use Sunlight to Produce Electricity

We can convert solar energy directly into electrical energy using **photovoltaic** (**PV**) **cells**, commonly called **solar cells**. Most solar cells are thin wafers of purified

Mark Edwards/Peter Arnold, Inc.

Figure 16-17 **Solutions:** This woman in India is using a solar cooker to prepare a meal for her family.



Sunpower (previously known as, PowerLight Corporation)/National Renewable Energy Laboratories

Courtesy of QD Soleil

Figure 16-18 **Solutions:** Photovoltaic (PV) or solar cells can provide electricity for a house or building using conventional solar panels such as those shown here (left) on the roof of a U.S. Postal Service processing and distribution center in Inglewood, California. They can also be incorporated into metal roofing materials that can simulate the look of ceramic roof tiles, as well as slate, wooden shake, or asphalt shingles in a wide variety of colors. A new plug-and-play light-weight modular rooftop solar cell system can be snapped together and installed in a few hours. In addition, new, flexible, thin-film solar cells (right) or even more efficient tiny silicon nanorods (made with the use of nanotechnology) can be applied to roofs, windows, building walls, bridges—almost any surface, even T-shirts.

silicon (Si) or polycrystalline silicon with trace amounts of metals that allow them to produce electricity. A typical solar cell has a thickness ranging from less than that of a human hair to that of a sheet of paper. When sunlight strikes these transparent cells, they emit electrons, and many cells wired together in a panel can produce electrical power. The cells can be connected to existing electrical grid systems or to batteries that store the electrical energy until it is needed.

We can mount solar cells on rooftops (Figure 16-18, left), incorporate them into almost any type of roofing material in different colors and shapes, or produce them in flexible sheets (Figure 16-18, right) that can be installed on roofs, the sides of buildings, or almost any surface. New, flexible, and extremely thin-film solar cells that are printed on metal foil use much less silicon, can be mass produced, and allow almost any surface to become a power plant. **GREEN CAREER:** solar-cell technology

The Rocky Mountain Institute headquarters (**Core Case Study**) uses photovoltaic panels on the building's roof (Figure 16-1) to generate electricity. The system includes a tracking mechanism and small electric motors to keep the panels pointed toward the sun during daylight hours. With this mechanism, these panels collect about 30–40% more energy than stationary panels can.

Nearly 1.6 billion people, or one of every four people in the world, live in less-developed countries in rural villages that are not connected to an electrical grid. With easily expandable banks of solar cells, these people could now get electrical service (Figure 16-19). Eventually, new solar cells based on nanotechnology (Figure 16-18, right) will drastically lower the cost of providing electricity to less-developed areas.

Large solar-cell power plants are in operation in Portugal, southern Spain, Germany, South Korea, and the southwestern United States (Figure 16-20, p. 414). Excess energy from such plants can be stored for use at

Jorgen Schytte/Peter Arnold, Inc.

Figure 16-19 **Solutions:** This system of solar cells provides electricity for a remote village in Niger, Africa. **Question:** Do you think your government should provide aid to help poor countries obtain solar-cell systems? Explain.

Tucson Electric Power Company

Figure 16-20 This solar-cell power plant in the U.S. state of Arizona near the city of Springerville has been in operation since 2000 and is the world's largest solar-cell power plant. Analysis shows that the plant, which is connected to the area's electrical grid, paid back the energy needed to build it in less than 3 years.

Trade-Offs

Solar Cells

Advantages	Disadvantages
Moderate net energy yield	Need access to sun
Little or no direct emissions of CO_2 and other air pollutants	Need electricity storage system or backup
Easy to install, move around, and expand as needed	High costs for older systems but decreasing rapidly
Competitive cost for newer cells	Solar-cell power plants could disrupt desert ecosystems

Figure 16-21 Using solar cells to produce electricity has advantages and disadvantages (**Concept 16-3**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

night or on cloudy days by using the excess electricity to run pumps that compress air into underground caverns. This stored pressure is released as needed to drive turbines and produce electricity. Such a system has been used for decades in Germany and in the U.S. state of Alabama. Excess energy from solar cells could also be stored by using the electricity to decompose water and produce hydrogen gas, which can be used as a fuel, as we discuss later in this chapter.

In 2010, the three largest producers of solar-cell electricity were Japan, China, and Germany. Figure 16-21 lists the major advantages and disadvantages of using solar cells (**Concept 16-3**).

Solar thermal power systems (Figure 16-15) and centralized solar-cell power plants (Figure 16-20) must be concentrated in sunny deserts, and they require an expensive modernized regional or national grid system to transfer the power they produce to users (see the map in Figure 20, p. S51, in Supplement 8). By contrast, smaller solar-cell systems for homes and businesses can be used in any sunny part of the world (see the maps in Figure 22, p. S52, and Figure 23, p. S53, in Supplement 8), and they produce the energy where it is needed.

Solar cells emit no greenhouse gases, although they are not carbon-free, because fossil fuels are used to produce and transport the panels. But these emissions are small compared to those of fossil fuels and the nuclear power fuel cycle. Conventional solar cells also contain toxic materials that must be recovered when the cells wear out after 20–25 years of use, or when they are replaced with new systems.

Until recently, the main problem with using solar cells to produce electricity has been their high cost. Despite this drawback, their production has soared in recent years and solar cells have become the world's fastest growing way to produce electricity (see the graph in Figure 11, p. S62, in Supplement 9.) This is because of their advantages (Figure 16-21, left) and because of increased government subsidies and tax breaks for solar cell producers and users. Production is likely to grow much more as new, thin-film nanotechnology solar cells (Figure 16-18, right) become cheap enough to compete with fossil fuels and to make more expensive conventional solar-cell panels obsolete. **GREEN CAREER:** solar-cell technology

RESEARCH FRONTIER

Developing more efficient and affordable solar cells; see **www.cengage.com/login**.

Energy analysts say that with increased research and development, plus much greater and more consistent government tax breaks and other subsidies, solar cells could provide 16% of the world's electricity by 2040. In 2007, Jim Lyons, chief engineer for General Electric, projected that solar cells will be the world's number-one source of electricity by the end of this century. If that happens, it will represent a huge global application of the solar energy **principle of sustainability** (see back cover).

HOW WOULD YOU VOTE?

Should the country where you live greatly increase its dependence on solar cells for producing electricity? Cast your vote online at **www.cengage.com/login**.

16-4 What Are the Advantages and Disadvantages of Using Hydropower?

▶ **CONCEPT 16-4 We can use water flowing over dams, tidal flows, and ocean waves to generate electricity, but environmental concerns and limited availability of suitable sites may limit our use of these energy resources.**

We Can Produce Electricity from Falling and Flowing Water

Hydropower uses the kinetic energy of flowing and falling water to produce electricity. It is an indirect form of solar energy because it is based on the evaporation of water, which is deposited at higher elevations where it can flow to lower elevations in rivers as part of the earth's solar-powered water cycle (see Figure 3-16, p. 67).

The most common approach to harnessing hydropower is to build a high dam across a large river to create a reservoir. Some of the water stored in the reservoir is allowed to flow through large pipes at controlled rates to spin turbines that produce electricity (see Figure 13-13, p. 328).

Hydropower is the world's leading renewable energy source used to produce electricity. In order, the world's top five producers of hydropower are Canada, China, Brazil, the United States, and Russia. In 2007, hydropower supplied about 20% of the world's electricity, including 99% of Norway's, 75% of New Zealand's, 59% of Canada's, and 21% of China's electricity. Hydropower supplied about 6% of the electricity used in the United States, (but about 50% of that used on the West Coast).

According to the United Nations, only about 13% of the world's potential for hydropower has been developed. Much of this untapped potential is in China, India, South America, Central Africa, and parts of the former Soviet Union. China has plans to more than double its hydropower output by 2020 and is also building or funding more than 200 dams around the world. Brazil has four large dams in its Amazon Basin and plans to build as many as 70 more. If completed, current and planned hydropower projects around the world would have the electrical output of several thousand large coal-burning power plants without the high emissions of CO_2 and other air pollutants.

But some analysts expect that use of large-scale hydropower plants will fall slowly over the next several decades as many existing reservoirs fill with silt and become useless faster than new systems are built. Also, there is growing concern over emissions of methane, a potent greenhouse gas, from the decomposition of submerged vegetation in hydropower plant reservoirs, especially in warm climates. In fact, scientists at Brazil's National Institute for Space Research estimate that the world's largest dams altogether are the single largest human-caused source of methane. In addition, eventually, projected climate change is likely to reduce the electrical output of many of the world's large dams as mountain glaciers, a primary source of their water, continue to melt.

Figure 13-13 (p. 328) lists the major advantages and disadvantages of large dams and reservoirs, and Figure 16-22 lists the major advantages and disadvantages of using large-scale hydropower plants to produce electricity (**Concept 16-4**).

HOW WOULD YOU VOTE? ✓

Should the world greatly increase its dependence on large-scale dams for producing electricity? Cast your vote online at **www.cengage.com/login**.

The use of *microhydropower generators* may become an increasingly important way to produce electricity. These are floating turbines, each about the size of an overnight suitcase. They use the power of flowing water to turn rotor blades, which spin a turbine to produce electric current. They can be placed in any

GOOD NEWS

Trade-Offs

Large-Scale Hydropower

Advantages	**Disadvantages**
Moderate to high net energy	Large land disturbance and displacement of people
Large untapped potential	High CH_4 emissions from rapid biomass decay in shallow tropical reservoirs
Low-cost electricity	Disrupts downstream aquatic ecosystems
Low emissions of CO_2 and other air pollutants in temperate areas	

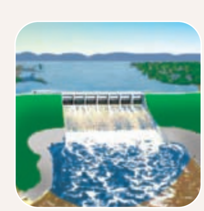


Figure 16-22 Using large dams and reservoirs to produce electricity has advantages and disadvantages (**Concept 16-4**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

stream or river without altering its course to provide electricity at a very low cost with a very low environmental impact.

We Can Use Tides and Waves to Produce Electricity

We can also produce electricity from flowing water by tapping into the energy from *ocean tides* and *waves*. In some coastal bays and estuaries, water levels can rise or fall by 6 meters (20 feet) or more between daily high and low tides. Dams have been built across the mouths of some bays and estuaries to capture the energy in these flows for hydropower. Only two large tidal energy dams are currently operating, one at La Rance on the northern coast of France, and the other in Nova Scotia's Bay of Fundy. Several countries plan to build some sort of tidal flow system, but costs are high and globally, suitable sites are limited.

Between 2006 and 2008, Verdant Power built and installed six underwater turbines to tap the tidal flow of the East River near New York City. The turbines resemble underwater wind turbines as they swivel to face the incoming and outgoing tides, and they have produced electricity efficiently. The next phase of this project involves installing 30 turbines. If the project is successful, as many as 300 turbines may be used in the river. Such a system powers a town in Norway. However, these systems are limited to the small number of rivers that have adequate tidal flows.

For decades, scientists and engineers have been trying to produce electricity by tapping wave energy along seacoasts where there are almost continuous waves. Large, snakelike chains of floating steel tubes have been installed off the coast of Portugal. The up and down motion of these chains by wave action generates electricity. In 2008, the system generated enough electricity to power 15,000 homes.

Wave power facilities are being developed in northern California, Ireland, and Great Britain. However, production is limited because there are few suitable sites for such systems, the costs are high, and the equipment is vulnerable to corrosion from saltwater and storm damage (**Concept 16-4**). However, improved technology could greatly increase the production of electricity from waves sometime during this century.

16-5 What Are the Advantages and Disadvantages of Using Wind Power?

CONCEPT 16-5 When we include the environmental costs of using energy resources in the market prices of energy, wind power is the least expensive and least polluting way to produce electricity.

Using Wind to Produce Electricity Is an Important Step toward Sustainability

The differences in the angles of the sun's rays hitting the earth between the equator and the poles create different amounts of solar heating; together with the earth's rotation, this creates flows of air called *wind* (see Figure 7-3, p. 149). We can capture this indirect form of solar energy with wind turbines on land and at sea that convert it into electrical energy (Figure 16-23). Such wind turbines are being erected in large numbers at some sites to create *wind farms*. Because today's wind turbines can be as tall as 22 stories and have blades as long as the height of 7-story building, they can tap into the stronger, more reliable, and less turbulent winds found at higher altitudes.

GOOD NEWS

In recent years, wind power has been the world's second-fastest-growing source of energy (see the graph in Figure 12, p. S62, in Supplement 9), after solar cells. In order, the largest wind-power producers in 2009 were China, the United States (see Case Study, p. 418), Germany, Spain, and India. The rapidly increasing use of wind power in China will help to reduce its use of coal and its emissions of CO_2 and other air pollutants. By 2020, China plans to be the world's largest manufacturer and seller of wind turbines.

Denmark, the world's most energy-efficient country, gets 20% of its electricity from wind and is aiming for 50%. Danish companies also control at least one-third of the global wind turbine market. Around the world, more than 400,000 people are employed in the production, installation, and maintenance (Figure 16-24) of wind turbines. These job numbers are likely to rise rapidly in coming years.

GOOD NEWS

In 2009, a Harvard University study led by Xi Lu estimated that wind power has the potential to produce 40 times the world's current use of electricity. The study used data on wind flows and strengths from thousands of meteorological measuring stations to determine that most electricity needs could be met by a series of large wind farms. Most of the land-based

Wind turbine **Wind farm** **Wind farm (offshore)**

Figure 16-23 **Solutions:** A single wind turbine (left) can produce electricity. Increasingly, they are interconnected in arrays of tens to hundreds of turbines. These *wind farms* or *wind parks* can be located on land (middle) or offshore (right). The land beneath these turbines can still be used to grow crops or to raise cattle. **Questions:** Would you object to having a wind farm located near where you live? Why or why not?

wind farms would be located in remote and sparsely populated areas of countries such as China, the United States, and Canada.

Even though offshore wind farms are more costly to install, analysts expect to see increasing use of them (Figure 16-23, right) because wind speeds over water are often stronger and steadier than those over land, and any noise that they make is muffled by surf sounds. Locating them offshore eliminates the need for negotiations among multiple landowners over the locations of turbines and electrical transmission lines. Also, there are more suitable sites at sea, and the turbines could be anchored on floating platforms far enough from shore to be out of sight for coastal residents while taking advantage of stronger and more constant offshore winds. Siting them offshore would avoid complaints about noise that have been voiced by some people living near land-based wind farms.

Suzlon Energy Ltd.

Figure 16-24 Maintenance workers get a long-distance view from atop a wind turbine, somewhere in North America, built by Suzlon Energy, a company established in India in 1995.

A 2009 study published in the Proceedings of the U.S. National Academy of Sciences estimated that the world's top CO_2-emitting countries have more than enough land-based and offshore wind potential to more than meet their current electricity needs. The U.S. has enough wind potential to meet an estimated 16 to 22 times its current electricity needs, and China has enough wind potential to meet 15 times its current electricity consumption. Canada has enough wind power to generate 39 times its electrical needs, and Russia could use wind power to meet its electrical needs 170 times over.

Unlike oil and coal, wind is widely distributed and inexhaustible, and wind power is mostly carbon-free and pollution-free. A wind farm can be built within 9 to 12 months and expanded as needed. The DOE and the Worldwatch Society estimate that, when we include the harmful environmental and health costs of various energy resources in comparative cost estimates, wind energy is the cheapest way to produce electricity (**Concept 16-5**).

GOOD NEWS

Like any energy source, wind power has some drawbacks. Areas with the greatest wind power potential are often sparsely populated and located far from cities. Thus, to take advantage of the potential for using wind energy, countries such as the United States will have to invest in a long overdue upgrading and expansion of their outdated electrical grid systems. The resulting large increase in the number of transmission towers and lines will cause controversy in some areas and could result in lawsuits challenging such changes. One way to deal with this problem could be to run many of the new lines along state-owned interstate highway corridors to avoid legal conflicts. Wind power proponents argue that continuing to rely mostly on the use of polluting and climate-changing coal and oil and the costly nuclear power fuel cycle is a far worse alternative.

Another problem is that winds can die down and thus require a backup source of power, such as natural gas, for generating electricity. However, analysts calculate that a large number of wind farms in different areas connected to an updated electrical grid could usually take up the slack when winds die down in any one area.

Scientists are working on ways to store wind energy. Electricity produced by wind can be passed through water and used to produce hydrogen fuel, which could be thought of as "stored" wind power. Another option is to use wind-generated electricity to pump pressurized air deep underground into aquifers, caverns, and abandoned natural gas wells. The energy stored in the compressed air could then be released as needed to spin turbines and generate electricity when wind power is not available. This process is being used in Germany and in the U.S. state of Alabama.

Trade-Offs

Wind Power

Advantages

Moderate to high net energy yield

Widely available

Low electricity cost

Little or no direct emissions of CO_2 and other air pollutants

Easy to build and expand

Disadvantages

Needs backup or storage system when winds die down

Visual pollution for some people

Low-level noise bothers some people

Can kill birds if not properly designed and located

Figure 16-25 Using wind to produce electricity has advantages and disadvantages (**Concept 16-5**). With sufficient and consistent government incentives, wind power could supply more than 10% of the world's electricity and 20% of the electricity used in the United States by 2030. **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

CONNECTIONS

Bird Deaths and Wind Turbines

Wildlife ecologists and ornithologists have estimated that that wind turbines kill as many as 440,000 birds each year in the United States, although other more recent estimates put the figure at 7,000 to 100,000. (Compare this to much larger numbers reported by Defenders of Wildlife: housecats and feral cats kill 100 million birds a year; hunters, more than 100 million; cars and trucks, about 80 million; and pesticide poisoning, 67 million.) Most of the wind turbines involved in bird deaths were built with the use of outdated designs, and some were built in bird migration corridors. Wind power developers now make sophisticated studies of these corridors in order to avoid them when building wind farms. Newer turbine designs use slower blade rotation speeds and do not provide places for birds to perch or nest, which also reduces bird casualties. Some wind power critics point out that many birds are killed by collisions with electrical transmission towers and lines. But this is a problem that will occur with or without wind power, and researchers will keep trying to find ways to minimize it. The bottom line is: wind power is much less of a threat to birds than other hazards are.

Some people in populated areas and in coastal areas oppose wind farms as being unsightly and noisy. But in windy parts of the U.S. Midwest and in Canada, many farmers and ranchers welcome them and some have become wind power producers themselves. For each wind turbine located on a farmer's land, the landowner typically receives $3,000 to $10,000 a year in royalties. And that farmer can still use the land for growing crops or grazing cattle.

Figure 16-25 lists the major advantages and disadvantages of using wind to produce electricity. According to energy analysts, wind power has more benefits and fewer serious drawbacks than any other energy resource, except for energy efficiency. **GREEN CAREER:** wind-energy engineering

HOW WOULD YOU VOTE?

Should the country where you live greatly increase its dependence on wind power? Cast your vote online at **www.cengage.com/login**.

CASE STUDY

The Astounding Potential for Wind Power in the United States

The map in Figure 24, p. S54, in Supplement 8 shows the land and offshore areas with the most potential for generating wind power in the United States. The DOE calls the four Great Plains states of North Dakota, South Dakota, Kansas, and Texas the "Saudi Arabia of wind power." The DOE estimates that wind farms in favorable sites in these four states could more than meet the electricity needs of the lower 48 states. In addition, offshore wind resources—off the Atlantic and Pacific coasts, and off the shores of the Great Lakes—could also supply all of the country's electricity. Wind power proponents call for developing more land-based and offshore wind farms instead of building more offshore oil-drilling rigs and more coal-fired and nuclear power plants.

GOOD NEWS

In 2009, wind farms generated enough electricity (30% of it in Texas) to replace the burning of enough coal to fill a coal train that would stretch 3,200 kilometers (2,000 miles). According to a 2009 study by the U.S. Department of the Interior, with expanded and sustained subsidies, wind farms off of the Atlantic and Gulf coasts could generate enough electricity to more than replace all of the country's coal-fired power plants.

In 2008, the DOE estimated that with sufficient and sustained government incentives, wind power could provide at least 20% of the country's electricity by 2030. This would reduce greenhouse gas emissions by an amount equal to the total emissions of 140 million motor vehicles. It would also create hundreds of thousands of jobs if the United States began building most of its own turbines instead of importing them from other countries.

CONNECTIONS

Wind Turbines and U.S. Jobs

GOOD NEWS

Greatly expanding the wind turbine industry in the United States would support about 500,000 jobs, by DOE estimates. It would also restore some of the shrinking U.S. manufacturing base. For example, according to the American Wind Energy Association, the country could use old manufacturing plants that once made gears for automobiles to make gears for wind turbines. Since 2007, more than 42 wind turbine manufacturing plants have been built or expanded in the United States. Each turbine manufacturer needs about 400 component suppliers. At one time, about 70% of the wind power equipment used in the United States was imported from Europe. Today that figure has been reduced to 50% and wind power proponents want it to keep dropping.

16-6 What Are the Advantages and Disadvantages of Using Biomass as an Energy Resource?

▶ **CONCEPT 16-6A Solid biomass is a renewable resource for much of the world's population, but burning it faster than it is replenished produces a net gain in atmospheric greenhouse gases, and creating biomass plantations can degrade soil and biodiversity.**

▶ **CONCEPT 16-6B We can use liquid biofuels derived from biomass in place of gasoline and diesel fuels, but creating biofuel plantations can degrade soil and biodiversity, and increase food prices and greenhouse gas emissions.**

We Can Produce Energy by Burning Solid Biomass

Biomass consists of plant materials (such as wood and agricultural waste) and animal wastes that we can burn directly as a solid fuel or convert into gaseous or liquid biofuels. Biomass is an indirect form of solar energy because it consists of combustible organic (carbon-containing) compounds produced by photosynthesis.

Solid biomass is burned mostly for heating and cooking, but also for industrial processes and for generating electricity. Wood, wood wastes, charcoal made from wood, and other forms of biomass used for heating and cooking supply 10% of the world's energy, 35% of the energy used in less-developed countries, and 95% of the energy used in the poorest countries. In agricultural areas, *crop residues* (such as sugarcane and cotton stalks, rice husks, straw, corn cobs, and coconut shells) and *animal manure* (see Photo 11 in the Detailed Contents) can be collected and burned.

Wood is a renewable fuel only if it is harvested no faster than it is replenished. The problem is, about 2.7 billion people in 77 less-developed countries face a *fuelwood crisis* and are often forced to meet their fuel needs by harvesting wood faster than it can be replenished. One way to deal with this problem is to produce solid biomass fuel by planting fast-growing trees such as cottonwoods, willows, and poplars, and by growing shrubs, perennial grasses such as switchgrass, and water hyacinths in *biomass plantations*. But repeated cycles of growing and harvesting these plantations can deplete the soil of key nutrients. Clearing forests and grasslands for such plantations destroys or degrades biodiversity. And plantation tree species such as European poplar and American mesquite are invasive species that can spread from plantations to takeover nearby ecosytems.

CONNECTIONS

Middlebury College and More Sustainable Biomass Burning

GOOD NEWS

Middlebury College in the U.S. state of Vermont is a leader among educational institutions in the quest to become more sustainable. Recently, it switched from burning oil to heat its buildings to burning wood chips in a state-of-the-art boiler that is part of a cogeneration system. The system heats about 100 college buildings and spins a turbine to generate about 20% of the electricity used by the college. The college has also planted an experimental patch of already-cleared land with fast-growing willow trees as a source of some of the wood chips for the new system. This demonstrates to students that it is preferable to establish biomass plantations only on land that has already been cleared. The college uses its tree-growing experiment and its wood-chip system to help its students learn more about environmental sustainability.

Another problem with depending on solid biomass as a fuel is that clearing forests to provide the fuel reduces the amount of vegetation that would otherwise capture CO_2, and burning biomass produces CO_2. However, if the rate of use of biomass does not exceed the rate at which it is replenished by new plant growth, there is no net increase in CO_2 emissions. But monitoring and managing this balance, globally or throughout any one country, is very difficult.

Still another problem is that burning solid biomass to produce electricity is only about 30-40% efficient. However, using a cogeneration system (Connections, p. 419) in which the excess heat produced by burning the biomass is used to heat water and nearby buildings raises the net energy yield to 60% or higher. Denmark, for example, gets almost half of its electricity by burning wood and agricultural wastes such as straw for cogeneration.

Figure 16-26 lists the general advantages and disadvantages of burning solid biomass as a fuel (**Concept 16-6A**).

HOW WOULD YOU VOTE?

Should we greatly increase our dependence on burning solid biomass to provide heat and produce electricity? Cast your vote online at **www.cengage.com/login**.

We Can Convert Plants and Plant Wastes to Liquid Biofuels

Liquid biofuels such as *biodiesel* (produced from vegetable oils) and *ethanol* (ethyl alcohol produced from plants and plant wastes) are being used in place of petroleum-based diesel fuel and gasoline. By 2009, about 1.7% of the world's liquid fuels were biofuels (mostly ethanol and biodiesel). The biggest producers of liquid biofuels are, in order, the United States (mostly ethanol from corn), Brazil (mostly ethanol from sugarcane residues), the European Union (mostly biodiesel from vegetable oils), and China (mostly producing ethanol from nongrain plant sources to avoid diverting grains from its food supply).

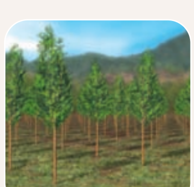
Biofuels have three major advantages over gasoline and diesel fuel produced from oil. *First*, while oil resources are concentrated in a small number of countries, biofuel crops can be grown almost anywhere, and thus they help countries to reduce their dependence on imported oil. *Second*, if these crops are not used faster than they are replenished by new plant growth, there is no net increase in CO_2 emissions, unless existing grasslands or forests are cleared to plant biofuel crops. *Third*, biofuels are available now, are easy to store and transport, can be distributed through existing fuel networks, and can be used in motor vehicles at little or no additional cost.

However, in a 2007 UN report on bioenergy, and in another study by R. Zahn and his colleagues, scientists warned that large-scale biofuel-crop farming could decrease biodiversity by increasing the clearing of natural forests and grasslands; increase soil degradation, erosion, and nutrient leaching; push small farmers off their land; and raise food prices if farmers can make more money by growing corn and other crops to fuel cars rather than to feed livestock and people (**Concept 16-6B**).

Trade-Offs

Solid Biomass

Advantages	Disadvantages
Widely available in some areas	Moderate to high environmental impact
Moderate costs	Increases CO_2 emissions if harvested and burned unsustainably
No net CO_2 increase if harvested, burned, and replanted sustainably	Clear cutting can cause soil erosion, water pollution, and loss of wildlife habitat
Plantations can help restore degraded lands	Often burned in inefficient and polluting open fires and stoves



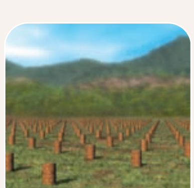


Figure 16-26 Burning solid biomass as a fuel has advantages and disadvantages (**Concept 16-6A**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

CONNECTIONS

Biofuels and Climate Change

In 2007, Nobel Prize–winning chemist Paul Crutzen warned that intensive farming of biofuel crops could speed up atmospheric warming and projected climate change by producing more greenhouse gases than would be produced by burning fossil fuels instead of biofuels. This would happen if nitrogen fertilizers were used to grow corn and other biofuel crops. Such fertilizers, when applied to the soil, release large amounts of the potent greenhouse gas nitrous oxide. A 2008 study by Finn Danielsen and a team of other scientists concluded that keeping tropical rain forests intact is a better way to slow projected climate change than burning and clearing such forests and replacing them with biofuel plantations.

Another problem with biofuels production is that growing corn and soybeans in climates that require irrigation could reduce water supplies in these arid regions. In fact, the two most water-intensive ways to produce a unit of energy are irrigating soybean crops to produce biodiesel fuel and irrigating corn to produce ethanol.

The challenge is to grow crops for food and biofuels by using more sustainable agriculture (see Figure 12-34, p. 310) with less irrigation, land degradation, air and water pollution, greenhouse gas emissions, and degradation of biodiversity. Also, any system for producing a biofuel should have a favorable net energy yield so that it can compete in the energy marketplace without large government subsidies.

In the remainder of this section we use three case studies to evaluate the usefulness of biofuels as energy resources. The first evaluates the current production of biodiesel, the second the current production of ethanol, and the third the potential for using algae and bacteria to produce biofuels.

■ CASE STUDY
Is Biodiesel the Answer?

If a truck or bus whizzing by you leaves a scent of fast food, it is probably running on *biodiesel*. This diesel biofuel is produced from vegetable oil extracted from soybeans, rapeseed (a type of mustard seed), sunflowers, oil palms, jatropha shrubs, and coffee grounds. It can also be made from used vegetable oils from restaurants. European Union countries (primarily Germany, France, and Italy) produce about 95% of the world's biodiesel, mostly from rapeseeds and sunflower seeds, and these countries hope to get 20% of their diesel fuel from this source by 2020. In Europe, more than half of all cars run on diesel, primarily because they are as much as 40% more efficient than gasoline engines.

Aided by government subsidies, biodiesel production is growing rapidly in the United States. But soybean and rapeseed crops grown for biodiesel production require huge areas of land and have low yields. Also, using industrialized agriculture to produce these crops results in topsoil loss and fertilizer runoff. Biodiesel production also requires energy (mostly from crude oil and natural gas), which reduces its net energy yield and increases emissions of greenhouse gases.

Brazil, Malaysia, and Indonesia produce biodiesel from palm oil, extracted from large plantations of African oil palm (see Figure 12-5, p. 282), and export much of it to Europe. The net energy yield for biodiesel from oil palm is five times that from rapeseeds used in Europe and about eight to nine times higher than the yield from soybeans used to produce biodiesel in the United States. But increased burning and clearing of tropical forests and other wooded lands to establish oil palm plantations in these countries poses a serious threat to their biodiversity.

Clearing such land also reduces CO_2 uptake by eliminating rain forests that store large amounts of carbon in order to grow crops that store much less carbon. Two studies in 2009 estimated that cutting down Brazilian rain forests to grow soybeans for biodiesel fuel would create a loss of carbon uptake that would take more than 300 years to replace. Also, African oil palm is an invasive plant that has taken over adjacent farms and forest areas in parts of Brazil. Figure 16-27 lists the major advantages and disadvantages of using biodiesel as a vehicle fuel, compared to gasoline.

Trade-Offs
Biodiesel

Advantages	Disadvantages
Reduced CO and CO_2 emissions	Increased NO_x emissions and smog
High net energy yield for oil palm crops	Low net energy yield for soybean crops
Reduced hydrocarbon emissions	Competes with food for cropland
Better mileage (up to 40%)	Clearing natural areas for plantations reduces biodiversity and increases atmospheric CO_2 levels

Figure 16-27 Using biodiesel as a vehicle fuel has advantages and disadvantages compared to gasoline. **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why? Do you think that the advantages of biodiesel fuel outweigh its disadvantages?

■ CASE STUDY
Is Ethanol the Answer?

Ethanol can be made from plants such as sugarcane, corn, and switchgrass, and from agricultural, forestry, and municipal wastes. This process involves converting plant starches into simple sugars, which are processed to produce ethanol.

Brazil, the Saudi Arabia of sugarcane, is the world's second largest ethanol producer after the United States. Brazil makes its ethanol from *bagasse* (Figure 16-28), a residue produced when sugarcane is crushed. This ethanol yields 8 times the amount of energy used to

National Renewable Energy Laboratory

Figure 16-28 Bagasse is a sugarcane residue that can be used to make ethanol.

produce it—compared with a net energy yield of 5 for gasoline. About 45% of Brazil's motor vehicles run on ethanol or ethanol–gasoline mixtures produced from sugarcane grown on only 1% of the country's arable land.

Within a decade, Brazil could expand its sugarcane production, eliminate all oil imports, and greatly increase ethanol exports to other countries. To do this, Brazil plans to clear and replace larger areas of its rapidly disappearing Cerrado, a wooded savanna region—one of the world's biodiversity hot spots (see Figure 10-27, p. 243)—with sugarcane plantations. This would increase the harmful environmental costs of this otherwise sustainable resource.

Environmental scientists David Pimentel and Tad Patzek warn that producing ethanol from sugarcane has a number of other harmful environmental effects. They include the CO_2 emissions from the burning of oil and gasoline to produce sugarcane, very high soil erosion after sugarcane plantations are harvested, and stresses on water supplies. Producing 1 liter (0.27 gallons) of ethanol from sugarcane requires the equivalent of about 174 bathtubs of water. The water that runs off of sugarcane plantations also contains significant amounts of the fertilizers, herbicides, and pesticides that are often applied at high levels to help increase crop yields.

In the United States, most ethanol is made from corn. (See Figure 13, p. S63, in Supplement 9 for a graph showing the rapid increase in ethanol production in the United States, Brazil, and the world since 1975.) U.S. farmers profit from growing corn to produce ethanol because they receive generous government subsidies as part of the nation's energy policy.

But studies indicate that using fossil fuel–dependent industrialized agriculture to grow corn and then using more fossil fuel to convert the corn to ethanol provides a net energy yield of only about 1.1–1.5 units of energy per unit of fossil fuel input. This low net energy yield explains why the U.S. government (taxpayers) must subsidize corn ethanol production to help it compete in the energy markets with other types of ethanol production that have higher net energy yields. It also helps to explain why Brazil, achieving a net energy yield of 8 from bagasse, can produce ethanol from sugarcane at about half the cost of producing it from corn in the United States. To make matters worse, cars running on E85 fuel (containing 85% ethanol and 15% gasoline) get about 30% lower gas mileage than comparable cars running on just gasoline.

CONNECTIONS

Corn, Ethanol, and Tortilla Riots in Mexico

Traditionally, the United States has supplied approximately 75% of the world's corn. Mexico imports 80% of its corn from the United States. Since 2005, when America began using much of its corn crop to produce ethanol, the prices of food items such as corn tortillas in Mexico have risen sharply. This has drastically affected the 53 million people living in poverty in Mexico and has led to food riots and massive citizen protests.

According to a 2007 study by environmental economist Stephen Polansky, processing all of the corn grown in the United States into ethanol each year would meet only about 30 days worth of the country's current demand for gasoline. This would leave no corn for other uses and would cause sharp increases in the prices of corn-based foods such as cereals, tortillas, poultry, beef, pork, and dairy products as well as prices of the thousands of food products that use corn syrup as a sweetener. This would increase the number of hungry and malnourished people who depend on these foods but could no longer afford to buy them. Energy expert Vaclav Smil has calculated that using ethanol produced from corn to replace conventional gasoline in the United States would require growing corn on six times the country's total area of farmable land, or 75% of the world's cultivated land.

There are conflicting analyses on how using corn to produce ethanol affects CO_2 emissions compared to burning gasoline. A 2008 study by Tim Searchinger at Princeton University and other researchers estimated that clearing and planting grasslands and forests to grow corn for producing ethanol would increase the net amount of CO_2 in the atmosphere by 93% compared to burning conventional gasoline over a 30-year period. But a 2007 EPA study estimated that using corn ethanol would reduce greenhouse gas emissions by about 22% compared to burning gasoline. More research is needed to resolve this issue.

An alternative to corn ethanol is *cellulosic ethanol*, which is produced from inedible cellulose that makes up most of the biomass of plants (see *The Habitable Planet*, Video 10, at **www.learner.org/resources/series209.html**). In this process, cellulose from plant material such as leaves, stalks, husks, and wood chips is isolated, and then enzymes convert the cellulose to sugars that can be processed to produce ethanol. By using these widely available inedible cellulose materials to produce ethanol, producers could dodge the food vs. biofuels dilemma.

A plant that could be used for cellulosic ethanol production is *switchgrass* (Figure 16-29), a tall perennial grass native to North American prairies that grows faster than corn. It is disease resistant and drought tolerant, can be grown without the use of nitrogen fertilizers on land unfit for other crops, and doesn't need to be replanted each year. According to a 2008 article by U.S. Department of Agriculture scientist Ken Vogel and his colleagues, using switchgrass to produce ethanol yields about 5.4 times as much energy as it takes to grow it—a yield much greater than the 1.1–1.5 net energy yield for corn ethanol. According to the U.S. Department of Agriculture, within a decade or two, we could produce much more ethanol than we could from corn by using cellulose from plants such as switchgrass, woodchips from forestry operations, and trash.

However, one drawback is reported by cellulosic ethanol expert Robert Ranier, who estimates that replacing half of U.S. gasoline consumption with cellulosic

National Renewable Energy Laboratory

Figure 16-29 **Natural capital:** The cellulose in this rapidly growing switchgrass can be converted into ethanol, but further research is needed to develop affordable production methods. This perennial plant can also help to slow projected climate change by removing carbon dioxide from the atmosphere and storing it as organic compounds in the soil.

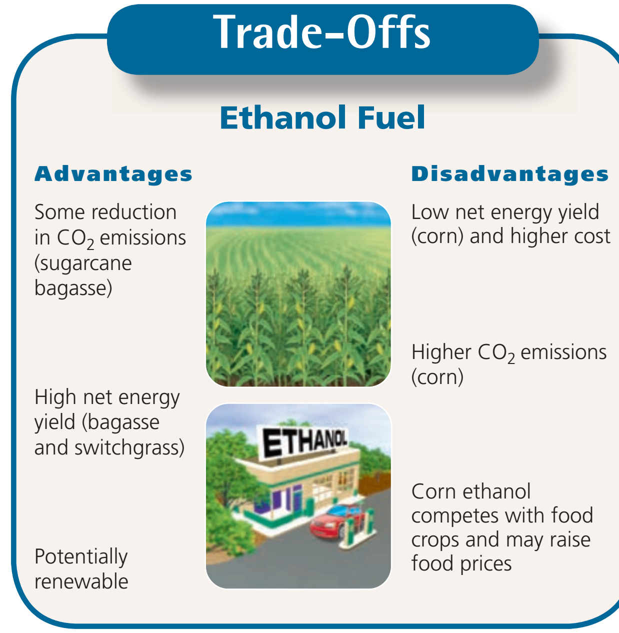


Figure 16-30 Using ethanol as a vehicle fuel has advantages and disadvantages compared to using gasoline (**Concept 16-6B**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

ethanol would require about seven times the land area currently used for all corn production. We also do not know how using cellulosic ethanol would affect CO_2 emissions. According to Daniel Kammen of the Berkeley Institute of the Environment, substituting cellulosic ethanol for gasoline would cut motor vehicle greenhouse gas emissions by 90% or more. But a 2009 study led by Tim Searchinger found that clearing and planting large areas of land to grow switchgrass for producing ethanol would increase the net amount of greenhouse gases in the atmosphere by 50% compared to burning gasoline instead of switchgrass ethanol.

Another problem is that it is difficult and costly to break down the cellulose and extract the glucose needed to make ethanol. As a result, affordable chemical processes for converting cellulosic material to ethanol are still being developed and are probably at least a decade away.

Figure 16-30 lists the major advantages and disadvantages of using ethanol as a vehicle fuel, compared to using gasoline.

HOW WOULD YOU VOTE?

Do the advantages of using liquid ethanol as a fuel outweigh its disadvantages? Cast your vote online at **www.cengage.com/login**.

CASE STUDY

Getting Gasoline and Diesel Fuel from Algae and Bacteria

Scientists are looking for ways to produce biofuels almost identical to gasoline and biodiesel from various types of existing or genetically engineered oil-rich algae (**www.oilgae.com**). Algae grow rapidly at any time of the year and can be cultivated in various aquatic environments.

As they grow, the algae remove CO_2 from the atmosphere and convert it to oil, proteins, and other useful products. They also require much less land, water, and other resources than biofuel plantations do and would not affect food prices by competing for cropland. The algae could be grown in wastewater from sewage treatment plants where they would help to clean up the wastewater while producing biofuel.

Another possibility would be to transfer carbon dioxide produced by coal-burning power plants into nearby algae ponds or bioreactors for use in making biofuel. This would be an application of the solar energy and nutrient recycling **principles of sustainability**.

There are four major challenges in converting such technological dreams into reality: cutting the very high cost of producing oil by such methods; learning whether it is economically better to grow the algae in open ponds or in enclosed bioreactors; finding an affordable way get the oil out of the algae (for example, by drying and crushing the algae or removing it with a solvent); and progressing from small-scale pilot projects to large-scale production systems.

A different approach is to make gasoline or diesel fuel from rapidly multiplying bacteria by using techniques developed in the new field of synthetic biology. One start-up company has a pilot plant near sugarcane fields in Louisiana that uses genetically engineered bacteria to convert the sugar in sugarcane juice into fatty acids that can be used as biodiesel fuel. But some environmental scientists warn that producing useful quantities of biodiesel from such organisms would require converting large areas of the world's land to much less diverse sugarcane plantations.

Making gasoline and diesel fuel from algae and bacteria probably will not wean the United States and other countries from crude oil because we use so much of it. But these emerging technologies could put a good dent in the world's dependence on conventional crude oil and heavy oil from tar sand (see Chapter 15, p. 379), which would reduce the severe environmental impacts of using these fuels.

Producing gasoline and diesel fuels from algae and bacteria could be done almost anywhere. The resulting fuels could be distributed by the world's current gasoline and diesel fuel distribution systems. Thus, it is not surprising that some of the major oil companies are investing heavily in research on producing oil-like compounds from algae and bacteria, hoping to lock in numerous patents for such processes. Stay tuned for new developments in these research ventures.

RESEARCH FRONTIER

Developing more energy-efficient, cheaper, and more sustainable ways to produce liquid biofuels; see **www.cengage.com/login**.

16-7 What Are the Advantages and Disadvantages of Using Geothermal Energy?

CONCEPT 16-7 Geothermal energy has great potential for supplying many areas with heat and electricity, and it has a generally low environmental impact, but the sites where it can be used economically are limited.

We Can Get Energy by Tapping the Earth's Internal Heat

Geothermal energy is heat stored in soil, underground rocks, and fluids in the earth's mantle (see Figure 14-2, p. 348). We can tap into this stored energy to heat and cool buildings and to produce electricity. GOOD NEWS Scientists estimate that using just 1% of the heat stored in the uppermost 5 kilometers (8 miles) of the earth's crust would provide 250 times more energy than that stored in all the earth's crude oil and natural gas reserves.

One way to capture geothermal energy is by using a *geothermal heat pump* system (Figure 16-31). It can heat and cool a house by exploiting the temperature difference, almost anywhere in the world, between the earth's surface and underground at a depth of 3–6 meters (10–20 feet), where the earth's temperature typically is 10–20ºC (50–60ºF) year round. In winter, a closed loop of buried pipes circulates a fluid, which extracts heat from the ground and carries it to a heat pump, which transfers the heat to a home's heat distribution system. In summer, this system works in reverse, removing heat from a home's interior and storing it in the ground.

According to the EPA, a well-designed geothermal heat pump system is the most energy-efficient, reliable, environmentally clean, and cost-effective way to heat or cool a space, second only to superinsulation. It produces no air pollutants and emits no CO_2. (For more information, see **www.ghpc.org** and **www.econar.com**.) Installation costs can be high but are generally recouped after 3–5 years; thereafter, such systems save money for their owners.

We can also tap into deeper, more concentrated *hydrothermal reservoirs* of geothermal energy. This is done by drilling wells into the reservoirs to extract their dry steam (with a low water content), wet steam (with a high water content), or hot water, which are then used to heat homes and buildings, provide hot water, grow vegetables in greenhouses, raise fish in aquaculture ponds, and spin turbines to produce electricity.

The United States is the world's largest producer of geothermal electricity from hydrothermal reservoirs. Most of it is produced in California, Nevada, Utah, and Hawaii (see Figure 26, p. S55, in Supplement 8 for a map of the best geothermal sites in the continental United States). It meets the electricity needs of about 6 million Americans—a number roughly equal to the

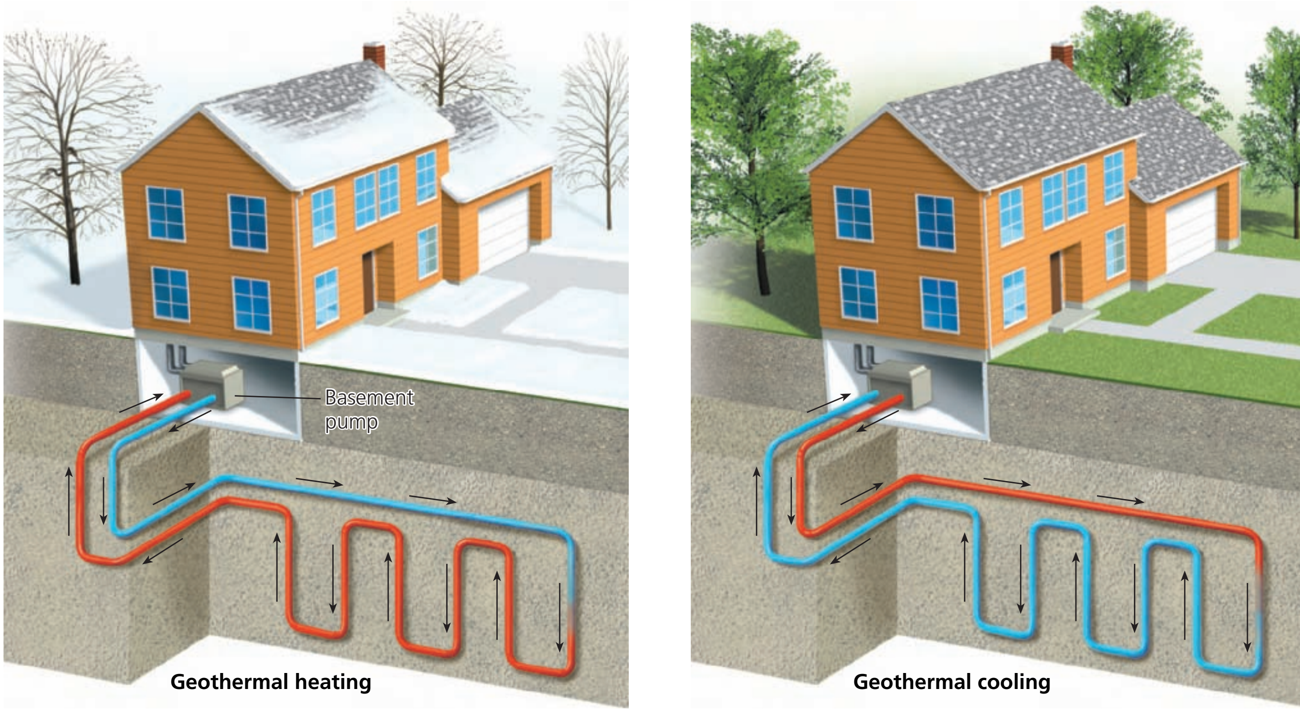


Figure 16-31 **Natural capital:** A geothermal heat pump system can heat or cool a house almost anywhere. It heats the house in winter by transferring heat from the ground into the house (shown here). In the summer, it cools the house by transferring heat from the house to the ground.

combined populations of Los Angeles, California, and Houston, Texas—and supplies almost 6% of California's electricity. But there is a lot of room for growth, because geothermal energy generates just 0.4% of the electricity used in the United States.

Iceland gets almost all of its electricity from hydroelectric and geothermal energy power plants (Figure 16-32). In the Philippines, geothermal plants provide electricity for 19 million people. China has a large potential for geothermal power, which could help the country to reduce its dependence on coal-fired power plants (see Figure 25, p. S54, in Supplement 8 for a map of the world's best geothermal sites).

Geothermal heat storage sites not far below the surface can be tapped by pumping water into them. Then the hot water is pumped to the surface and used to heat

Biophoto/Grenet M. & Soumillard A. PHONE-Auteurs/Peter Arnold, Inc.

Figure 16-32 This geothermal power plant in Iceland produces electricity and heats a nearby spa called the Blue Lagoon.

fluids with low boiling points. This releases vapor that can spin a turbine to generate electricity. So far, such systems are inefficient but scientists are working on ways to improve their efficiency.

Another source of geothermal energy is *hot, dry rock* found 5 or more kilometers (3 or more miles) underground almost everywhere. Water can be injected through wells drilled into this rock. After it absorbs some of the heat, the water is pumped to the surface, used to generate electricity, and then injected back into the earth. According to the U.S. Geological Survey, tapping just 2% of this source of geothermal energy in the United States could produce more than 2,000 times the country's current annual use of electricity.

But digging so deep into the earth's crust is costly. It may also carry the risk of triggering small earthquakes. This possibility led to the cancelling of a major hot rock project in Switzerland in 2009. The high cost could be brought down by more research and improved technology. **GREEN CAREER:** geothermal engineer

Figure 16-33 lists the major advantages and disadvantages of using geothermal energy (**Concept 16-7**). Some analysts see geothermal energy, combined with improvements in energy efficiency, the use of solar cells and wind farms to produce electricity, and the use of natural gas as a temporary bridge fuel, as keys to a more sustainable energy future.

Trade-Offs

Geothermal Energy

Advantages	Disadvantages
Moderate net energy and high efficiency at accessible sites	High cost and low efficiency except at concentrated and accessible sites
Lower CO_2 emissions than fossil fuels	Scarcity of suitable sites
Low cost at favorable sites	Noise and some CO_2 emissions

Figure 16-33 Using geothermal energy for space heating and for producing electricity or high-temperature heat for industrial processes has advantages and disadvantages (**Concept 16-7**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

HOW WOULD YOU VOTE?

Should the country where you live greatly increase its dependence on geothermal energy to provide heat and to produce electricity? Cast your vote online at **www.cengage .com/login**.

16-8 What Are the Advantages and Disadvantages of Using Hydrogen as an Energy Resource?

▶ **CONCEPT 16-8 Hydrogen fuel holds great promise for powering cars and generating electricity, but for it to be environmentally beneficial, we would have to produce it without using fossil fuels.**

Will Hydrogen Save Us?

Hydrogen is the simplest and most abundant chemical element in the universe. The sun produces its energy, which sustains life on the earth, through the nuclear fusion of hydrogen atoms (see Figure 2-9, bottom, p. 43).

Some scientists say that the fuel of the future is hydrogen gas (H_2). In the quest to make it so, most research has been focused on using fuel cells (Figure 16-34) that combine H_2 and oxygen gas (O_2) to produce electricity and water vapor ($2\ H_2 + O_2 \rightarrow 2\ H_2O$ + energy), which is emitted into the atmosphere.

Widespread use of hydrogen as a fuel would eliminate most outdoor air pollution problems that we face today. It would also greatly reduce the threat of projected climate disruption, because using it emits no CO_2—as long as the H_2 is not produced with the use of fossil fuels or nuclear power. Hydrogen also provides more energy per gram than does any other fuel, making it a lightweight fuel ideal for aviation.

GOOD NEWS

So what is the catch? There are three challenges in turning the vision of hydrogen as a fuel into reality. *First*, there is hardly any hydrogen gas (H_2) in the earth's atmosphere, so it must be produced from elemental hydrogen (H), which is chemically locked up in water and in organic compounds such as methane and gasoline. We can produce H_2 by heating water or passing electricity through it; by stripping it from the methane (CH_4) found in natural gas and from gasoline molecules; and through a chemical reaction involving coal, oxygen, and steam. The problem is that it takes energy and money to produce H_2 using these methods. In other words, hydrogen gas is not an energy resource like coal or oil. It is a fuel produced by using other forms of energy, and thus *has a negative net energy yield.* Therefore, it will always take more energy to make it from these sources than the energy we get by burning it as a fuel.

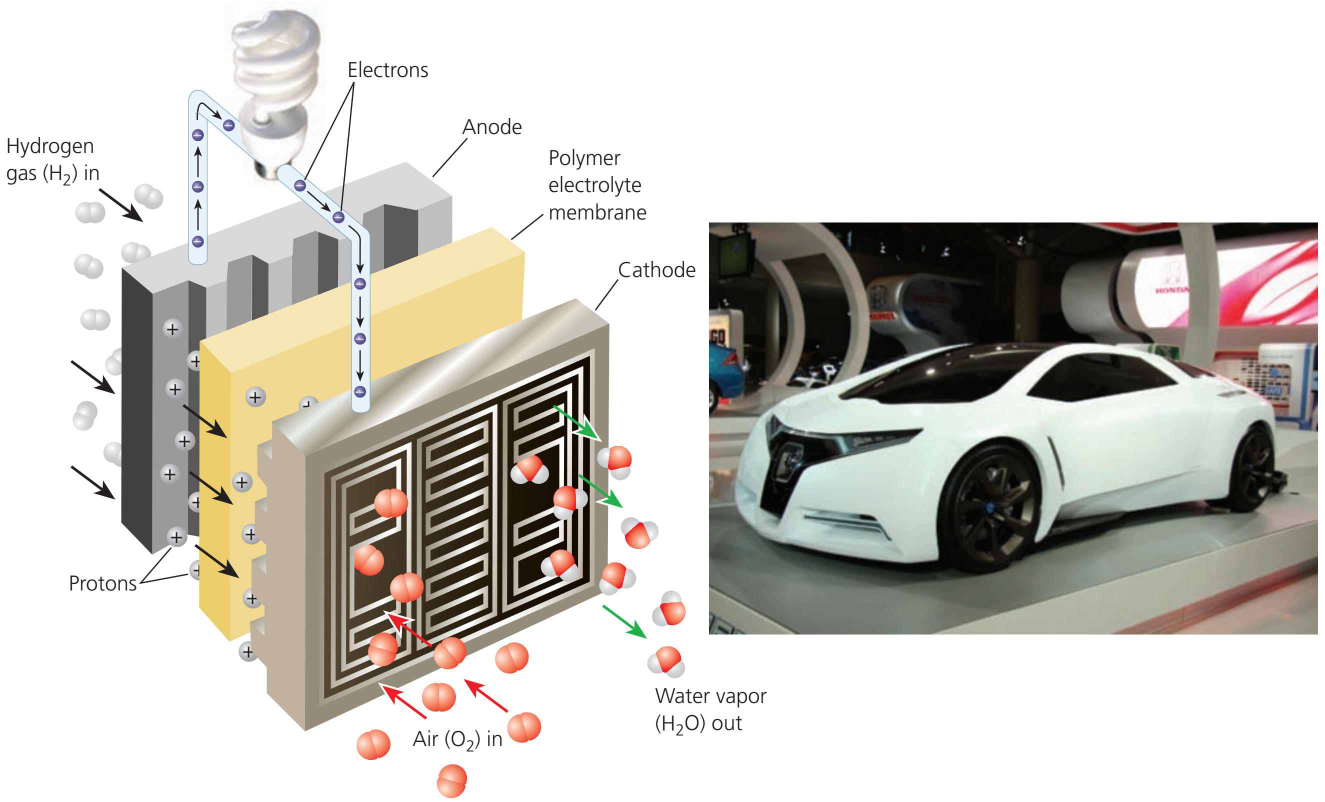


Figure 16-34 A *fuel cell* takes in hydrogen gas and separates the hydrogen atoms' electrons from their protons. The electrons flow through wires to provide electricity, while the protons pass through a membrane and combine with oxygen gas to form water vapor. Note that this process is the reverse of *electrolysis*, the process of passing electricity through water to produce hydrogen fuel. The photo (right) shows a fuel-cell concept car introduced by Honda Motor Company in 2009 at an international car show in Toronto, Canada. All of the exhaust from this car is water vapor.

Second, fuel cells are the best way to use H_2 to produce electricity, but current versions of fuel cells are expensive. However, progress in the development of nanotechnology (see Chapter 14, Science Focus, p. 365, and Supplement 4, p. S16) could lead to cheaper and more efficient fuel cells.

Third, whether or not a hydrogen-based energy system produces less outdoor air pollution and CO_2 than a fossil fuel system depends on how the H_2 is produced. We could use electricity from coal-burning and nuclear power plants to decompose water into H_2 and O_2. But this approach does not avoid the harmful environmental effects associated with using coal and the nuclear fuel cycle. We can also make H_2 from coal and strip it from organic compounds found in fuels such as gasoline. However, according to a 2002 study, using these methods to produce H_2 would add much more CO_2 to the atmosphere per unit of heat generated than does burning carbon-containing fuels directly. If renewable energy sources were used to make H_2, these CO_2 emissions would be avoided.

Hydrogen's negative net energy yield is a serious limitation and means that this fuel will have to be subsidized in order for it to compete in the open marketplace with fuels that have moderate to high net energy yields. However, because hydrogen is such a clean burning fuel, it may eventually be widely used.

For example, in the 1990s, Amory Lovins (**Core Case Study**) and his colleagues at the Rocky Mountain Institute designed a very light, safe, extremely efficient hydrogen-powered car. It is the basis of most prototype hydrogen fuel-cell cars now being tested by major automobile companies (Figure 16-34, right). Some analysts project that fuel-cell cars, running on affordable H_2 produced from natural gas, could be in widespread use by 2030 to 2050. However, in 2009, the U.S. government reduced its research and development support for hydrogen fuel and put more emphasis on wind, direct solar energy, cleaner coal, and nuclear power.

CORE CASE STUDY

Larger, stationary fuel cells could provide electricity and heat for commercial and industrial users. In 2010, Bloom Energy in California began selling fuel-cell stacks, each about the size of a trash dumpster, to power buildings. They use natural gas to provide the hydrogren gas, and the company depends on significant state and federal subsidies to be competitive with producers of electricity from coal-burning plants. In addition, Japan has built a large fuel cell that produces enough electricity to run a small town.

Canada's Toronto-based Stuart Energy is developing a fueling unit about the size of a dishwasher that will allow consumers to use electricity to produce their own H_2 from tap water. The unit could be installed in a garage and used to fuel a hydrogen-powered vehicle overnight. In sunny areas, people could install rooftop panels of solar cells to produce and store H_2 for their cars.

Another promising application is in homes, where a fuel-cell stack about the size of a refrigerator could provide heat, hot water, and electricity. Some Japanese homeowners get their electricity and hot water from such fuel cell units, which produce H_2 from the methane in natural gas. **GREEN CAREER:** hydrogen energy

With all of these possibilities, using taxpayer funds to subsidize H_2 production may still be a good investment, but only if the H_2 is made with electricity produced by low-polluting, renewable sources that emit little or no CO_2 (Science Focus, below).

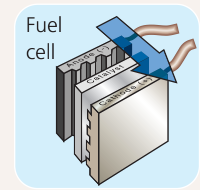
RESEARCH FRONTIER

Developing better and more affordable ways to produce hydrogen from renewable energy resources and practical ways to store and distribute it; see **www.cengage.com/login**.

Figure 16-35 lists the major advantages and disadvantages of using hydrogen as an energy resource (**Concept 16-8**).

Trade-Offs

Hydrogen



Advantages	Disadvantages
Can be produced from plentiful water at some sites	Negative net energy yield
No direct CO_2 emissions if produced from water	CO_2 emissions if produced from carbon-containing compounds
Good substitute for oil	High costs require subsidies
High efficiency (45–65%) in fuel cells	Needs H_2 storage and distribution system

Figure 16-35 Using hydrogen as a fuel for vehicles and for providing heat and electricity has advantages and disadvantages (**Concept 16-8**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

HOW WOULD YOU VOTE?

Do the advantages of producing and burning hydrogen as an energy resource outweigh the disadvantages? Cast your vote online at **www.cengage.com/login**.

SCIENCE FOCUS

The Quest to Make Hydrogen Workable

Scientists are proposing various schemes for producing and storing hydrogen gas (H_2) as fuel. For example, naturally occurring bacteria and algae can produce H_2 by biodegrading almost any organic material in a microbiological fuel cell.

The most likely H_2 production methods will use electricity generated by solar cell power plants, wind farms, and geothermal energy. In 2008, MIT scientists Daniel Nocera and Matthew Kanan developed a catalyst made from inexpensive cobalt and phosphate salts that can split water into hydrogen and oxygen using a fairly small amount of electricity. This could make it affordable to use electricity produced by wind turbines or solar cells to produce H_2 and thus to store in H_2 the energy produced by the wind and sun.

Once produced, H_2 can be stored in a pressurized tank as liquid hydrogen. It can also be stored in solid metal hydride compounds and in sodium borohydride, both of which release H_2 when heated. Scientists are also evaluating ways to store H_2 by coating the surfaces of activated charcoal or carbon nanofibers with it; when heated the coated surfaces release the H_2. Another possibility is to store H_2 inside nanosize glass microspheres that can easily be filled and refilled.

H_2 could also be stored in the hollow tubes of chicken feathers. In 2009, a team of scientists led by chemical engineer Richard Wool estimated that a hydrogen storage tank using chicken feathers could be mass-produced for about $200 per tank. This would also make use of the almost 3 billion tons of chicken feather waste produced each year in the United States. Yet another possibility is the development of *ultracapacitors* that could quickly store large amounts of electrical energy, which would then be used to propel cars or to produce H_2 on demand.

Metal hydrides, sodium borohydride, carbon nanotubes, and glass microspheres containing H_2 will not explode or burn if a vehicle's fuel tank is ruptured in an accident. Thus, H_2 stored in such ways is a much safer fuel than gasoline, diesel fuel, natural gas, and concentrated ethanol. Also, the use of ultralight car bodies would improve fuel efficiency so that large hydrogen fuel tanks would not be needed.

In 2007, engineering professor Jerry Woodall invented a new way to produce hydrogen by exposing pellets of an aluminum-gallium alloy to water. If this process is perfected and proves economically feasible, H_2 could be generated as needed inside a tank about the same size as an average car's gasoline tank.

Critical Thinking

Do you think that governments should subsidize research and development of these and other technologies in order to help make H_2 a workable fuel? Explain.

16-9 How Can We Make the Transition to a More Sustainable Energy Future?

CONCEPT 16-9 We can make the transition to a more sustainable energy future by greatly improving energy efficiency, using a mix of renewable energy resources, and including the environmental costs of energy resources in their market prices.

Choosing Energy Paths

We must develop energy policies with the future in mind, because experience shows that it usually takes at least 50 years and huge investments to phase in new energy alternatives. Creating energy policy involves trying to answer the following questions for *each* energy alternative:

- How much of the energy resource is likely to be available in the near future (the next 25 years) and in the long term (the next 50 years)?
- What is the estimated net energy yield (see Chapter 15, Science Focus, pp. 371–373) for the resource?
- What are the estimated costs for developing, phasing in, and using the resource?
- What government research and development subsidies and tax breaks will be needed to help develop the resource?
- How will dependence on the resource affect national and global economic and military security?
- How vulnerable is the resource to terrorism?
- How will extracting, transporting, and using the resource affect the environment, the earth's climate, and human health? Should we include these harmful costs in the market price of the resource through mechanisms like taxing and reducing environmentally harmful subsidies?
- Does use of the resource produce hazardous, toxic, or radioactive substances that we must safely store for very long periods of time?

In 1977, Amory Lovins (**Core Case Study**) CORE CASE STUDY published his pioneering book, *Soft Energy Paths*. In it, he compared what he called *hard energy paths*—based on increasing use of nonrenewable coal, oil, natural gas, and nuclear energy—to what he called *soft energy paths*—based on improving energy efficiency and increasing the use of various renewable energy resources. At that time, many energy experts criticized Lovins as being unrealistic and not really understanding the energy business. Today, he is one of the world's most prominent energy experts and is helping the world make the transition to the soft energy path that he proposed over three decades ago.

Our energy future—the energy path we choose—depends primarily on what energy resources governments and private companies decide to *promote*, which will be influenced partly by political and economic pressure from citizens and consumers. In considering possible energy futures, scientists and energy experts who have evaluated energy alternatives have come to three general conclusions. First, *there will likely be a gradual shift from large, centralized macropower systems to smaller, decentralized micropower systems* (Figure 16-36, p. 430) such as wind turbines, household solar-cell panels, rooftop solar water heaters, small natural gas turbines, and eventually fuel cells for cars and stationary fuel cells for houses and commercial buildings.

Currently, most countries have a system of centralized, large power plants, refineries, pipelines, and other infrastructure that are vulnerable to disruption from events such as terrorist attacks and natural disasters. For example, in 2005, Hurricane Katrina crippled about 10% of America's oil- and gas-producing wells (see the map in Figure 18, bottom, p. S49, in Supplement 8) and oil refineries in the Gulf of Mexico for more than a year.

This shift from centralized macropower to dispersed micropower would be similar to the computer industry's shift from large, centralized mainframes to increasingly smaller, widely dispersed PCs, laptops, and handheld computers. Such a shift would improve national and economic security, because countries would GOOD NEWS rely on diverse, dispersed, domestic, and renewable energy resources instead of on a smaller number of large power plants that are vulnerable to storm damage and sabotage.

The second general conclusion of experts is that *a combination of greatly improved energy efficiency and the temporary use of natural gas will be the best way to make the transition to a diverse mix of locally available renewable energy resources over the next several decades* (**Concept 16-9**). By using a variety of often locally available renewable energy resources, we would be applying the diversity **principle of sustainability** and not putting all of our "energy eggs" in only one or two baskets. SUSTAINABILITY

The third general conclusion is that *because of their still-abundant supplies and artificially low prices, fossil fuels will continue to be used in large quantities*. This presents two major challenges. One is to find ways to reduce the harmful environmental impacts of widespread fossil fuel use, with special emphasis on reducing outdoor emissions of greenhouse gases and other air pollutants. The other is to find ways to include more of the harmful environmental costs of using fossil fuels

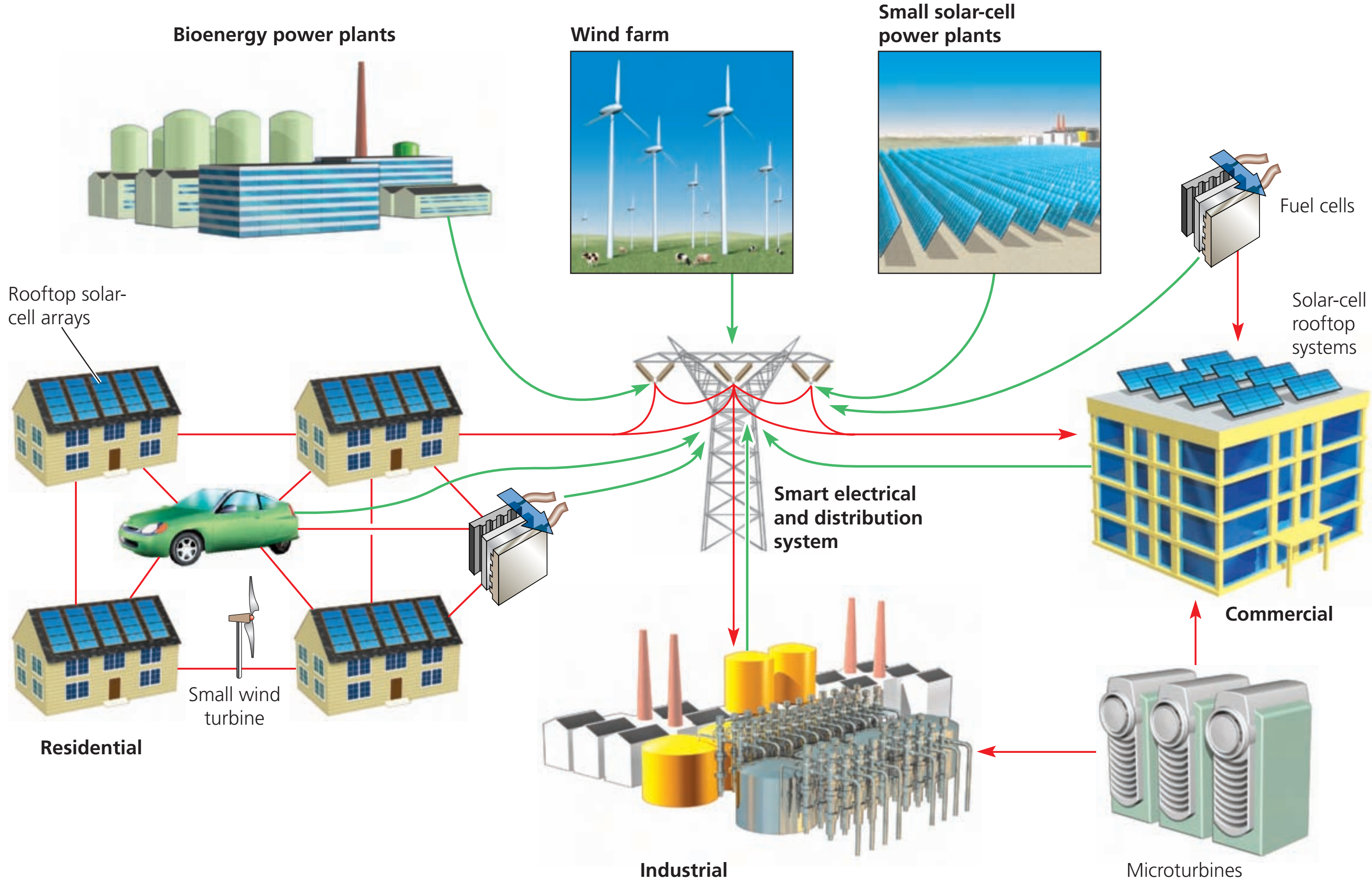


Figure 16-36 **Solutions:** During the next few decades, we will probably shift from dependence on a *centralized macropower system*, based on a few hundred large coal-burning and nuclear power plants to a *decentralized micropower system*, in which electricity is produced by a large number of dispersed, small-scale, local power generating systems. Some of the smaller systems would produce power on site; others would feed the power they produce into a modern electrical distribution system. Over the next few decades, many energy and financial analysts expect a shift to this type of power system, largely based on locally available renewable energy resources. **Question:** Can you think of any disadvantages of a decentralized power system?

in their market prices, as less environmentally harmful alternatives are phased in.

Figure 16-37 summarizes these and other strategies for making the transition to a more sustainable energy future over the next 50 years (**Concept 16-9**). GOOD NEWS

Economics, Politics, and Education Can Help Us Shift to More Sustainable Energy Resources

To most analysts, economics, politics, and consumer education hold the keys to making a shift to more sustainable energy resources. Governments can use three strategies to help stimulate or reduce the short-term and long-term use of a particular energy resource.

First, they can *keep the prices of selected energy resources artificially low to encourage use of those resources*. They do this by providing research and development subsidies, tax breaks, and loan guarantees to encourage the development of those resources, and by enacting regulations that favor them. For decades, this approach has been employed to stimulate the development and use of fossil fuels and nuclear power in the United States as well as in most other more-developed countries. This has created an uneven economic playing field that *encourages* energy waste and rapid depletion of nonrenewable energy resources, while it *discourages* improvements in energy efficiency and the development of a variety of renewable energy resources.

Many energy analysts argue that one of the most important steps that governments can take to level the economic playing field is to phase out the $250–300 billion in annual subsidies and tax breaks now provided worldwide for fossil fuels and nuclear energy—both of which are mature industries that could be left to stand on their own economically. These analysts call for greatly increasing subsidies and tax breaks for developing and using renewable energy and energy-efficiency technologies.

Solutions

Making the Transition to a More Sustainable Energy Future

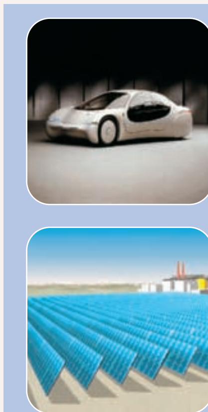
Improve Energy Efficiency

Increase fuel-efficiency standards for vehicles, buildings, and appliances

Provide large tax credits or feebates for buying efficient cars, houses, and appliances

Reward utilities for reducing demand for electricity

Greatly increase energy efficiency research and development



More Renewable Energy

Greatly increase use of renewable energy

Provide large subsidies and tax credits for use of renewable energy

Greatly increase renewable energy research and development

Reduce Pollution and Health Risk

Phase out coal subsidies and tax breaks

Levy taxes on coal and oil use

Phase out nuclear power subsidies, tax breaks, and loan guarantees

Figure 16-37 Energy analysts have made a number of suggestions for helping us make the transition to a more sustainable energy future (**Concept 16-9**). **Questions:** Which five of these solutions do you think are the most important? Why?

However, making such a shift in energy subsidies is difficult because of the immense political and financial power of the fossil fuel and nuclear power industries. They vigorously oppose the loss of their subsidies and tax breaks, as well as any significant increase in subsidies and tax breaks for energy efficiency, which reduces the use of fossil fuels and nuclear power. They also oppose subsidies for competing renewable energy sources.

The *second* major strategy that governments can use is to *keep the prices of selected energy resources artificially high to discourage their use*. They can do this by eliminating existing tax breaks and other subsidies that favor use of the targeted resource, and by enacting restrictive regulations or taxes on its use. Such measures can increase government revenues, encourage improvements in energy efficiency, reduce dependence on imported energy, and decrease the use of energy resources that have limited supplies. To make such changes acceptable to the public, analysts suggest that governments can offset energy taxes by reducing income and payroll taxes and providing an energy safety net for low-income users.

Third, governments can *emphasize consumer education*. Even if governments offer generous financial incentives for energy efficiency and renewable energy use, people will not make such investments if they are uninformed—or misinformed—about the availability, advantages, disadvantages, and hidden environmental costs of various energy resources.

An excellent example of what a government can do to bring about a more sustainable energy mix is the case of Germany. It is the world's most solar-powered nation, with half of the world's installed capacity. Why does cloudy Germany have more solar water heaters and solar cell panels than sunny France and Spain have? There are two main reasons. One is that the German government made the public aware of the environmental benefits of these technologies. The other is that the government provided consumers with substantial economic incentives for using the technologies.

The government did not accomplish this by raising taxes. Instead, it allowed utilities to raise electricity rates slightly on all users to subsidize those who installed solar systems. This arrangement was based on a direct subsidy called a *feed-in tariff*: users installing solar panels get a guaranteed payment for 20 years for each kilowatt of excess energy that they feed into the grid. As a result, when German homeowners and businesses install solar cell systems, they get a guaranteed 8% return on their investments for 20 years. This is a key reason why the German city of Freiburg in the sunnier southern part of Germany relies more on solar energy than most other communities in the world. Seventeen other European nations and more than 20 other nations around the world, including China, have adopted feed-in tariffs.

We have the creativity, wealth, and most of the technology needed to make the transition to a more sustainable energy future within your lifetime. GOOD NEWS Making this transition depends primarily on *education*, *economics*, and *politics*—on how well individuals understand environmental and energy problems and their possible solutions, and on how they vote and then influence their elected officials. People can also vote with their wallets by refusing to buy energy-inefficient and environmentally harmful products and services, and by letting company executives know about their choices. Figure 16-38 (p. 432) lists some ways in which you can contribute to making the transition to a more sustainable energy future.

What Can You Do?

Shifting to More Sustainable Energy Use

- Get an energy audit done for your house or office
- Drive a vehicle that gets at least 15 kilometers per liter (35 miles per gallon)
- Use a carpool to get to work or to school
- Walk, bike, and use mass transit
- Superinsulate your house and plug all air leaks
- Turn off lights, TV sets, computers, and other electronic equipment when they are not in use
- Wash laundry in warm or cold water
- Use passive solar heating
- For cooling, open windows and use ceiling fans or whole-house attic or window fans
- Turn thermostats down in winter and up in summer
- Buy the most energy-efficient home heating and cooling systems, lights, and appliances available
- Turn down the thermostat on water heaters to 43–49°C (110–120°F) and insulate hot water heaters and pipes

Figure 16-38 **Individuals matter:** you can reduce your use and waste of energy. **Questions:** Which three of these items do you think are the most important? Why? Which things in this list do you already do or plan to do?

Here are this chapter's *three big ideas*:

- We should evaluate energy resources on the basis of their potential supplies, how much net useful energy they provide, and the environmental impacts of using them.
- Using a mix of renewable energy sources—especially solar, wind, flowing water, sustainable biofuels, and geothermal energy—can drastically reduce pollution, greenhouse gas emissions, and biodiversity losses.
- Making the transition to a more sustainable energy future will require sharply reducing energy waste, using a mix of environmentally friendly renewable energy resources, and including the harmful environmental costs of energy resources in their market prices.

REVISITING The Rocky Mountain Institute and Sustainability

CORE CASE STUDY

SUSTAINABILITY

By relying mostly on nonrenewable fossil fuels, we violate the three **principles of sustainability** (see back cover), and this has become a serious long-term problem. We depend mostly on nonrenewable energy resources such as oil and coal and not on direct and indirect forms of renewable solar energy. The technologies we use to obtain energy from these nonrenewable resources disrupt the earth's chemical cycles by diverting huge amounts of water, degrading or destroying terrestrial and aquatic ecosystems, and emitting large quantities of greenhouse gases and other air pollutants. Using these technologies also destroys and degrades biodiversity and ecosystem services.

The work of Amory Lovins and the Rocky Mountain Institute, described in the **Core Case Study** that opens this chapter, is all about sustainability. For more than 25 years, the research and consulting done by the institute around the world has helped businesses, governments, and individuals to make the transition to a more sustainable energy future. In choosing soft energy paths as recommended by Lovins, we would be applying the three **principles of sustainability**. This means

- relying much more on direct and indirect forms of solar energy for our electricity, heating and cooling, and other needs,
- recycling and reusing materials and thus reducing wasteful and excessive consumption of energy and matter, and
- mimicking nature's reliance on biodiversity by using a diverse mix of locally and regionally available renewable energy resources.

A transition to renewable energy is inevitable, not because fossil fuel supplies will run out—large reserves of oil, coal, and gas remain in the world—but because the costs and risks of using these supplies will continue to increase relative to renewable energy.

MOHAMED EL-ASHRY

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 398. Describe the work of Amory Lovins at the Rocky Mountain Institute.

2. What is **energy efficiency**? Explain why we can think of energy efficiency as an energy resource. What percentage of the energy used in the United States is unnecessarily wasted? List four widely used energy-wasting technologies. What are the major advantages of reducing energy waste? List three reasons why this source of energy has been neglected.

3. Describe three ways to save energy and money in **(a)** industry, **(b)** transportation, **(c)** new buildings, and **(d)** existing buildings. What is **cogeneration (combined heat and power** or **CHP)**? How could we encourage electric utility companies to reduce their energy waste? What is a smart grid and why is it important?

4. Describe the trends in fuel efficiency in the United States since the 1970s. Explain why the price of gasoline is much higher than what consumers pay at the pump. What is a fee-bate? Distinguish among hybrid, plug-in hybrid, and fuel-cell motor vehicles. Describe the possible connection between wind farms and plug-in hybrid cars. Summarize the search for better batteries and describe two promising developments. What is a living roof? What is the importance of a white or light-colored roof? What is a superinsulated house? Compare the energy efficiency of incandescent, compact fluorescent, and LED lightbulbs. Explain how using compact fluorescent lightbulbs can reduce overall air pollution from toxic mercury. What are green buildings and why are they important? List six ways in which you can save energy where you live. Give three reasons why we waste so much energy.

5. List five advantages of relying more on a variety of renewable energy sources and describe two factors holding back such a transition. Distinguish between a **passive solar heating system** and an **active solar heating system** and discuss the major advantages and disadvantages of such systems for heating buildings. What are three ways to cool houses naturally? Discuss the major advantages and disadvantages of concentrating solar energy to generate high-temperature heat and electricity. What is a **solar cell (photovoltaic** or **PV cell)** and what are the major advantages and disadvantages of using such devices to produce electricity?

6. What are the major advantages and disadvantages of using hydropower? What is the potential for using tides and waves to produce electricity?

7. What is a wind turbine? What is a wind farm? What are the major advantages and disadvantages of using wind to produce electricity? Explain why the United States is the "Saudi Arabia of wind energy." What are the major advantages and disadvantages of burning wood to provide heat and electricity? What are biofuels and what are the major advantages and disadvantages of using biodiesel and ethanol to power motor vehicles? Evaluate the use of corn, sugarcane, and cellulose plants to produce ethanol. Describe the potential for using algae and bacteria to produce gasoline and diesel fuel.

8. What is **geothermal energy** and what are three sources of such energy? What are the major advantages and disadvantages of using geothermal energy as a source of heat and to produce electricity? What are the major advantages and disadvantages of using hydrogen as a fuel to produce electricity and to power motor vehicles?

9. List three general conclusions of energy experts about possible future energy paths for the world. List five major strategies for making the transition to a more sustainable energy future. Describe three roles that governments play in determining which energy resources we use.

10. What are this chapter's *three big ideas*? Describe how the Rocky Mountain Institute applies the three **principles of sustainability** to evaluating and using energy resources.

SUSTAINABILITY

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. Imagine that you live in the Rocky Mountain Institute's building (Figure 16-1), powered mostly by the sun (**Core Case Study**). Do you think that you would have to give up any of the conveniences you now enjoy? If so, what are they? Describe any adjustments you might have to make in your way of living.

CORE CASE STUDY

2. List five ways in which you unnecessarily waste energy during a typical day, and explain how these actions violate the three scientific **principles of sustainability** (see back cover).

SUSTAINABILITY

3. Congratulations! You have won $500,000 to build a more sustainable house of your choice. With the goal of maximizing energy efficiency, what type of house would you build? How large would it be? Where would you locate it? What types of materials would you use? What types of materials would you *not* use? How would you

heat and cool the house? How would you heat water? What types of lighting, stove, refrigerator, washer, and dryer would you use? Which, if any, of these appliances could you do without?

4. A homebuilder installs electric baseboard heat and claims, "It is the cheapest and cleanest way to go." Apply your understanding of the second law of thermodynamics (see Chapter 2, p. 47) and net energy (see Figure 15-3, p. 373) to evaluate this claim.

5. Should buyers of energy-efficient motor vehicles receive large rebates funded by fees levied on gas guzzlers? Explain.

6. Explain why you agree or disagree with the following proposals made by various energy analysts:
   a. We should eliminate government subsidies for all energy alternatives so that all energy providers can compete in a true free-market system.
   b. We should phase out all government tax breaks and other subsidies for conventional fossil fuels (oil, natural gas, and coal), synthetic natural gas and oil, and nuclear power (fission and fusion). We should replace them with subsidies and tax breaks for improving energy efficiency and developing solar, wind, geothermal, hydrogen, and biomass energy alternatives.
   c. We should leave development of solar, wind, and hydrogen energy to private enterprise and it should receive little or no help from the federal government, but nuclear energy and fossil fuels should continue to receive large federal government subsidies.

7. Imagine that you are in charge of the U.S. Department of Energy (or the energy agency in the country where you live). What percentages of your research and development budget will you devote to fossil fuels, nuclear power, renewable energy, and improving energy efficiency? How would you distribute your funds among the various types of renewable energy? Explain your thinking.

8. China is investing 10 times as much as the United States is spending (as a percentage of its gross domestic product) in new, cleaner energy technologies such as electric cars, wind power, and solar energy. Chinese leaders understand that these technologies represent one of the biggest money-making opportunities of this century, and they plan to sell these technologies to the world. Energy analysts and economists call for the United States to launch a massive research and development program to join China in becoming a technological and economic leader in the area of clean energy. Do you agree with this proposal? Explain.

9. Congratulations! You are in charge of the world. List the five most important features of your energy policy.

10. List two questions that you would like to have answered as a result of reading this chapter.

ECOLOGICAL FOOTPRINT ANALYSIS

Make calculations to fill in the missing data in this table. Show all calculations. (1 liter = 0.265 gallon; 1 kilogram = 2.20 pounds; 1 hectare = 10,000 square meters = 2.47 acres) Then answer the questions that follow this table.

EPA Size Class/ Model	Compact Honda Civic Hybrid	Midsize Car Toyota Camry Hybrid	Sports Utility Vehicle (SUV) Hummer H3
Combined highway and city fuel efficiency in kpl (mpg)	17.8 (42.0)	14.4 (34.0)	6.40 (15.0)
Liters (gallons) of gasoline consumed per year, assuming an average mileage of 19,300 kilometers (12,000 miles)			
Kilograms (pounds) of CO_2 produced per year, assuming that the combustion of gasoline releases 2.3 kilograms per liter (19 pounds per gallon)			
Hectares (acres) of tropical rain forest needed to take up the CO_2 produced per year, assuming that the uptake of an undisturbed forest is 0.5 kilograms of CO_2 per square meter			

Source: www.fueleconomy.gov/feg/findacar.htm

1. About how many times as much CO_2 per year is produced by the SUV as is produced by the compact car?
2. About how many times as much CO_2 per year is produced by the SUV as is produced by the midsize car?
3. How many hectares (acres) of tropical rain forest are needed to take up the CO_2 produced annually by 1 million SUVs?
4. How many hectares (acres) of tropical rain forest are needed to take up the CO_2 produced annually by 1 million midsize cars?
5. How many hectares (acres) of tropical rain forest are needed to take up the CO_2 produced annually by 1 million compact cars?

LEARNING ONLINE

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17 Environmental Hazards and Human Health

CORE CASE STUDY Are Baby Bottles and Food Cans Safe to Use? The BPA Controversy

In the human body, very low levels of chemicals called *hormones* control sexual reproduction, growth, development, learning ability, and behavior. Scientists have discovered that certain pesticides and other synthetic chemicals can act as hormone imposters that may impair reproductive systems and sexual development or cause various physical and behavioral disorders.

Some of these *hormone mimics* are chemically similar to female sex hormones called *estrogens*. In males, excess levels of female hormones can cause feminization, smaller penises, lower sperm counts, and the presence of both male and female sex organs (hermaphroditism).

A widely used estrogen mimic is bisphenol A (BPA). It is a chemical building block in certain hardened plastics (especially shatter-proof polycarbonate) that are used in a variety of products including baby bottles (Figure 17-1) and sipping cups, reusable water bottles, sports drink and juice bottles, microwave dishes, and food storage containers. BPA is also used in the plastic resins that line nearly all food and soft drink cans. In 2009, Consumer Reports product testers found BPA in the contents of many leading brands of canned foods such as soups, juices, tuna, and green beans.

In another 2009 study, scientists confirmed that certain containers do release BPA into liquids stored in them, even when they are not heated, according to lead researcher Karin Michels of Harvard Medical School. In the experiment, 77 students spent a week drinking only out of stainless steel bottles to minimize their BPA exposure. They then spent the next week drinking their cold liquids from polycarbonate water bottles. During that second week, BPA levels in their urine increased by 69%.

Another 2009 study challenged BPA manufacturers' claims that BPA breaks down rapidly and is quickly eliminated from the human body. Researchers studied data from more than 1,600 Americans and found that some BPA remains in the body for at least 24 hours after being ingested.

A 2007 study by the Centers for Disease Control and Prevention (CDC) indicated that 93% of Americans over the age of 6 had trace levels of BPA in their urine above the current threshold level set by the U.S. Environmental Protection Agency (EPA). The CDC study also found that children and adolescents had higher BPA levels than adults had. There is scientific controversy over whether exposure to such trace amounts of BPA and other hormone imposters poses a serious threat to human health, especially for fetuses and infants.

This raises a number of important questions: How do scientists determine the potential harm from exposure to various chemicals? How serious is the risk of harm from a particular chemical compared to other risks? What should government health and regulatory officials do if there is preliminary but not conclusive evidence of harm?

In this chapter, we will look at how scientists try to answer these questions about our exposure to chemicals. We also consider questions about health threats from disease-causing bacteria, viruses, and protozoa, and from other hazards that kill millions of people each year.

Anyka/Shutterstock

Figure 17-1 There is concern that bisphenol A (BPA), an estrogen mimic, can leach out of polycarbonate baby bottles, especially when they are warmed, microwaved, or used to hold acidic juices. In 2008, Canada became the first country to classify BPA as a toxic substance and announced that it would ban its use in baby bottles. Some manufacturers are no longer using polycarbonate plastic in baby bottles, in sipping cups, or in the plastic lining of baby formula cans. But almost all food and soft drink cans are lined with a plastic resin that some researchers believe can release BPA into the contents of the cans.

Key Questions and Concepts

17-1 What major health hazards do we face?

CONCEPT 17-1 We face health hazards from biological, chemical, physical, and cultural factors, and from the lifestyle choices we make.

17-2 What types of biological hazards do we face?

CONCEPT 17-2 The most serious biological hazards we face are infectious diseases such as flu, AIDS, tuberculosis, diarrheal diseases, and malaria.

17-3 What types of chemical hazards do we face?

CONCEPT 17-3 There is growing concern about chemicals in the environment that can cause cancers and birth defects, and disrupt the human immune, nervous, and endocrine systems.

17-4 How can we evaluate chemical hazards?

CONCEPT 17-4A Scientists use live laboratory animals, case reports of poisonings, and epidemiological studies to estimate the toxicity of chemicals, but these methods have limitations.

CONCEPT 17-4B Many health scientists call for much greater emphasis on pollution prevention to reduce our exposure to potentially harmful chemicals.

17-5 How do we perceive risks and how can we avoid the worst of them?

CONCEPT 17-5 We can reduce the major risks we face by becoming informed, thinking critically about risks, and making careful choices.

Note: Supplements 2 (p. S3), 4 (p. S11), and 8 (p. S30) can be used with this chapter.

The dose makes the poison.

PARACELSUS, 1540

17-1 What Major Health Hazards Do We Face?

▶ **CONCEPT 17-1 We face health hazards from biological, chemical, physical, and cultural factors, and from the lifestyle choices we make.**

Risks Are Usually Expressed as Probabilities

A **risk** is the *probability* of suffering harm from a hazard that can cause injury, disease, death, economic loss, or damage. It is usually expressed as a mathematical statement about how likely it is that a harm will be suffered from a hazard. Scientists often state probability in terms such as "The lifetime probability of developing lung cancer from smoking one pack of cigarettes per day is 1 in 250." This means that 1 of every 250 people who smoke a pack of cigarettes every day will likely develop lung cancer over a typical lifetime (usually considered to be 70 years). Probability can also be expressed as a percentage, as in a 30% chance of rain.

It is important to distinguish between *possibility* and *probability*. When we say that it is *possible* that a smoker can get lung cancer, we are saying that this event could happen. *Probability* gives us an estimate of the likelihood of such an event.

Risk assessment is the process of using statistical methods to estimate how much harm a particular hazard can cause to human health or to the environment. It helps us to estimate the probability of a risk, compare it with the probability of other risks, and establish priorities for avoiding or managing risks. **Risk management** involves deciding whether or how to reduce a particular risk to a certain level and at what cost. Figure 17-2 summarizes how risks are assessed and managed.

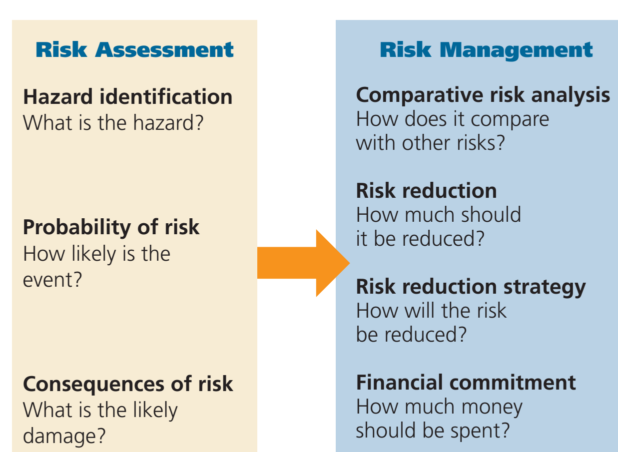

Figure 17-2 Science: Risk assessment and risk management are used to estimate the seriousness of various risks and how to reduce such risks. **Question:** What is an example of how you have applied this process in your daily living?

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. GOOD NEWS refers to good news about the environmental challenges we face.

A major problem with risk management is that most people are not good at understanding and comparing risks. Because of sensational news coverage about the latest scare, many people worry about the highly unlikely possibility of minor risks, such as dying from a shark attack, and ignore the significant probability of harm from major risks, such as dying from a heart attack—the single leading cause of death in the United States. Thus, educating people and members of the news media about the meaning of risk assessments and about how to make risk comparisons is an important priority.

We Face Many Types of Hazards

All of us take risks every day. Examples include choosing to drive or ride in a car through heavy traffic; talking on a phone or texting while driving; eating foods with a high cholesterol or fat content that contributes to heart attacks, which kill far more people each year than any other risk; drinking alcohol; smoking or being in an enclosed space with a smoker; lying out in the sun or going to a tanning parlor, which increases the risk of getting skin cancer; and living in a hurricane-prone area. The key questions are *how serious are the risks we face* and *do the benefits of certain activities outweigh the risks?*

We can suffer harm from five major types of hazards (**Concept 17-1**):

- *Biological hazards* from more than 1,400 pathogens that can infect humans. A **pathogen** is an organism that can cause disease in another organism. Examples are bacteria, viruses, parasites, protozoa, and fungi.
- *Chemical hazards* from harmful chemicals in air, water, soil, food, and human-made products. (**Core Case Study**) CORE CASE STUDY
- *Natural hazards* such as fire, earthquakes, volcanic eruptions, floods, and storms.
- *Cultural hazards* such as unsafe working conditions, unsafe highways, criminal assault, and poverty.
- *Lifestyle choices* such as smoking, making poor food choices, drinking too much alcohol, and having unsafe sex.

THINKING ABOUT
Hazards

Think of a hazard from each of these categories that you may have faced recently. Which one was the most threatening?

17-2 What Types of Biological Hazards Do We Face?

CONCEPT 17-2 The most serious biological hazards we face are infectious diseases such as flu, AIDS, tuberculosis, diarrheal diseases, and malaria.

Some Diseases Can Spread from One Person to Another

An **infectious disease** is caused when a pathogen such as a bacterium, virus, or parasite invades the body and multiplies in its cells and tissues. Some examples are flu, malaria, tuberculosis, and measles. A *bacterial disease* such as tuberculosis spreads as the bacteria multiply. A *viral disease* such as flu or HIV spreads as viruses take over a cell's genetic mechanisms to copy themselves. A **transmissible disease** (also called a *contagious* or *communicable disease*) is an infectious disease that can be transmitted from one person to another. Examples are flu, tuberculosis, and measles.

A **nontransmissible disease** is caused by something other than a living organism and does not spread from one person to another. Such diseases tend to develop slowly and have multiple causes. They include cardiovascular (heart and blood vessel) diseases, most cancers, asthma, diabetes, and malnutrition. As average life expectancy increases, people are more likely to suffer and die from nontransmissible diseases such as cardiovascular diseases and cancers.

In 1900, infectious disease was the leading cause of death in the world and in the United States. Since then, and especially since 1950, the incidences of infectious diseases and the death rates from such diseases have been greatly reduced. GOOD NEWS This has been achieved mostly by a combination of better health care, better sanitation, the use of antibiotics to treat infectious diseases caused by bacteria, and the development of vaccines to prevent the spread of some viral diseases. As a result, average life expectancy has increased in most countries. The leading cause of death is now nontransmissible cardiovascular disease, and the percentage of people dying from cancers is increasing in all countries.

Infectious Diseases Are Still Major Health Threats

Despite the shift in risk levels from transmissible to nontransmissible diseases, infectious diseases remain as serious health threats, especially in less-developed countries. Figure 17-3 shows major pathways on which infectious disease organisms can enter the human body. Such dis-

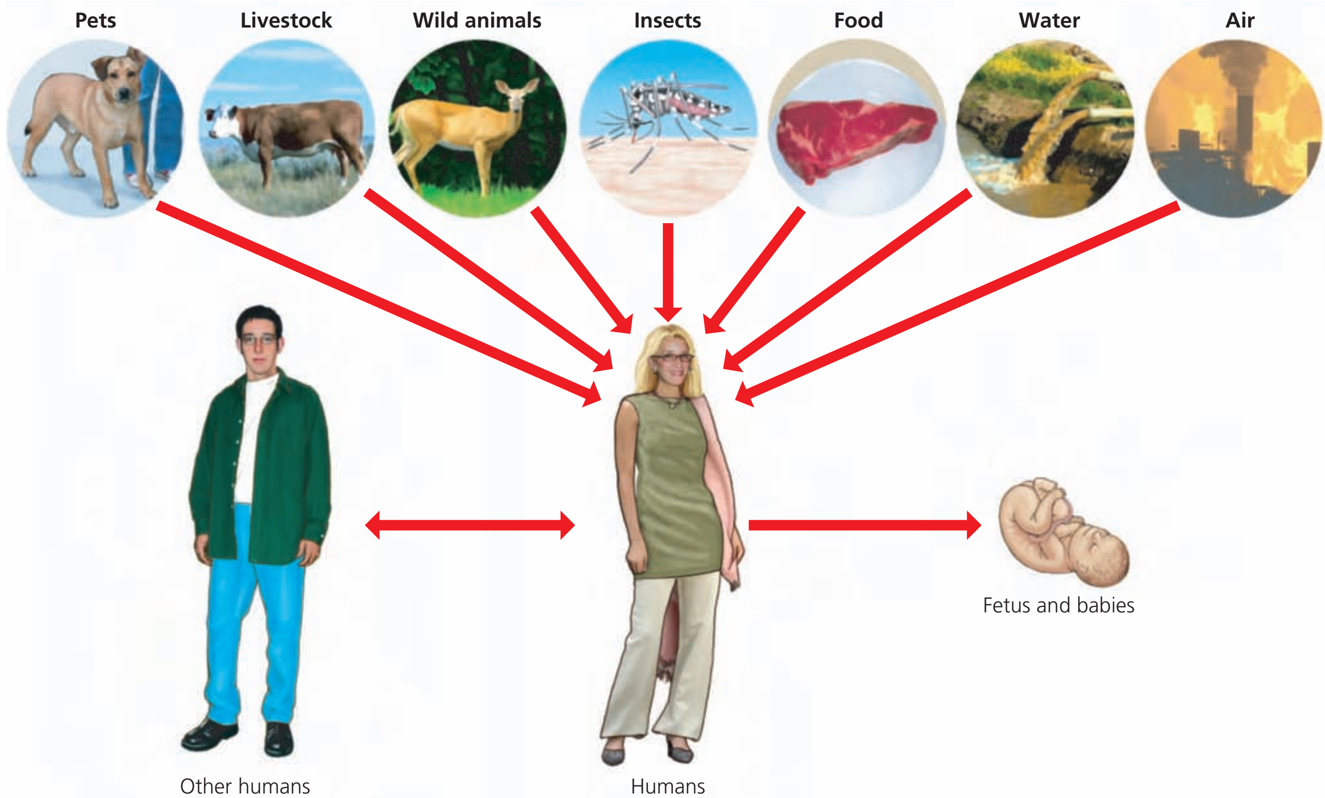

Figure 17-3 **Science:** There are a number of pathways on which infectious disease organisms can enter the human body. **Question:** Can you think of other pathways not shown here?

eases can then be spread through air, water, food, and body fluids such as feces, urine, blood, and mucus droplets sprayed by sneezing and coughing.

A large-scale outbreak of an infectious disease in an area or a country is called an *epidemic*. A global epidemic such as tuberculosis or AIDS is called a *pandemic*.

Figure 17-4 shows the annual death toll from the world's seven deadliest infectious diseases (**Concept 17-2**). The World Health Organization (WHO) is developing a Global Health Atlas, which contains a database and maps based on health statistics, including the incidence of major infectious diseases in the world's countries (see **http://www.who.int/GlobalAtlas/**).

One reason why infectious disease is still a serious threat is that many disease-carrying bacteria have developed *genetic resistance* to widely used antibiotics (Science Focus, p. 440). Also, many disease-transmitting species of insects such as mosquitoes have become immune to widely used pesticides such as DDT that once helped to control their populations.

■ CASE STUDY
The Growing Global Threat from Tuberculosis

Since 1990, one of the world's most underreported stories has been the rapid spread of tuberculosis (TB), an extremely contagious bacterial infection of the lungs. One of every three persons on the planet is infected with the TB bacterium and one in ten of them will eventually become sick with active TB.

Many TB-infected people do not appear to be sick, and about half of them do not know they are infected. Left untreated, each person with active TB typically infects a number of other people. Without treatment,

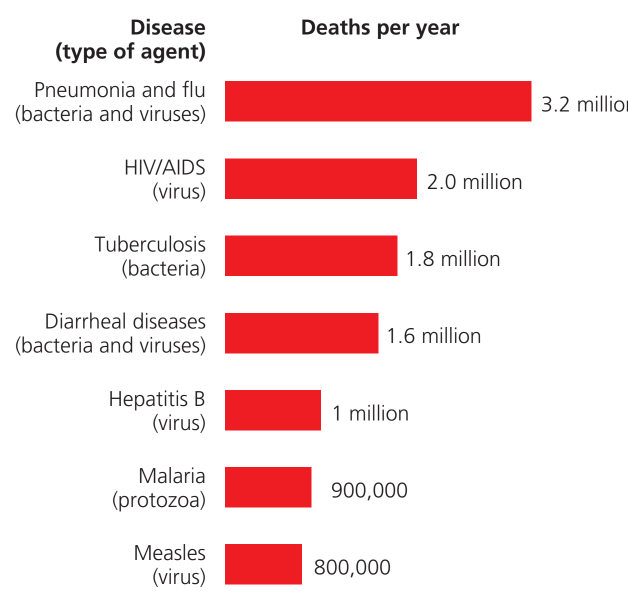

Figure 17-4 *Global outlook:* The World Health Organization estimates that each year, the world's seven deadliest infectious diseases kill 11.3 million people—most of them poor people in less-developed countries (**Concept 17-2**). This averages about 31,000 mostly preventable deaths every day—roughly the same as wiping out everyone in the U.S. states of Massachusetts and Alabama or all the people in Delhi, India, each year. **Question:** How many people, on average, die prematurely from these diseases every hour? (Data from the World Health Organization, 2007)

SCIENCE FOCUS

Genetic Resistance to Antibiotics Is Increasing

Antibiotics are chemicals that can kill bacteria, but not viruses. We risk falling behind in our efforts to prevent infectious bacterial diseases because of the astounding reproductive rate of bacteria, some of which can produce well over 16 million offspring in 24 hours. This allows bacteria to quickly become *genetically resistant* to an increasing number of antibiotics through natural selection (see Figure 4-7, p. 87).

Other factors play key roles in fostering such genetic resistance. One is the spread of bacteria around the globe by human travel and international trade. Another is the overuse of pesticides, which increases populations of pesticide-resistant insects and other carriers of bacterial diseases. In addition, some drug-resistant bacteria can quickly transfer their resistance to nonresistant bacteria by exchanging genetic material.

Yet another factor is overuse of antibiotics for colds, flu, and sore throats, many of which are viral diseases that cannot be treated with antibiotics. In many countries, antibiotics are available without a prescription, which promotes unnecessary use. Bacterial resistance to some antibiotics has increased because of their widespread use in livestock and dairy animals to control disease and to promote growth. In addition, the growing use of antibacterial hand soaps and other cleansers is probably promoting genetic resistance in bacteria as well.

As a result of these factors acting together, every major disease-causing bacterium now has strains that resist at least one of the roughly 160 antibiotics used to treat bacterial infections such as tuberculosis (Figure 17-5). Each year, at least 80,000 people die from infections they picked up while staying in U.S. hospitals, and genetic resistance to antibiotics plays a role in these deaths, according to the U.S. Centers for Disease Control and Prevention (CDC). This serious problem is much worse in hospitals in many other countries.

A bacterium known as *methicillin-resistant staphylococcus aureus*, commonly known as MRSA (pronounced "mersa"), has become resistant to most common antibiotics. This staph infection first appears on the skin as a red, swollen, sometimes painful pimple or boil. Many victims think they have a spider bite that will not heal. MRSA can cause a vicious type of pneumonia, flesh-eating wounds, and a quick death if it gets into the bloodstream.

This staph germ typically thrives on the body (mostly on the skin and in the nose) in health-care settings where people are being treated for open wounds. But in recent years, it has been increasingly found in the general population. It can be picked up on playgrounds, in meeting rooms, and in gyms. It can be spread through skin contact, unsanitary use of tattoo needles, and contact with poorly laundered clothing and shared items such as towels. Also, farm workers and meat processing workers have acquired MRSA from handling the carcasses of livestock animals whose feed contained antibiotics. In 2007, the CDC reported that more than 94,000 people in the United States had MRSA infections, which contributed to the premature deaths of almost 18,600 people.

Critical Thinking

What are three things that we could do to slow the rate at which disease-causing organisms develop resistance to antibiotics?

about half of the people with active TB die from bacterial destruction of their lung tissue (Figure 17-5).

According to the WHO, this highly infectious bacterial disease strikes about 9 million people per year and kills 1.8 million—about 84% of them in less-developed countries. On average, someone dies of TB every 20 seconds.

Several factors account for the recent spread of TB. One is that there are too few TB screening and control programs, especially in less-developed countries, where 95% of the new cases occur. A second problem is that most strains of the TB bacterium have developed genetic resistance to the majority of the effective antibiotics (Science Focus, above). Also, population growth, urbanization, and air travel have greatly increased person-to-person contacts, and TB is spreading faster in areas where large numbers of poor people crowd together. A person with active TB might infect several people during a single bus or plane ride.

In addition, AIDS (see Case Study, p. 443) greatly weakens its victims' immune systems, making AIDS patients highly susceptible to unchecked growth of the TB bacteria. As a result, people with AIDS are 30 to 50 times more likely to develop active TB. The WHO reported in 2009 that one of every four deaths from TB was an AIDS victim.

SIU/Peter Arnold, Inc.

Figure 17-5 The colorized red areas in this chest X-ray show where TB bacteria have destroyed lung tissue.

Slowing the spread of the disease requires early identification and treatment of people with active TB, especially those with a chronic cough, which is the primary way in which the disease is spread from person to person. Treatment with a combination of four inexpensive drugs can cure 90% of individuals with active TB. To be effective, the drugs must be taken every day for 6–9 months. Because the symptoms disappear after a few weeks, many patients, thinking they are cured, stop taking the drugs, allowing the disease to recur in drug-resistant forms and to spread to other people.

In recent years, a deadly and apparently incurable form of tuberculosis, known as *multi-drug resistant TB* has been increasing, especially in parts of Africa, China, India, and Russia. According to the WHO, this drug-resistant form of TB is now found in 49 countries, and each year, there are about 490,000 new cases and 120,000 deaths. Because this disease cannot be treated effectively with antibiotics, victims must be permanently isolated from the rest of society. Victims also pose a threat to health workers. Potentially every person who takes a train, bus, or a plane and is exposed to undiagnosed carriers of this form of TB is also threatened.

Most people with active TB live in the world's poorest countries such as Haiti, and many of them cannot afford treatments. Thus, there is little financial incentive for large drug companies to invest a great deal of money on developing drugs to treat the disease. However, efforts to develop better antibiotics are being undertaken by governments and private groups such as the Bill and Melinda Gates Foundation. Also, researchers are developing new and easier ways to detect TB in its victims—a key improvement that could save millions of lives (Individuals Matter, below).

GOOD NEWS

THINKING ABOUT
Dealing with Tuberculosis

If you were a public health official, what would you do to try to slow the spread of tuberculosis?

Viral Diseases and Parasites Kill Large Numbers of People

Viruses evolve quickly, are not affected by antibiotics, and can kill large numbers of people. The biggest killer is the *influenza* or *flu* virus (**Concept 17-2**), which is transmitted by the body fluids or airborne emissions of an infected person. Easily transmitted and especially potent flu viruses could spread around the world in a pandemic that could kill millions of people in only a few months. **Explore More:** Go to a Science Focus at **www.cengage.com/login** to learn more about the nightmarish effects of a possible global flu epidemic.

The second biggest viral killer is the *human immunodeficiency virus* (HIV) (see Case Study, p. 443). On a global scale, HIV infects about 2.5 million people each year, and the complications resulting from AIDS kill about 2 million people annually.

The third largest viral killer is the *hepatitis B virus* (HBV), which damages the liver and kills about a million people each year. Like HIV, it is transmitted by unsafe sex, sharing of hypodermic needles by drug users, infected mothers who pass the virus to their children before or during birth, and exposure to infected blood.

In recent years, several other previously unknown diseases have received widespread media coverage. They are examples of **emergent diseases** that were newly discovered or were absent in human populations for at least 20 years. One is the *West Nile virus*, which is transmitted to humans by the bite of a common mosquito that has been infected by feeding on birds that carry the virus. Since 1992 when this virus emerged in the United States, it has spread from coast to coast. Between 1999 and 2009, it caused severe illness in more than 23,500 people, including viral encephalitis, an acute infection of the brain and spinal cord, and viral meningitis, an infection in the membranes that cover the brain and spinal cord. It has killed more than 1,000 people. Fortunately, the chance of being infected and killed by

INDIVIDUALS MATTER

Three College Students Have Saved Thousands of Lives

When Hersh Tapadia, Daniel Jeck, and Pavak Shah were seniors in the engineering school of North Carolina State University, they recognized a problem that was contributing to the deaths of many thousands of tuberculosis (TB) victims. For their senior project, they chose to tackle this problem, and as a result, they have prevented an untold number of TB fatalities.

If TB is diagnosed early enough, a victim can receive treatment and go on to live a healthy life. However, early diagnosis requires testing a sample of a patient's feces. Many health clinics in poor countries have to send their patients' samples to labs for analysis, which can take months. Patients often die waiting for lab results, and in most cases, they have spread the disease to other people. Even worse, international health officials estimate that perhaps 40% of TB cases are missed because of outdated, inadequate methods of diagnosis.

Enter the three engineering students who developed a relatively simple device to detect TB. When a microscope slide with a sample from a patient is inserted into the device, any TB bacteria that are present glow white against a black background. This allows health-care workers with little training to detect TB in seconds at a cost of less than a dollar per case.

The three inventors are working on adapting this device so that it can be used to diagnose malaria, AIDS, and other infectious diseases. They plan to create a business that will manufacture and sell the devices. In this way, they hope to make a living by helping millions of people to live longer and healthier lives.

GOOD NEWS

SCIENCE FOCUS

Ecological Medicine: Tracking How Humans Can Get Infectious Diseases from Other Animals

There are increasing occurrences of infectious diseases that move from one animal species to another and from wild and domesticated animal species to humans. Examples of such diseases and their origins include:

- avian flu—moved from wild birds to chickens to humans
- Lyme disease—moved from wild deer and mice through ticks to humans
- HIV—moved from chimpanzees to humans (see Case Study at right)
- Plague—moved from rats to rat fleas to humans
- Hepatitis B and Dengue fever—moved from apes to humans
- African sleeping sicknesses—moved from wild and domestic grazing animals to humans

Most people do not realize that pets such as rabbits, hamsters and other "pocket pets," as well as turtles can transfer various infectious diseases to humans. A 2008 study Peter Daszak and other scientists found that about 60% of 325 diseases emerging between 1940 to 2004 were transmitted from animals to humans, and the majority of those came from wild animals.

Ecological medicine is a new interdisciplinary field devoted to tracking down these unwanted connections between animals and humans. For example, immunologist Nathan Wolfe of Stanford University and his colleagues have spent time in the wilds of Africa watching wild animals and the people who come in contact with them. They also examine these people for signs of microorganisms that they might have picked up in their interactions with animals.

The scientists have identified several human practices that encourage the spread of diseases among animals and people. One is the clearing or fragmenting of forests to make way for settlements, farms, and growing cities. For example, in the United States, the push of suburban development into forests has increased the chances of many suburbanites becoming infected with debilitating Lyme disease. The bacterium that causes this disease lives in the bodies of deer and white mice and is passed between these two animals and to humans by certain types of ticks. Left untreated, Lyme disease can cause debilitating arthritis, heart disease, and nervous disorders.

Expanding suburbs into increasingly fragmented woodland areas has also led to greatly reduced populations of foxes and wildcats, which had kept down populations of the white-footed mouse that carries the Lyme bacterium. The result: white-footed mouse and tick populations have exploded and more people are becoming infected with Lyme disease.

Cutting down tropical forests has displaced fruit bats, causing them to visit both orchards and the fruit trees that grow in people's yards. Bats can be infected with viruses that they can then transfer to humans. In 2007, for example, villagers in the Congo shot thousands of fruit bats. Then, 360 people who came in contact with the blood from bat corpses became infected with the deadly Ebola virus and 168 of them died.

In 1998, feces and urine from fruit bats feeding on fruit trees in Malaysia dropped into pig feeding troughs below. This infected the pigs with the lethal Nipah virus, which then infected pig farmers and their families. Within a few weeks, almost half of those infected with the virus died from encephalitis.

The practice of hunting wild game for food has also increased the spread of infectious diseases. In parts of Africa and Asia, local people who kill monkeys and other animals for bush meat (see Figure 9-18, p. 207) come in regular contact with primate blood and can be exposed to a simian (ape or monkey) strain of the HIV virus that causes AIDS.

Another important factor in the spread of these diseases is the legal and illegal international trade in wild species. According to the U.S. Fish and Wildlife Service, more than 200 million wild animals—from kangaroos to iguanas to tropical fish—are legally imported into the United States each year with little quarantining or screening for disease. Most are imported for commercial sale in the pet trade. In addition, countless live animals as well as bush meat and animal parts are smuggled illegally across international borders each year. A backpack carried off a flight from Nigeria may contain bush meat that could harbor the lethal Ebola virus. Salted duck eggs from South Korea could carry the deadly bird flu virus. Smuggled exotic birds could harbor various diseases that can jump to humans.

The U.S. government employs only 120 full-time workers to inspect the millions of wild animals arriving legally—and to intercept those arriving illegally—each year at 39 airports and border crossings. This small group of overwhelmed inspectors is responsible for screening some 317 million automobile passengers, 86 million airplane passengers, and 11 million seaborne containers entering the United States annually. In 2009, researchers Katherine Smith and Peter Daszak reported that this faulty system poses a serious threat to ecosystems (from invasive species) and to human health.

Industrialized meat production is another major factor in the spread of food-borne infectious diseases to humans. For example, a deadly form of *E. coli* bacteria sometimes spreads from livestock to humans when people eat meat contaminated by animal manure. Salmonella bacteria found on animal hides and in poorly processed, contaminated meat also can cause food-borne disease.

A number of scientists are also looking at the connections between projected climate change from atmospheric warming and the spread of infectious diseases such as malaria, meningitis, dengue fever, West Nile virus, and cholera. Warmer temperatures will likely allow these diseases to spread more easily from tropical to temperate areas. **GREEN CAREER:** ecological medicine

Critical Thinking

Do you think that air travelers should be more carefully monitored in the face of threats such as the Ebola and bird flu viruses? Explain.

West Nile virus is low (about 1 in 2,500). For example, in 2008, the virus killed 44 people, while common flu killed about 36,000 people in the United States.

Scientists believe that more than half of all infectious diseases throughout history were originally transmitted to humans from wild or domesticated animals. Avian flu, HIV/AIDS, and West Nile virus all fall in this category. The development of such diseases has spurred the growth of the relatively new field of *ecological medicine* (Science Focus, above).

RESEARCH FRONTIER

Ecological medicine; see **www.cengage.com/login**.

Health officials are concerned about the spread of West Nile virus, the newest avian flu, and other emergent diseases. But in terms of annual infection rates and deaths, the three most dangerous viruses by far are still flu, HIV, and HBV (**Concept 17-2**).

GOOD NEWS

You can greatly reduce your chances of getting infectious diseases by practicing good old-fashioned hygiene. Wash your hands thoroughly and frequently, avoid touching your face, and stay away from people who have flu or other viral diseases. However, it is not necessary to use antibacterial soaps, liquids, and sprays in order to avoid infectious diseases. Some health officials warn that these products may be doing more harm than good, because they can contribute to genetic resistance in infectious bacteria (Science Focus, p. 440). Plain hand soap will do the job.

Yet another growing health hazard is infectious diseases caused by parasites, especially malaria (see second Case Study below).

■ **CASE STUDY**

The Global HIV/AIDS Epidemic

The global spread of *acquired immune deficiency syndrome (AIDS),* caused by infection with the *human immunodeficiency virus (HIV)*, is a major global health threat. The virus itself is not deadly, but it cripples the immune system and leaves the body vulnerable to infections such as TB and rare forms of cancer such as *Kaposi's sarcoma*. The virus is transmitted from one person to another through unsafe sex, the sharing of hypodermic needles by drug users, infected mothers who pass the virus on to their children before or during birth, and exposure to infected blood.

Since the HIV virus was identified in 1981, this viral infection has spread around the globe. According to the WHO, in 2008, a total of about 33 million people worldwide (more than 1 million in the United States) were living with HIV. About 72% of them were in African countries located south of the Sahara Desert (sub-Saharan Africa). In 2008 there were about 2.7 million new cases of AIDS—an average of about 7,400 new cases per day—half of them in people between the ages of 15 and 24. Some 37,000 of these cases occurred in the United States.

Treatment that includes combinations of expensive antiviral drugs can slow the progress of AIDS, but they are expensive. With such drugs, a person with AIDS, on average, can expect to live about 24 years after being infected at a cost of about $25,200 a year. Such drugs cost too much for most AIDS victims living in less-developed countries where AIDS infections are widespread.

It takes an average of 10 to 11 years for an HIV infection to progress to AIDS for people who do not take such antiviral drugs. This long incubation period means that infected people often spread the virus for a number of years without knowing they are infected. Currently, there is no cure for HIV or AIDS. Those who get AIDS will almost certainly die from it, unless something else kills them.

Between 1981 and 2008, more than 25 million people worldwide—roughly the number of people living in the U.S. states of Texas and Vermont—died of AIDS-related diseases. During this same period, there were more than 500,000 AIDS-related deaths in the United States—a death toll equivalent to wiping out the population of Raleigh, North Carolina (USA). Each year, AIDS claims about 2 million more lives—an average of nearly 5,500 premature deaths every day. This includes about 15,000 in the United States, or about 41 per day, and almost 350,000 per year, or about 960 per day in South Africa. Globally, according to the WHO, AIDS is the number one killer of women between the ages of 15 and 49.

AIDS has reduced the life expectancy of the 750 million people living in sub-Saharan Africa from 62 to 47 years, on average, and to 40 years in the seven countries most severely affected by AIDS. The premature deaths of teachers, health-care workers, soldiers, and other young, productive adults affect the population age structures in African countries such as Botswana (see Figure 6-16, p. 139). These deaths also lead to diminished education and health care, decreased food production and economic development, and the disintegration of families.

Since 2006, the number of people infected with HIV seems to have stabilized except in sub-Saharan Africa, where each year there are about 1.9 million new HIV cases. Also each year in that region, 400,000 babies are born with AIDS and 50,000 women die from AIDS-related causes during childbirth.

CENGAGE**NOW**™ Examine the HIV virus and how it replicates by using a host cell at CengageNOW.

■ **CASE STUDY**

Malaria—The Spread of a Deadly Parasite

About one of every five people in the world—most of them living in poor African countries—is at risk from malaria (Figure 17-6, p. 444). So is anyone traveling to malaria-prone areas, because there is no vaccine for preventing this disease.

Malaria is caused by a parasite that is spread by the bites of certain types of mosquitoes. It infects and destroys red blood cells, causing intense fever, chills, drenching sweats, severe abdominal pain, vomiting, headaches, and increased susceptibility to other diseases. It kills an

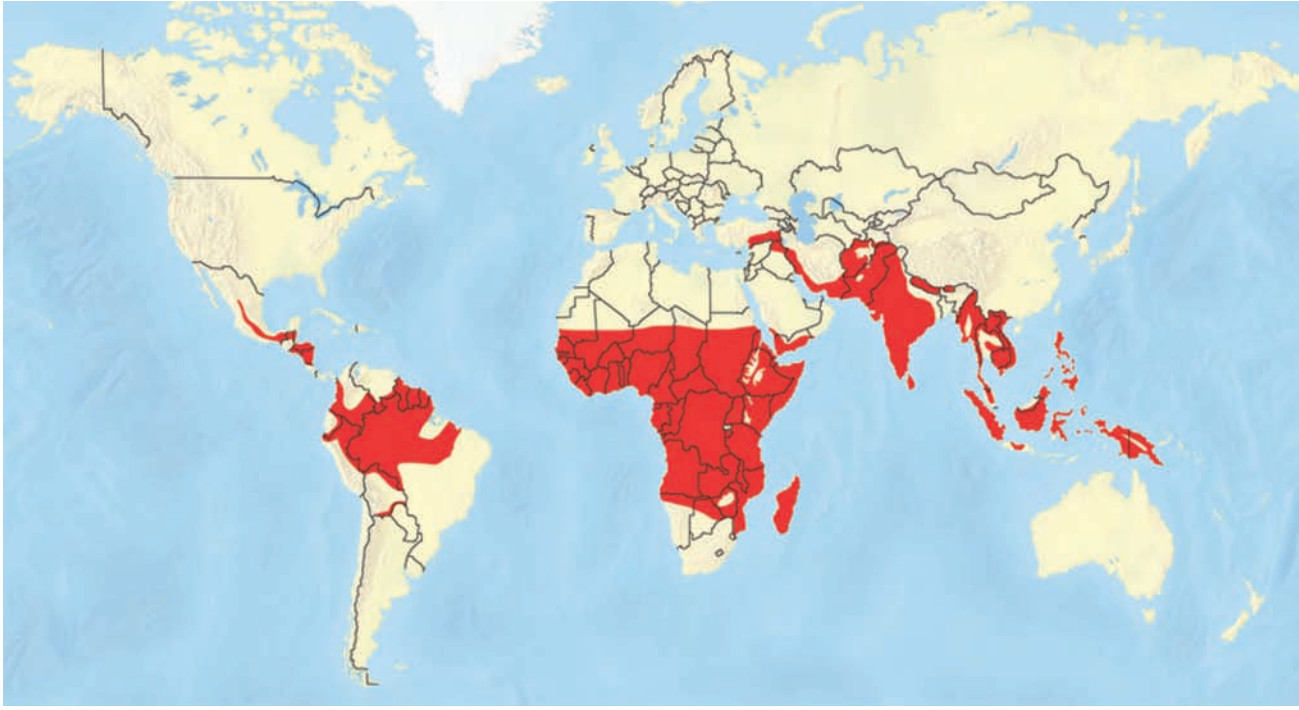

Figure 17-6 *Global outlook:* About 40% of the world's population lives in areas in which malaria is prevalent. Malaria kills at least 1 million people a year or about 2 people every minute. More than 80% of these victims live in sub-Saharan Africa and most of them are children younger than age 5. According to the WHO, every 45 seconds, a child in Africa dies of malaria. (Data from the World Health Organization and U.S. Centers for Disease Control and Prevention)

average of at least 2,700 people per day (**Concept 17-2**). (How many people died from malaria while you were having lunch today?) About 90% of those dying are children younger than age 5. Many of the children who survive suffer brain damage or impaired learning ability.

Four species of protozoan parasites in the genus *Plasmodium* cause malaria. Most infections occur when an uninfected female of any of about 60 *Anopheles* mosquito species bites a person (usually at night) who is infected with the *Plasmodium* parasite, ingests blood that contains the parasite, and later bites an uninfected person. *Plasmodium* parasites then move out of the mosquito and into the human's bloodstream and liver where they multiply. Malaria can also be transmitted by contaminated blood transfusions and by drug users sharing needles.

Over the course of human history, malarial protozoa probably have killed more people than all the wars ever fought. During the 1950s and 1960s, the spread of malaria was sharply curtailed when swamplands and marshes where mosquitoes bred were drained or sprayed with insecticides, and drugs were used to kill the parasites in victims' bloodstreams. Since 1970, however, malaria has come roaring back. Most species of the *Anopheles* mosquito have become genetically resistant to most insecticides. Worse, the *Plasmodium* parasites have become genetically resistant to common antimalarial drugs.

In addition, the clearing and development of tropical forests has led to the spread of malaria among workers and the settlers who follow them. Also, people with HIV are more vulnerable to malaria, and people with malaria are more vulnerable to HIV.

CONNECTIONS

Climate Change and Malaria

During this century, climate change as projected by scientists is likely to spread cases of malaria across a wider area of the globe. As the average atmospheric temperature increases, populations of malaria-carrying mosquitoes will likely spread from tropical areas to warmer temperate areas of the earth.

Researchers are working to develop new antimalarial drugs, vaccines, and biological controls for *Anopheles* mosquitoes. But these approaches receive too little funding and have proved more difficult to implement than they were originally thought to be.

U.S. researchers are also developing mosquitoes, through genetic engineering, to resist the malaria parasite and outbreed malaria-carrying mosquitoes. Biochemist David Schooley and his colleagues are taking a different approach. They are looking for a way to kill mosquitoes through dehydration, before they have a chance to bite and infect a human, by exposing the mosquitoes to a hormone that dramatically increases their urination. Other researchers are studying bacteria that act as parasites in some mosquitoes, hoping the bacteria can kill the mosquitoes before they can spread the malaria parasites to humans.

Yet another approach is to provide poor people in malarial regions with free or inexpensive, long-lasting, insecticide-treated bed nets (Figure 17-7) and window screens. Zinc and vitamin A supplements could also be given to children to boost their resistance to malaria. In addition, we can greatly reduce the incidence of malaria,

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Figure 17-7 This boy, who lives in Brazil's Amazon Basin, is sleeping under an insecticide-treated mosquito net to reduce his risk of being bitten by malaria-carrying mosquitoes. Such nets cost about $5 each and can be donated through groups such as www.MalariaNoMore.org.

at a low cost, by spraying the insides of homes with low concentrations of the pesticide DDT twice a year. While DDT is being phased out in most countries, the WHO supports limited use of DDT for malaria control.

Some public health officials believe the world needs to make a more coordinated and aggressive effort to control malaria. This will gain increasing urgency as malaria parasites develop greater genetic resistance to treatments, and as the range of *Anopheles* mosquitoes expands due to projected climate change. Columbia University economist Jeffrey Sachs estimates that spending $2–3 billion a year on preventing and treating malaria might save more than a million lives a year. Sachs notes, "This is probably the best bargain on the planet."

RESEARCH FRONTIERS

Finding new drugs and other treatments for malaria, and finding ways to hinder the mosquitoes that transmit the malaria parasite; see **www.cengage.com/login**.

CENGAGENOW™ Watch through a microscope what happens when a mosquito infects a human with malaria at CengageNOW.

We Can Reduce the Incidence of Infectious Diseases

According to the WHO, the global death rate from infectious diseases decreased by more than two-thirds between 1970 and 2006 and is projected to continue dropping. Also, between 1971 and 2006, the percentage of children in less-developed countries who were immunized with vaccines to prevent tetanus, measles, diphtheria, typhoid fever, and polio increased from 10% to 90%. This saved about 10 million lives each year. Between 1990 and 2008, the estimated annual number of children younger than age 5 who died from preventable diseases such as diarrhea, pneumonia, and malaria dropped from nearly 12 million to 7.7 million.

GOOD NEWS

Figure 17-8 lists measures promoted by health scientists and public health officials to help prevent or reduce the incidence of infectious diseases—especially in less-developed countries. An important breakthrough has been the development of simple *oral rehydration therapy* to help prevent death from dehydration for victims of severe diarrhea, which causes about one-fourth of all deaths of children younger than age 5 (**Concept 17-2**). This therapy involves administering a simple solution of boiled water, salt, and sugar or rice at a cost of only a few cents per person. It has been the major factor in reducing the annual number of deaths from diarrhea from 4.6 million in 1980 to 1.6 million in 2008. The WHO has estimated that implementing the solutions in Figure 17-8 could save the lives of as many as 4 million children younger than age 5 each year.

GOOD NEWS

Solutions

Infectious Diseases

- Increase research on tropical diseases and vaccines
- Reduce poverty
- Decrease malnutrition
- Improve drinking water quality
- Reduce unnecessary use of antibiotics
- Educate people to take all of an antibiotic prescription
- Reduce antibiotic use to promote livestock growth
- Require careful hand washing by all medical personnel
- Immunize children against major viral diseases
- Provide oral rehydration for diarrhea victims
- Conduct global campaign to reduce HIV/AIDS

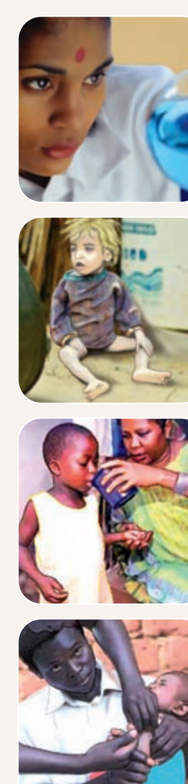


Figure 17-8 There are a number of ways to prevent or reduce the incidence of infectious diseases, especially in less-developed countries. **Question:** Which three of these approaches do you think are the most important?

CONNECTIONS

Drinking Water, Latrines, and Infectious Diseases

More than a third of the world's people—2.6 billion—do not have sanitary bathroom facilities, and more than 1 billion get their water for drinking, washing, and cooking from sources polluted by animal and human feces. A key to reducing sickness and premature death from infectious disease is to focus on providing people with simple latrines and access to safe drinking water. The UN estimates that this could be done for about $20 billion a year—about what people in wealthier countries, who already have almost universal access to cheap clean water, spend each year on bottled water.

The WHO estimates that only 10% of global medical research and development money goes toward preventing infectious diseases in less-developed countries, even though more people suffer and die from these diseases than from all other diseases combined. But the problem is getting more attention. In recent years, philanthropists, including Bill and Melinda Gates and Warren E. Buffet, have donated billions of dollars to improve global health, with primary emphasis on preventing infectious diseases in less-developed countries. GOOD NEWS **GREEN CAREER:** infectious disease prevention

17-3 What Types of Chemical Hazards Do We Face?

CONCEPT 17-3 There is growing concern about chemicals in the environment that can cause cancers and birth defects, and disrupt the human immune, nervous, and endocrine systems.

Some Chemicals Can Cause Cancers, Mutations, and Birth Defects

A **toxic chemical** is one that can cause temporary or permanent harm or death to humans and animals. In 2004, the EPA listed arsenic, lead, mercury, vinyl chloride (used to make PVC plastics), and polychlorinated biphenyls (PCBs; see the Case Study that follows) as the top five toxic substances in terms of human and environmental health.

There are three major types of potentially toxic agents. **Carcinogens** are chemicals, types of radiation, or certain viruses that can cause or promote *cancer*—a disease in which malignant cells multiply uncontrollably and create tumors that can damage the body and often lead to premature death. Examples of carcinogens are arsenic, benzene, formaldehyde, gamma radiation, PCBs, radon, certain chemicals in tobacco smoke, ultraviolet (UV) radiation, and vinyl chloride. (For a longer list, see **http://ntp.niehs.nih.gov/index.cfm?objectid=32BA9724-F1F6-975E-7FCE50709CB4C932**).

Typically, 10–40 years may elapse between the initial exposure to a carcinogen and the appearance of detectable cancer symptoms. Partly because of this time lag, many healthy teenagers and young adults have trouble believing that their smoking, drinking, eating, and other habits today could lead to some form of cancer before they reach age 50.

The second major type of toxic agent, **mutagens**, includes chemicals or forms of radiation that cause or increase the frequency of *mutations*, or changes, in the DNA molecules found in cells. Most mutations cause no harm but some can lead to cancers and other disorders. For example, nitrous acid (HNO_2), formed by the digestion of nitrite (NO_2^-) preservatives in foods, can cause mutations linked to increases in stomach cancer in people who consume large amounts of processed foods and wine containing such preservatives. Harmful mutations occurring in reproductive cells can be passed on to offspring and to future generations. (For a list of mutagens, see **http://www.iephb.nw.ru/~spirov/hazard/mutagen_lst.html**.)

Third, **teratogens** are chemicals that cause harm or birth defects to a fetus or embryo. Ethyl alcohol is a teratogen. Drinking during pregnancy can lead to offspring with low birth weight and a number of physical, developmental, behavioral, and mental problems. Other teratogens are angel dust, benzene, formaldehyde, lead, mercury (see Case Study, p. 448), PCBs (see the Case Study that follows), phthalates, thalidomide, and vinyl chloride. Between 2001 and 2006, birth defects in Chinese infants soared by nearly 40%. Officials link this to the country's growing pollution, especially from coal-burning power plants and industries. (For a list of teratogens, see **http://ptcl.chem.ox.ac.uk/MSDS/teratogens.html**.)

CASE STUDY

PCBs Are Everywhere— A Legacy of Industry

PCBs are a class of more than 200 chlorine-containing organic compounds that are very stable and nonflammable. They exist as oily liquids or solids that, under certain conditions, can enter the air as a vapor. Between 1929 and 1977, PCBs were widely used as lubricants, hydraulic fluids, and insulators in electrical transformers and capacitors. They also became ingredients in a variety of products including paints, fire retardants in fabrics, preservatives, adhesives, and pesticides.

The U.S. Congress banned the domestic production of PCBs in 1977 after research showed that they could cause liver and other cancers in test animals and, according to the EPA, probably can cause cancers in humans. In addition, a 1996 study related fetal exposure to PCBs in the womb to learning disabilities in children.

Production of PCBs has also been banned in most other countries. But the potential health threats from these chemicals will be with us for a long time. For decades, PCBs entered the air, water, and soil during their manufacture, use, and disposal, as well as from accidental spills and leaks. Because PCBs break down very slowly in the environment, they can travel long distances in the air and be deposited far away from where they were released. Because they are fat soluble, PCBs can also be biologically magnified in food chains and webs, as can DDT (see Figure 9-15, p. 203).

As a result, PCBs are now found almost everywhere—in soil, air, lakes, rivers, fish, birds, your body, and even the bodies of polar bears in the Arctic. PCBs are even present in the milk of some nursing mothers, although most scientists say the health benefits of mother's milk outweigh the risk of infants' exposure to trace amounts of PCBs in breast milk.

According to the EPA, about 70% of all the PCBs made in the United States are still in the environment. Figure 17-9 shows potential pathways on which persistent toxic chemicals such as PCBs move through the living and nonliving environment.

THINKING ABOUT
PCBs

We are stuck with long-term exposure to trace amounts of PCBs and their mostly unknown long-term health effects, but what environmental lesson can we learn from the widespread use of these persistent chemicals?

Some Chemicals May Affect Our Immune and Nervous Systems

Since the 1970s, research on wildlife and laboratory animals, along with some studies of humans, have yielded a growing body of evidence that suggests that long-term exposure to some chemicals in the environment can disrupt the body's immune, nervous, and endocrine systems (**Concept 17-3**).

The *immune system* consists of specialized cells and tissues that protect the body against disease and harmful substances by forming antibodies that render invading agents harmless. Some chemicals such as arsenic, methylmercury, and dioxins can weaken the human immune system and leave the body vulnerable to attacks by allergens and infectious bacteria, viruses, and protozoa.

Some natural and synthetic chemicals in the environment, called *neurotoxins*, can harm the human *nervous system* (brain, spinal cord, and peripheral nerves). Effects can include behavioral changes, learning disabilities, retardation, attention deficit disorder, paralysis, and death. Examples of neurotoxins are PCBs, arsenic, lead, and certain pesticides. For example, a 2007 study by scientists Beate Ritz and Caroline Tanner found that farm workers exposed to the widely used weed killer Paraquat™ had two to three times the normal risk of suffering from Parkinson's disease, a degenerative brain disease that eventually paralyzes its victims.

An especially dangerous neurotoxin is *methylmercury* (Science Focus, p. 448). It has received a great deal of attention from scientists and environmentalists because it is so persistent in the environment. It can be biologically magnified in food chains and webs just as DDT and PCBs are.

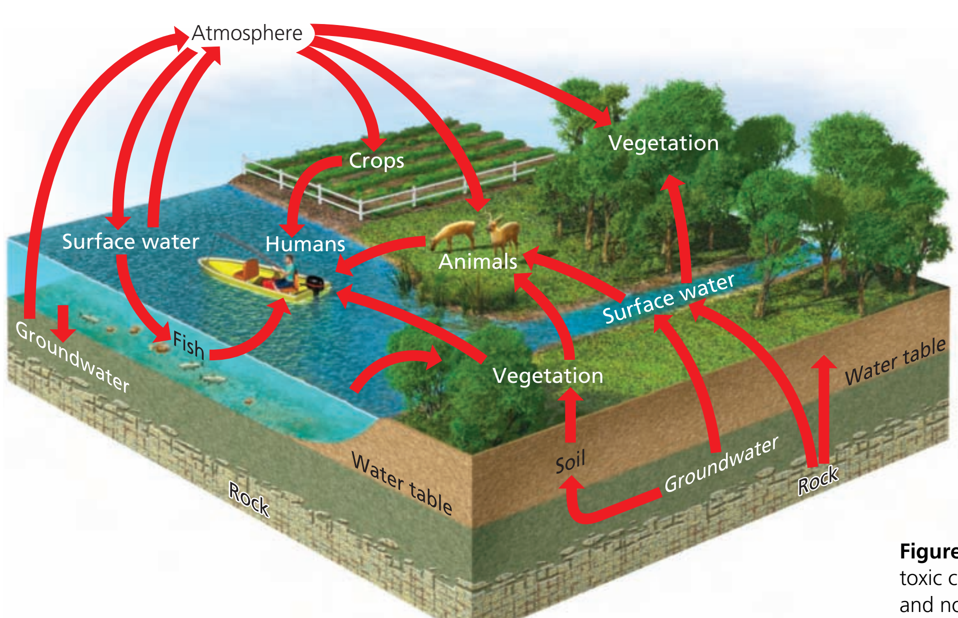


Figure 17-9 PCBs and other persistent toxic chemicals can move through the living and nonliving environment on a number of pathways.

SCIENCE FOCUS

Mercury's Toxic Effects

Mercury (Hg) (see Figure 2-4, right, p. 38) and its compounds are all toxic. Research indicates that long-term exposure to high levels of mercury can permanently damage the human nervous system, kidneys, and lungs. Fairly low levels of mercury can also harm fetuses and cause birth defects.

This toxic metal is released into the air from rocks, soil, and volcanoes and by vaporization from the ocean. Such natural sources account for about one-third of the mercury reaching the atmosphere each year. According to the EPA, the remaining two-thirds come from human activities—primarily from the smokestacks of coal-burning power plants, waste incinerators, cement kilns, and coal-burning industrial facilities. When it rains, these emissions are washed out of the atmosphere onto the soil and into bodies of water.

Because mercury is an element, it cannot be broken down or degraded. Therefore, this indestructible global pollutant accumulates in soil and water and in the bodies of people, fish, and other animals that feed high on food chains and food webs. This includes polar bears, toothed whales, and seals living in the Arctic, which is a global mercury hotspot. According to the National Resources Defense Council, predatory fish such as large tuna, swordfish, mackerel, and sharks can have mercury concentrations in their bodies that are up to 10,000 times higher than the levels in the water around them.

In the atmosphere, some elemental mercury is converted to more toxic inorganic and organic mercury compounds that can be deposited in aquatic environments. Under certain conditions in aquatic systems, bacteria can convert inorganic mercury compounds to highly toxic *methylmercury*, which can be biologically magnified in food chains and webs. As a result, in such aquatic systems, high levels of methylmercury are often found in the tissues of large fishes, which feed at high trophic levels.

Humans are exposed to mercury in three ways. *First*, we may inhale vaporized elemental mercury (Hg) or particles of inorganic mercury salts such as mercury sulfide (HgS) and mercuric chloride ($HgCl_2$). *Second*, we can eat fish contaminated with highly toxic methylmercury (CH_3Hg^+). The *third* way involves consuming high-fructose corn syrup (HFCS), widely used as a sweetener in beverages and food products. A 2005 study by former FDA scientist Renee Dufault found detectable levels of mercury in 9 of 20 samples of HFCS. A 2005 study by food safety researcher David Wallinga also found detectable levels of mercury in one out of three supermarket food products that contained high levels of HFCS. The average American consumes almost 23 liters (6 gallons) of HFCS each year. There is concern that exposure to this source of mercury could pose a health threat to fetuses of pregnant women who consume large quantities of HFCS. The U.S. Corn Refiners Association disputes these findings.

The greatest risk from exposure to low levels of methylmercury is brain damage in fetuses and young children. Studies estimate that 30,000–60,000 of the children born each year in the United States are likely to have reduced IQs and possible nervous system damage because of such exposure. Also, methylmercury has been shown to harm the heart, kidneys, and immune system of some adults.

In 2004, the U.S. Food and Drug Administration (FDA) and the EPA advised nursing mothers, pregnant women, and women who may become pregnant not to eat shark, swordfish, king mackerel, or tilefish and to limit their consumption of albacore tuna to no more than 170 grams (6 ounces) per week. A 2009 EPA study found that almost half of the fish tested in 500 lakes and reservoirs across the United States had levels of mercury that exceeded what the EPA says is safe for people eating fish more than two times a week. Similarly, a 2009 study by the U.S. Geological Survey of nearly 300 streams across the United States found traces of mercury in every fish tested, with one-fourth of the fish exceeding levels determined by the EPA to be safe. For this reason, all but two U.S. states—Wyoming and Alaska—have issued advisories warning people not to eat certain types of fish. (For a full list of these advisories, see **http://www.epa.gov/waterscience/fish/advisories/**.)

The EPA estimates that about one of every 12 women of childbearing age in the United States has enough mercury in her blood to harm a developing fetus. According to the EPA, about 75% of all human exposure to mercury comes from eating fish. (See **http://www.sierraclub.org/communities/mercury/fishguide.pdf** for a list of what fish to eat and avoid.)

In its 2003 report on global mercury pollution, the UN Environment Programme recommended phasing out coal-burning power plants and waste incinerators throughout the world as rapidly as possible. Other recommendations are to reduce or eliminate mercury in the production of batteries, paints, and chlorine by no later than 2020. Substitute materials and processes are available for these products.

Critical Thinking

To sharply reduce mercury pollution, should we phase out all coal burning as rapidly as possible? Explain. How might your lifestyle change if this were done?

CONNECTIONS

Climate Change and Mercury Pollution

Mercury particles from active volcanoes and from coal-burning power plant emissions are transported through the atmosphere to arctic regions where they can get trapped in arctic ice. Scientists are concerned that as more arctic ice melts as a result of climate change, more of these mercury particles will flow into the oceans and into food chains. Evidence bears this out. In some arctic ringed seals and beluga whales, mercury levels have increased fourfold since the early 1980s.

As with all forms of pollution, prevention is the best policy. Figure 17-10 lists ways to prevent or reduce human inputs of mercury into the environment.

Some Chemicals Affect the Human Endocrine System

The *endocrine system* is a complex network of glands that release tiny amounts of *hormones* into the bloodstreams of humans and other vertebrate animals. Low levels of

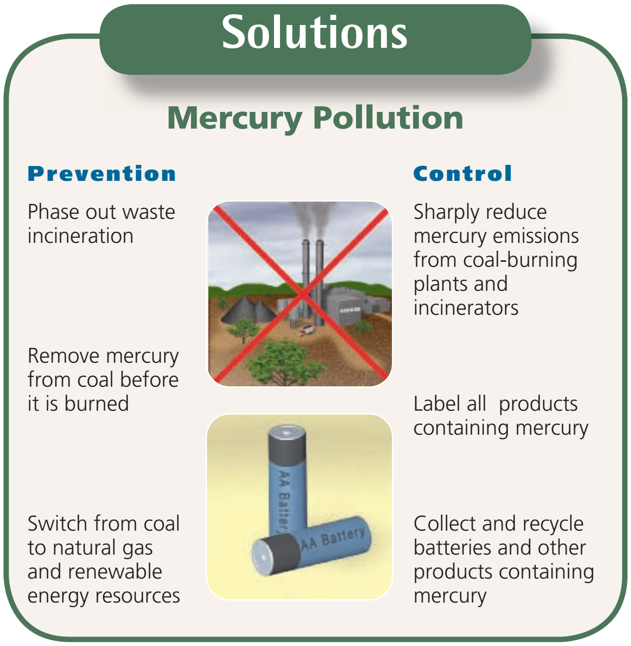


Figure 17-10 There are a number of ways to prevent or control inputs of mercury into the environment from human sources—mostly coal-burning power plants and incinerators. **Question:** Which four of these solutions do you think are the most important?

these chemical messengers regulate the bodily systems that control sexual reproduction, growth, development, learning ability, and behavior. Each type of hormone has a unique molecular shape that allows it to attach to certain parts of cells called *receptors*, and to transmit its chemical message (Figure 17-11, left). In this "lock-and-key" relationship, the receptor is the lock and the hormone is the key.

Molecules of certain pesticides and other synthetic chemicals such as bisphenol A (BPA) (**Core Case Study**) have shapes similar to those of natural hormones. This allows them to attach to molecules of natural hormones and to disrupt the endocrine systems in people and some other animals. These molecules are called *hormonally active agents* (HAAs).

Examples of HAAs include aluminum, Atrazine™ and several other widely used weed killers, DDT, PCBs (see Case Study, p. 446), mercury (Science Focus, at left), phthalates, and BPA (**Core Case Study**). Some hormone imposters such as BPA are chemically similar to estrogens (female sex hormones) and can disrupt the endocrine system by attaching to estrogen receptor molecules (Figure 17-11, center). Others, called *hormone blockers*, disrupt the endocrine system by preventing natural hormones such as androgens (male sex hormones) from attaching to their receptors (Figure 17-11, right).

Estrogen mimics and hormone blockers are sometimes called *gender benders* because of their possible effects on sexual development and reproduction. Numerous studies on wild animals, laboratory animals, and humans suggest that the males of species that are exposed to hormonal disruption are generally becoming more feminine. For example, a 2010 study found that Atrazine™ had turned male frogs into females. There is also growing concern about another group of HAAs—pollutants that can act as *thyroid disrupters* and cause growth and weight-control problems as well as brain and behavioral disorders.

More than 100 studies by independent laboratories have found a number of adverse effects on test animals from exposure to very low levels of BPA (**Core Case Study**). These effects include brain

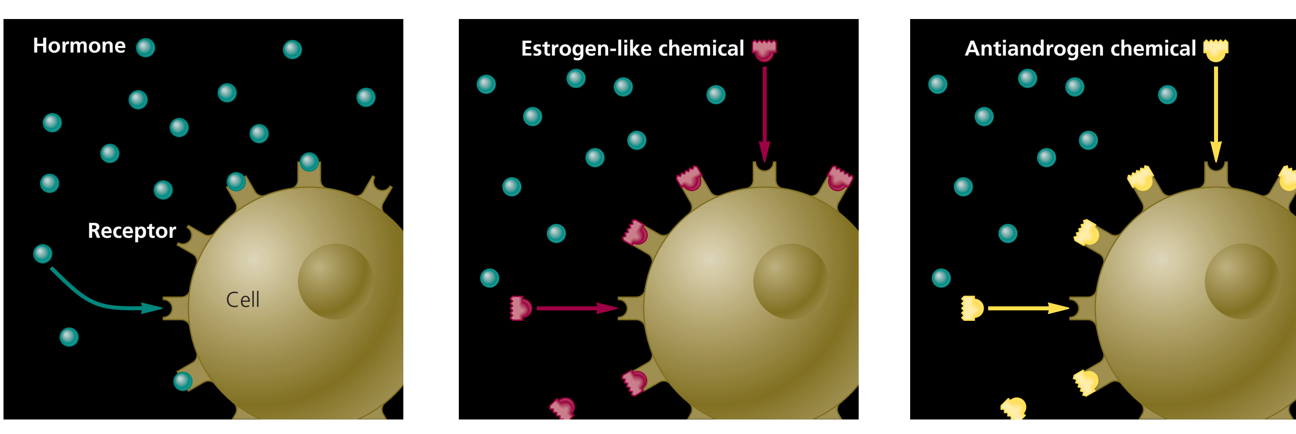


Figure 17-11 Hormones are molecules that act as messengers in the endocrine system to regulate various bodily processes, including reproduction, growth, and development. Each type of hormone has a unique molecular shape that allows it to attach to specially shaped receptors on the surface of, or inside, cells and to transmit its chemical message (left). Molecules of certain pesticides and other synthetic chemicals have shapes similar to those of natural hormones, allowing them to attach to the hormone molecules and disrupt the endocrine system in people and various other animals. These molecules are called *hormonally active agents* (HAAs). Because of the difficulty in determining the harmful effects of long-term exposure to low levels of HAAs, there is uncertainty about their effects on human health.

damage, early puberty, prostate disease, breast cancer, heart disease, obesity, liver damage, reduced sperm count, impaired immune function, type 2 diabetes, and hyperactivity.

On the other hand, 12 studies funded by the chemical industry found no evidence or weak evidence of adverse effects from low-level exposure to BPA in test animals. According to chemical industry officials, numerous studies have found that BPA degrades rapidly and does not bioaccumulate in tissues and that BPA levels in the environment are too low to cause harm.

In 2008, the U.S. Food and Drug Administration (FDA) concluded that BPA in food and drink containers does not pose a health hazard. However, a number of environmental and health scientists dispute this finding, including the FDA's science advisory panel. In 2009, a National Academy of Sciences report by a panel of experts strongly criticized the FDA for not taking into account numerous BPA studies by some of the country's best independent health scientists. In the 2009 Food Safety bill, Congress ordered the FDA to establish that BPA was safe, or to restrict its use in products made for pregnant women, babies, and young children.

In 2008, Canada classified BPA as a toxic substance and announced a ban on its use in baby bottles. It plans to develop strict regulations for the use of BPA in can liners. Some baby bottle companies in Europe and the United States have voluntarily stopped using BPA in baby bottles. The states of Minnesota and Connecticut have banned the use of BPA in children's products, as has the city of Chicago, Illinois.

In 2010, the FDA announced that it had some concerns about the potentially harmful health effects of BPA and that it would study such effects and look for ways to reduce BPA in food packaging. Also in 2010, the EPA announced a plan to address the potentially harmful health effects of BPA. This included the possibility of using its authority under the Toxic Substances Control Act (TSCA) to list BPA as a chemical that may present an unreasonable risk of injury to health or to the environment. However, critics say that TSCA's burden of proof is so high that it is extremely difficult for the EPA to restrict the use of a chemical.

There is also growing concern over possible harmful effects from exposure to low levels of certain *phthalates* (pronounced THALL-eights). These chemicals are used to soften polyvinyl chloride (PVC) plastic found in a variety of products, and they are used as solvents in many consumer products. Phthalates are found in many perfumes, cosmetics, baby powders, body lotions for adults and babies, hair sprays, deodorants, nail polishes, and shampoos for adults and babies. They are also found in PVC products such as soft vinyl toys, teething rings, and blood storage bags, IV bags, and medical tubing used in hospitals.

In a 2008 study, Sheela Sathyanarayana and her colleagues tested urine from the diapers of 163 infants aged 2 to 28 months. They found that 81% of the urine had measurable amounts of seven or more phthalates related to the use of phthalate-containing baby lotions, baby powders, and baby shampoos.

Exposure of laboratory animals to high doses of various phthalates has caused birth defects and liver cancer, kidney and liver damage, premature breast development, immune system suppression, and abnormal sexual development. The European Union and at least 14 other countries have banned phthalates.

But scientists, government regulators, and manufacturers in the United States are divided on the risks of phthalates to human health and reproductive systems. Toy makers in the United States say that phthalates, which have been used for more than 20 years in baby products, pose no threats. In addition, they warn that substitutes could make plastic toys more brittle and subject to breaking, and thus less safe for children.

Some scientists hypothesize that an increase in certain health problems may be related to rising levels of hormone disruptors in our bodies. Such problems include sharp drops in male sperm counts and male sperm mobility found in 20 countries on six continents, rising rates of testicular cancer and genital birth defects in men, and increased breast cancer rates in women. Other scientists disagree and point out that there are not enough scientific studies and statistical evidence to link these medical problems with HAA levels in humans. They call for more research before banning or severely restricting HAAs, which would cause huge economic losses for companies that make them.

The scientific and economic controversies over possible health risks from exposure to chemicals such as BPA and phthalates highlight the difficulty in assessing possible harmful health effects from exposure to very low levels of various chemicals widely found in the environment and in the products that we use. Resolving these uncertainties will take decades of research.

Some scientists believe that as a precaution, during this period of research, governments and individual consumers should act to sharply reduce the use of potentially harmful hormone disrupters, especially in products used widely by pregnant women, infants, and young children. They also call for manufacturers to search for less harmful substitutes for such chemicals. Consumers now have a choice, since most makers of baby bottles, sipping cups, and sports water bottles offer BPA-free alternatives. To avoid BPA contamination, some consumers are also choosing glass bottles and food containers instead of those lined with plastic resins.

RESEARCH FRONTIERS

Evaluating the health effects of HAAs and looking for substitutes for such chemicals; see **www.cengage.com/login**.

THINKING ABOUT
Hormone Disrupters

Should we ban or severely restrict the use of potential hormone disrupters? What beneficial or harmful effects might this have in your life?

17-4 How Can We Evaluate Chemical Hazards?

▶ **CONCEPT 17-4A Scientists use live laboratory animals, case reports of poisonings, and epidemiological studies to estimate the toxicity of chemicals, but these methods have limitations.**

▶ **CONCEPT 17-4B Many health scientists call for much greater emphasis on pollution prevention to reduce our exposure to potentially harmful chemicals.**

Many Factors Determine the Harmful Health Effects of a Chemical

We are exposed to small amounts of potentially harmful chemicals every day in the air we breathe, the water we drink, and the food we eat. **Toxicology** is the study of the harmful effects of chemicals on humans and other organisms. In effect, it is a study of poisons.

Toxicity is a measure of the harmfulness of a substance—its ability to cause injury, illness, or death to a living organism. A basic principle of toxicology is that *any synthetic or natural chemical can be harmful if ingested in a large enough quantity*. But the critical question is this: *At what level of exposure to a particular toxic chemical will the chemical cause harm?* This is the meaning of the chapter-opening quote by the German scientist Paracelsus: *The dose makes the poison.*

The question raised above is difficult to answer because of the many variables involved in estimating the effects of human exposure to chemicals (Figure 17-12, p. 452). A key factor is the **dose**, the amount of a harmful chemical that a person has ingested, inhaled, or absorbed through the skin.

The effects of a particular chemical can also depend upon the age of the person exposed to it. For example, toxic chemicals usually have a greater effect on fetuses, infants, and children than on adults (see the Case Study that follows). Toxicity also depends on *genetic makeup*, which determines an individual's sensitivity to a particular toxin. Some people are sensitive to a number of toxins—a condition known as *multiple chemical sensitivity* (MCS). Another factor is how well the body's detoxification systems (such as the liver, lungs, and kidneys) work.

Several other variables can affect the level of harm caused by a chemical. One is its *solubility*. Water-soluble toxins (which are often inorganic compounds) can move throughout the environment, get into water supplies, and enter the aqueous solutions that surround the cells in our bodies. Oil- or fat-soluble toxins (which are usually organic compounds) can penetrate the membranes surrounding cells, because the membranes allow similar oil-soluble chemicals to pass through them. Thus, oil- or fat-soluble toxins can accumulate in body tissues and cells.

Another factor is a substance's *persistence*, or resistance to breakdown. Many chemicals such as DDT and PCBs have been widely used because they are not easily broken down in the environment. This means that more people and forms of wildlife are likely to come in contact with them. It also means they are more likely to remain in the body and have long-lasting harmful health effects.

Biological magnification is another factor in toxicity. Animals higher on the food chain are more susceptible to the effects of fat-soluble toxic chemicals because of the magnified concentrations of the toxins in their bodies. Examples of chemicals that can be biomagnified in food chains and webs include DDT (see Figure 9-15, p. 203), PCBs, and methylmercury.

The damage to health resulting from exposure to a chemical is called the **response**. One type of response, an *acute effect*, is an immediate or rapid harmful reaction ranging from dizziness and nausea to death. A *chronic effect* is a permanent or long-lasting consequence (kidney or liver damage, for example) of exposure to a single dose or to repeated lower doses of a harmful substance.

Some people have the mistaken idea that all natural chemicals are safe and all synthetic chemicals are harmful. In fact, many synthetic chemicals, including many of the medicines we take, are quite safe if used as intended, while many natural chemicals such as mercury and lead are deadly.

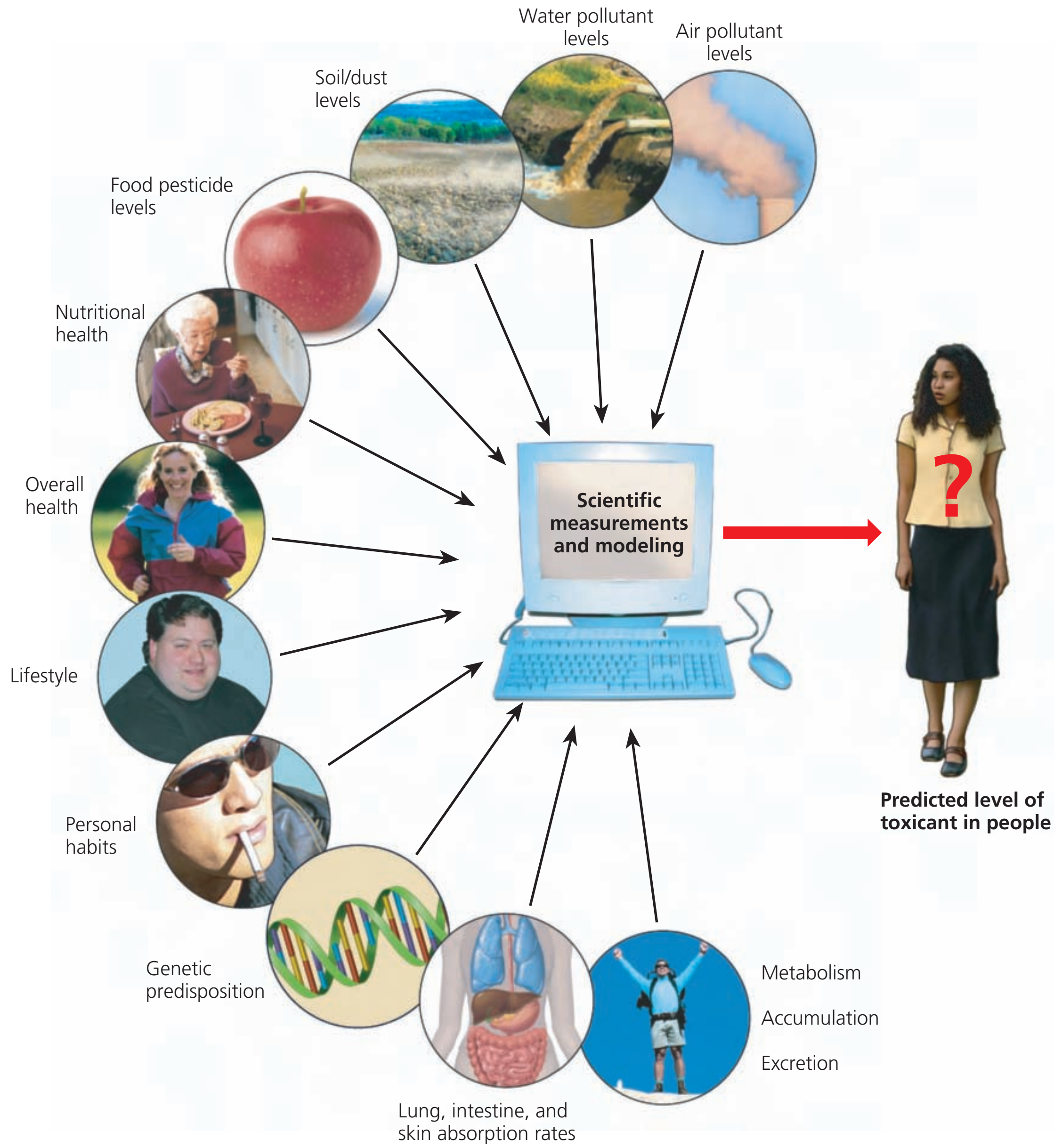
■ **CASE STUDY**

Protecting Children from Toxic Chemicals

Everyone on the planet is exposed to an array of toxic chemicals whose long-term effects are largely unknown. Even less is known about the effects of chemicals on young children and fetuses. But some scientists are alarmed about what has been found.

In 2005, the Environmental Working Group analyzed umbilical cord blood from 10 randomly selected newborns in U.S. hospitals. Of the 287 chemicals detected, 180 have been shown to cause cancers in humans or animals, 217 have damaged the nervous systems in test animals, and 208 have caused birth defects or abnormal development in test animals. Scientists do not know what harm, if any, might be caused by the very low concentrations of these chemicals found in infants' blood.

Figure 17-12 Science: Estimating human exposure to chemicals and measuring the effects of that exposure are very difficult because of the many and often poorly understood variables involved. **Question:** Which of these factors, if any, might make you more vulnerable to the harmful effects of chemicals?



However, more recent scientific findings have caused some experts to suggest that exposure to chemical pollutants in the womb may be related to increasing rates of autism, childhood asthma, and learning disorders. In 2009, researchers for the first time, found a connection between exposure to air pollutants for pregnant women and lower IQ scores in their children as they grew. Lead researcher Frederica Perera of Columbia University reported that children exposed to high levels of air pollution before birth scored 4–5 points lower, on average, in IQ tests than did children with less exposure.

An example of a common chemical that has recently been blamed for health problems in children is melamine. It is added to some industrialized food products as well as to cleaning products and building materials. In 2008, at least four infants in China died and tens of thousands were sickened by baby formula containing melamine. Children are also exposed to this chemical in some play areas and through some plastic toys. Chronic exposure to melamine could contribute to long-term kidney and liver problems.

Infants and young children are more susceptible to the effects of toxic substances than are adults for three major reasons. *First*, they generally breathe more air, drink more water, and eat more food per unit of body weight than do adults. *Second*, they are exposed to toxins in dust or soil when they put their fingers, toys, or other objects in their mouths. *Third*, children usually have less well-developed immune systems and body detoxification processes than adults have. Fetuses are also highly vulnerable to trace amounts of toxic chemicals that they receive from their mothers.

In 2003, the U.S. EPA proposed that in determining any risk, regulators should assume children have a 10-times higher risk factor than do adults. Some health scientists suggest that to be on the safe side, we should assume that this risk for children is 100 times the risk for adults.

THINKING ABOUT
Toxic Chemical Levels for Children

Should environmental regulations require that allowed exposure levels to toxic chemicals for children be 100 times lower than for adults? Explain your reasoning.

Scientists Use Live Laboratory Animals and Non-Animal Tests to Estimate Toxicity

The most widely used method for determining toxicity is to expose a population of live laboratory animals to measured doses of a specific substance under controlled conditions. Laboratory-bred mice and rats are widely used because, as mammals, their systems function, to some degree, similarly to human systems. Also, they are small and can reproduce rapidly under controlled laboratory conditions.

Animal tests can take 2–5 years to complete, involve hundreds to thousands of test animals, and cost as much as $2 million per substance tested. Such tests can be painful to the test animals and can kill or harm them. Animal welfare groups want to limit or ban the use of test animals and, at the very least, to ensure that they are treated in the most humane manner possible.

Scientists estimate the toxicity of a chemical by determining the effects of various doses of the chemical on test organisms and plotting the results in a **dose-response curve** (Figure 17-13). One approach is to determine the *lethal dose*—the dose that will kill an animal. A chemical's *median lethal dose (LD50)* is the dose that can kill 50% of the animals (usually rats and mice) in a test population within an 18-day period.

Chemicals vary widely in their toxicity (Table 17-1). Some poisons can cause serious harm or death after a single exposure at very low dosages. Others cause such harm only at dosages so huge that it is nearly impossible to get enough into the body to cause injury or death. Most chemicals fall between these two extremes.

There are two general types of dose-response curves (Figure 17-14, p. 454). With the *nonthreshold dose-response model* (Figure 17-14, left), any dosage of a toxic chemical causes harm that increases with the dosage. With the *threshold dose-response model* (Figure 17-14, right), a certain level of the chemical must be reached before any detectable harmful effects occur, presumably because the body can repair the damage caused by low dosages of some substances.

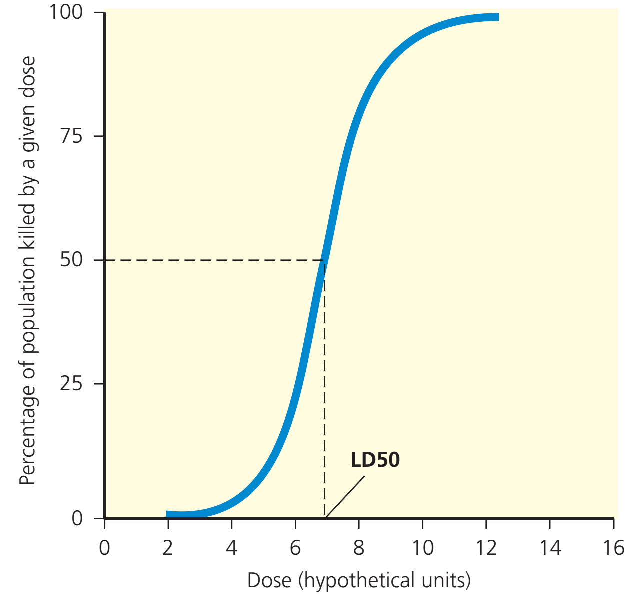


Figure 17-13 **Science:** This hypothetical *dose-response curve* illustrates how scientists can estimate the LD50, the dosage of a specific chemical that kills 50% of the animals in a test group. Toxicologists use this method to compare the toxicities of different chemicals.

Establishing which model applies at low dosages is extremely difficult and controversial. To be on the safe side, scientists often choose the no-threshold dose-response model. Fairly high dosages are used to reduce the number of test animals needed, obtain results quickly, and lower costs. Otherwise, manufacturers would need to run tests on millions of laboratory animals for many years, which means they could not afford to test most chemicals.

For the same reasons, scientists usually use mathematical models to *extrapolate*, or estimate, the effects

Table 17-1 Toxicity Ratings and Average Lethal Doses for Humans

Toxicity Rating	LD50 (milligrams per kilogram of body weight)*	Average Lethal Dose**	Examples
Supertoxic	Less than 5	Less than 7 drops	Nerve gases, botulism toxin, mushroom toxin, dioxin (TCDD)
Extremely toxic	5–50	7 drops to 1 teaspoon	Potassium cyanide, heroin, atropine, parathion, nicotine
Very toxic	50–500	1 teaspoon to 1 ounce	Mercury salts, morphine, codeine
Moderately toxic	500–5,000	1 ounce to 1 pint	Lead salts, DDT, sodium hydroxide, sodium fluoride, sulfuric acid, caffeine, carbon tetrachloride
Slightly toxic	5,000–15,000	1 pint to 1 quart	Ethyl alcohol, Lysol, soaps
Essentially nontoxic	15,000 or greater	More than 1 quart	Water, glycerin, table sugar

*Dosage that kills 50% of individuals exposed.
**Amounts of substances in liquid form at room temperature that are lethal when given to a 70-kilogram (150-pound) human.

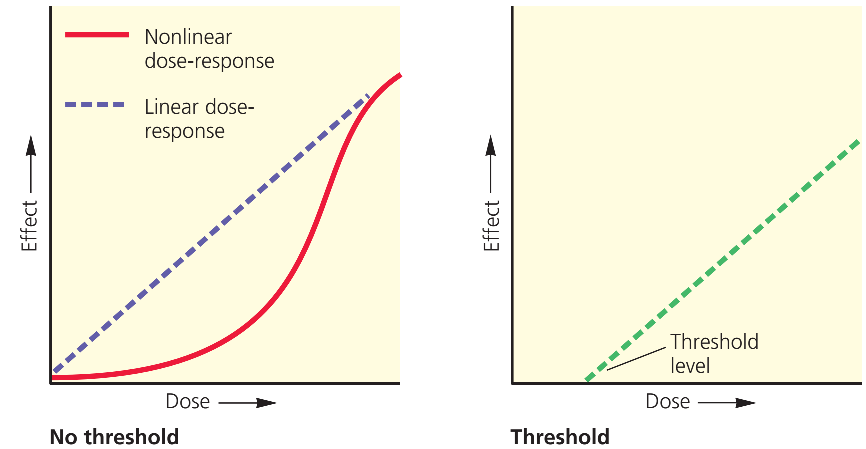


Figure 17-14 **Science:** Scientist use two types of *dose-response curves* to help them estimate the toxicity of various chemicals. The linear and nonlinear curves in the left graph apply if even the smallest dosage of a chemical has a harmful effect that increases with the dosage. The curve on the right applies if a harmful effect occurs only when the dosage exceeds a certain *threshold level*. Which model is better for measuring the effects of a specific harmful agent is uncertain and controversial because of the difficulty in estimating the responses to very low dosages.

of low-dose exposures based on the measured results of high-dose exposures. Then they extrapolate these results from test organisms to humans as a way of estimating LD50 values for acute toxicity (Table 17-1).

Some scientists challenge the validity of extrapolating data from test animals to humans, because human physiology and metabolism often differ from those of the test animals. Other scientists say that such tests and models work fairly well (especially for revealing cancer risks) when the correct experimental animal is chosen or when a chemical is toxic to several different test-animal species.

More humane methods for toxicity testing are available and are being used more often to replace testing on live animals. They include making computer simulations and using tissue cultures of cells and bacteria, chicken egg membranes, and individual animal cells, instead of whole, live animals. High-speed robot testing devices can now screen more than one million compounds a day to help determine their possible toxic effects.

In 2008, U.S. government labs began making much greater use of such non-animal testing methods because they are faster and cheaper than animal tests, and because of growing public concern over animal testing. For example, government toxicity testing labs can run between 10 and 100 tests a year using live rodents such as rats and mice but can run more than 10,000 tests a day using specialized cells and computerized testing measurements.

RESEARCH FRONTIERS

Computer modeling and other alternatives to animal testing; see **www.cengage.com/login**.

The problems with estimating toxicities by using laboratory experiments are complicated. In real life, each of us is exposed to a variety of chemicals, some of which can interact in ways that decrease or enhance their short- and long-term individual effects. Toxicologists already have great difficulty in estimating the toxicity of a single substance. Adding the problem of evaluating *mixtures of potentially toxic substances*, separating out which substances are the culprits, and determining how they can interact with one another is overwhelming from a scientific and economic standpoint. For example, just considering all possible interactions among 3 of the 500 most widely used industrial chemicals would take 20.7 million experiments—a physical and financial impossibility.

THINKING ABOUT
Animal Testing

Should laboratory-bred mice, rats, and other animals be used to determine toxicity and other effects of chemicals? Explain.

There Are Other Ways to Estimate the Harmful Effects of Chemicals

Scientists use several other methods to get information about the harmful effects of chemicals on human health. For example, *case reports*, usually made by physicians, provide information about people suffering some adverse health effect or dying after exposure to a chemical. Such information often involves accidental or deliberate poisonings, drug overdoses, homicides, or suicide attempts.

Most case reports are not reliable sources for estimating toxicity because the actual dosage and the exposed person's health status are often unknown. But such reports can provide clues about environmental hazards and suggest the need for laboratory investigations.

Another source of information is *epidemiological studies*, which compare the health of people exposed to a particular chemical (the *experimental group*) with the health of a similar group of people not exposed to the agent (the *control group*). The goal is to determine whether the statistical association between exposure to a toxic chemical and a health problem is strong, moderate, weak, or undetectable.

Four factors can limit the usefulness of epidemiological studies. *First*, in many cases, too few people have been exposed to high enough levels of a toxic agent to detect statistically significant differences. *Second*, the studies usually take a long time. *Third*, closely linking an observed effect with exposure to a particular chemical is difficult because people are exposed to many different toxic agents throughout their lives and can vary in their sensitivity to such chemicals. *Fourth*, we cannot use epidemiological studies to evaluate hazards from new technologies or chemicals to which people have not yet been exposed.

Are Trace Levels of Toxic Chemicals Harmful?

Almost everyone is now exposed to potentially harmful chemicals (Figure 17-15) that have built up to trace levels in their blood and in other parts of their bodies. One source of such chemicals is wastewater. Trace amounts of estrogen-containing birth control pills, blood pressure medicines, antibiotics, and a host of other chemicals with largely unknown effects on human health are being released into waterways from sewage treatment plants or are leaching into groundwater from home septic systems. The U.S. Geological Survey found that 80% of the U.S. streams and almost one-fourth of the groundwater that it sampled was contaminated with trace amounts of a variety of medications. And chemicals given to cows in India and South Asia to increase their milk production unexpectedly led to a higher amount of human deaths from rabies (see Science Focus, p. 209).

Should we be concerned about trace amounts of various synthetic chemicals in the environment? The honest answer is, in most cases, we do not know because there is too little data and because of the difficulty in determining their effects.

Some scientists view trace amounts of such chemicals with alarm, especially because of their potential long-term effects on the human immune, nervous, and endocrine systems (**Core Case Study**). Others view the risks from trace levels as minor. CORE CASE STUDY

Chemists are now able to detect increasingly smaller amounts of potentially toxic chemicals in air, water, and food. This is good news, but it can give the false impression that dangers from toxic chemicals are increasing. In some cases, we may simply be finding low levels of chemicals that have been around for a long time.

RESEARCH FRONTIER

Learning more about the long-term effects of trace amounts of chemicals; see **www.cengage.com/login**.

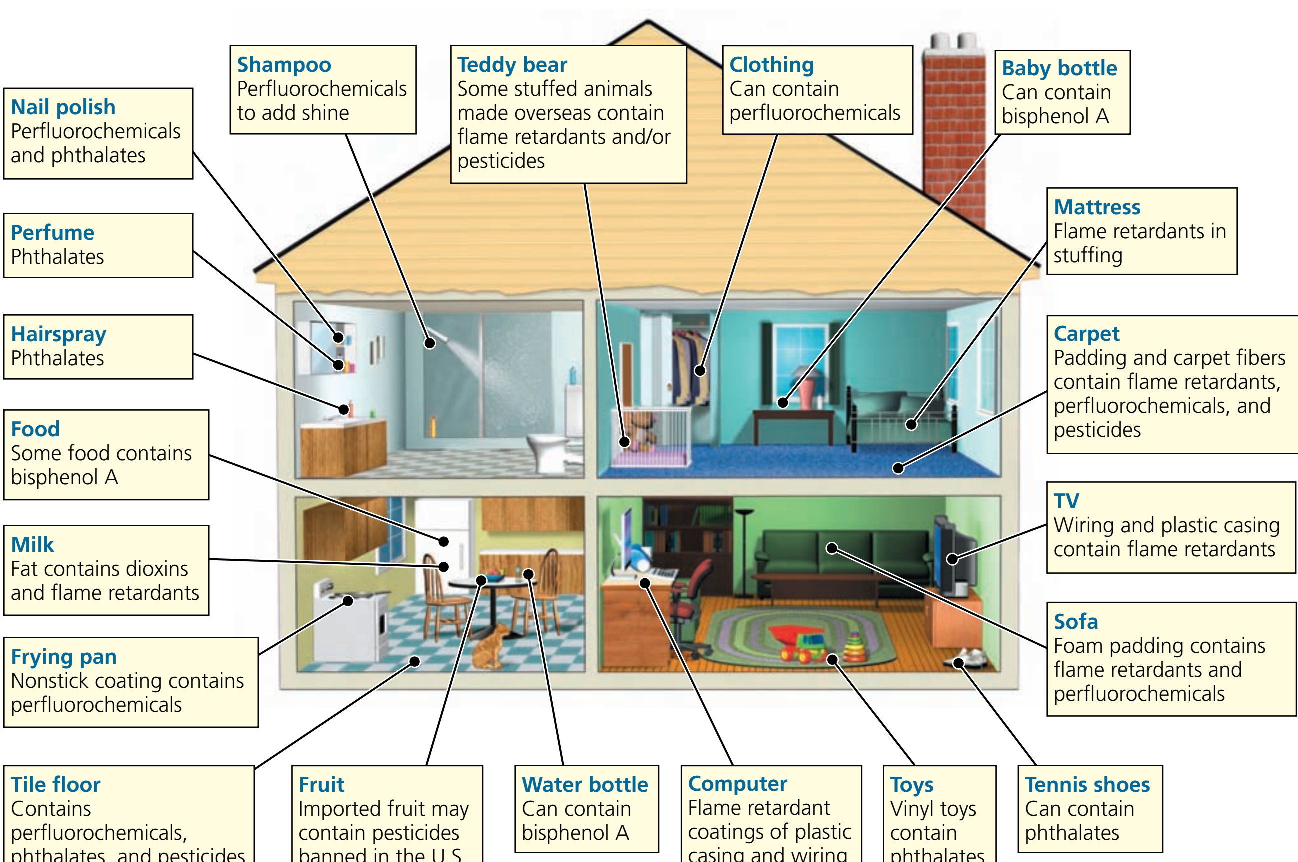


Figure 17-15 A number of potentially harmful chemicals are found in many homes. Most people have traces of these chemicals in their blood and body tissues. We do not know the long-term effects of exposure to low levels of such chemicals. (Data from U.S. Environmental Protection Agency, Centers for Disease Control and Prevention, and New York State Department of Health) **Questions:** Does the fact that we do not know much about the long-term harmful effects of these chemicals make you more likely or less likely to minimize your exposure to them? Why?

Why Do We Know So Little about the Harmful Effects of Chemicals?

As we have seen, all methods for estimating toxicity levels and risks have serious limitations (**Concept 17-4A**). But they are all we have. To take this uncertainty into account and to minimize harm, scientists and regulators typically set allowed levels of exposure to toxic substances at 1/100 or even 1/1,000 of the estimated harmful levels.

According to risk assessment expert Joseph V. Rodricks, "Toxicologists know a great deal about a few chemicals, a little about many, and next to nothing about most." The U.S. National Academy of Sciences estimates that only 10% of 100,000 registered synthetic chemicals in commercial use have been thoroughly screened for toxicity, and only 2% have been adequately tested to determine whether they are carcinogens, mutagens, or teratogens. (See **www.HealthyStuff.org** for test results on over 5,000 commonly used items.) Hardly any of the chemicals in commercial use have been screened for possible damage to the human nervous, endocrine, and immune systems. Because of insufficient data and the high costs of regulation, federal and state governments do not supervise the use of nearly 99.5% of the commercially available chemicals in the United States.

How Far Should We Go in Using Pollution Prevention and the Precautionary Principle?

We know little about the potentially toxic chemicals around us and inside of us, and estimating their effects is very difficult, time-consuming, and expensive. So where does this leave us?

Some scientists and health officials, especially those in European Union countries, are pushing for much greater emphasis on *pollution prevention*. They say we should not release into the environment chemicals that we know or suspect can cause significant harm. This means looking for harmless or less harmful substitutes for toxic and hazardous chemicals (Individuals Matter, at right). Another option is to recycle them within production processes to keep them from reaching the environment, as the U.S. companies 3M (see Chapter 14, p. 366) and DuPont have been doing.

Pollution prevention is a strategy for implementing the *precautionary principle* (see Chapter 9, p. 213). According to this principle, when there is substantial preliminary evidence that an activity, technology, or chemical substance can harm humans or the environment, we should take precautionary measures to prevent or reduce such harm, rather than waiting for more conclusive (reliable) scientific evidence (**Concept 17-4B**).

There is controversy over how far we should go in using pollution prevention based on the precautionary principle. With this approach, those proposing to introduce a new chemical or technology would bear the burden of establishing its safety. This requires two major changes in the way we evaluate risks. *First*, we would assume that new chemicals and technologies are harmful until scientific studies show otherwise. *Second*, we would remove existing chemicals and technologies that appear to have a strong chance of causing significant harm from the market until we could establish their safety. For example, after decades of research revealed the harmful effects of lead, especially on children, lead-based paints and leaded gasoline were phased out in most developed countries.

Some movement is being made in the direction of the precautionary approach, especially in the European Union. In 2000, negotiators agreed to a global treaty that would ban or phase out the use of 12 of the most notorious *persistent organic pollutants (POPs)*, also called the *dirty dozen* (see **http://www.pops.int/**). These highly toxic chemicals have been shown to produce numerous harmful effects in test animals and in humans, including cancers, birth defects, compromised immune systems, and a 50% decline in sperm counts and sperm quality in men in several countries. The POPs list includes DDT and eight other pesticides, PCBs, and dioxins. In 2009, nine more POPs were added, some of which are widely used in pesticides and in flame retardants added to clothing, furniture, and other goods.

New chemicals will be added to the list when the harm they could potentially cause is seen as outweighing their usefulness. The POPs treaty went into effect in 2004 but has not been ratified and implemented by the United States.

In 2007, the European Union enacted regulations known as REACH (for registration, evaluation, and authorization of chemicals). It required the registration of 30,000 untested, unregulated, and potentially harmful chemicals. Under REACH, the most hazardous substances are not approved for use if safer alternatives exist. And when there is no alternative, producers must present a plan for finding one.

REACH puts more of the burden on industry to show that chemicals are safe. Conventional regulation has put the burden on governments to show that they are dangerous. For example, the U.S. chemical regulation structure was enacted in 1976. At Congressional hearings in 2009, experts testified that the system makes it virtually impossible for the government to limit or ban the use of toxic chemicals. The hearings found that under this system, the EPA had required testing for only 200 of the more than 100,000 chemicals used in industry, and had issued regulations to control just 5 of those chemicals.

Manufacturers and businesses contend that widespread application of the much more precautionary REACH approach would make it too expensive and almost impossible to introduce any new chemical or technology. They argue that we will never have a risk-free society.

INDIVIDUALS MATTER

Ray Turner and His Refrigerator

Life as we know it could not exist on land or in the upper layers of the oceans and other bodies of water without the thin layer of ozone (O_3) found in the lower stratosphere (see Figure 3-4, p. 57). It is critical for protecting us from the sun's harmful UV rays. Therefore, a basic rule of sustainability relating to pollution prevention is: *Do not mess with the ozone layer*.

However, for decades we violated this version of the pollution prevention principle by releasing large amounts of chemicals called chlorofluorocarbons (CFCs) into the troposphere. These chemicals have drifted into the stratosphere where they react with and destroy some of the ozone.

In 1974, scientists alerted the world to this threat. After further research and lengthy debate, in 1992, most of the world's nations signed a landmark international agreement to phase out the use of CFCs and other ozone-destroying chemicals. The discovery of these chemicals led scientists to use the principle of pollution prevention to search for less harmful alternatives.

Ray Turner, a manager at Hughes Aircraft in the U.S. state of California, was concerned about this problem. His company was using CFCs as cleaning agents to remove films caused by oxidation from the electronic circuit boards they manufactured. Turner's concern for the environment led him to search for a cheap and simple substitute for these chemicals. He found it in his refrigerator.

Turner decided to put drops of some common kitchen substances on a corroded penny to see whether any of them would remove the film caused by oxidation. Then he used his soldering gun to see whether solder would stick to the surface of the penny, indicating the film had been cleaned off.

First he tried vinegar. No luck. Then he tried some ground-up lemon peel. Another failure. Next he tried a drop of lemon juice and watched as the solder took hold. The rest, as they say, is history.

Today, Hughes Aircraft uses inexpensive, CFC-free, citrus-based solvents to clean circuit boards. This cleaning technique has reduced the company's circuit board defects by about 75%. In addition, Turner got a hefty bonus. Now, other companies clean computer boards and chips using acidic chemicals extracted from cantaloupes, peaches, and plums. Maybe you can find a solution to an environmental problem in your refrigerator.

Proponents of pollution prevention agree that it could be taken too far, but argue we have an ethical responsibility to reduce known or potentially serious risks to human health and to our life-support system (**Concept 17-4B**). They also point out that using the precautionary principle focuses the efforts and creativity of scientists, engineers, and businesses on finding solutions to pollution problems based on prevention rather than on cleanup. It also reduces health risks for employees and society and reduces a company's risk of lawsuits from harmed parties. In some cases, it helps companies to increase their profits from sales of safer products and innovative technologies, and it improves the public image of businesses operating in this manner.

For almost 40 years, most laws and technologies for dealing with pollution have focused on cleaning up or diluting pollution after it has been produced. Experience shows that such pollution control is only a temporary solution that can be overwhelmed by a growing population consuming more resources and producing more pollution. Environmental and health scientists say we can do better than this by putting much greater emphasis on pollution prevention.

HOW WOULD YOU VOTE?

Should we rely more on the use of the precautionary principle to implement pollution prevention as a way to reduce the potential risks from chemicals and technologies? Cast your vote online at **www.cengage.com/login**.

17-5 How Do We Perceive Risks and How Can We Avoid the Worst of Them?

CONCEPT 17-5 **We can reduce the major risks we face by becoming informed, thinking critically about risks, and making careful choices.**

The Greatest Health Risks Come from Poverty, Gender, and Lifestyle Choices

Risk analysis involves identifying hazards and evaluating their associated risks (*risk assessment;* Figure 17-2, left), ranking risks (*comparative risk analysis*), determining options and making decisions about reducing or eliminating risks (*risk management;* Figure 17-2, right), and informing decision makers and the public about risks (*risk communication*).

Statistical probabilities based on past experience, animal testing, and other research are used to estimate risks from older technologies and chemicals. To evaluate new technologies and products, risk evaluators use more uncertain statistical probabilities, based on models rather than on actual experience and testing.

The greatest risks many people face today are rarely dramatic enough to make the daily news. In terms of the number of premature deaths per year (Figure 17-16) and reduced life span (Figure 17-17), *the greatest risk by far is poverty*. The high death toll ultimately resulting from poverty is caused by malnutrition, increased susceptibility to normally nonfatal infectious diseases (such as diarrhea and measles), and often-fatal infectious diseases transmitted by unsafe drinking water.

After poverty and gender, the greatest risks of premature death result primarily from lifestyle choices that people make (Figures 17-16 and 17-17) (**Concept 17-1**). The best ways to reduce one's risk of premature death and serious health problems are to avoid smoking and exposure to smoke (see the Case Study that follows), lose excess weight, reduce consumption of foods containing cholesterol and saturated fats, eat a variety of fruits and vegetables, exercise regularly, drink little or no alcohol (no more than two drinks in a single day), avoid excess sunlight (which ages skin and can cause skin cancer), and practice safe sex (**Concept 17-5**). A 2005 study by Majjid Ezzati with participation by 100 scientists around the world estimated that one-third of the 7.6 million annual deaths from cancer could be prevented if individuals were to follow these guidelines. The number of lives this would save each year is more than the entire population of the U.S. city of Houston, Texas.

About two-thirds of Americans are either overweight or obese. In 2009, the American Cancer Society reported that an 18-year study of 900,000 cancer-free U.S. adults indicated that more than 90,000 cancer deaths could be prevented each year if Americans maintained healthy body weights.

CASE STUDY
Death from Smoking

What is roughly the diameter of a 30-caliber bullet, can be bought almost anywhere, is highly addictive, and kills an average of about 14,800 people every day, or about one every 6 seconds? It is a cigarette. *Cigarette smoking is the world's most preventable major cause of suffering and premature death among adults.*

In 2007, the WHO estimated that tobacco use contributed to the premature deaths of 100 million people during the 20th century and could kill 1 billion people during this century unless governments act now to dramatically reduce smoking.

The WHO estimates that each year, tobacco contributes to the premature deaths of at least 5.4 million people (about half from more-developed and half from less-developed countries) from 25 illnesses including heart disease, stroke, lung and other cancers, and bronchitis. Another disease related to smoking is *emphysema*, which results in irreversible damage to air sacs in the lung and chronic shortness of breath (Figure 17-18).

Some scientists hypothesize that smoking is also related to various mental illnesses. A 2007 study by Dutch neurologist Monique Breteler found that long-time smokers have a 50% greater risk of developing dementia and a 70% higher risk of suffering from Alzheimer's disease.

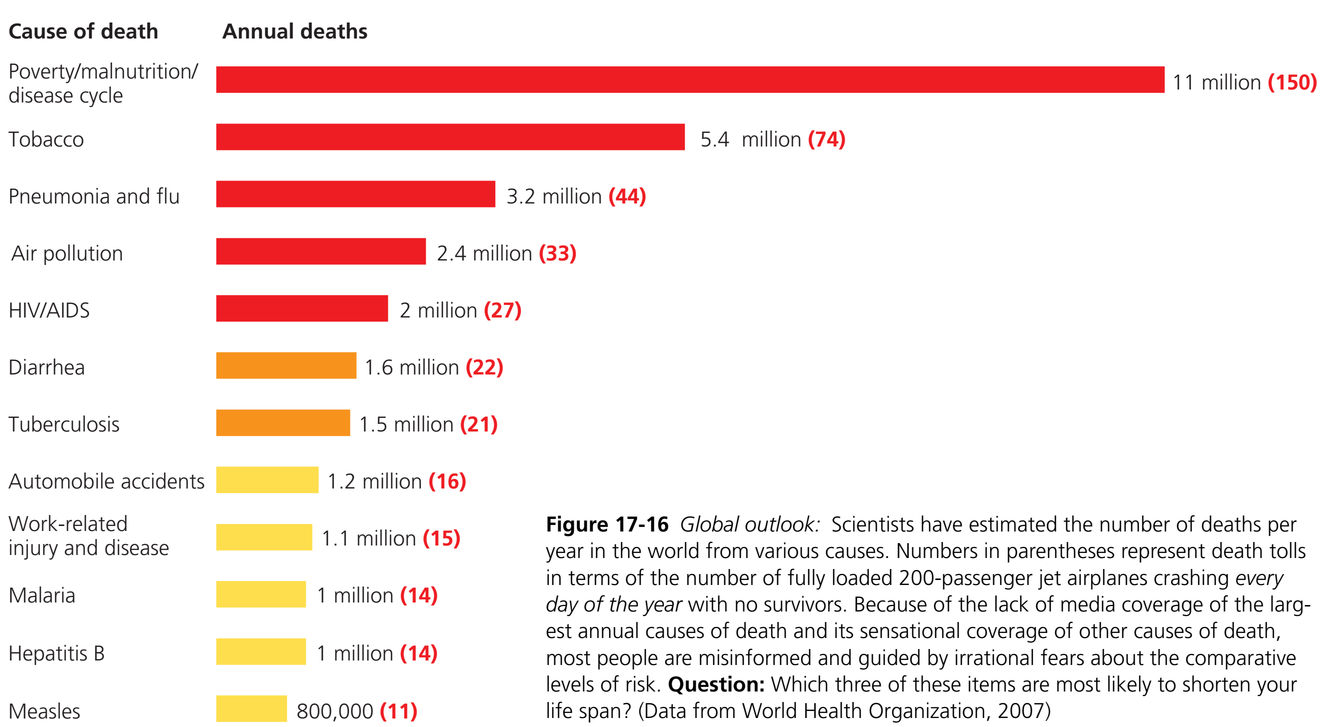


Figure 17-16 *Global outlook:* Scientists have estimated the number of deaths per year in the world from various causes. Numbers in parentheses represent death tolls in terms of the number of fully loaded 200-passenger jet airplanes crashing *every day of the year* with no survivors. Because of the lack of media coverage of the largest annual causes of death and its sensational coverage of other causes of death, most people are misinformed and guided by irrational fears about the comparative levels of risk. **Question:** Which three of these items are most likely to shorten your life span? (Data from World Health Organization, 2007)

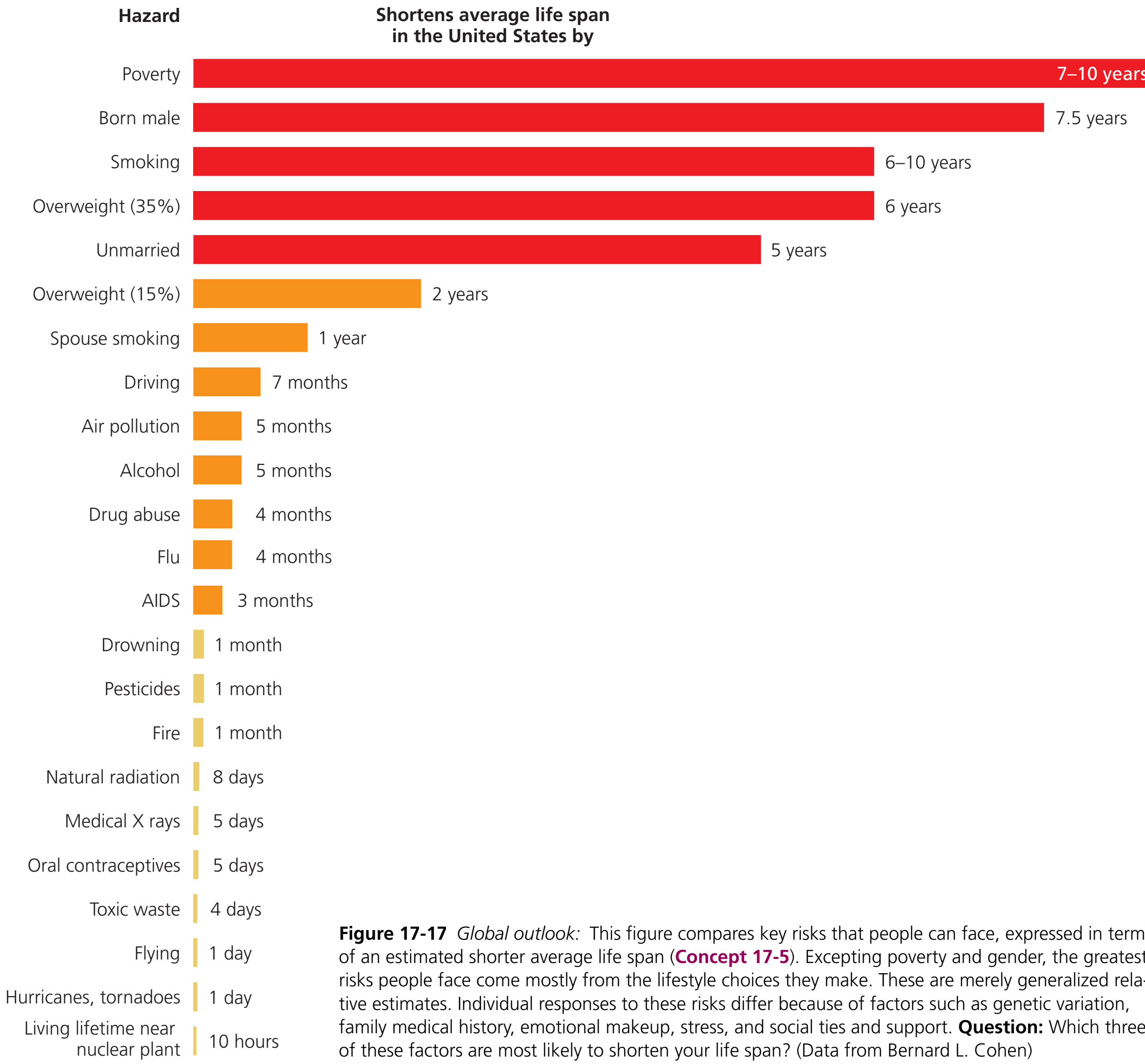


Figure 17-17 *Global outlook:* This figure compares key risks that people can face, expressed in terms of an estimated shorter average life span (**Concept 17-5**). Excepting poverty and gender, the greatest risks people face come mostly from the lifestyle choices they make. These are merely generalized relative estimates. Individual responses to these risks differ because of factors such as genetic variation, family medical history, emotional makeup, stress, and social ties and support. **Question:** Which three of these factors are most likely to shorten your life span? (Data from Bernard L. Cohen)

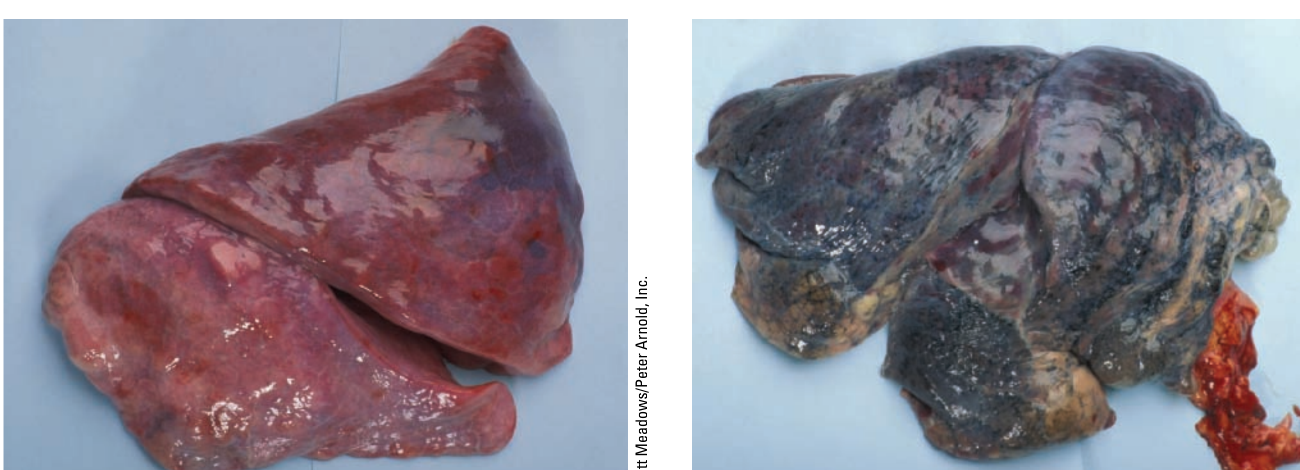


Figure 17-18 There is a startling difference between normal human lungs (left) and the lungs of a person who died of emphysema (right). The major cause is prolonged smoking and exposure to air pollutants.

According to the WHO, lifelong smokers reduce their life spans by an average of 15 years. By 2030, the annual death toll from smoking-related diseases is projected to reach more than 8 million—an average of 21,900 preventable deaths per day. About 80% of these deaths are expected to occur in less-developed countries, especially China, with 30% of the world's smokers, and India, with 11% of all smokers.

According to the U.S. Centers for Disease Control and Prevention (CDC), smoking kills about 442,000 Americans per year prematurely—an average of 1,211 deaths per day, or nearly one every minute (Figure 17-19). This death toll is roughly equivalent to six fully loaded 200-passenger jet planes crashing *every day of the year* with no survivors—a major human tragedy that rarely makes the news. A 2010 study by CDC scientist David L. Ashley and his colleagues found that U.S.-made cigarettes tend to contain more cancer-causing chemicals than cigarettes made elsewhere around the world.

The overwhelming scientific consensus is that the nicotine inhaled in tobacco smoke is highly addictive. Only one in ten people who try to quit smoking succeeds. Smokers suffer about the same relapse rate as do recovering alcoholics and those addicted to heroin or crack cocaine. A British government study showed that adolescents who smoke more than one cigarette have an 85% chance of becoming smokers.

Studies also show that *passive smoking*, or breathing secondhand smoke, poses health hazards for children and adults. Children who grow up living with smokers are more likely to develop allergies and asthma. Among adults, nonsmoking spouses of smokers have a 30% higher risk of both heart attack and lung cancer than spouses of nonsmokers have. In 2006, the CDC estimated that each year, secondhand smoke causes an estimated 3,000 lung cancer deaths and 46,000 deaths from heart disease in the United States.

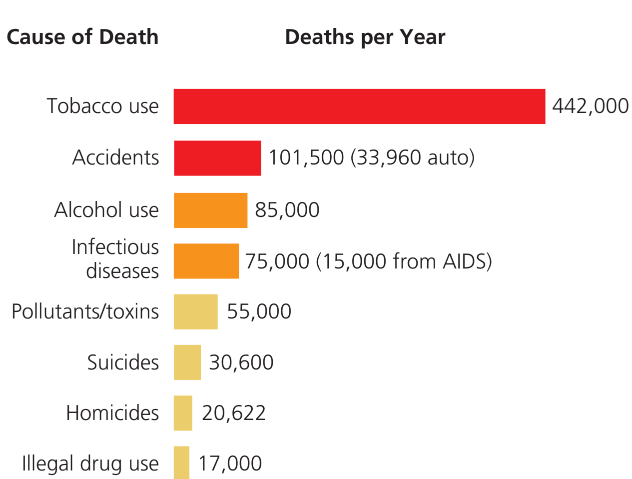


Figure 17-19 Smoking is by far the nation's leading cause of preventable death, causing more premature deaths each year than all the other categories in this figure combined. (Data from U.S. National Center for Health Statistics, Centers for Disease Control and Prevention, and U.S. Surgeon General)

A 2004 study by Richard Doll and Richard Peto found that cigarette smokers die, on average, 10 years earlier than nonsmokers, but that kicking the habit—even at 50 years of age—can cut a person's risk in half. If people quit smoking by the age of 30, they can avoid nearly all the risk of dying prematurely, but, the longer one smokes, the harder it is to quit.

Many health experts urge that a $3–5 federal tax be added to the price of a pack of cigarettes in the United States. With such a tax, users of tobacco products would pay a much greater share of the $158 billion per year (an average of $301,000 per minute) in health, economic, and social costs associated with smoking in the United States. U.S. tobacco companies have fought such proposals with a very effective campaign that misled the public about the dangers of smoking and held off serious regulation of smoking for more than 30 years.

In 2009, the government gave the U.S. Food and Drug Administration the power to classify and regulate tobacco as a drug. This was an important step forward, according to some analysts. These experts also call for eliminating all federal subsidies and tax breaks to tobacco farmers and tobacco companies, and using higher cigarette tax revenues to finance an aggressive antitobacco advertising and education program.

Some other countries are enacting smoking bans. In 2004, Ireland, Norway, and Scotland enacted bans on smoking in all indoor workplaces, bars, and restaurants. In 2004, India also banned smoking in public places, as well as tobacco advertising in the mass media and tobacco sales to minors. Studies had shown that smoking was killing 2,200 people a day in India. In 2006, France banned smoking in public facilities and Great Britain did so in 2007.

Still, in 2009, tobacco companies produced more than 5 trillion cigarettes—more than 700 for every person on the earth—as per capita cigarette smoking is increasing in several countries. In China, 350 million people—well over the total number of people living in the United States—are smokers.

GOOD NEWS

There is some encouraging news: the average number of cigarettes smoked per person in the United States declined by 56% between 1976 and 2006 and dropped globally by 16% between 1988 and 2004. That number is dropping in most other countries, as well. In the United States, the percentage of adults who smoke dropped from roughly 40% in the 1960s to 21% in 2009. Such declines can be attributed to media coverage about the harmful health effects of smoking, sharp increases in cigarette taxes in many states, mandatory health warnings on cigarette packs, and the banning of smoking in workplaces, bars, restaurants, and public buildings.

HOW WOULD YOU VOTE?

Do you favor banning the use of tobacco in all workplaces and public buildings? Cast your vote online at **www.cengage.com/login**.

Estimating Risks from Technologies Is Not Easy

The more complex a technological system and the more people needed to design and run it, the more difficult it is to estimate the risks of using the system. The overall *reliability* or the probability (expressed as a percentage) that a person, device, or complex technological system will complete a task without failing is the product of two factors:

$$\text{System reliability (\%)} = \text{Technology reliability (\%)} \times \text{Human reliability (\%)}$$

With careful design, quality control, maintenance, and monitoring, a highly complex system such as a nuclear power plant or space shuttle can achieve a high degree of technological reliability. But human reliability usually is much lower than technological reliability and is almost impossible to predict: *To err is human.*

Suppose the technological reliability of a nuclear power plant is 95% (0.95) and human reliability is 75% (0.75). Then the overall system reliability is 71% (0.95 × 0.75 = 71%). Even if we could make the technology 100% reliable (1.0), the overall system reliability would still be only 75% (1.0 = 0.75 = 75%). The crucial dependence of even the most carefully designed systems on unpredictable human reliability helps to explain tragedies that had been deemed almost impossible, such as the Chernobyl nuclear power plant accident (see Chapter 15, Case Study, p. 389), the *Challenger* and *Columbia* space shuttle accidents, and the massive oil spill from the blowout of a deep-water oil well in U.S. Gulf Coast waters in 2010.

One way to make a system more foolproof, is to move more of the potentially fallible elements from the human side to the technological side. However, chance events such as a lightning strike can knock out an automatic control system, and no machine or computer program can completely replace human judgment. Also, the parts in any automated control system are manufactured, assembled, tested, certified, and maintained by fallible human beings. In addition, computer software programs used to monitor and control complex systems can be flawed because of human error or can be sabotaged.

Most People Do a Poor Job of Evaluating Risks

Most of us are not good at assessing the relative risks from the hazards that surround us. Many people deny or shrug off the high-risk chances of death (or injury) from voluntary activities they enjoy such as *motorcycling* (1 death in 50 participants), *smoking* (1 in 250 by age 70 for a pack-a-day smoker), *hang gliding* (1 in 1,250), and *driving* (1 in 3,300 without a seatbelt and 1 in 6,070 with a seatbelt). Indeed, the most dangerous thing a majority of people in many countries do each day is to drive or ride in a car.

Yet some of these same people may be terrified about their chances of being killed by *the flu* (1 in 130,000), *a nuclear power plant accident* (1 in 200,000), *West Nile virus* (1 in 1 million), *lightning* (1 in 3 million), *a commercial airplane crash* (1 in 9 million), *snakebite* (1 in 36 million), or *shark attac*k (1 in 281 million). Worldwide each year, sharks kill an average of 6 people, while elephants kill at least 200 people.

Five factors can cause people to see a technology or a product as being more or less risky than experts judge it to be. First is *fear.* Research going back 3 decades shows that fear causes people to overestimate risks and worry more about unusual risks than they do for common, everyday risks. Studies show that people tend to overestimate numbers of deaths caused by tornadoes, floods, fires, homicides, cancer, and terrorist attacks, and to underestimate numbers of deaths from flu, diabetes, asthma, heart attack, stroke, and automobile accidents. Many people also fear a new, unknown product or technology more than they do an older, more familiar one. For example, some people fear genetically modified foods and trust foods produced by traditional plant-breeding genetic techniques.

The second factor in our estimation of risk is the *degree of control* we have in a given situation. Most of us have a greater fear of things over which we do not have personal control. For example, some individuals feel safer driving their own car for long distances through heavy traffic than traveling the same distance on a plane. But look at the numbers. The risk of dying in a car accident in the United States while using a seatbelt is 1 in 6,070, whereas the risk of dying in a commercial airliner crash is 1 in 9 million.

The third factor is *whether a risk is catastrophic*, not chronic. We usually are more frightened by news of catastrophic accidents such as a plane crash than we are of a cause of death such as smoking, which has a much larger death toll spread out over time.

Fourth, some people suffer from *optimism bias*, the belief that risks that apply to other people do not apply to them. While people get upset when they see others driving erratically while talking on a cell phone, they may believe that talking on the cell phone or text messaging does not impair their own driving ability.

A fifth factor is that many of the risky things we do are highly pleasurable and give *instant gratification*, while the potential harm from such activities comes later. Examples are smoking cigarettes, eating lots of ice cream, and getting a tan.

Several Principles Can Help Us Evaluate and Reduce Risk

Here are some guidelines for evaluating and reducing risk (**Concept 17-5**):

- *Compare risks.* Is there a risk of getting cancer by eating a charcoal-broiled steak once or twice a week for a lifetime? Yes, because almost any chemical can harm you if the dose is large enough. The question is whether this danger is great enough for you to worry about. In evaluating a risk, the key question is not "Is it safe?" but rather "*How risky is it compared to other risks?*"

- *Determine how much of a risk you are willing to accept.* For most people, a 1 in 100,000 chance of dying or suffering serious harm from exposure to an environmental hazard is a threshold for changing their behavior. However, in establishing standards and reducing risk, the U.S. EPA generally assumes that a 1 in 1 million chance of dying from an environmental hazard is acceptable. People involuntarily exposed to such risks believe that this standard is too high.
- *Determine the actual risk involved.* The news media usually exaggerate the daily risks we face in order to capture our interest and sell newspapers and magazines or gain television viewers. As a result, most people who are exposed to a daily diet of such exaggerated reports believe that the world is much more risk-filled than it really is.
- *Concentrate on evaluating and carefully making important lifestyle choices*, and you will have a much greater chance of living a longer, healthier, happier, and less fearful life. When you worry about a risk, the most important question to ask is, "Do I have any control over this?" There is no point worrying about risks over which you have no control. But you do have control over major ways to reduce risks from heart attack, stroke, and many forms of cancer, because you can decide whether to smoke, what to eat, and how much alcohol to drink. Other factors under your control are whether you practice safe sex, how much exercise you get, how safely you drive, and how often you expose yourself to the ultraviolet rays from the sun or from a tanning booth.

GOOD NEWS

Here are this chapter's *three big ideas*:

- We face significant hazards from infectious diseases such as flu, AIDS, diarrheal diseases, malaria, and tuberculosis, and from exposure to chemicals that can cause cancers and birth defects, and disrupt the human immune, nervous, and endocrine systems.
- Because of the difficulty in evaluating the harm caused by exposure to chemicals, many health scientists call for much greater emphasis on pollution prevention.
- Becoming informed, thinking critically about risks, and making careful choices can reduce the major risks we face.

REVISITING Bisphenol A and Sustainability

CORE CASE STUDY

SUSTAINABILITY

In the **Core Case Study** that opens this chapter, we saw that certain chemicals such as bisphenol A can act as hormone disruptors and may have a number of harmful health effects on humans, especially children. In this chapter, we also saw how difficult it is to evaluate the nature and severity of threats from this and other such chemicals. In addition, we evaluated the risks to human health from other chemical, biological, physical, cultural, and lifestyle hazards.

One of the important facts discussed in this chapter is that on a global basis, the greatest threat to human health is the poverty–malnutrition–disease cycle, followed by the threats from smoking, pneumonia and flu, air pollution, and HIV/AIDS. There are some threats that we can do little to avoid, but we can reduce other threats, partly by applying the three **principles of sustainability**. For example, we can greatly reduce exposure to air and water pollutants by shifting from nonrenewable fossil fuels (especially coal) to a diversity of renewable energy resources, including solar energy, wind, flowing water, and biomass. We can reduce our exposure to harmful chemicals used in the manufacturing of various goods by cutting resource use and waste, and by reusing and recycling material resources. We can also mimic biodiversity by using diverse strategies for solving environmental and health problems, and especially for reducing poverty and controlling population growth. In so doing, we also help to preserve the earth's biodiversity.

Is this idealistic? Sure. But if creative and caring people throughout human history had not acted to improve the world by pursuing goals that others said were impossible or too idealistic, we would have accomplished very little on this marvelous planet. Each of us can make a difference.

The burden of proof imposed on individuals, companies, and institutions should be to show that pollution prevention options have been thoroughly examined, evaluated, and used before lesser options are chosen.

JOEL HIRSCHORN

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 437. Describe the potential risks from exposure to trace amounts of hormone mimics such as bisphenol A.

2. Define **risk** and distinguish between **risk assessment** and **risk management**. Distinguish between possibility and probability. What is a **pathogen**? Give an example of a risk from each of the following: biological hazards, chemical hazards, physical hazards, cultural hazards, and lifestyle choices.

3. Distinguish among an **infectious disease**, a **transmissible disease**, and a **nontransmissible disease**, and give an example of each. In terms of death rates, what are the world's four most serious infectious diseases? Distinguish between an epidemic and a pandemic of an infectious disease. Describe the causes and possible solutions for the increasing genetic resistance to commonly used antibiotics.

4. Describe the global threat from tuberculosis (TB). Describe the threat from flu. Describe the health threats from the global HIV/AIDS pandemic and list six ways to reduce this threat. Describe the threat from the hepatitis B virus. Define **emergent diseases** and describe the threat from the West Nile virus. Describe the threat from malaria for 40% of the world's people and how we can reduce this threat.

5. Give three examples of problems being studied within the field of ecological medicine. What are two ways in which people have exposed themselves to such threats? List five major ways to reduce the global threat from infectious diseases.

6. What is a **toxic chemical**? Discuss the threat from PCBs. Distinguish among **mutagens**, **teratogens**, and **carcinogens**, and give an example of each. Describe the human immune, nervous, and endocrine systems and give an example of a chemical that can threaten each of these systems. Describe the toxic effects of the various forms of mercury and ways to reduce these threats. What are hormonally active agents, what risks do they pose, and how can we reduce these risks?

7. Define **toxicology**, **toxicity**, **dose**, and **response**. Give three reasons why children are more vulnerable to harm from toxic chemicals than are adults. Describe how the toxicity of a substance can be estimated by testing laboratory animals, and discuss the limitations of this approach. What is a **dose-response curve**? Describe how toxicities are estimated through use of case reports and epidemiological studies, and discuss the limitations of these approaches. Why do we know so little about the harmful effects of chemicals? Discuss the use of the precautionary principle and pollution prevention in dealing with health threats from chemicals.

8. What is **risk analysis**? In terms of premature deaths, what are the three greatest threats that humans face? Describe the health threats from smoking and what we can do to reduce these threats.

9. How can we reduce the threats from the use of various technologies? What five factors can cause people to misjudge risks? List four principles that can help us evaluate and reduce risk.

10. What are this chapter's *three big ideas*? Discuss how we can lessen the threats of harm from chemicals such as hormone mimics by applying the three scientific **principles of sustainability**.

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. Should we ban the use of hormone mimics such as bisphenol A (**Core Case Study**) in products used by children younger than age 7? Should we ban them for use in all products? Explain.

2. What are three actions you would take to reduce the global threats to human health and life from **(a)** tuberculosis, **(b)** HIV/AIDS, and **(c)** malaria?

3. Evaluate the following statements:
   a. We should not worry much about exposure to toxic chemicals because almost any chemical, at a large enough dosage, can cause some harm.
   b. We should not worry much about exposure to toxic chemicals because, through genetic adaptation, we can develop immunities to such chemicals.
   c. We should not worry much about exposure to toxic chemicals because we can use genetic engineering to reduce our susceptibility to their effects.

4. Workers in a number of industries are exposed to higher levels of various toxic substances than is the general public. Should we reduce workplace levels allowed for such chemicals? What economic effects might this have?

5. Explain why you agree or disagree with the proposals for reducing the death toll and other harmful effects of smoking listed in the Case Study, p. 458. Do you believe there should be a ban on smoking indoors in all public places? Explain.

6. What are the three major risks you face from **(a)** your lifestyle, **(b)** where you live, and **(c)** what you do for a living? Which of these risks are voluntary and which are involuntary? List three steps you could take to reduce these risks. Which of these steps do you already take or plan to take?

7. In deciding what to do about risks from chemicals in the country where you live, would you support legislation requiring the use of pollution prevention based on the precautionary principle? Explain.

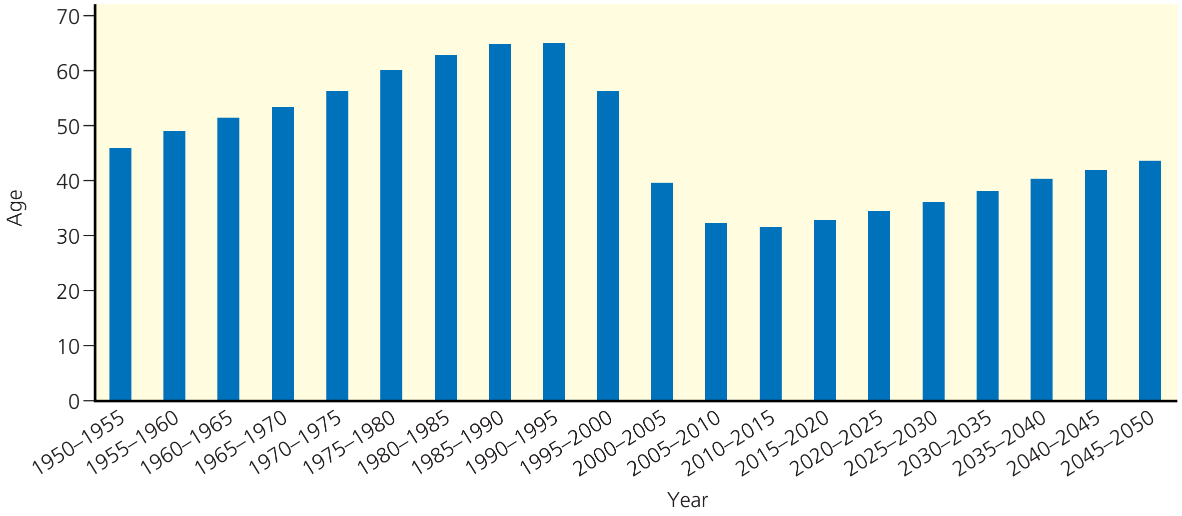
8. Congratulations! You are in charge of the world. List the three most important features of your program to reduce the risks from exposure to **(a)** infectious disease organisms and **(b)** toxic and hazardous chemicals.

9. List three ways in which you could apply **Concept 17-5** to making your lifestyle more environmentally sustainable while reducing the major risks you face.

10. List two questions that you would like to have answered as a result of reading this chapter.

DATA ANALYSIS

The graph below shows the effects of AIDS on life expectancy at birth in Botswana, 1950–2000, and projects these effects to 2050. Study the chart and answer the questions below.



Source: Data from United Nations and U.S. Census Bureau

1. **a.** By what percentage did life expectancy in Botswana increase between 1950 and 1995?
   b. By what percentage is life expectancy in Botswana projected to decrease between 1995 and 2015?

2. **a.** By what percentage is life expectancy in Botswana projected to increase between 2015 and 2050?
   b. By what percentage is life expectancy in Botswana projected to decrease between 1995 and 2050?

LEARNING ONLINE

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Air Pollution

18

South Asia's Massive Brown Clouds

CORE CASE STUDY

Air pollution is no longer viewed as primarily a localized urban problem. Annual satellite images and recent studies by the UN Environment Programme (UNEP) have found massive, dark brown clouds of pollution—called the *South Asian Brown Clouds*—stretching across much of India, Bangladesh, and the industrial heart of China as well as parts of the western Pacific Ocean (Figure 18-1).

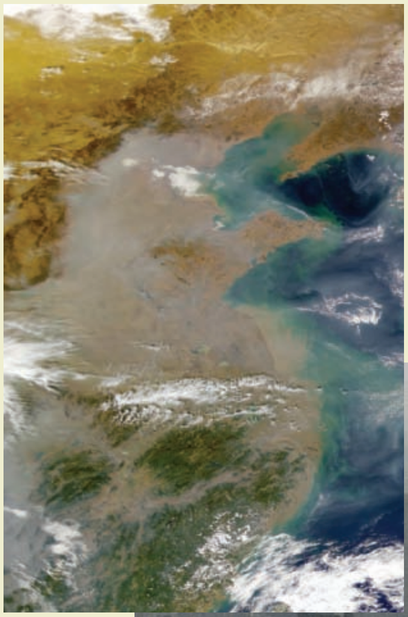
In most years, this 3-kilometer- (2-mile) thick set of clouds covers an area about the size of the continental United States. The clouds contain small particles of dust, smoke, and ash resulting from drought and the clearing and burning of forests for planting crops. They also contain particles of soot (mostly from the burning of biomass such as wood and animal dung); acidic compounds from vehicle exhaust and from emissions from coal-burning power plants; and particles of toxic metals such as mercury and lead, produced mostly by coal-burning facilities, smelters (see Figure 14-11, p. 355) and waste incinerators.

Instead of blue skies, many of the people living under these clouds see brown or gray polluted skies much of the year (Figure 18-2). The clouds are changing weather patterns and affecting food production in China by causing decreased rainfall in the north and increased flooding in the south.

Another problem with the enormous South Asian Brown Clouds is that they do not stay put—they can move across continents within three to four days. Also, satellites have tracked the spread of dense clouds of pollutants from northern China across the Pacific Ocean to the west coast of the United States. The U.S. Environmental Protection Agency (EPA), using measurements by atmospheric scientists, estimates that on certain days, nearly 25% of the particulate matter, 77% of the black carbon (soot), and 33% of the toxic mercury in the skies above Los Angeles, California, can be traced to China's coal-fired power plants, smelters, wood and dung fires, diesel trucks, and dust storms blowing out of drought-stricken and deforested areas.

Satellite measurements show that these and other long-lived air pollutants from China, India, the United States, or anywhere else on the planet can circle the entire globe in about 2 weeks. Air pollution connects us all.

The history of air pollution control in Europe and the United States shows that pollution such as that in the South Asian Brown Clouds can be reduced fairly quickly by enacting and enforcing standards for coal-burning industries and utilities, and by shifting from coal to cleaner-burning natural gas for industries and homes. China and India are beginning to take such steps but they have a long way to go.



The SeaWiFS Project, NASA/Goddard Space Flight Center, and Orbimage

Figure 18-1 The *South Asian Brown Clouds* are gigantic clouds of dust, smoke, soot, and other pollutants that stretch over much of South Asia. One is visible here over eastern China.

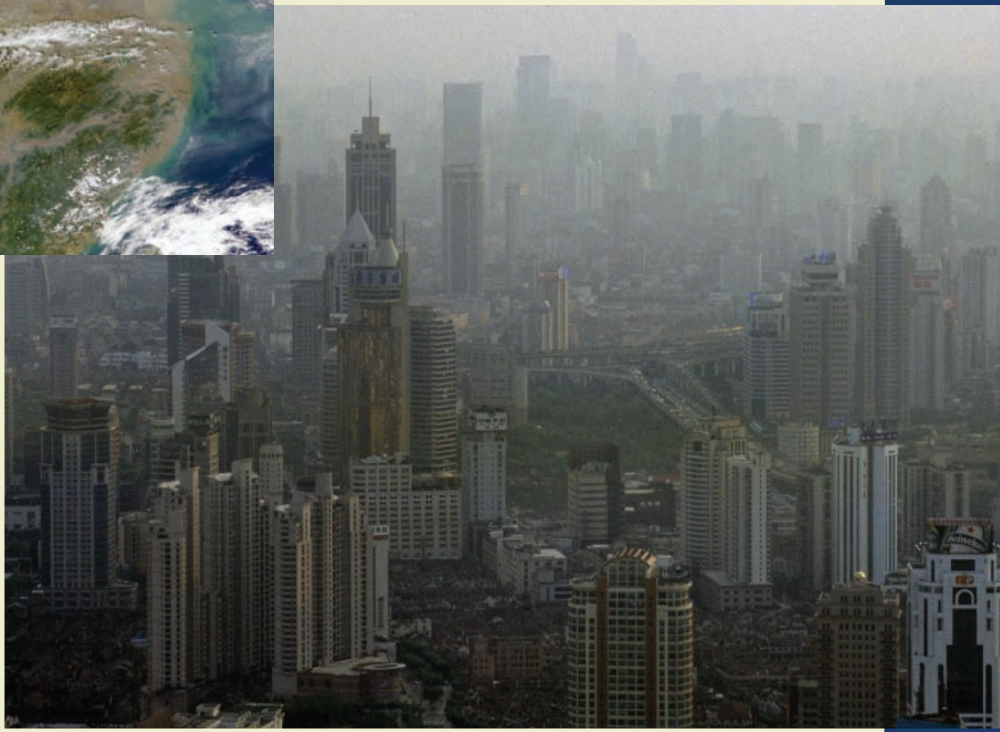


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Figure 18-2 Shanghai, China, is one of a number of Asia's large cities that have been polluted and darkened by the regional haze from the cocktail of pollutants in the South Asian Brown Clouds. Other cities affected by these clouds include Beijing, China; Bangkok, Thailand; Cairo, Egypt; and Mumbai and New Delhi, India.

Key Questions and Concepts

18-1 What is the nature of the atmosphere?

CONCEPT 18-1 The two innermost layers of the atmosphere are the *troposphere*, which supports life, and the *stratosphere*, which contains the protective ozone layer.

18-2 What are the major outdoor air pollution problems?

CONCEPT 18-2 Pollutants mix in the air to form *industrial smog*, primarily as a result of burning coal, and *photochemical smog*, caused by emissions from motor vehicles, industrial facilities, and power plants.

18-3 What is acid deposition and why is it a problem?

CONCEPT 18-3 Acid deposition is caused mainly by coal-burning power plants and motor vehicle emissions, and in some regions it threatens human health, aquatic life and ecosystems, forests, and human-built structures.

18-4 What are the major indoor air pollution problems?

CONCEPT 18-4 The most threatening indoor air pollutants are smoke and soot from the burning of wood and coal in cooking fires (mostly in less-developed countries), cigarette smoke, and chemicals used in building materials and cleaning products.

18-5 What are the health effects of air pollution?

CONCEPT 18-5 Air pollution can contribute to asthma, chronic bronchitis, emphysema, lung cancer, heart attack, and stroke.

18-6 How should we deal with air pollution?

CONCEPT 18-6 Legal, economic, and technological tools can help us to clean up air pollution, but the best solution is to prevent it.

Note: Supplements 2 (p. S3), 3 (p. S6), 4 (p. S11), 7 (p. S26), and 8 (p. S30) can be used with this chapter.

Pollution is nothing but the resources we are not harvesting.
We allow them to disperse because we've been ignorant of their value.

RICHARD BUCKMINSTER (BUCKY) FULLER

18-1 What Is the Nature of the Atmosphere?

CONCEPT 18-1 The two innermost layers of the atmosphere are the *troposphere*, which supports life, and the *stratosphere*, which contains the protective ozone layer.

The Atmosphere Consists of Several Layers

We live under a thin blanket of gases surrounding the earth, called the *atmosphere*. It is divided into several spherical layers (Figure 18-3). Our focus in this book is on the atmosphere's two innermost layers: the troposphere and the stratosphere.

The *density*, or the number of gas molecules per unit of air volume, varies throughout the troposphere (and other layers) because gravity pulls its gas molecules toward the earth's surface. This means that lower layers have more gases (more weight) in them than upper layers do, and are more densely packed with molecules. Thus, the air we breathe at sea level has a higher density than the air we would inhale on top of a high mountain.

Atmospheric pressure is the force, or mass, per unit area of a column of air. This force is caused by the bombardment of a surface such as your skin by the molecules in air. Atmospheric pressure decreases with altitude (see black line in Figure 18-3) because there are fewer gas molecules at higher altitudes.

Air Movements in the Troposphere Play a Key Role in the Earth's Weather and Climate

About 75–80% of the earth's air mass is found in the **troposphere**, the atmospheric layer closest to the earth's surface. This layer extends only about 17 kilometers (11 miles) above sea level at the equator and 6 kilometers (4 miles) above sea level over the poles.

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. GOOD NEWS refers to good news about the environmental challenges we face.

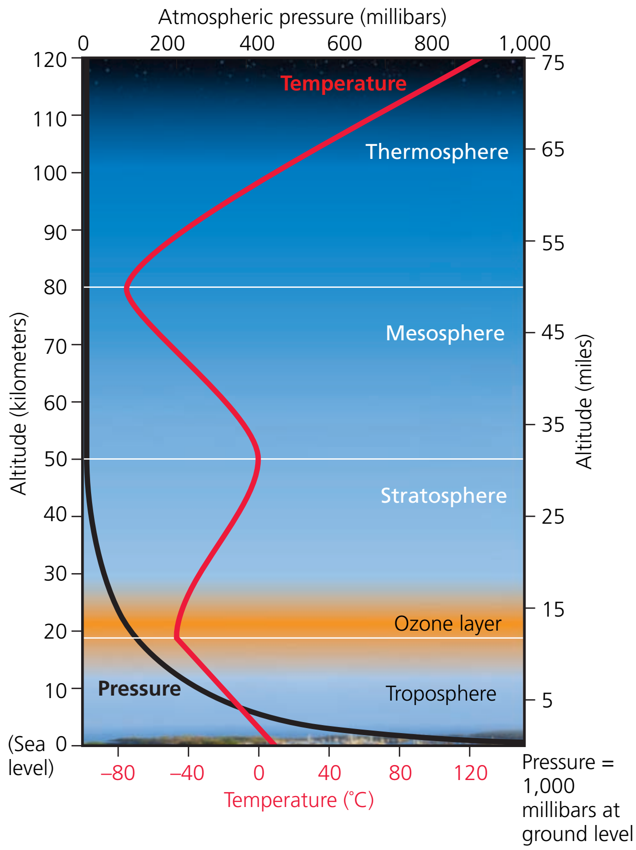

Figure 18-3 **Natural capital:** The earth's atmosphere is a dynamic system that includes four layers. The average temperature of the atmosphere varies with altitude (red line) and with differences in the absorption of incoming solar energy. Note how the atmosphere's temperature falls and rises again twice as we move from lower to upper layers. Because the troposphere receives most of its heat from the earth's surface, it cools as its air gets further from the surface. Most ultraviolet radiation from the sun is absorbed by ozone, found primarily in the stratosphere's *ozone layer*, 17–26 kilometers (11–16 miles) above sea level. This ozone absorption causes the temperature to rise in the stratosphere. **Question:** Why do you think most of the planet's air is in the troposphere?

If the earth were the size of an apple, this lower layer containing the air we breathe would be no thicker than the apple's skin.

Take a deep breath. About 99% of the volume of air you inhaled consists of two gases: nitrogen (78%) and oxygen (21%). The remainder consists of water vapor (varying from 0.01% at the frigid poles to 4% in the humid tropics, for an average of about 1%), 0.93% argon (Ar), 0.039% carbon dioxide (CO_2), and trace amounts of dust and soot particles as well as other gases including methane (CH_4), ozone (O_3), and nitrous oxide (N_2O).

Rising and falling air currents, winds, and concentrations of CO_2 and other greenhouse gases in the troposphere play a major role in the planet's short-term *weather* (see Supplement 7, p. S26) and long-term *climate*. Recall that climate is the average weather in a given area, as measured mostly by temperature and precipitation, over a period of at least three decades (see the Case Study that follows).

CASE STUDY

The South Asian Brown Clouds, Melting Glaciers, and Atmospheric Cooling

In 2008, the UN Environment Programme (UNEP) reported the results of a seven-year study of the effects of the South Asian Brown Clouds (**Core Case Study**) carried out by an international team of scientists led by climate scientist V. Ramanathan of Scripps Institution of Oceanography at the University of California in San Diego (USA). According to these scientists, the South Asian Brown Clouds have been a factor in the gradual melting of the Himalayan glaciers, which are the source of water for most of Asia's major rivers.

The researchers hypothesized that soot and some of the other particles in the brown clouds absorb sunlight and heat the air above the glaciers. Black soot falling on the white surface of the glaciers also decreases their ability to reflect sunlight back into space. The glaciers then absorb more solar energy, which adds to the warming of the air above them and also increases the rate of glacial melting.

The very slow melting of some Himalayan glaciers and of many other mountain glaciers is taken as a sign of atmospheric warming and climate change (which we discuss fully in Chapter 19). But the UNEP study also pointed out that the South Asian Brown Clouds, in addition to contributing to such warming, have helped to mask the full impact of global atmospheric warming. This occurs because certain types of particles in the clouds reflect some incoming sunlight back into space, which has helped to cool part of the earth's surface beneath them.

The net effect is that during this century the South Asian Brown Clouds have helped to slow atmospheric warming and the resulting projected climate change. But this benefit from a form of severe air pollution is more than outweighed by the pollution's harmful effects on water and food supplies, and by its direct link to the deaths of at least 380,000 people a year in China and India.

The Stratosphere Is Our Global Sunscreen

The atmosphere's second layer is the **stratosphere**, which extends from about 17 to about 48 kilometers (from 11 to 30 miles) above the earth's surface (Figure 18-3). Although the stratosphere contains less matter than the troposphere, its composition is similar, with two notable exceptions: its volume of water vapor is about 1/1,000 that of the troposphere and its concentration of ozone (O_3) is much higher.

Much of the atmosphere's small amount of ozone (O_3) is concentrated in a portion of the stratosphere called the **ozone layer**, found roughly 17–26 kilometers (11–16 miles) above sea level. Stratospheric ozone is produced when some of the oxygen molecules in this layer interact with ultraviolet (UV) radiation emitted by the sun ($3\ O_2 + UV \rightleftharpoons 2\ O_3$). This "global sunscreen" of ozone in the stratosphere keeps about 95% of the sun's harmful UV radiation (see Figure 3-4, p. 57) from reaching the earth's surface.

The UV filtering effect of ozone in the lower stratosphere allows us and other forms of life to exist on land and helps to protect us from sunburn, skin and eye cancers, cataracts, and damage to our immune systems. It also prevents much of the oxygen in the troposphere from being converted to photochemical ozone, a harmful air pollutant found near the ground.

18-2 What Are the Major Outdoor Air Pollution Problems?

▶ **CONCEPT 18-2 Pollutants mix in the air to form *industrial smog*, primarily as a result of burning coal, and *photochemical smog*, caused by emissions from motor vehicles, industrial facilities, and power plants.**

Air Pollution Comes from Natural and Human Sources

Air pollution is the presence of chemicals in the atmosphere in concentrations high enough to harm organisms, ecosystems, or human-made materials, or to alter climate. Note that almost any chemical in the atmosphere can become a pollutant if it occurs in a high enough concentration. The effects of air pollution range from annoying to lethal.

Air pollutants come from natural and human sources. Natural sources include wind-blown dust, pollutants from wildfires and volcanic eruptions, and volatile organic chemicals released by some plants. Most natural air pollutants are spread out over the globe or removed by chemical cycles, precipitation, and gravity. But in areas experiencing volcanic eruptions or forest fires, chemicals emitted by these events can temporarily reach harmful levels.

Most human inputs of outdoor air pollutants occur in industrialized and urban areas with their higher concentrations of people, cars, and factories. These pollutants are generated mostly by the burning of fossil fuels (Figure 18-4) in power plants and industrial facilities (*stationary sources*) and in motor vehicles (*mobile sources*). However, human inputs began long before the industrial era, and have steadily increased. Air pollution is a very old problem (see Case Study, p. S9, in Supplement 3).

Some Pollutants in the Atmosphere Combine to Form Other Pollutants

Scientists classify outdoor air pollutants into two categories: **Primary pollutants** are chemicals or substances emitted directly into the air from natural processes and human activities (Figure 18-5) at concentrations high

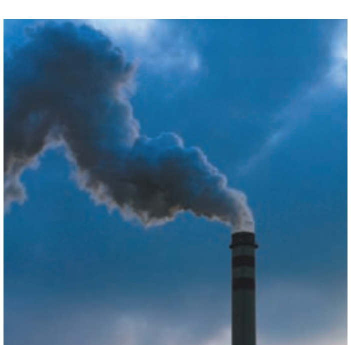

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Figure 18-4 We burn carbon-containing fossil fuels to provide about 79% of the energy used in the world and 85% of the energy used in the United States. These fuels include coal (left), oil products such as gasoline (center), and natural gas (right). Use of these fuels has a number of harmful health and environmental effects. According to the World Health Organization, outdoor air pollution (most of it from burning fossil fuels, especially coal) kills at least 800,000 people each year and causes health problems for tens of millions of others. Technology is available to reduce such air pollution, but using it is costly and results in higher fuel prices. **Question:** How many times a day do you use any or all three of these types of fuel?

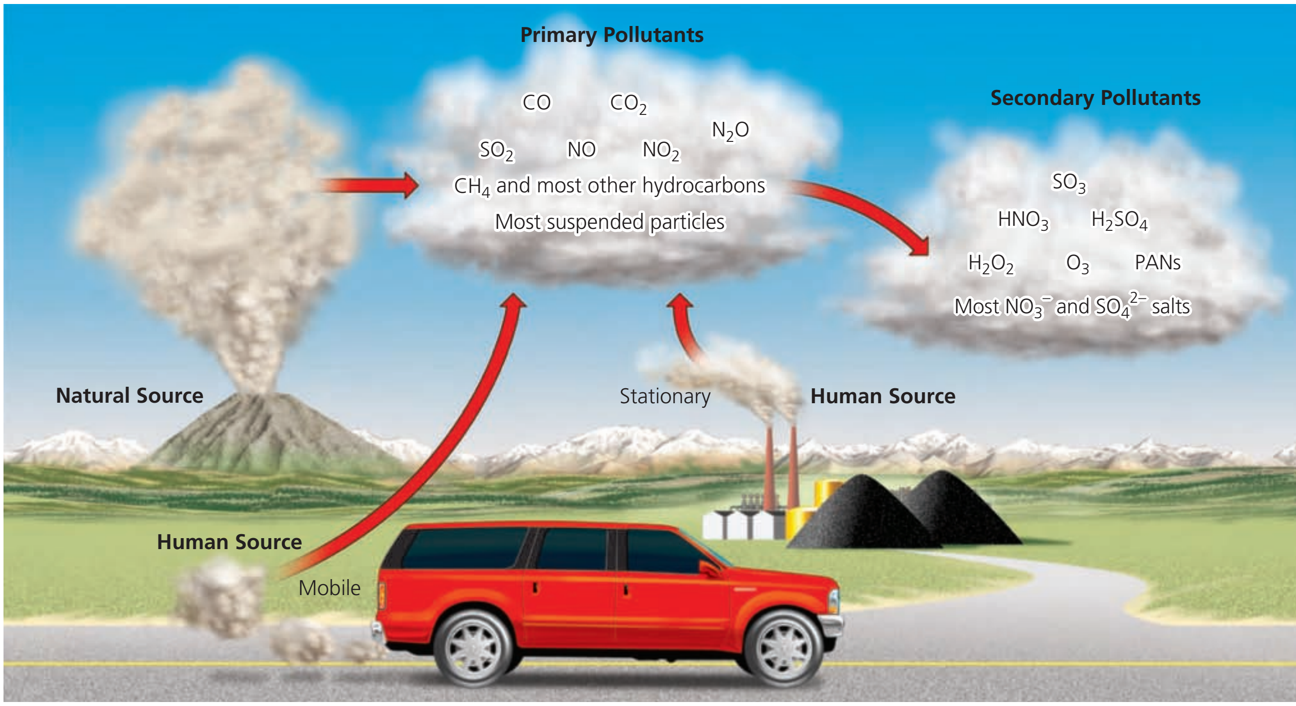


Figure 18-5 Human inputs of air pollutants come from *mobile sources* (such as cars) and *stationary sources* (such as industrial, power, and cement plants). Some *primary air pollutants* react with one another and with other chemicals in the air to form *secondary air pollutants.*

enough to cause harm. While in the atmosphere, some primary pollutants react with one another and with other natural components of air to form new harmful chemicals, called **secondary pollutants** (Figure 18-5, right).

With their high concentrations of cars and factories, urban areas normally have higher outdoor air pollution levels than rural areas have. But prevailing winds can spread long-lived primary and secondary air pollutants from urban and industrial areas to the countryside and to other urban areas.

GOOD NEWS

Over the past 30 years, the quality of outdoor air in most more-developed countries has improved greatly. This has occurred primarily because grassroots pressure from citizens has led governments to pass and enforce air pollution control laws.

On the other hand, according to the World Health Organization (WHO) more than 1.1 billion people (one of every six people on the earth) live in urban areas where outdoor air is unhealthy to breathe. Most of them live in densely populated cities in less-developed countries where air pollution control laws do not exist or are poorly enforced.

However, the biggest pollution threat to poor people is *indoor air pollution* caused by their burning of wood, charcoal, coal, or dung in open fires or poorly designed stoves to heat their dwellings and cook their food. Cigarette smoke is another important part of this problem. Also, they often must work in poorly ventilated and highly polluted areas (Figure 18-6). According to the WHO, each year indoor air pollution kills about 1.6 million people—an average of nearly 4,400 deaths per day—and causes health problems for hundreds of millions of other people

Outdoor air pollution was once a regional problem limited mostly to cities. Now it is a global problem, largely due to the sheer volume of pollutants produced by human activities. Long-lived pollutants entering the atmosphere in India and China (Figure 18-1) now find

Jorgen Schytte/Peter Arnold, Inc.

Figure 18-6 *Indoor air pollution:* These children are working in a plastics factory in an urban slum in Dhaka, Bangladesh. They spend very long working days in this highly polluted room with little ventilation.

their way across the Pacific where they affect the west coast of North America (**Core Case Study**). Even in arctic regions where very few people live, air pollutants flowing north from Europe, Asia, and North America collect to form *arctic haze*. There is no place on the planet that has not been affected by air pollution, caused mostly by the burning of forests (see Figure 10-15, p. 228) and the use of fossil fuels (Figure 18-4).

What Are the Major Air Pollutants?

Carbon oxides. *Carbon monoxide* (CO) is a colorless, odorless, and highly toxic gas that forms during the incomplete combustion of carbon-containing materials (see Table 18-1). Major sources are motor vehicle exhaust, burning of forests and grasslands, smokestacks of fossil fuel–burning power plants and industries, tobacco smoke, and open fires and inefficient stoves used for cooking.

Carbon monoxide can combine with hemoglobin in red blood cells, which prevents the normal binding of oxygen with hemoglobin molecules. This in turn reduces the ability of blood to transport oxygen to body cells and tissues. Long-term exposure can trigger heart attacks and aggravate lung diseases such as asthma and emphysema. At high levels, CO can cause headache, nausea, drowsiness, confusion, collapse, coma, and death.

Carbon dioxide (CO_2) is a colorless, odorless gas. About 93% of the CO_2 in the atmosphere is the result of the natural carbon cycle (see Figure 3-19, p. 70). The rest comes from human activities, mostly the burning of fossil fuels and the clearing of CO_2-absorbing forests and grasslands. Until recently it has not been classified in many countries as an air pollutant. But there is considerable and growing scientific evidence that increasing levels of CO_2 (see Figure 14, p. S63, in Supplement 9) caused by human activities are contributing to atmospheric warming and projected climate change, because CO_2 is being added to the atmosphere faster than it is removed by the natural carbon cycle. This can contribute to human health problems such as heat exhaustion and to the reduction of food supplies in some areas, while causing water shortages, prolonged drought, or excessive flooding in other areas. We discuss this problem in detail in Chapter 19.

Nitrogen oxides and nitric acid. *Nitric oxide* (NO) is a colorless gas that forms when nitrogen and oxygen gas react under high-combustion temperatures in automobile engines and coal-burning power and industrial plants (Table 18-1). Lightning and certain bacteria in soil and water also produce NO as part of the nitrogen cycle (see Figure 3-20, p. 71).

In the air, NO reacts with oxygen to form *nitrogen dioxide* (NO_2), a reddish-brown gas. Collectively, NO and NO_2 are called *nitrogen oxides* (NO_X). Some of the NO_2 reacts with water vapor in the air to form *nitric acid* (HNO_3) and nitrate salts (NO_3^-), components of harmful *acid deposition*, which we discuss later in this chapter. Both NO and NO_2 play a role in the formation of *photochemical smog*—a mixture of chemicals formed under the influence of sunlight in cities with heavy traffic (discussed further below). *Nitrous oxide* (N_2O), a greenhouse gas, is emitted from fertilizers and animal wastes, and is produced by the burning of fossil fuels.

At high enough levels, nitrogen oxides can irritate the eyes, nose, and throat, aggravate lung ailments such as asthma and bronchitis, suppress plant growth, and reduce visibility when they are converted to nitric acid and nitrate salts.

Table 18-1 Chemical Reactions That Form Major Air Pollutants

Pollutant	Chemical Reaction
Carbon monoxide (CO)	$2C + O_2 \rightarrow 2CO$
Carbon dioxide (CO_2)	$C + O_2 \rightarrow CO_2$
Nitric oxide (NO)	$N_2 + O_2 \rightarrow 2NO$
Nitrogen dioxide (NO_2)	$2NO + O_2 \rightarrow 2NO_2$
Sulfur dioxide (SO_2)	$S + O_2 \rightarrow SO_2$

Sulfur dioxide and sulfuric acid. *Sulfur dioxide* (SO_2) is a colorless gas with an irritating odor. About one-third of the SO_2 in the atmosphere comes from natural sources as part of the sulfur cycle (see Figure 3-22, p. 74). The other two-thirds (and as much as 90% in some urban areas) come from human sources, mostly combustion of sulfur-containing coal in power and industrial plants (Table 18-1), oil refining (see Figure 15-4, p. 375), and smelting (see Figure 14-11, p. 355) of sulfide ores.

In the atmosphere, SO_2 can be converted to *aerosols*, which consist of microscopic suspended droplets of *sulfuric acid* (H_2SO_4) and suspended particles of sulfate (SO_4^{2-}) salts that return to the earth as a component of acid deposition (discussed in Section 18-3). Sulfur dioxide, sulfuric acid droplets, and sulfate particles reduce visibility and aggravate breathing problems. They can also damage crops, trees, soils, and aquatic life in lakes, and they corrode metals and damage paint, paper, leather, and stone on buildings and statues (Figure 18-7). They are a major component of the South Asian Brown Clouds (**Core Case Study**). SO_2 emissions that feed into the clouds have increased by more than a third in the past decade, according to a 2007 U.S. National Academy of Sciences report.

Particulates. *Suspended particulate matter* (SPM) consists of a variety of solid particles and liquid droplets that are small and light enough to remain suspended in the air for long periods. The EPA classifies particles as fine, or PM-10 (with diameters less than 10 micrometers), and ultrafine, or PM-2.5 (with diameters less than 2.5 micrometers). About 62% of the SPM in outdoor air comes from natural sources such as dust, wild fires, and sea salt. The remaining 38% comes from human sources such as coal-burning power and industrial plants, motor vehicles, and road construction. Such particulates are a major component of the South Asian Brown Clouds

Lionel Delevingne/Phototake

Figure 18-7 Acid deposition and other forms of air pollution have corroded this statue in Newport, Rhode Island (USA).

(**Core Case Study**). Indoor air pollution from particulates comes mainly from cigarette smoke and from burning wood, charcoal, dung, and coal in open fires or in leaky stoves for heating and cooking.

CONNECTIONS

The South Asian Brown Clouds, Food Production, and Solar Power

Black carbon and sulfate particles in the South Asian Brown Clouds (Figure 18-1) decrease the amount of sunlight that penetrates the atmosphere. This dimming can decrease food production by reducing photosynthesis and by cooling land and ocean surfaces, which decreases evaporation and reduces rainfall. The UNEP projects that unless the pollutants in these clouds are reduced, they could increase crop losses in South Asia by up to 40%. The dimming of sunlight also reduces the output of centralized solar energy power plants (see Figure 16-15, p. 411). A 2009 study by Kaicun Wang found that global dimming, mostly from air pollution, is occurring everywhere except in most of Europe, where decreases in air pollution have led to brighter skies.

According to the American Lung Association, more than 2,000 studies published since 1990 link SPM with adverse health effects. These particles can irritate the nose and throat, damage the lungs, aggravate asthma and bronchitis, and shorten life. Toxic particulates such as lead (see the Case Study that follows), cadmium, and polychlorinated biphenyls (PCBs; see Chapter 17, Case Study, p. 446), can cause genetic mutations, reproductive problems, and cancer. Particulates also reduce visibility, corrode metals, and discolor clothes and paints. In the United States, outdoor particulate air pollution, mostly from coal-burning power and industrial plants, is responsible for about 70,000 premature deaths a year, according to the EPA and the Harvard School of Public Health.

Ozone. *Ozone* (O_3), a colorless and highly reactive gas, is a major ingredient of photochemical smog. It can cause coughing and breathing problems, aggravate lung and heart diseases, reduce resistance to colds and pneumonia, and irritate the eyes, nose, and throat. It also damages plants, rubber in tires, fabrics, and paints.

Ozone in the troposphere near ground level is often referred to as "bad" ozone, while we view ozone in the stratosphere as "good" ozone because it protects us from harmful UV radiation. However, both are the same chemical. Significant evidence indicates that some human activities are *decreasing* the amount of beneficial ozone in the stratosphere and *increasing* the amount of harmful ozone in the troposphere near ground level—especially in some urban areas. We examine the issue of stratospheric ozone thinning in the next chapter.

Volatile organic compounds (VOCs). Organic compounds that exist as gases in the atmosphere or that evaporate from sources on earth into the atmosphere are called *volatile organic compounds* (VOCs). Examples are hydrocarbons emitted by the leaves of many plants and *methane* (CH_4), a greenhouse gas that is 20 times more effective per molecule than CO_2 is at warming the atmosphere through the greenhouse effect (see Figure 3-4, p. 57).

About a third of global methane emissions comes from natural sources, mostly plants, wetlands, and termites. The rest comes from human sources, primarily rice paddies, landfills, oil and natural gas wells, and cows (mostly from their belching). Other VOCs are liquids than can evaporate into the atmosphere. Examples are benzene and other liquids used as industrial solvents, dry-cleaning fluids, and various components of gasoline, plastics, and other products.

CASE STUDY
Lead Is a Highly Toxic Pollutant

Lead (Pb) is a pollutant that is found in air, water, soil, plants, and animals. Because it is a chemical element, lead does not break down in the environment. This indestructible and potent neurotoxin can harm the nervous system, especially in young children. Each year, 12,000–16,000 American children under age 9 are treated for acute lead poisoning, and about 200 die. About 30% of the survivors suffer from palsy, partial paralysis, blindness, and mental retardation.

Children under age 6 and unborn fetuses, even with only low blood levels of lead, are especially vulnerable to nervous system impairment, lowered IQ (by an average of 7.4 points), shortened attention span, hyperactivity, hearing damage, headaches, and various behavior disorders. A 1993 study by the U.S. National Academy of Sciences as well as numerous other studies since then indicate there is no safe level of lead in children's blood. As a result, health scientists call for sharply reducing current allowed levels of lead in the air and water.

Between 1976 and 2006, the percentage of U.S. children ages 1 to 5 years with blood lead levels above the safety standard dropped from 85% to about 1%, which prevented at least 9 million childhood lead poisonings. The primary reason for this drop was that government regulations banned leaded gasoline in 1976 (with a complete phase-out by 1986) and greatly reduced the allowable levels of lead in paints in 1970 (even though illegal use continued until about 1978). This is an excellent example of the effectiveness of pollution prevention.

Despite this success, the U.S. Centers for Disease Control and Prevention (CDC) estimates that at least 310,000 U.S. children still have unsafe blood levels of lead caused by exposure from a number of sources. The major source is peeling lead-based paint found in about 38 million houses built before 1978. The EPA has certified 125,000 workers to safely remove lead paint from U.S. houses. Lead can also leach from water pipes and faucets containing lead parts or lead solder. In addition, major U.S. toy companies in 2007 had to recall millions of toys made in China that contained lead. Other sources are lead smelters and waste incinerators.

Figure 18-8 **Individuals matter:** There are several ways to help protect children from lead poisoning. **Questions:** Which two of these solutions do you think are the most important? Why?

CONNECTIONS

Lead and Urban Gardening

In 2009, health officials and scientists warned citizens who grow some of their own food in urban gardens to have their garden soil tested for lead. For decades, lead particles fell from the air into urban soils. It came from the exhaust fumes of vehicles burning leaded gasoline and from particles of lead-based paint scraped off of old houses and buildings. Urban gardeners in the United States can call the EPA lead hotline at (800) 424-5323 to find out how and where to have their soil tested. Soil found to have lead in it can be treated or removed from urban gardens and replaced with uncontaminated soil.

Health scientists have proposed a number of ways to help protect children from lead poisoning, as listed in Figure 18-8. Although the threat from lead has been greatly reduced in the United States, this is not the case in many less-developed countries. About 80% of the gasoline sold in the world today is unleaded, but about 100 countries still use leaded gasoline and most countries have not banned lead-based paint. According to a 2009 study by Scott Clark and other environmental health researchers, 73% of consumer brands of paint, tested in 12 countries with nearly half of the world's population, had lead levels greater than the current U.S. standard for lead in paint.

The WHO estimates that 130 million to 200 million children around the world are at risk of lead poisoning, and 15 million to 18 million children in less-developed countries—a number roughly equal to the entire population of Florida (USA) or that of Mexico City, Mexico—have permanent brain damage because of lead poisoning. These children are so affected mostly because of the use of leaded gasoline and poorly regulated lead smelters and waste incinerators in their countries. In 2009, nearly all of the children in two villages near a smelting plant in northern China were found to be suffering from lead poisoning.

Environmental and health scientists call for global bans on leaded gasoline and lead-based paints, and for much stricter controls on emissions from smelters and waste incinerators. China recently phased out leaded gasoline in less than 3 years, a process that took several decades in the United States.

THINKING ABOUT

Lead Pollution Regulations

Why do you think the decline in lead poisoning in the United States since 1976 is a good example of the power of pollution prevention?

SCIENCE FOCUS

Detecting Air Pollutants

We can detect the presence of pollutants in the air with the use of chemical instruments and satellites armed with various sensors. The scientists who discovered the components and effects of the South Asian Brown Clouds (Figure 18-1) used small unmanned aircraft carrying miniaturized instruments to study the clouds. The aircraft flew in stacked formations and measured chemical concentrations and temperatures at different altitudes.

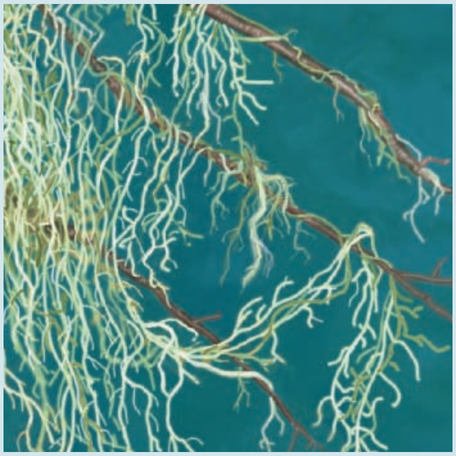
CORE CASE STUDY

Aerodyne Research in the U.S. city of Boston, Massachusetts, has developed a mobile laboratory that uses sophisticated instruments to take instantaneous measurements of primary and secondary air pollutants from motor vehicles, factories, and other sources. The laboratory also monitors changes in concentrations of the pollutants throughout a day and under different weather conditions. (See *The Habitable Planet*, Video 11, at **http://www.learner.org/resources/series209.html**.) The mobile lab can also measure the effectiveness of various air pollution control devices used in cars, trucks, and buses.

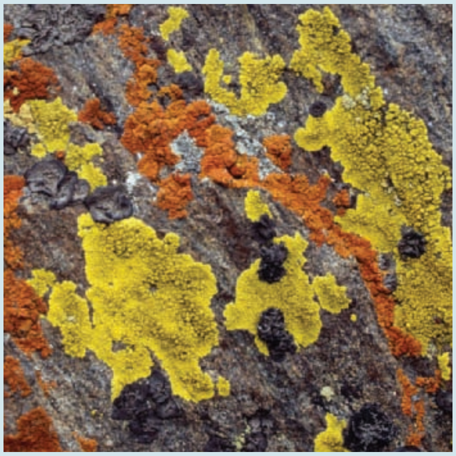
However, the United States has fallen behind some European countries, which since 1990 have used lasers and remote sensors to detect air pollutants. As a result, air pollution emissions in the United States are underestimated, according to the EPA.

Another way to detect air pollutants is through biological indicators, including lichens (Figure 18-A). A lichen consists of a fungus and an alga living together, usually in a mutually beneficial (mutualistic) relationship. These hardy pioneer species are good biological indicators of air pollution because they continually absorb air as a source of nourishment. A highly polluted area around an industrial plant may have only gray-green crusty lichens or may have none at all. An area with moderate air pollution may have orange crusty lichens on outdoor walls.

Some lichen species are sensitive to specific air-polluting chemicals. Old man's beard (*Usnea trichodea*, Figure 18-A, left) and yellow *Evernia* lichens, for example, can sicken or die in the presence of excess sulfur dioxide, even if the pollutant originates far away. For example, scientists discovered sulfur dioxide pollution on Isle Royale, Michigan (USA) in Lake Superior, an island where no car or smokestack has ever intruded. They used *Evernia* lichens to point the finger northward to coal-burning facilities at Thunder Bay, Ontario, Canada. Damaged leaves on some plants are also a sign of air pollution.



Milton Rand/Tom Stack & Associates



Gerald & Buff Corsi/Visuals Unlimited

Figure 18-A **Natural capital:** Old man's beard (*Usnea trichodea*) lichen (left) is growing on a branch of a larch tree in Gifford Pinchot National Park in the state of Washington (USA), and red and yellow crustose lichens (right) are growing on slate rock in the foothills of the Sierra Nevada near Merced, California (USA). Scientists can use such lichens to detect the presence of specific air pollutants and to track down their sources.

Critical Thinking

Examine leaves around the area where you live of go to school for signs of damage. How could you run a controlled experiment to determine whether the damage is from air pollution or from some other factor such as insects or plant diseases?

Burning Coal Produces Industrial Smog

Sixty years ago, cities such as London, England, and the U.S. cities of Chicago, Illinois, and Pittsburgh, Pennsylvania, burned large amounts of coal in power plants and factories and for heating homes and often for cooking food. People in such cities, especially during winter, were exposed to **industrial smog** consisting mostly of an unhealthy mix of sulfur dioxide, suspended droplets of sulfuric acid, and a variety of suspended solid particles.

The chemistry of industrial smog is fairly simple. When burned, most of the carbon in coal and oil is converted to carbon monoxide (CO) and carbon dioxide (CO_2). Unburned carbon in coal also ends up in the atmosphere as suspended particulate matter (soot).

When coal and oil are burned (Figure 18-9, p. 474), the sulfur compounds they contain react with oxygen to produce sulfur dioxide (SO_2) gas, some of which is converted to tiny suspended droplets of sulfuric acid (H_2SO_4). Some of these droplets react with ammonia (NH_3) in the atmosphere to form solid particles of ammonium sulfate or $(NH_4)_2SO_4$. The suspended particles of such salts and soot give the resulting smog a gray color (Figure 18-2), which is why it is sometimes called *gray-air smog* (**Concept 18-2**).

CORE CASE STUDY

Today, urban industrial smog is rarely a problem in most developed countries where coal and heavy oil are burned only in large power and industrial plants with reasonably good pollution control or in facilities with tall smokestacks that send the pollutants high into air, where prevailing winds carry them downwind to rural areas. However, industrial smog remains a problem in

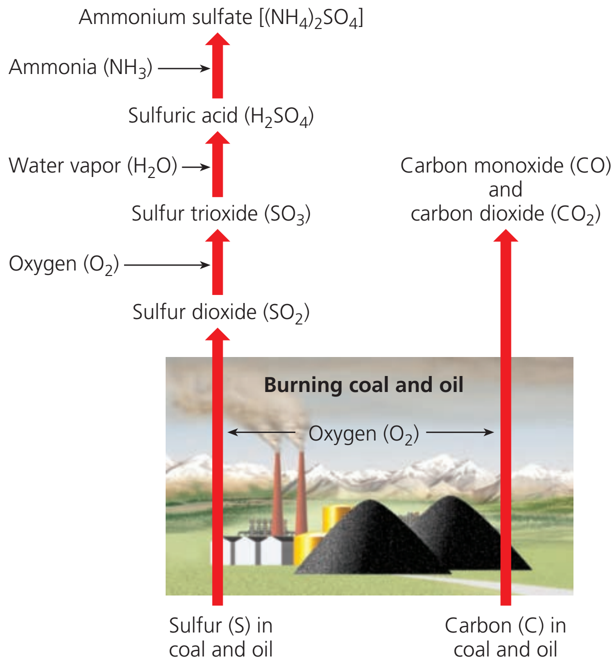


Figure 18-9 This is a greatly simplified model of how pollutants are formed when coal and oil are burned. The result is industrial smog.

industrialized urban areas of China (Figure 18-2), India (Figure 18-10), Ukraine, and some other eastern European countries, where large quantities of coal are still burned in houses, power plants, and factories with inadequate pollution controls. Such coal burning is a major contributor to the gigantic South Asian Brown Clouds (**Core Case Study**).

Because of its heavy reliance on coal, China has some of the world's highest levels of industrial smog and 16 of the world's 20 most polluted cities. A 2007 study by the World Bank puts the annual death toll from air pollution in China at about 750,000; about 250,000 of those deaths are from outdoor air pollution and 500,000 are from indoor air pollution (mostly from burning coal for heating and cooking and from smoking).

The history of air pollution control in Europe and the United States shows that we can reduce industrial smog fairly quickly by setting standards for coal-burning industries and utilities, and by shifting from coal to cleaner-burning natural gas in urban industries and dwellings. China and India are slowly beginning to take such steps, but they have a long way to go.

Deb Kushal/Peter Arnold, Inc.

Figure 18-10 *Industrial smog* hangs over a factory in an Indian city.

Sunlight Plus Cars Equals Photochemical Smog

A *photochemical reaction* is any chemical reaction activated by light. **Photochemical smog** is a mixture of primary and secondary pollutants formed under the influence of UV radiation from the sun. In greatly simplified terms,

$$\text{VOCs} + NO_x + \text{heat} + \text{sunlight} \rightarrow \text{ground level ozone } (O_3) + \text{other photochemical oxidants} + \text{aldehydes} + \text{other secondary pollutants}$$

The formation of photochemical smog (Figure 18-11) begins when exhaust from morning commuter traffic releases large amounts of NO and VOCs into the air over a city. The NO is converted to reddish-brown NO_2, explaining why photochemical smog is sometimes called *brown-air smog*. When exposed to ultraviolet radiation from the sun, some of the NO_2 reacts in complex ways with VOCs released by certain trees (such as some oak species, sweet gums, and poplars), motor vehicles, and businesses (such as bakeries and dry cleaners).

The resulting photochemical smog is a mixture of ozone, nitric acid, aldehydes, peroxyacyl nitrates (PANs), and other secondary pollutants. Collectively, NO_2, O_3, and PANs in this chemical brew are called *photochemical oxidants* because these damaging chemicals can react with, and oxidize, certain compounds in the atmosphere or inside our lungs.

Hotter days lead to higher levels of ozone and other components of smog. As traffic increases on a sunny day, photochemical smog (dominated by ozone) usually builds up to peak levels by late morning, irritating people's eyes and respiratory tracts.

All modern cities have some photochemical smog, but it is much more common in cities with sunny, warm, and dry climates, and a great number of motor vehicles. Examples are Los Angeles, California, and Salt Lake City, Utah, in the United States; Sydney, Australia; São Paulo, Brazil; Bangkok, Thailand (see Photo 12 in the Detailed Contents); Mexico City, Mexico; and Santiago, Chile (Figure 18-12). According to a 1999 study, if

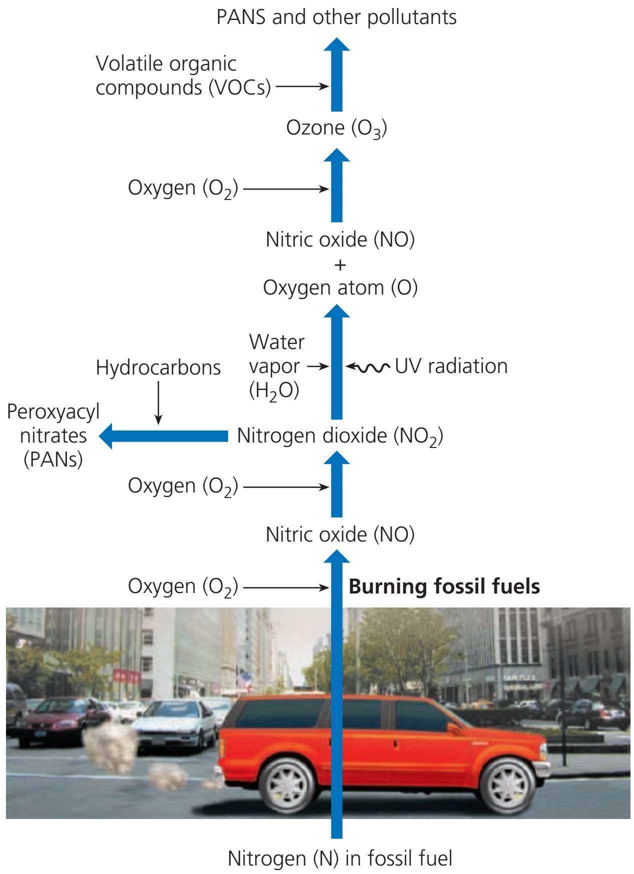


Figure 18-11 This is a greatly simplified model of how the pollutants that make up photochemical smog are formed.

400 million people in China were to drive conventional gasoline-powered cars by 2050, the resulting photochemical smog could regularly cover the entire western Pacific, extending to the United States.

The already poor air quality in urban areas of many less-developed countries is worsening as the number of motor vehicles rises. Many of these vehicles are 10 or more years old, have no pollution control devices, and burn leaded gasoline.

CENGAGENOW™ See how photochemical smog forms and how it affects us at CengageNOW™.

Several Factors Can Decrease or Increase Outdoor Air Pollution

Five natural factors help *reduce* outdoor air pollution. First, *particles heavier than air* settle out as a result of gravitational attraction to the earth. Second, *rain and snow* partially cleanse the air of pollutants. Third, *salty sea spray from the oceans* washes out many pollutants from air that flows from land over the oceans. Fourth, *winds* sweep pollutants away and mix them with cleaner air. Fifth, some pollutants are removed by *chemical reactions*. For example, SO_2 can react with O_2 in the atmosphere to form SO_3, which reacts with water vapor to form droplets of H_2SO_4 that fall out of the atmosphere as acid precipitation.

Six other factors can *increase* outdoor air pollution. First, *urban buildings* slow wind speed and reduce the dilution and removal of pollutants. Second, *hills and mountains* reduce the flow of air in valleys below them and allow pollutant levels to build up at ground level. Third, *high temperatures* promote the chemical reactions leading to formation of photochemical smog. Fourth, *emissions of volatile organic compounds (VOCs)* from certain trees and plants in heavily wooded urban areas can play a large role in the formation of photochemical smog.

Julio Etchart/Peter Arnold, Inc.

Figure 18-12 *Global Outlook:* Photochemical smog is a serious problem in Santiago, Chile. **Question:** How serious is photochemical smog where you live?

A fifth factor—the so-called *grasshopper effect*—occurs when air pollutants are transported at high altitudes by evaporation and winds from tropical and temperate areas through the atmosphere to the earth's polar areas. This happens mostly during winter. It explains why, for decades, pilots have reported seeing dense layers of reddish-brown haze over the Arctic. It also explains why polar bears, sharks, and native peoples in remote arctic areas have high levels of various toxic pollutants in their bodies.

Michael Ledray/Shutterstock

Figure 18-13 Frequent thermal inversions and the presence of many cars and industries lead to photochemical smog in downtown Los Angeles, California (USA).

Sixth, *temperature inversions* can cause pollutants to build to high levels. During daylight, the sun warms the air near the earth's surface. Normally, this warm air and most of the pollutants it contains rise to mix with the cooler air above and are dispersed. Under certain atmospheric conditions, however, a layer of warm air can temporarily lie atop a layer of cooler air nearer the ground, creating a **temperature inversion**. Because the cooler air is denser than the warmer air above it, the air near the surface does not rise and mix with the air above. If this condition persists, pollutants can build up to harmful and even lethal concentrations in the stagnant layer of cool air near the ground.

Two types of areas are especially susceptible to prolonged temperature inversions. The first is a town or city located in a valley surrounded by mountains where the weather turns cloudy and cold during part of the year. In such cases, the clouds block much of the winter sunlight that causes air to heat and rise, and the mountains block winds that could disperse the pollutants. As long as these stagnant conditions persist, pollutants in the valley below will build up to harmful and even lethal concentrations. The tragic pollution event in Donora, Pennsylvania (see Case Study, p. S9, in Supplement 3), was partly the result of such a temperature inversion.

The other type of area vulnerable to temperature inversions is a city with many motor vehicles in an area with a sunny climate, mountains on three sides, and an ocean on the fourth side. Here, the conditions are ideal for the formation of photochemical smog, worsened by frequent thermal inversions. The surrounding mountains prevent the polluted surface air from being blown away by breezes coming off the sea. This describes several cities, including heavily populated Los Angeles, California (USA), which has prolonged temperature inversions, mostly during summer and fall (Figure 18-13).

CENGAGE**NOW**™ Learn more about thermal inversions and what they can mean for people in some cities at CengageNOW.

18-3 What Is Acid Deposition and Why Is It a Problem?

▶ CONCEPT 18-3 Acid deposition is caused mainly by coal-burning power plants and motor vehicle emissions, and in some regions it threatens human health, aquatic life and ecosystems, forests, and human-built structures.

Acid Deposition Is a Serious Regional Air Pollution Problem

Most coal-burning power plants, ore smelters, and other industrial facilities in more-developed countries use tall smokestacks to vent the exhausts from burned fuel, which contain sulfur dioxide, suspended particles, and nitrogen oxides, high into the atmosphere where wind can dilute and disperse them.

These tall smokestacks reduce *local* air pollution, but they can increase *regional* air pollution downwind. Prevailing winds may transport the primary pollutants SO_2 and NO_x, emitted high into the atmosphere, as far as 1,000 kilometers (600 miles). During their trip, these compounds form secondary pollutants such as droplets of sulfuric acid (H_2SO_4), nitric acid vapor (HNO_3), and particles of acid-forming sulfate (SO_4^{2-}) and nitrate (NO_3^-) salts (Figure 18-5).

These acidic substances remain in the atmosphere for 2–14 days, depending mostly on prevailing winds, precipitation, and other weather patterns. During this period, they descend to the earth's surface in two forms: *wet deposition*, consisting of acidic rain, snow, fog, and cloud vapor with a pH (see Chapter 2, p. 40, and Figure 5, p. S13, in Supplement 4) of less than 5.6,* and *dry deposition*, consisting of acidic particles. The resulting mixture is called **acid deposition** (Figure 18-14)—sometimes called *acid rain*. Most dry deposition occurs within 2–3 days of emission, fairly near the industrial sources, whereas most wet deposition takes place within 4–14 days in more distant downwind areas.

Acid deposition has been occurring since the Industrial Revolution began in the mid-1700s. In 1872, British chemist Robert A. Smith coined the term *acid rain* after observing that rain was eating away stone in the walls of buildings in major industrial areas. Acid deposition is the result of human activities that disrupt the natural nitrogen and sulfur cycles (see Figure 3-20, p. 71, and Figure 3-22, p. 74) by adding excessive amounts of nitrogen oxides and sulfur dioxide to the atmosphere.

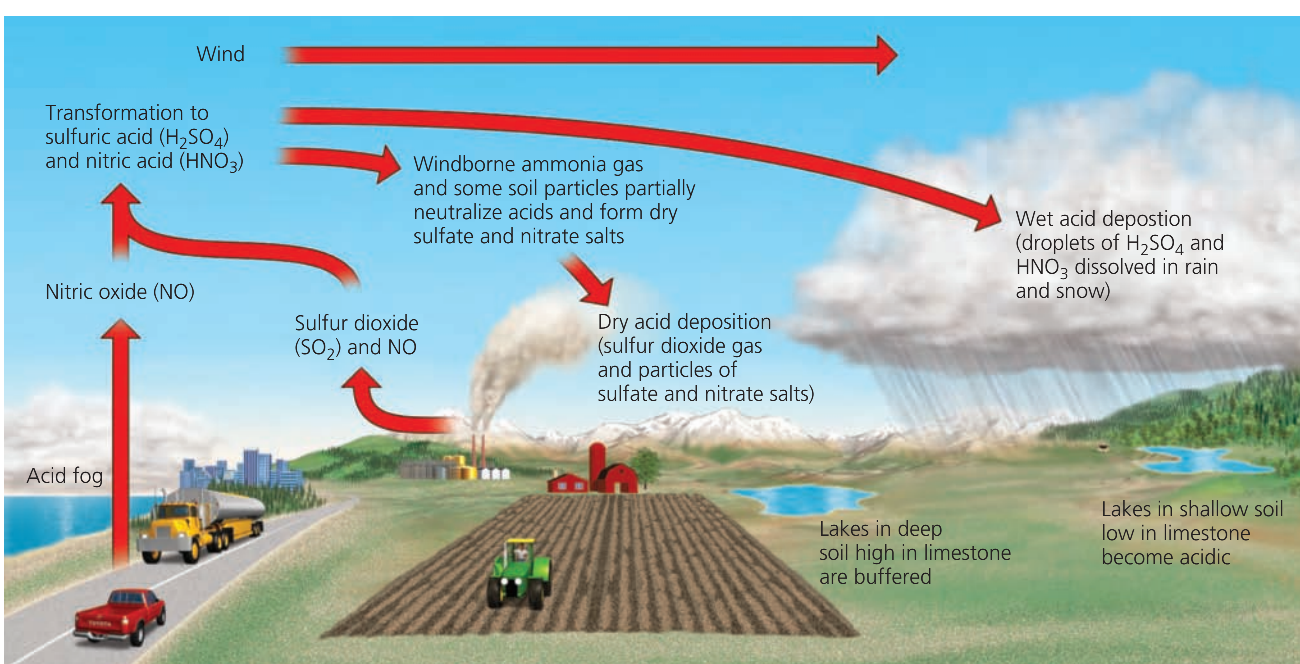
Acid deposition is mostly a *regional* air pollution problem (**Concept 18-3**) in areas that lie downwind from coal-burning facilities and from urban areas with large numbers of cars, as shown in Figure 18-15 (p. 478). In some areas, soils contain *basic* compounds such as calcium carbonate ($CaCO_3$) or limestone that can react with and neutralize, or *buffer,* some inputs of acids. The areas most sensitive to acid deposition are those with thin, already acidic soils that provide no such natural buffering (Figure 18-15, p. 478, green and most red areas) and those where the buffering capacity of soils has been depleted by decades of acid deposition.

In the United States, older coal-burning power and industrial plants without adequate pollution controls, mostly located in the Midwest, emit the largest quantities of SO_2 and other pollutants that cause acid deposition. Because of these emissions and those of other urban industries and motor vehicles, as well as the prevailing west-to-east winds, typical precipitation in the eastern United States is at least 10 times more acidic than natural precipitation would be. Some mountaintop forests in the eastern United States, as well as east of Los Angeles, California, are bathed in fog and dews that are as acidic as lemon juice—with about 1,000 times the acidity of normal precipitation.

Many acid-producing chemicals generated in one country are exported to other countries by prevailing winds. For example, acidic emissions from the United Kingdom and Germany blow south and east into Switzerland and Austria, and north and east into Norway and other neighboring countries.

The worst acid deposition occurs in Asia, especially in China, which gets 70% of its total energy and 80% of its electricity from burning coal. According to its government, China is the world's top emitter of SO_2. The resulting acid precipitation is damaging crops and threatening food security in China, Japan, and North

*Unpolluted rain is mildly acidic, with a pH of about 5.6, because of the reaction of CO_2 and water to form carbonic acid (H_2CO_3).



CENGAGENOW™ **Active Figure 18-14 Natural capital degradation:** *Acid deposition*, which consists of rain, snow, dust, or gas with a pH lower than 5.6, is commonly called acid rain. Soils and lakes vary in their ability to neutralize excess acidity. *See an animation based on this figure at* CengageNOW. **Question:** What are three ways in which your daily activities contribute to acid deposition?

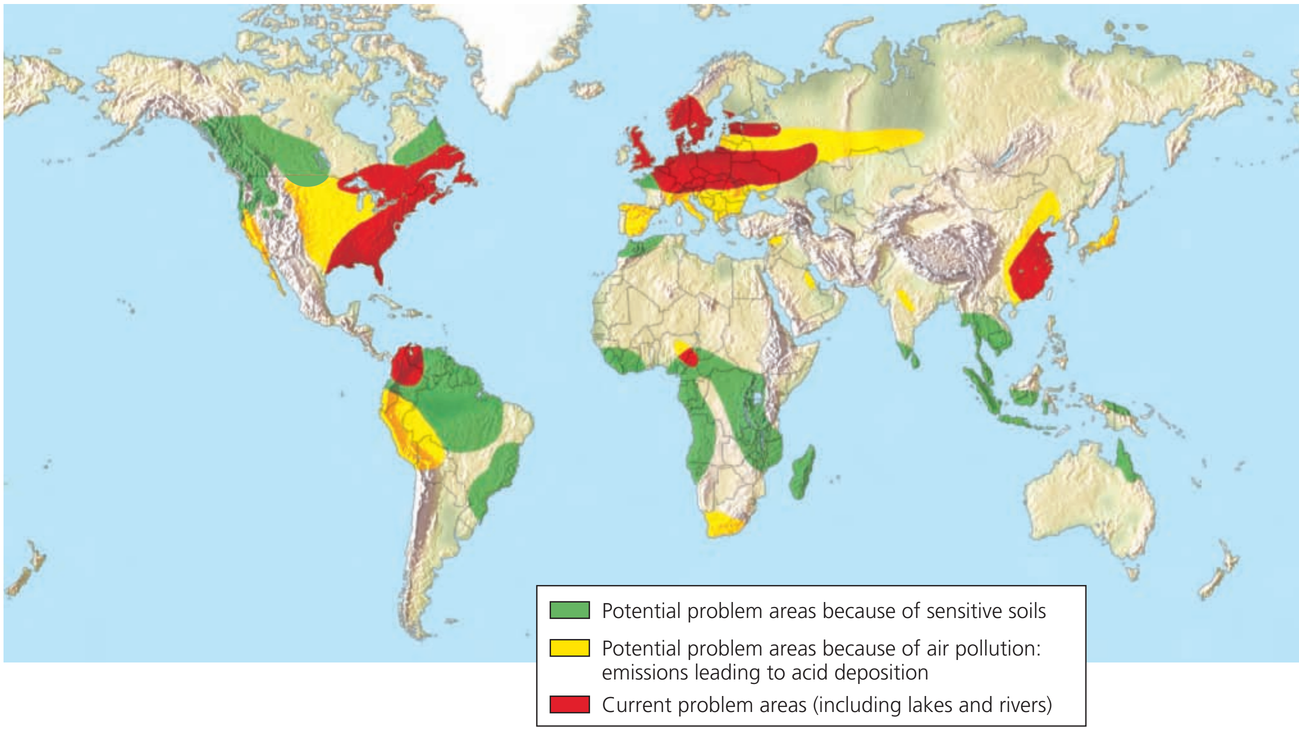


Figure 18-15 This map shows regions where acid deposition is now a problem and regions with the potential to develop this problem. Such regions have large inputs of air pollution (mostly from power plants, industrial facilities, and ore smelters) or are sensitive areas with naturally acidic soils and bedrock that cannot neutralize (buffer) additional inputs of acidic compounds. **Question:** Do you live in or near an area that is affected by acid deposition or an area that is likely to be affected by acid deposition in the future? (Data from World Resources Institute and U.S. Environmental Protection Agency)

and South Korea. It also contributes to the South Asian Brown Clouds (**Core Case Study**). CORE CASE STUDY

CENGAGENOW™ Learn more about the sources of acid deposition, how it forms, and what it can do to lakes and soils at CengageNOW.

Acid Deposition Has a Number of Harmful Effects

Acid deposition damages statues (Figure 18-7) and buildings, contributes to human respiratory diseases, and can leach toxic metals (such as lead and mercury) from soils and rocks into lakes used as sources of drinking water. These toxic metals can accumulate in the tissues of fish eaten by people (especially pregnant women) and other animals. Currently, 45 U.S. states have issued warnings telling people to avoid eating fish caught from waters that are contaminated with mercury (see Chapter 17, Science Focus, p. 448).

THINKING ABOUT
Acid Deposition and Mercury

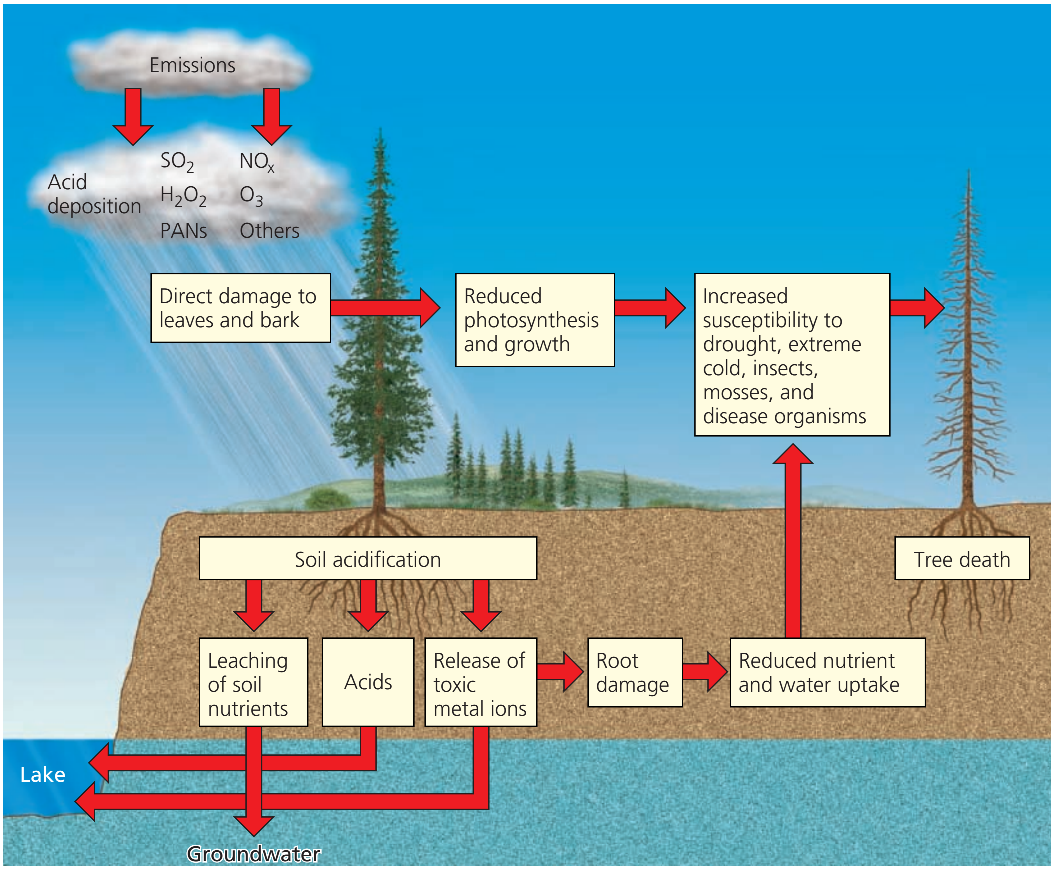
Do you live in or near an area where government officials have warned people not to eat fish caught from waters contaminated with mercury? If so, what do you think are the specific sources of the mercury pollution?

Acid deposition harms aquatic ecosystems. Most fish cannot survive in water with a pH less than 4.5. Acid deposition can also release aluminum ions (Al^{3+}), which are attached to minerals in some soils bordering lakes. These ions asphyxiate many kinds of fish by stimulating excessive mucus formation, which clogs their gills.

Because of excess acidity, several thousand lakes in Norway and Sweden, and 1,200 in Ontario, Canada, contain few if any fish. In the United States, several hundred lakes (most in the Northeast) are similarly threatened. In addition, scientists are only just beginning to study the effects of the South Asian Brown Clouds on oceans (**Core Case Study**). Aerosols in the clouds are pulled into thunderstorms that then dump acid rain into the Indian and Pacific Oceans, possibly harming marine life and ecosystems. CORE CASE STUDY

Acid deposition (often along with other air pollutants such as ozone) can harm crops, especially when the soil pH is below 5.1. Low pH reduces plant productivity and the ability of soils to buffer or neutralize acidic inputs. An estimated 30% of China's cropland suffers from excess acidity.

Such acid deposition can also affect forests in two ways. One is by leaching essential plant nutrients such as calcium and magnesium from forest soils. The other is by releasing ions of aluminum, lead, cadmium, and mercury to the soil where they can damage tree roots. These chemicals are toxic to the trees (Figure 18-16). These two effects rarely kill trees directly, but they can



Carolina Biological/Visuals Unlimited

CENGAGENOW™ **Active Figure 18-16** **Natural capital degradation:** Air pollution is one of several interacting stresses that can damage, weaken, or kill trees and pollute surface and groundwater. The photo insert shows air pollution damage to trees at a high elevation in Mount Mitchell State Park, North Carolina (USA). *See an animation based on this figure at* CengageNOW.

weaken them and leave them vulnerable to stresses such as severe cold, diseases, insect attacks, and drought. Mountaintop forests are especially vulnerable to acid deposition because they tend to have thin soils with little buffering capacity and are continuously exposed to highly acidic fog and clouds.

Mountaintop forests are the terrestrial areas hardest hit by acid deposition (Figure 18-16, right). These areas tend to have thin soils without much buffering capacity. In addition, mountaintop trees (especially conifers such as red spruce and balsam fir) are bathed almost continuously in highly acidic fog and clouds. As a result, uncontrolled emissions of sulfur dioxide and other pollutants can devastate the vegetation in these sensitive areas.

CENGAGENOW™ Examine how acid deposition can harm a pine forest and what it means to nearby land and waters at CengageNOW.

Most of the world's forests and lakes are not being destroyed or seriously harmed by acid deposition. Rather, this mostly regional problem is harming forests and lakes that lie downwind from coal-burning facilities and from large, motor vehicle–dominated cities without adequate pollution controls (**Concept 18-3**). Also, acid deposition has not reduced overall tree growth in the vast majority of forests in the United States and Canada, partly because of significant reductions in SO_2 and NO_x emissions from coal-fired power and industrial plants under the 1990 amendments to the U. S. Clean Air Act, which established stronger air pollution regulations for key pollutants in the United States.

However, acid deposition has accelerated the leaching of plant nutrients from soils in some areas, which has hindered tree growth, as researchers have found in various research studies. **Explore More:** See a Case Study at **www.cengage.com/login** to learn about recent studies at the Hubbard Brook Experimental Forest (Chapter 2 Core Case Study, p. 32) on the effects of acid rain on forests and soils. Scientists estimate that an additional 80% reduction in SO_2 emissions from coal-burning power and industrial plants in the midwestern United States will be needed before northeastern lakes, forests, and streams can recover from past and projected effects of acid deposition.

RESEARCH FRONTIER

Learning more about the extent and effects of acid deposition throughout the world; see **www.cengage.com/login**.

We Know How to Reduce Acid Deposition

GOOD NEWS

Figure 18-17 (p. 480) summarizes ways to reduce acid deposition. According to most scientists studying the problem, the best solutions are *preventive*

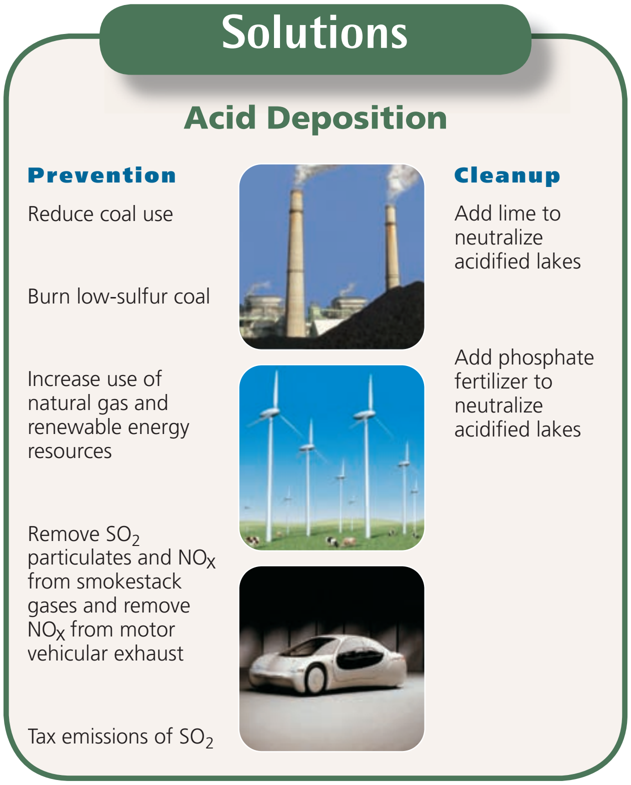


Figure 18-17 There are several ways to reduce acid deposition and its damage. **Questions:** Which two of these solutions do you think are the most important? Why?

approaches that reduce or eliminate emissions of sulfur dioxide, nitrogen oxides, and particulates.

Although we know how to prevent acid deposition (Figure 18-17, left), implementing these solutions is politically difficult. One problem is that the people and ecosystems it affects often are quite far downwind from the sources of the problem. Also, countries with large supplies of coal (such as China, India, Russia, and the United States) have a strong incentive to use it as a major energy resource. In addition, owners of coal-burning power plants resist adding the latest pollution control equipment to their facilities, using low-sulfur coal, or removing sulfur from coal before burning it. They argue that these measures would increase the cost of electricity for consumers.

Environmental scientists counter that affordable and much cleaner resources are available to produce electricity, including wind, hydropower, and natural gas (see Figure 15-12, p. 381). They also point out that the largely hidden, harmful health and environmental costs of burning coal are up to five times its market price. Including these costs in the market prices of coal would reduce coal use, spur the use of cleaner ways to generate electricity, help to reduce acid deposition, and reduce CO_2 emissions.

In addition, the emissions that lead to acid deposition could be greatly reduced by improving energy efficiency in industries (see p. 400), raising gas mileage standards (see Figure 16-5, p. 402), and switching to more efficient hybrid and plug-in hybrid motor vehicles (see Figure 16-6, p. 403). Such emissions would also be reduced by improving the design and energy efficiency of homes and other buildings (see pp. 405–406 and Figure 16-10, p. 407).

As for technological fixes, large amounts of limestone or ground lime are used to neutralize some acidified lakes and surrounding soils. However, this expensive and temporary remedy usually must be repeated annually. Also, it can kill some types of plankton and aquatic plants, and can harm certain wetland plants that need acidic water. And it is difficult to know how much lime to use or whether to put it in the water or at selected places on the shore.

Researchers in England found that adding small amounts of phosphate fertilizers can neutralize excess acidity in lakes. However, the effectiveness and costs of this approach are being evaluated. There is concern that such fertilization can cause excessive growth of algae and other vegetation (Figure 8-17, right, p. 182), deplete dissolved oxygen, and disrupt ecosystems in such lakes.

According to the U.S. National Emissions Inventory, between 1980 and 2008, air pollution laws in the United States helped to reduce sulfur dioxide emissions from all sources in the United States by 56% and nitrogen oxide missions by 40%. This has helped to reduce the acidity of rainfall in parts of the Northeast, Mid-Atlantic, and Midwest regions. But there is still a long way to go in reducing emissions from older coal-burning power and industrial plants. As a result, much of the rainwater in the eastern United States is between 2.5 and 8 times more acidic than it should be.

Meanwhile, China has become the world's largest emitter of sulfur dioxide and has one of the world's most serious acid deposition problems. These emissions also become part of the South Asian Brown Clouds (**Core Case Study**) that affect air quality in much of the world. In 2009, the Chinese government announced that by 2010, it would reduce its SO_2 emissions by 10% from 2005 levels. This is a step in the right direction, but China has a very long way to go in dealing with this serious air pollution problem.

CONNECTIONS

Low-Sulfur Coal, Atmospheric Warming, and Toxic Mercury

Some U.S. power plants have lowered SO_2 emissions by switching from high-sulfur to low-sulfur coals. However, this has increased CO_2 emissions that contribute to atmospheric warming and projected climate change, because low-sulfur coal has a lower heat value, which means that more coal must be burned to generate a given amount of electricity. Low-sulfur coal also has higher levels of toxic mercury and other trace metals, so burning it emits more of these hazardous chemicals into the atmosphere.

THINKING ABOUT

Low-Sulfur Coal

Do you think that the advantages of burning low-sulfur coal outweigh the disadvantages? Explain. Are there better options?

18-4 What Are the Major Indoor Air Pollution Problems?

▶ **CONCEPT 18-4 The most threatening indoor air pollutants are smoke and soot from the burning of wood and coal in cooking fires (mostly in less-developed countries), cigarette smoke, and chemicals used in building materials and cleaning products.**

Indoor Air Pollution Is a Serious Problem

In less-developed countries, the indoor burning of wood, charcoal, dung, crop residues, coal, and other fuels in open fires (Figure 18-18) or in unvented or poorly vented stoves exposes people to dangerous levels of particulate air pollution. Workers, including children (Figure 18-6), are also exposed to high levels of indoor air pollution in countries where there are few if any air pollution laws or regulations. According to the WHO and the World Bank, *indoor air pollution is the world's most serious air pollution problem, especially for poor people*. This is a glaring example of the connections between poverty, environmental quality, and human health.

Indoor air pollution is also a serious problem in developed areas of all countries, mostly because of chemicals used in building materials and products. Figure 18-19 (p. 482) shows some typical sources of indoor air pollution in a modern home.

EPA studies have revealed some alarming facts about indoor air pollution. *First*, levels of 11 common pollutants generally are 2 to 5 times higher inside U.S. homes and commercial buildings than they are outdoors, and in some cases they are as much as 100 times higher. *Second*, pollution levels inside cars in traffic-clogged urban areas can be up to 18 times higher than outside levels. *Third*, the health risks from exposure to such chemicals are magnified because most people in developed urban areas spend 70–98% of their time indoors or inside vehicles.

Since 1990, the EPA has placed indoor air pollution at the top of the list of 18 sources of cancer risk. It causes as many as 6,000 premature cancer deaths per year in the United States. At greatest risk are smokers, children younger than age 5, the elderly, the sick, pregnant women, people with respiratory or heart problems, and factory workers.

Pesticide residues and lead particles brought indoors on shoes can collect in carpets and furnishings. According to the EPA, pesticides are used indoors at least once a year in three of every four U.S. homes. Many chemicals containing potentially harmful organic solvents are also found in paints and various sprays.

Living organisms and their excrements can also pollute indoor air. Evidence indicates that exposure to allergens such as *dust mites* and *cockroach droppings* found in some homes plays an important role in the

Joerg Boethling/Peter Arnold, Inc.

Figure 18-18 Burning wood to cook food inside this dwelling in India (right) exposes the occupants to dangerous levels of air pollution.

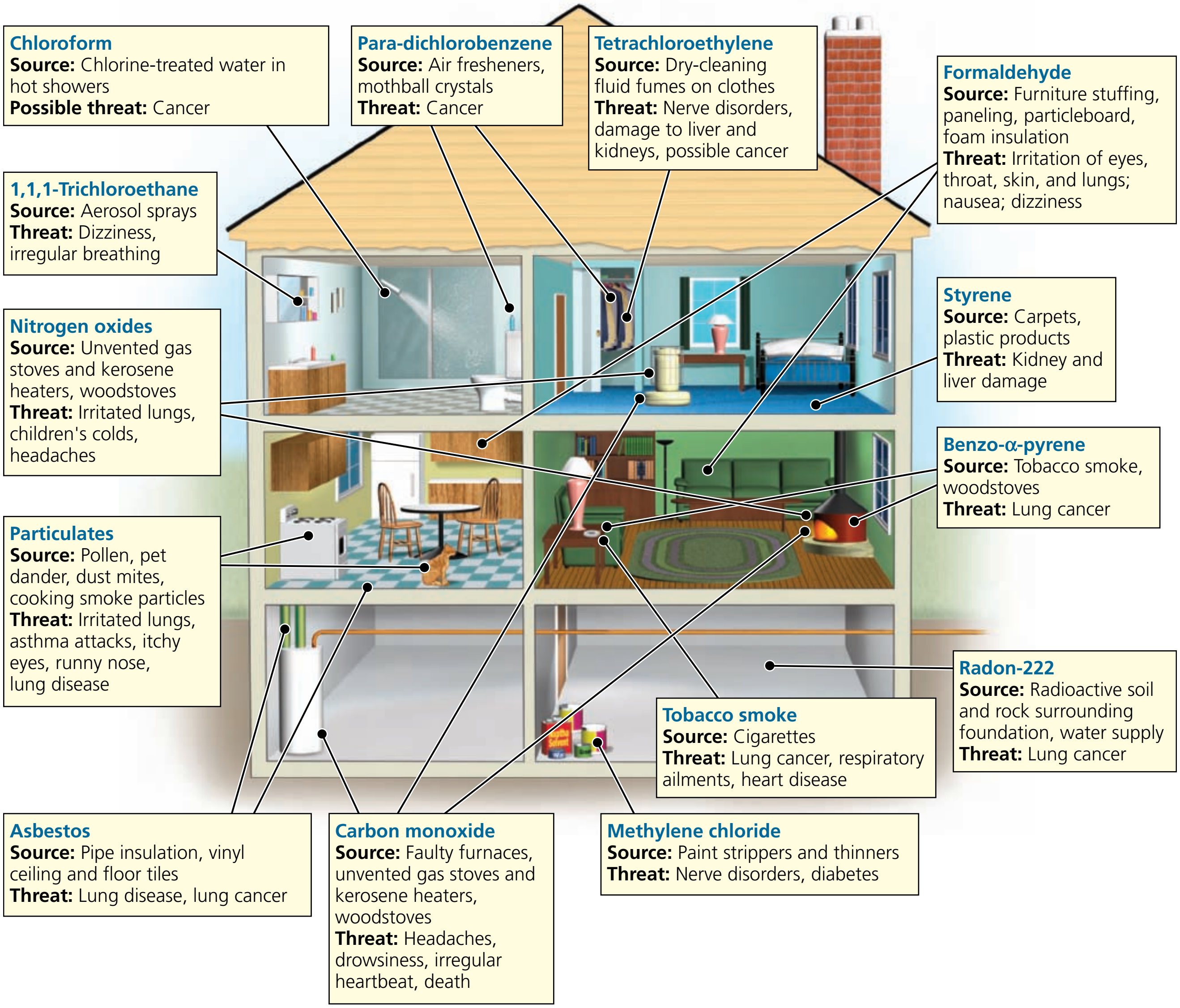


Figure 18-19 Numerous indoor air pollutants are found in most modern homes (**Concept 18-4**). **Question:** To which of these pollutants are you exposed? (Data from U.S. Environmental Protection Agency)

increasing number of people suffering from asthma in the United States.

Another living source of indoor air pollution is toxic *airborne spores of fungal growths* such as *molds* and *mildew* that can cause headaches and allergic reactions and aggravate asthma and other respiratory diseases. Some evidence suggests that spores from molds and mildew growing underneath houses and on interior walls are the single greatest cause of allergic reactions to indoor air.

Danish and U.S. EPA studies have linked various air pollutants found in buildings to a number of health effects, a phenomenon known as the *sick-building syndrome*. Such effects include dizziness, headaches, coughing, sneezing, shortness of breath, nausea, burning eyes, sore throats, chronic fatigue, irritability, skin dryness and irritation, respiratory infections, flu-like symptoms, and depression. EPA and Labor Department studies in the United States indicate that almost one in five commercial buildings in the United States is considered "sick" and is exposing employees to these health risks. **GREEN CAREER:** indoor air pollution specialist

According to the EPA and public health officials, the four most dangerous indoor air pollutants in more-developed countries are *tobacco smoke* (see Chapter 17, Case Study, p. 458) *formaldehyde* emitted from many building materials and various household products; *radioactive radon-222 gas*, which can seep into houses from underground rock deposits (see the Case Study that follows); and *very small (ultrafine) particles* of various substances in emissions from motor vehicles, coal-burning and industrial power plants, wood burning, and forest and grass fires.

The chemical that causes most people in more-developed countries difficulty is *formaldehyde* (CH_2O, a colorless, extremely irritating chemical). According to the EPA and the American Lung Association, 20–40 million Americans suffer from chronic breathing problems, dizziness, rashes, headaches, sore throats, sinus and eye irritation, skin irritation, wheezing, and nausea caused by daily exposure to low levels of formaldehyde emitted from common household materials.

These materials include building materials (such as plywood, particleboard, paneling, and high-gloss wood used on floors and for cabinets), furniture, drapes, upholstery, adhesives in carpeting and wallpaper, urethane-formaldehyde foam insulation, fingernail hardener, and wrinkle-free coatings on permanent-press clothing. The EPA estimates that 1 of every 5,000 people who live in manufactured (mobile) homes for more than 10 years are likely to develop cancer from formaldehyde exposure.

In 2008, the U.S. Centers for Disease Control and Prevention measured unhealthy levels of formaldehyde in many of the trailers and mobile homes provided by the government to house thousands of people displaced from their Louisiana homes in 2005 by Hurricane Katrina. This prompted the government to test these trailers more thoroughly before providing them, and it raised the public awareness of this issue. However, formaldehyde is still an ingredient of building materials included in mobile homes as well as in many other newly built structures.

RESEARCH FRONTIER

Learning more about indoor air pollutants and how to prevent them; see **www.cengage.com/login**.

■ CASE STUDY
Radioactive Radon Gas

Radon-222 is a colorless, odorless, radioactive gas that is produced by the natural radioactive decay of uranium-238, small amounts of which are contained in most rocks and soils. But this isotope is much more concentrated in underground deposits of minerals such as uranium, phosphate, granite, and shale.

When radon gas from such deposits seeps upward through the soil and is released outdoors, it disperses quickly in the air and decays to harmless levels. However, in buildings above such deposits, radon gas can enter through cracks in a foundation's slab and walls, openings around sump pumps and drains, and hollow concrete blocks (Figure 18-20). Once inside, it can build up to high levels, especially in unventilated lower levels of homes and buildings.

Radon-222 gas quickly decays into solid particles of other radioactive elements such as polonium-210, which if inhaled, expose lung tissue to large amounts of ionizing radiation from alpha particles. This exposure can damage lung tissue and lead to lung cancer over the course of a 70-year lifetime.

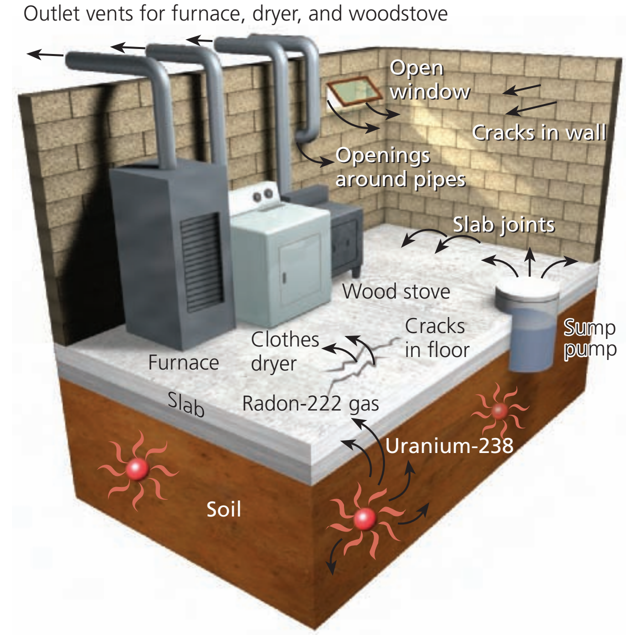


Figure 18-20 **Science:** There are a number of ways that radon-222 gas can enter homes and other buildings. **Question:** Have you tested the indoor air where you live for radon-222? (Data from U.S. Environmental Protection Agency)

Your chances of getting lung cancer from radon depend mostly on how much radon is in your home, how much time you spend in your home, and whether you are a smoker or have ever smoked. About 90% of radon-related lung cancers occur among current or former smokers. According to the EPA, radioactive radon is the second leading cause of lung cancer and is responsible for 3% to 14% of lung cancer deaths in the United States. In 2010, the WHO estimated that radioactive radon gas in homes had killed an estimated 20,000 Americans in the previous year.

Ideally, radon levels should be monitored continuously in the main living areas (not basements or crawl spaces) for 2 months to a year. But less than 20% of U.S. households have followed the EPA's recommendation to conduct radon tests (most lasting only 2–7 days and costing $20–100 per home).

For information about radon testing, visit the EPA website at **http://www.epa.gov/radon/index.html**. According to the EPA, radon control could add $350–500 to the cost of a new home, and correcting a radon problem in an existing house could run $800–2,500. Remedies include sealing cracks in the foundation's slab and walls, increasing ventilation by cracking a window or installing vents in the basement, and using a fan to create cross ventilation.

THINKING ABOUT
Preventing Indoor Air Pollution

What are some steps you could take to prevent indoor air pollution, especially regarding the four most dangerous indoor air pollutants listed above?

18-5 What Are the Health Effects of Air Pollution?

▶ **CONCEPT 18-5 Air pollution can contribute to asthma, chronic bronchitis, emphysema, lung cancer, heart attack, and stroke.**

Your Body's Natural Defenses against Air Pollution Can Be Overwhelmed

Your respiratory system (Figure 18-21) has a number of ways to help protect you from air pollution. Hairs in your nose filter out large particles. Sticky mucus in the lining of your upper respiratory tract captures smaller (but not the smallest) particles and dissolves some gaseous pollutants. Sneezing and coughing expel contaminated air and mucus when pollutants irritate your respiratory system.

In addition, hundreds of thousands of tiny, mucus-coated, hair-like structures, called *cilia*, line your upper respiratory tract. They continually move back and forth and transport mucus and the pollutants it traps to your throat where they are swallowed or expelled.

Prolonged or acute exposure to air pollutants, including tobacco smoke, can overload or break down these natural defenses. Fine and ultrafine particulates get lodged deep in the lungs, contributing to lung cancer, asthma, heart attack, and stroke. According to the National Institutes of Health, almost 7% of the U.S. population suffers from asthma and about 14 of these asthma victims die each day from asthma attacks. A French study found that such attacks increased by about 30% on smoggy days. Years of smoking or breathing polluted air can lead to other lung ailments such as chronic bronchitis and emphysema, which leads to acute shortness of breath and usually to death (see Figure 17-18, p. 459).

Air Pollution Is a Big Killer

According to the WHO, at least 2.4 million people worldwide die prematurely each year—an average of nearly 274 deaths every hour—from the effects of air pollution. According to a 2007 World Bank study, most of these deaths occur in Asia, with about 750,000 deaths per year in China alone (500,000 from indoor air pollution). According to a 2009 study by a team of Princeton University researchers led by Junfeng Liu, pollution in the South Asian Brown Clouds (**Core Case Study**) contributes to at least 380,000 premature deaths every year, mostly in China and India.

CORE CASE STUDY

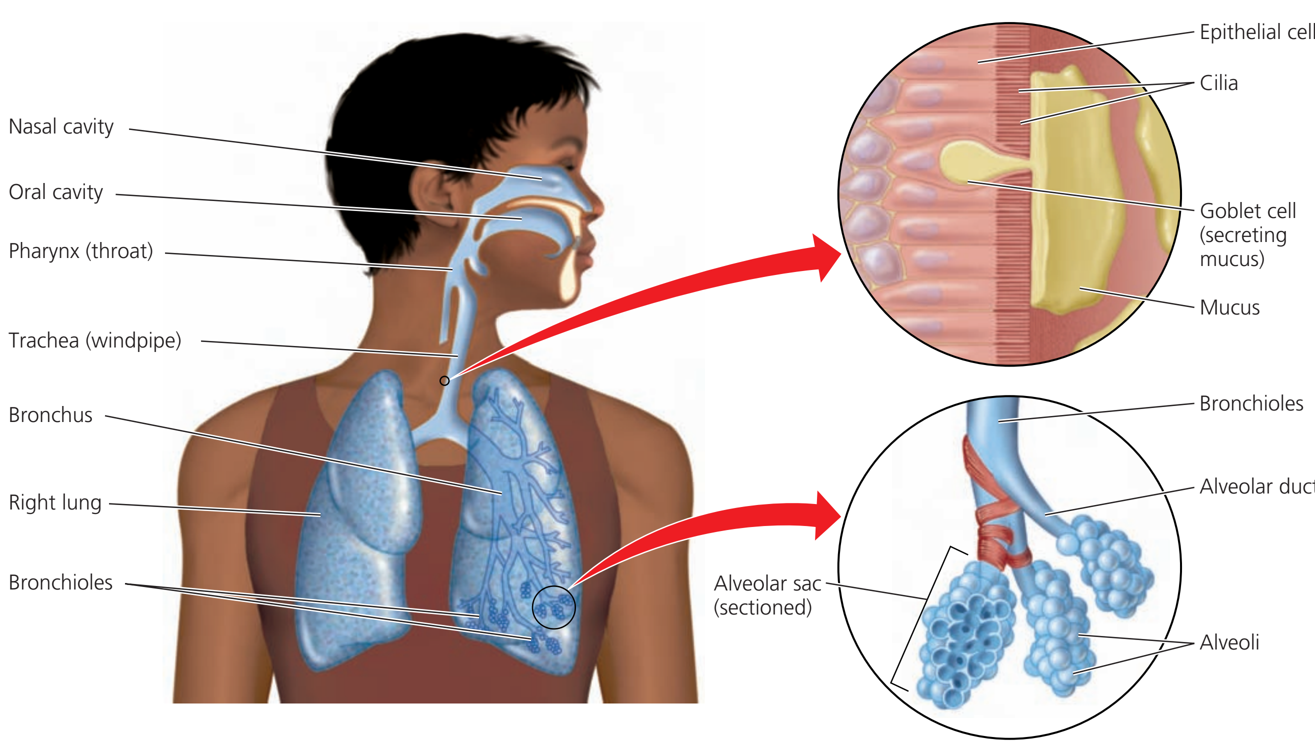


Figure 18-21 Major components of the human respiratory system can help to protect you from air pollution, but these defenses can be overwhelmed or breached.

In the United States, the EPA estimates that the annual number of deaths related to indoor and outdoor air pollution ranges from 150,000 to 350,000 people—equivalent to 2–5 fully loaded, 200-passenger airliners crashing *every day* with no survivors. Millions more suffer from asthma attacks and other respiratory disorders. Inhalation of very small particulates, mostly from coal-burning power plants, is responsible for as many as 68,000 premature deaths a year in the United States (Figure 18-22). A 2009 study by University of Ottawa scientists examined health data from 500,000 people living in soot-laden areas in 116 U.S. cities. The researchers found that inhalation of soot particles raised the chances of deadly heart attacks by 26% for this group of people.

According to recent EPA studies, each year, more than 125,000 Americans (96% of them in urban areas) get cancer from breathing soot-laden diesel fumes emitted by buses and trucks. Other sources of these fumes include tractors, bulldozers and other construction equipment, trains, and large ships. According to the EPA, a large diesel truck emits as much particulate matter as 150 cars, and particulate emissions from a diesel train engine equal those from 1,500 cars. Also, according to a 2009 study by Daniel Lack and other scientists, the world's 100,000 or more diesel-powered oceangoing ships emit almost half as much particulate pollution as do the world's 760 million cars. This makes the largely unregulated shipping industry one of the world's largest polluters of the atmosphere.

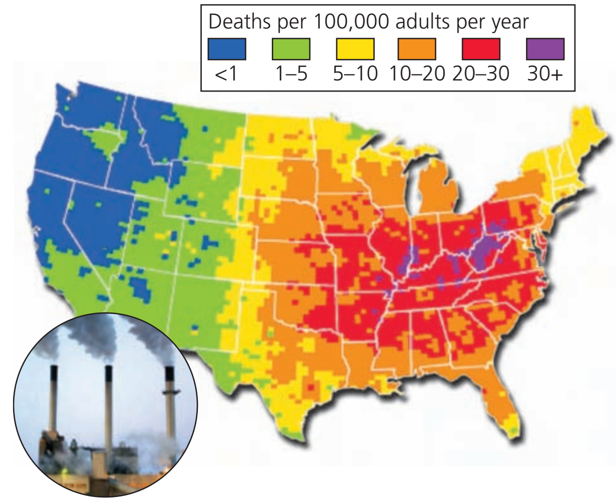


Figure 18-22 This map shows the distribution of premature deaths from air pollution in the United States, mostly from very small, fine, and ultra-fine particles added to the atmosphere by coal-burning power plants. **Questions:** Why do the highest death rates occur in the eastern half of the United States? If you live in the United States, what is the risk at your home or where you go to school? (Data from U.S. Environmental Protection Agency)

18-6 How Should We Deal with Air Pollution?

▶ **CONCEPT 18-6 Legal, economic, and technological tools can help us to clean up air pollution, but the best solution is to prevent it.**

Laws and Regulations Can Reduce Outdoor Air Pollution

The United States provides an excellent example of how a regulatory approach can reduce air pollution (**Concept 18-6**). The U.S. Congress passed the Clean Air Acts in 1970, 1977, and 1990. With these laws, the federal government established air pollution regulations for key pollutants that are enforced by states and major cities.

Congress directed the EPA to establish air quality standards for six major outdoor pollutants—carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), suspended particulate matter (SPM, smaller than PM-10), ozone (O_3), and lead (Pb). One limit, called a *primary standard,* is set to protect human health. Another limit, called a *secondary standard,* is intended to prevent environmental and property damage. Each standard specifies the maximum allowable level for a pollutant, averaged over a specific period.

The EPA has also established national emission standards for more than 188 *hazardous air pollutants (HAPs)* that may cause serious health and ecological effects. Most of these chemicals are chlorinated hydrocarbons, volatile organic compounds, or compounds of toxic metals. An important public source of information about HAPs is the annual *Toxic Release Inventory (TRI)*. The TRI law (passed in 1990 as part of the Pollution Prevention Act) requires 21,500 refineries, power plants, mines, chemical manufacturers, and factories to report their releases and waste management methods for 667 toxic chemicals. The TRI, which is now available on the Internet, lists this information by community, allowing individuals and local groups to evaluate potential threats to their health. Since the first TRI report was released in 1988, reported emissions of toxic chemicals have dropped sharply.

According to a 2009 EPA report (see **http://www.epa.gov/airtrends/aqtrends.html**), the combined emissions of the six major pollutants GOOD NEWS decreased by about 54% between 1980 and 2008, even with significant increases during the same period in gross domestic product (up 126%), vehicle miles traveled (up 91%) energy consumption (up 46%), and population (up 34%). The decreases in emissions during this period were 78% for lead, 68% for CO, 59% for SO_2, 54% for VOCs, 35% for NO_2, 31% for SPM (PM-10 with particle diameters less than 10 micrometers), and 14% for ground-level ozone (O_3). However, during this same period, CO_2 emissions increased by 16%.

According to the EPA, in 2008, about 57% of Americans lived in an area where the air was unhealthy to breathe *during part of the year*. This occurred mostly because levels of ground level ozone and particulate matter exceeded the national air quality standards at various times. In 2008, the EPA warned that projected atmospheric warming during this century is likely to increase the rates of the chemical reactions that produce photochemical smog. If this happens, there will be a significant increase in ground-level concentrations of ozone, especially in the eastern half of the United States.

Despite some weaknesses (see Case Study that follows), Denis Hayes, coordinator of the first Earth Day in 1970, calls the improvement of U.S. air quality a major environmental success story. In 2010, he said, "The air is cleaner despite the fact that we have twice as many vehicles traveling twice as many miles."

Elsewhere in the world, especially in less-developed countries, pollution levels are much worse. But some countries, such as Taiwan, Singapore, Malaysia, South Korea, Thailand, and parts of China, are making some progress in improving outdoor urban air quality.

CASE STUDY

U.S. Air Pollution Laws Can Be Improved

The reduction of outdoor air pollution in the United States since 1970 has been a remarkable success story, primarily because of two factors. *First*, U.S. citizens insisted that laws be passed and enforced to improve air quality. *Second*, the country was affluent enough to afford such controls and improvements.

Environmental scientists applaud this success, but they call for strengthening U.S. air pollution laws by:

- Putting much greater emphasis on preventing air pollution. The power of prevention is clear (**Concept 18-6**). In the United States, the air pollutant with the largest drop in its atmospheric level was lead, which was largely banned in gasoline (see Case Study, p. 471).
- Sharply reducing emissions from older coal-burning power and industrial plants, cement plants, oil refineries, and waste incinerators. Approximately 20,000 older coal-burning power plants, industrial facilities, and oil refineries in the United States have not been required to meet the air pollution standards for new facilities under the Clean Air Acts.
- Improving fuel efficiency standards for motor vehicles to match or exceed those of Europe, Japan, and China (see Figure 16-5, right, p. 402).
- More strictly regulating emissions from motorcycles and two-cycle gasoline engines. The EPA estimates that using a typical gas-powered riding lawn mower for 1 hour creates as much air pollution as driving a car for 34 hours.
- Setting much stricter air pollution regulations for airports and oceangoing ships in U.S. waters.
- Sharply reducing indoor air pollution.
- Greatly increasing and modernizing the monitoring of air pollutants.

Executives of companies that would be affected by stronger air pollution regulations claim that correcting these problems would cost too much and would hinder economic growth. Proponents of stronger regulations contend that history has shown that most industry cost estimates for implementing U.S. air pollution control standards have been much higher than the costs actually proved to be. Also, implementing such standards has boosted economic growth by stimulating companies to develop new pollution control technologies.

HOW WOULD YOU VOTE?

Should the 1990 U.S. Clean Air Act be strengthened? Cast your vote online at **www.cengage.com/login**.

We Can Use the Marketplace to Reduce Outdoor Air Pollution

One approach to reducing pollutant emissions has been to allow producers of air pollutants to buy and sell government air pollution allotments in the marketplace. This approach has had mixed results.

With the goal of reducing SO_2 emissions, the Clean Air Act of 1990 authorized an *emissions trading*, or *cap-and-trade program*, which enables the 110 most polluting coal-fired power plants in 21 states to buy and sell SO_2 pollution rights. Each plant is annually given a number of pollution credits, which allow it to emit a certain amount of SO_2. A utility that emits less than its allotted amount has a surplus of pollution credits. That utility can use its credits to offset SO_2 emissions at its other plants, keep them for future plant expansions, or sell them to other utilities or private parties.

Proponents of this approach say it is cheaper and more efficient than government regulation of air pollution. Critics of this approach contend that it allows utilities with older, dirtier power plants to buy their way out of their environmental responsibilities and to continue polluting. In addition, without strict government oversight, this approach makes cheating possible, because cap-and-trade is based largely on self-reporting of emissions.

The ultimate success of any emissions trading approach depends on two factors: how low the initial cap is set and how often it is lowered in order to promote continuing innovation in air pollution prevention and control. Without these two elements, emissions trading programs mostly shift pollution problems from one area to another without achieving any overall improvement in air quality.

Between 1990 and 2006, the emissions trading system helped to reduce SO_2 emissions from power plants in the United States by 53%, at a cost of less than one-tenth what was projected by the industry.

An emissions trading system is also being used for NO_x. However, environmental and health scientists strongly oppose a cap-and-trade program for controlling emissions of toxic mercury (Hg) by coal-burning power plants and industries. They warn that coal-burning plants that choose to buy permits instead of sharply reducing their mercury emissions will create toxic hotspots with unacceptably high levels of mercury.

The jury is still out for emissions trading programs in general. In 2002, the EPA reported results from the country's oldest and largest emissions trading program in southern California, in effect since 1993. According to the EPA, this cap-and-trade model fell far short of projected emissions reductions. The same study also found accounting inaccuracies. This highlights the need for more careful monitoring of all cap-and-trade programs.

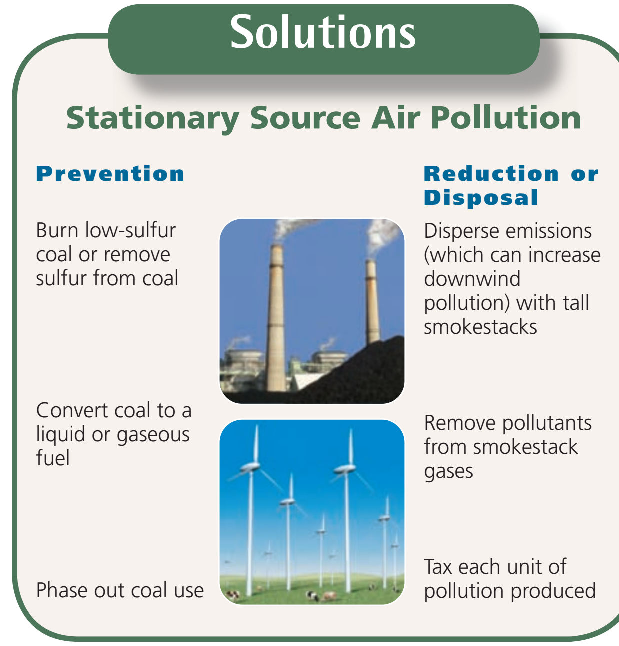


Figure 18-23 There are several ways to prevent, reduce, or disperse emissions of sulfur oxides, nitrogen oxides, and particulate matter from stationary sources such as coal-burning power plants and industrial facilities (**Concept 18-6**). **Questions:** Which two of these solutions do you think are the most important? Why?

HOW WOULD YOU VOTE?

Should we use emissions trading to help control emissions of all major air pollutants? Cast your vote online at **www.cengage.com/login**.

There Are Many Ways to Reduce Outdoor Air Pollution

Figure 18-23 summarizes ways to reduce emissions of sulfur oxides, nitrogen oxides, and particulate matter from stationary sources such as coal-burning power plants and industrial facilities.

HOW WOULD YOU VOTE?

Should older coal-burning power and industrial plants have to meet the same air pollution standards that new facilities must meet? Cast your vote online at **www.cengage.com/login**.

Figure 18-24 There are a number of ways to prevent and reduce emissions from motor vehicles (**Concept 18-6**). To find out what and how much your car emits, go to **www.cleancarsforkids.org**. **Questions:** Which two of these solutions do you think are the most important? Why?

Figure 18-24 lists ways to prevent and reduce emissions from motor vehicles, the primary factor in the formation of photochemical smog.

Unfortunately, the already poor air quality in urban areas of many less-developed countries is worsening as the numbers of motor vehicles in these countries rises. Many of these vehicles are 10 or more years old, have no pollution control devices, and burn leaded gasoline.

However, because of the Clean Air Acts, a new car today in the United States emits 75% less pollution than did a pre-1970 car. Over the next 10–20 years, technology will bring more gains through improved engine and emission systems, conventional hybrid-electric vehicles, and plug-in hybrids (see Figure 16-6, p. 403).

Reducing Indoor Air Pollution Should Be a Priority

Little effort has been devoted to reducing indoor air pollution even though it poses a much greater threat to human health than does outdoor air pollution. Air pollution experts suggest several ways to prevent or reduce indoor air pollution, as shown in Figure 18-25.

GOOD NEWS

In less-developed countries, indoor air pollution from open fires (Figure 18-18) and leaky, inefficient stoves that burn wood, charcoal, or coal could be reduced. More people could use inexpensive clay or metal stoves (Figure 18-26) that burn fuels (including straw and other crop wastes) more efficiently and vent their exhausts to the outside, or they could use stoves that use solar energy to cook food (see Figure 16-17, p. 412). This would also reduce deforestation by cutting the demand for fuelwood and charcoal.

In more-developed countries, where VOCs present the greatest indoor air pollution threats, houseplants may provide some relief. Scientists have found that some common houseplants—such as the Boston fern, Feston Rose plant, Devil's ivy, English ivy, peace lily, rubber plant, African violets, and bamboo palm—absorb VOCs, using them as nutrients.

Figure 18-27 lists some ways in which you can reduce your exposure to indoor air pollution.

Figure 18-25 There are several ways to prevent and reduce indoor air pollution (**Concept 18-6**). **Questions:** Which two of these solutions do you think are the most important? Why?

National Renewable Energy Laboratories

Figure 18-26 The energy-efficient Turbo Stove™ can greatly reduce indoor air pollution and the resulting premature deaths in less-developed countries such as India.

Emphasize Pollution Prevention

GOOD NEWS

Since 1970, most of the world's more-developed countries have enacted laws and regulations that have significantly reduced outdoor air pollution. Most of these laws emphasize controlling outdoor air pollution by using *output approaches*. Environmental and health scientists argue that the next step is to shift our emphasis to *preventing* air pollution. With this approach, the question is not *What can we do about the air pollutants we produce?* but rather *How can we avoid producing these pollutants in the first place?*

Like the shift to *controlling outdoor air pollution* between 1970 and 2010, this new shift to *preventing outdoor and indoor air pollution* will not take place unless individual citizens and groups put political pressure on elected officials to enact appropriate regulations. In addition, citizens can, through their purchases, put eco-

What Can You Do?

Indoor Air Pollution

- Test for radon and formaldehyde inside your home and take corrective measures as needed
- Do not buy furniture and other products containing formaldehyde
- Remove your shoes before entering your house to reduce inputs of dust, lead, and pesticides
- Switch to phthalate-free detergents
- Use baked lemons as natural fragrance
- Test your house or workplace for asbestos fiber levels, and check for any crumbling asbestos materials if it was built before 1980
- Do not store gasoline, solvents, or other volatile hazardous chemicals inside a home or attached garage
- If you smoke, do it outside or in a closed room vented to the outside
- Make sure that wood-burning stoves, fireplaces, and kerosene and gas-burning heaters are properly installed, vented, and maintained
- Install carbon monoxide detectors in all sleeping areas

Figure 18-27 **Individuals matter:** You can reduce your exposure to indoor air pollution. **Questions:** Which three of these actions do you think are the most important? Why?

nomic pressure on companies to get them to manufacture and sell products and services that do not add to pollution problems.

Here are this chapter's *three big ideas:*

- Outdoor air pollution, in the forms of industrial smog, photochemical smog, and acid deposition, and indoor air pollution are serious global problems.
- Each year, at least 2.4 million people die prematurely from the effects of air pollution; indoor air pollution, primarily in less-developed countries, causes about two-thirds of these deaths.
- We need to put our primary emphasis on preventing outdoor and indoor air pollution throughout the world.

REVISITING The South Asian Brown Clouds and Sustainability

CORE CASE STUDY SUSTAINABILITY

The South Asian Brown Clouds (**Core Case Study**) are a striking example of how bad air pollution can get. They result from large and dense populations of people relying mostly on wood, animal dung, and fossil fuels for their energy, and wasting too many resources instead of recycling and reusing products. It is an example of what can happen when people violate all three **principles of sustainability** (see back cover) on a massive scale.

However, we can use these three principles to help reduce air pollution. First, we can reduce inputs of air pollutants into the atmosphere by relying more on direct and indirect forms of solar energy than on fossils fuels, wood, and animal dung. Second, we can also reduce the waste of matter and energy resources by recycling and reusing matter resources. Third, we can mimic nature's biodiversity by using a diversity of nonpolluting or low-polluting renewable energy resources.

A key strategy for solving air pollution problems is to focus on preventing or sharply reducing outdoor and indoor air pollution at global, regional, national, local, and individual levels. Each of us has an important role to play in protecting the atmosphere that sustains life and supports our economies.

The atmosphere is the key symbol of global interdependence. If we can't solve some of our problems in the face of threats to this global commons, then I can't be very optimistic about the future of the world.

MARGARET MEAD

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 466. Describe the nature and harmful effects of the massive South Asian Brown Clouds (**Core Case Study**). CORE CASE STUDY
2. Define **atmospheric pressure**, **troposphere**, **stratosphere**, and **ozone layer**. Describe the major differences between the troposphere and stratosphere.

3. What is **air pollution**? Distinguish between **primary pollutants** and **secondary pollutants** and give an example of each. List the major outdoor air pollutants and their harmful effects. Describe the effects of lead as a pollutant and how we can reduce our exposure to this chemical. Describe a chemical method and a biological method for detecting air pollutants.

4. Distinguish between **industrial smog** and **photochemical smog** in terms of their chemical composition and formation. List and briefly describe five natural factors that help to reduce outdoor air pollution and six natural factors that help to worsen it. What is a **temperature inversion** and how can it affect air pollution levels?

5. What is **acid deposition** and how does it form? What are its major environmental impacts on vegetation, lakes, human-built structures, and human health? List three major ways to reduce acid deposition.

6. What is the major indoor air pollutant in many less-developed countries? What are the top four indoor air pollutants in the United States? Describe indoor air pollution caused by radon-222 and what can be done about it.

7. Briefly describe the human body's defenses against air pollution, how they can be overwhelmed, and the illnesses that can result. Approximately how many people die prematurely from air pollution each year in the world and in the United States? What percentage of these deaths are caused by indoor air pollution?

8. Describe air pollution laws in the United States. Summarize the positive effects of such laws and discuss how the laws can be improved.

9. List the advantages and disadvantages of using an emissions trading program. Summarize the major ways to reduce emissions from power plants and motor vehicles. What are four ways to reduce indoor air pollution? Why is preventing air pollution more important than controlling it?

10. What are the *three big ideas* for this chapter? Discuss the relationship between the South Asian Brown Clouds (**Core Case Study**) and the ways in which people have violated the three **principles of sustainability**. Describe how we can apply these principles to the problems of air pollution.

CORE CASE STUDY

SUSTAINABILITY

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. The South Asian Brown Clouds (**Core Case Study**) exist mainly in southern and eastern Asia, and some people blame Asians for their existence. Others argue that their causes, as well as their effects, are global in nature. What is your position on this? Explain your reasoning.

CORE CASE STUDY

2. Suppose someone tells you that carbon dioxide (CO_2) should not be classified as an air pollutant because it is a natural chemical that is part of the carbon cycle (see Figure 3-19, p. 70) and a chemical that we add to the atmosphere every time we exhale. Explain the faulty reasoning in this statement about CO_2.

3. China relies on coal for two-thirds of its commercial energy usage, partly because the country has abundant supplies of this resource. Yet China's coal burning has caused innumerable and growing problems for the country and for its neighboring nations. And now, because of the South Asian Brown Clouds (**Core Case Study**), the Pacific Ocean and the west coast of North America are experiencing pollution problems from this phenomenon. Do you think China is justified in developing this resource to the maximum, as other countries including the United States have done with their coal resources? Explain. What are China's alternatives?

CORE CASE STUDY

4. Photochemical smog is largely the result of motor vehicle emissions. Considering your use of motor vehicles, now and in the future, what are three ways in which you could reduce your contribution to photochemical smog?

5. Should the construction of tall smokestacks be banned in an effort to promote greater emphasis on preventing air pollution and acid deposition? Explain.

6. Explain how sulfur impurities in coal can lead to increased acidity in rainwater and to the subsequent depletion of soil nutrients.

7. If you live in the United States, list three important ways in which your life would be different today if political action by U.S. citizens between the 1970s and 1990s had not led to the Clean Air Acts of 1970, 1977, and 1990, despite strong political opposition by the affected industries. List three important ways in which your life in the future might be different if such actions do not lead now to the strengthening of the U.S. Clean Air Act or, if you do not live in the United States, to a similar law in the country where you reside.

8. List three ways in which you could apply **Concept 18-6** to making your lifestyle more environmentally sustainable.

9. Congratulations! You are in charge of the world. List your three most important strategies for dealing with the problems of **(a)** outdoor air pollution and **(b)** indoor air pollution.

10. List two questions that you would like to have answered as a result of reading this chapter.

DATA ANALYSIS

Coal often contains sulfur (S) as an impurity that is released as gaseous SO_2 during combustion, and SO_2 is one of six primary air pollutants monitored by the U.S. Environmental Protection Agency. The U.S. Clean Air Act limits sulfur emissions from large coal-fired boilers to 0.54 kilograms (1.2 pounds) of sulfur per million Btus (British thermal units; see Supplement 1) of heat generated. (1 metric ton = 1,000 kilograms = 2,200 pounds = 1.1 ton; 1 kilogram = 2.20 pounds)

1. Given that coal used by power plants has a heating value of 27.5 million Btus per metric ton (25 million Btus per ton), determine the number of kilograms (and pounds) of coal needed to produce 1 million Btus of heat.

2. Assuming that all of the sulfur in the coal is released to the atmosphere during combustion, what maximum percentage of sulfur can the coal contain and still allow the utility to meet the standards of the Clean Air Act?

3. About 10,000 Btus of heat input are required for an electric utility to produce 1 kilowatt-hour (kwh) of electrical energy. How many metric tons (and how many tons) of coal must be supplied each hour to provide the input heat requirements for a 1,000-megawatt (1 million-kilowatt, or 10^6-kilowatt) power plant?

4. Assuming that this power plant uses coal with 1% sulfur and operates at full capacity 24 hours per day, how many metric tons (and how many tons) of sulfur will be released into the atmosphere each year?

LEARNING ONLINE

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19 Climate Disruption and Ozone Depletion

CORE CASE STUDY Melting Ice in Greenland

Greenland is a largely ice-covered island that straddles the line between the Arctic and Atlantic Oceans (Figure 19-1). It is the world's largest island, nearly the size of Mexico, and has a population of about 60,000 people.

Greenland's ice lies in glaciers that are as deep as 3.2 kilometers (2 miles) and cover about 80% of the mountainous island. This ice formed during the last ice age and survives because of its huge mass. Scientists are now studying Greenland's ice intently because it appears to be melting at a slow but accelerating rate. Some hypothesize that this melting is one effect of *atmospheric warming*—the gradual rise of the average temperature of the atmosphere near the surface of the earth. There is concern that this warming could lead to rapid *climate disruption* during this century that could have harmful effects on most of the planet, its ecosystems, and its people.

Greenland's glaciers contain about 10% of the world's freshwater. One concern among some scientists is that if this ice were to melt, it would raise sea levels, just as an ice cube raises the level of water in a glass when you drop it in. Greenland's ice contains enough water to raise the global sea level by as much as 7 meters (23 feet) if all of it were to melt and drain into the sea. It is highly unlikely that all of the ice will melt, but even a moderate loss of this ice over one or several centuries would raise sea levels considerably.

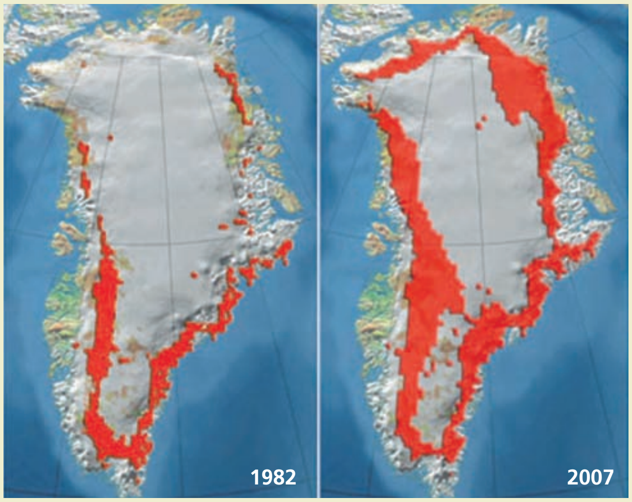


Figure 19-1 The total area of Greenland's glacial ice that melted during the summer months of 2007 (red area on right image) was much greater than the amount that melted during the summer of 1982. Some of this ice is replaced by snow during winter months. But the annual net loss of Greenland's land-based ice has increased during recent years, and if this trend continues over a number of decades, the world's average sea level will rise. (Data from Konrad Steffen and Russell Huff, University of Colorado, Boulder)

The large, moving ice mass in a glacier scrapes along extremely slowly, but scientists have demonstrated that it can pick up speed when meltwater on its surface, flowing down through its crevices, lubricates its bottom layer, which sits on bedrock. Some scientists hypothesize this is what is happening to some of northern Greenland's glaciers. In 2009, scientists noted another important factor that can speed this glacial melting: they found that glaciers flowing to the sea are getting thinner at their ocean outlets. As a glacier gets thinner, at some point it can float free of the ground at the shore, which is like taking off the brakes, and it can then flow faster toward the sea.

Also, as the overall thickness of a glacier decreases, its grip on the land weakens, further accelerating its movement toward the sea. Finally, as the weight of the glacier lessens due to melting, the land under it rebounds, somewhat like a cushion resuming its shape when a person sitting on it gets up. This further destabilizes the ice and can also cause it to slide faster.

These effects are still extremely slow—undetectable to the human eye. But according to a 2009 study by scientists led by Michiel van den Broeke, satellite measurements and computer modeling confirm that the Greenland ice sheet has been losing mass at an accelerating rate since the 1990s (Figure 19-1).

The Intergovernmental Panel on Climate Change (IPCC), created in 1988, is a group of more than 2,500 climate scientists and other scientists working in disciplines related to climate studies. For over two decades, these researchers have volunteered without pay to study the origins of climate change and its possible effects, and to report their findings to the world.

In its latest report in 2007, the IPCC made several projections. One of them was that the average global sea level is likely to rise by 18–59 centimeters (7–23 inches) by the end of this century. Since then, however, several scientists studying the melting of Greenland's ice have concluded that the rise in the average global sea level by 2100 will likely be closer to 100 centimeters (39 inches) and perhaps twice that. They estimate that Greenland's ice loss will make up half to two-thirds of that rise.

This change in projections about the rising average global sea level and Greenland's contribution to it is one example of how scientists are revising some IPCC projections upward due to the acceleration of rising temperatures at the earth's poles. There have also been findings that have caused these scientists to revise some of their projections downward. Throughout this chapter, we examine the findings of the IPCC and other climate scientists about likely causes and effects of projected climate disruption during this century. We also look at some possible ways to deal with this environmental challenge.

Key Questions and Concepts

19-1 **How might the earth's temperature and climate change in the future?**

CONCEPT 19-1 Considerable scientific evidence indicates that the earth's atmosphere is warming, because of a combination of natural effects and human activities, and that this warming is likely to lead to significant climate disruption during this century.

19-2 **What are some possible effects of a warmer atmosphere?**

CONCEPT 19-2 The projected rapid change in the atmosphere's temperature could have severe and long-lasting consequences, including increased drought and flooding, rising sea levels, and shifts in the locations of croplands and wildlife habitats.

19-3 **What can we do to slow projected climate disruption?**

CONCEPT 19-3 To slow the projected rate of atmospheric warming and climate disruption, we can increase energy efficiency, sharply reduce greenhouse gas emissions, rely more on renewable energy resources, and slow population growth.

19-4 **How have we depleted ozone in the stratosphere and what can we do about it?**

CONCEPT 19-4A Our widespread use of certain chemicals has reduced ozone levels in the stratosphere, which has allowed more harmful ultraviolet radiation to reach the earth's surface.

CONCEPT 19-4B To reverse ozone depletion, we must stop producing ozone-depleting chemicals and adhere to the international treaties that ban such chemicals.

Note: Supplements 2 (p. S3), 4 (p. S11), 7 (p. S26), 8 (p. S30), and 9 (p. S57) can be used with this chapter.

Civilization has evolved during a period of remarkable climate stability, but this era is drawing to a close. We are entering a new era, a period of rapid and often-unpredictable climate change.

LESTER R. BROWN

19-1 How Might the Earth's Temperature and Climate Change in the Future?

CONCEPT 19-1 Considerable scientific evidence indicates that the earth's atmosphere is warming, because of a combination of natural effects and human activities, and that this warming is likely to lead to significant climate disruption during this century.

Weather and Climate Are Not the Same

In talking about climate change it is very important to distinguish between weather and climate. *Weather* consists of short-term changes in atmospheric variables such as the temperature, precipitation, wind, and barometric pressure in a given area over a period of hours or days (see Supplement 7 on p. S26 for more about weather basics).

By contrast, *climate* is determined by the *average* weather conditions of the earth or of a particular area, especially temperature and precipitation, over a long period of time ranging from decades and centuries to thousands of years. According to the World Meteorological Organization, the minimum period considered for purposes of measuring climate is three decades. Scientists have used such long-term measurements to divide the earth into various climate zones (see Figure 7-2, p. 149).

During any period of 30 or more years, in a given area of the planet, there will often be hot years and cooler years and wet years and drier years as weather fluctuates widely from day to day and from year to year. Some natural events can have global effects on the weather. A large volcanic eruption, for example, can lead to warmer or cooler average global weather for 1 to 3 years. Climate scientists look at data on the normally fluctuating weather conditions for the earth or for a particular area of the earth to see if there has been a general rise or fall in any measurements such as average temperature or precipitation over a period of at least 30 years.

There is now a growing controversy over atmospheric warming and its projected effects on the earth's climate, largely because not everyone understands the difference between weather and climate. Having 1 or 2 colder years or a decade or two of cooler weather does not tell us that the earth's climate or the climate of a particular area is cooling or that we are headed toward a new ice age. And having 1 or 2 warmer years or a decade or two of warmer weather does not tell us that the earth's climate or that of a particular area is warming.

Before we can make any meaningful statements about climate change for the earth or any area of the earth, we need to see at least 30 years, and ideally 60 or more years, of data concerning average temperatures and average precipitation and whether they have increased, decreased, or remained about the same. So has the climate warmed or cooled or gotten wetter or drier where you live? You would have to find data on the average annual temperatures and average annual precipitation in your area over the past 30 to 60 years in order to know the answer. Knowing the difference between weather and climate can help you to filter out misleading and uninformed arguments and conclusions made by people who do not understand this important difference.

Climate Change Is Not New

Climate change is neither new nor unusual and the earth's climate system is very complex. Over the past 3 billion or more years, the planet's climate has been altered by a number of factors. They include changes in the sun's output of energy, impacts by large meteorites that throw immense amounts of dust into the atmosphere, and slight changes in the earth's orbit around the sun.

The earth's climate is also affected by global air circulation patterns (see Figure 7-3, p. 149), global ice cover (Figure 19-1) that reflects incoming solar energy and helps cool the atmosphere, varying concentrations of the different gases that make up the atmosphere, and occasional slight changes in ocean currents (see Figure 7-5, p. 150). We explore all of these factors further, later on in this chapter. Average temperature and precipitation are the two main factors affecting global, regional, and local climates. But temperature is the key variable that climate scientists watch.

Over the past 900,000 years, the atmosphere has experienced prolonged periods of *global cooling* and *global warming* (Figure 19-2, top left). These alternating cycles of freezing and thawing are known as *glacial and interglacial* (between ice ages) *periods*.

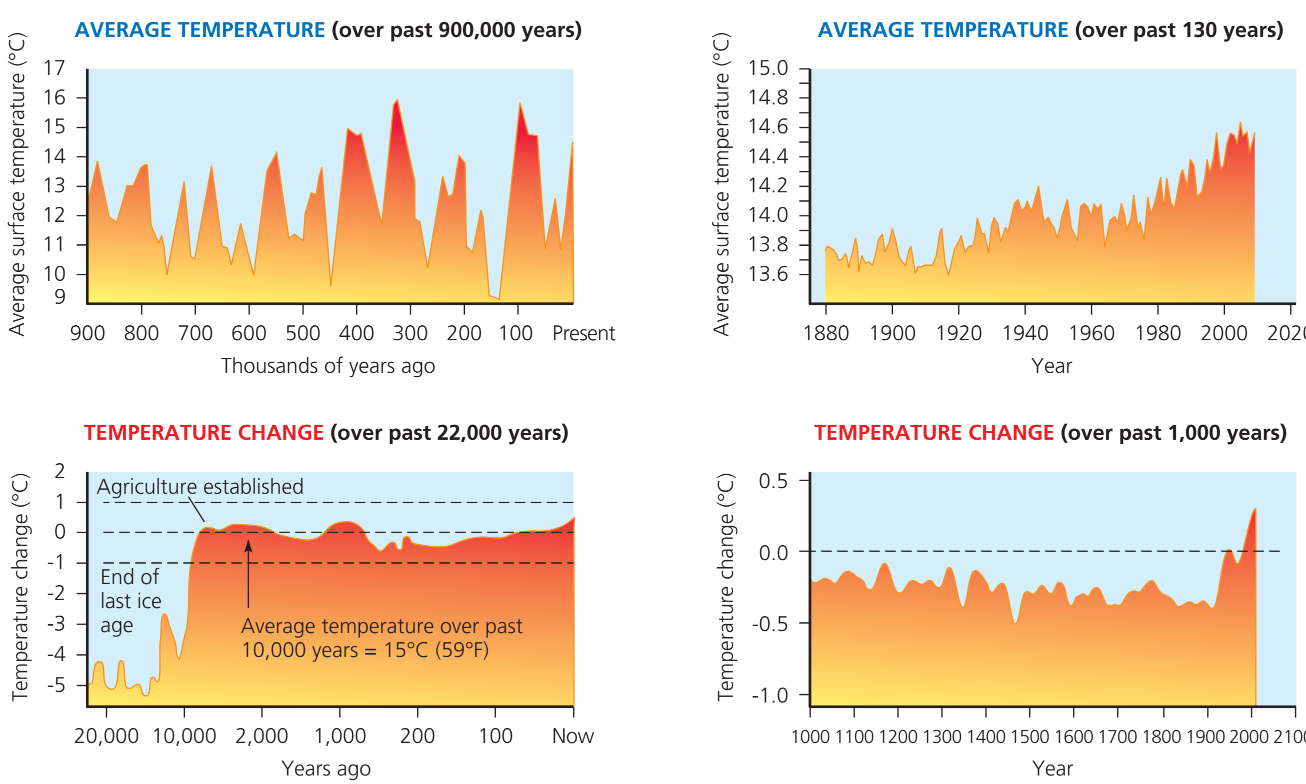


Figure 19-2 Science: The global average temperature of the atmosphere near the earth's surface has changed significantly over different periods of time. The two graphs in the top half of this figure are rough estimates of long- and short-term global average temperatures, and the two graphs on the bottom are estimates of changes in the average temperature of the earth's lower atmosphere over thousands of years. They are based on scientific evidence that contains gaps, but they do indicate general trends. **Question:** Assuming these are good estimates, what are two conclusions you can draw from these graphs? (Data from Goddard Institute for Space Studies, Intergovernmental Panel on Climate Change, National Academy of Sciences, National Aeronautics and Space Administration, National Center for Atmospheric Research, and National Oceanic and Atmospheric Administration)

For roughly 10,000 years, we have had the good fortune to live in an interglacial period characterized by a fairly stable climate based mostly on a generally steady global average surface temperature (Figure 19-2, bottom left). These favorable climate conditions allowed the human population to grow as agriculture developed, and later as cities grew. For the past 1,000 years, the average temperature of the atmosphere has remained fairly stable but began to rise during the last century (Figure 19-2, bottom right) when more people began clearing more forests and burning more fossil fuels. The top right graph in Figure 19-2 shows that most of the recent increase in temperature has taken place since 1975.

Past temperature changes such as those depicted in Figure 19-2 are estimated through analysis of a number of types of evidence, including radioisotopes in rocks and fossils; plankton and radioisotopes in ocean sediments; tiny bubbles of ancient air found in ice cores from glaciers (Figure 19-3); pollen from the bottoms of lakes and bogs; tree rings; and temperature measurements taken regularly since 1861. Such measurements have limitations, but they show general changes in temperature, which in turn can affect the earth's climate. (See *The Habitable Planet*, Video 12, at **www.learner.org/resources/series209.html** for a discussion of how scientists are analyzing ice cores from mountain glaciers to understand past climate change.)

The Climate and Our Lives and Economies Depend on the Natural Greenhouse Effect

Along with solar energy, a natural process called the *greenhouse effect* warms the earth's lower atmosphere and surface (see Figure 3-4, p. 57) and thus affects the earth's climate. It occurs when some of the solar energy absorbed by the earth radiates into the atmosphere as infrared radiation (heat) with various wavelengths (see Figure 2-11, p. 45). About 1% of the earth's lower atmosphere is composed of *greenhouse gases*, primarily water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Heat radiated into the atmosphere by the earth causes molecules of these gases to vibrate and release infrared radiation with an even longer wavelength into the lower atmosphere. As this radiation interacts with molecules in the air, it increases their kinetic energy and warms the lower atmosphere and the earth's surface, which over time affects the earth's climate.

Swedish chemist Svante Arrhenius first recognized the natural greenhouse effect in 1896. Since then, numerous laboratory experiments and measurements of temperatures at different altitudes have confirmed this effect—now one of the most widely accepted theories in the atmospheric sciences.

U.S. Geological Survey

U.S. Geological Survey National Ice Core Laboratory

Figure 19-3 Science: *Ice cores* are extracted by drilling deep holes into ancient glaciers at various sites such as this one (left) near the South Pole in Antarctica. Thousands of these ice cores, containing valuable climate and other data, are stored in places such as the National Ice Core Laboratory in the U.S. city of Denver, Colorado (right). Scientists analyze tiny air bubbles, layers of soot, and other materials trapped in different layers of these ice cores to uncover information about the past composition of the lower atmosphere, temperature trends such as those shown in Figure 19-2, greenhouse gas concentrations, solar activity, snowfall, and forest fire frequency.

Life on the earth and the world's economies are totally dependent on the natural greenhouse effect—one of the planet's most important forms of natural capital. Without this natural greenhouse effect, the planet would be a frigid, uninhabitable place.

CENGAGE**NOW**™ See how greenhouse gases help to generate heat in the lower atmosphere and raise the earth's temperature at CengageNOW™.

Human Activities Emit Large Quantities of Greenhouse Gases

Since the beginning of the Industrial Revolution in the mid-1700s, human actions—mainly the burning of fossil fuels in industry and for transportation, burning coal to generate electricity, deforestation, and agriculture, in that order—have led to significant increases in the greenhouse gases CO_2 and CH_4, in the lower atmosphere (Figure 19-4). Measurements of CO_2 and CH_4

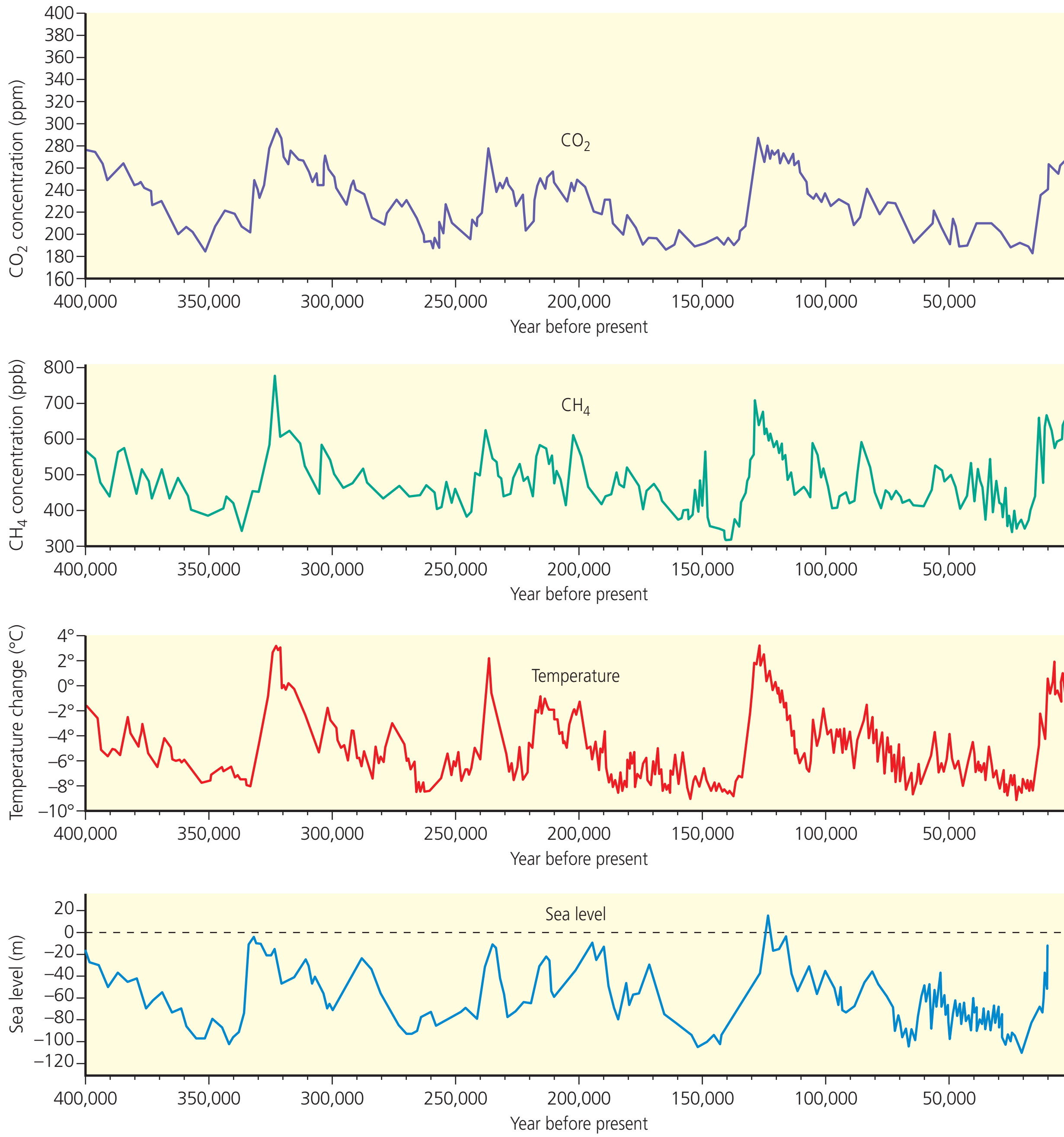


Figure 19-4 **Science:** Atmospheric levels of carbon dioxide (CO_2) and methane (CH_4), as well as the global average temperature of the atmosphere near the earth's surface and the average global sea level have changed drastically over the past 400,000 years. These data were obtained by analysis of ice cores removed at Russia's Vostok Research Station in Antarctica. More recent ice core analyses from Antarctica in 2007 indicate that current levels of CO_2 in the atmosphere are higher than at any time during the past 800,000 years. Carbon dioxide remains in the atmosphere for 80–120 years compared to about 15 years for methane. However, each molecule of methane has 25 times the warming potential of a molecule of carbon dioxide. These curves show general correlations between these different sets of data but do not establish a direct relationship among these variables. **Question:** What are two conclusions that you can draw from these data? (Data from Intergovernmental Panel on Climate Change, National Center for Atmospheric Research, and F. Vimeux et al., *Earth and Planetary Science Letters*, vol. 203 (2002): 829–843)

in bubbles at various depths in ancient glacial ice (Figure 19-3) indicate that changes in the levels of these gases in the lower atmosphere correlate fairly closely with changes in the global average temperature near the earth's surface during the past 400,000 years, and with changes in the average global sea level (Figure 19-4).

The burning of fossil fuels tops the list of human activities that emit CO_2, with coal being by far the highest emitter (see Figure 15-17, p. 383). The average atmospheric concentration of carbon dioxide rose from a level of 280 parts per million at the start of the Industrial Revolution to 389 parts per million in 2010 (see Figure 14, p. S63, in Supplement 9). Figure 19-5 shows changes in atmospheric CO_2 concentrations and the average temperature of the atmosphere between 1880 and 2009.

Ice core analysis also reveals that about 70% of methane (CH_4) emissions during the last 275 years are the result of human activities such as raising cattle and sheep, extracting fossil fuels, creating landfills, and flooding land to create reservoirs. In that time, methane levels in the atmosphere have tripled. Methane emissions are expected to rise in the future if the atmosphere warms as projected and melts some of the permafrost in the arctic tundra, which will release CH_4 into the atmosphere.

Nitrous oxide (N_2O) levels have risen about 20% during the last 275 years, mostly as a result of the increased use of nitrogen fertilizers. This gas accounts for about 9% of greenhouse gas emissions from human activities, but each molecule of N_2O has 298 times the warming potential of a molecule of CO_2. Fertilizers and other sources of nitrogen have greatly increased nitrogen inputs into the environment (see the graph in Figure 16, p. S64, in Supplement 9).

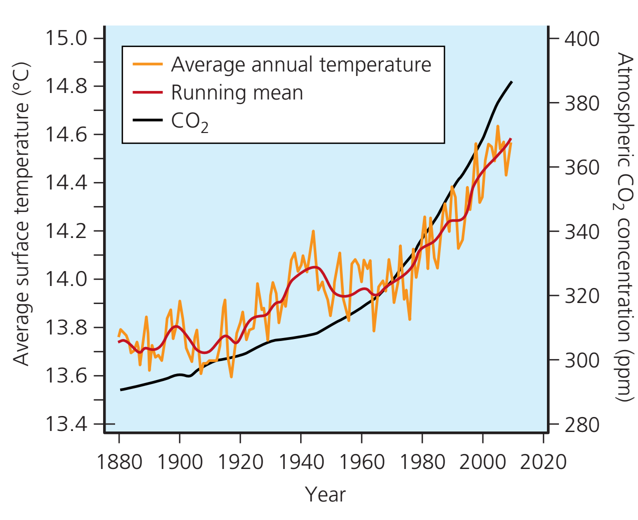


Figure 19-5 This graph compares atmospheric concentrations of carbon dioxide (CO_2) and the atmosphere's average temperature for the period 1880–2009. The temperature data show the average temperature by year as well as a mean of these data. While the data show an apparent correlation between these two variables, they do not firmly establish such a correlation. (Data from Intergovernmental Panel on Climate Change, NASA Goddard Institute for Space Studies, and NOAA Earth System Research Laboratory)

Human Activities Play a Key Role in Recent Atmospheric Warming

Working through the World Meteorological Organization and the United Nations Environment Programme, several nations established the Intergovernmental Panel on Climate Change (IPCC) in 1988 to document past climate changes and project future changes. The IPCC network includes more than 2,500 climate scientists and scientists in disciplines related to climate studies from more than 130 countries. Here are the major findings of the 2007 IPCC report based on more than 29,000 sets of data (see Science Focus, p. 498), as well as of 2010 reports by the U.S. National Academy of Sciences supported by the work of the British Royal Society, and the U.S. Environmental Protection Agency.

1. The earth's lower atmosphere is warming, especially since 1960, due primarily to increased concentrations of CO_2 and other greenhouse gases (Figure 19-5).
2. Most of the increase in the concentrations of these gases since 1960 is due to human activities, especially the burning of fossil fuels and deforestation.
3. These human-induced changes in the chemical composition and the temperature of the atmosphere are beginning to change the earth's climate.
4. If greenhouse gas concentrations continue to increase, the earth is likely to experience rapid atmospheric warming and climate disruption during this century (see Science Focus, p. 500).
5. Rapid and significant climate disruption will likely cause ecologica1, economic, and social disruption by degrading food and water supplies and terrestrial and aquatic ecosystems, flooding low-lying coastal communities and cities, and eliminating many of the earth's species.

Here are a few of the many pieces of evidence that the IPCC used to help support the major conclusions in its 2007 report, plus additional scientific data collected after that report was made:

- Between 1906 and 2005, the average global surface temperature has risen by about 0.74 C° (1.3 F°). Most of this increase has taken place since 1980 (Figure 19-2, top right, and Figure 19-5).
- Annual greenhouse gas emissions from human activities rose 70% between 1970 and 2009 (see Figure 14, p. S63, in Supplement 9 and Figure 19-5).
- The first decade in this century (2000–2009) was the warmest decade since 1881 (Figure 19-2, top right, and Figure 19-5).
- In some parts of the world, glaciers are melting (Figure 19-6, p. 499, and **Core Case Study**) and floating sea ice is shrinking (Figure 19-7, p. 499), both at increasing rates.

CORE CASE STUDY

SCIENCE FOCUS

How Valid Are IPCC Conclusions?

Scientists are professional skeptics who are always saying *show me your evidence and explain your reasoning*. They vigorously debate with one another over almost everything with the goal of reaching general agreement on any scientific problem. They often question scientific data, the statistical methods used to evaluate the data, and the conclusions drawn from the data. Throughout the history of science, skeptical scientists have played a key role in encouraging other scientists to improve their measurements and models and to take a closer look at their assumptions and hypotheses.

For over two decades, more than 2,500 of the world's top scientists in a variety of disciplines related to climate studies have been examining all of the evidence they could find about climate and past climate change. They have poured over tens of thousands of peer-reviewed studies and looked into the validity of a variety of climate models used to make projections about future climate change. During this long period, they have also been debating about what valid conclusions can be drawn from such evidence.

This unprecedented effort to evaluate climate data has been one of the longest and most thorough studies in the history of science. The goals of this continuing effort have been to see if these top scientists can reach a general agreement, or *consensus*, about the usefulness of the data and conclusions that they have evaluated, and to report their findings to the world.

Scientific consensus does not mean unanimous agreement, which is essentially impossible to achieve, because of built-in scientific skepticism. Thus, in climate science, there are still gaps in the data and debate about interpretations of the data. There is also a need for much improvement in our understanding of the complex mix of variables in the earth's climate system and in the climate models that attempt to mimic how these variables interact (see Science Focus, p. 500).

But despite many uncertainties, after more than two decades of research and debate, there is general agreement among most of the earth's climate scientists that the earth's climate has warmed by about 0.6 C° (1 F°) since 1980 (Figure 19-5), that human activities played a major role in this warming, and that human activities are likely to alter the planet's climate during this century. This high level of general agreement among the world's top scientific experts on the subject of climate change or on any scientific subject is extremely rare.

In 2007, the IPCC and former U.S. Vice President Al Gore shared the Nobel Peace Prize for their efforts to alert the world about the projected harmful effects of climate disruption during this century. However, outspoken skeptics and certain industrial leaders have mounted an aggressive political campaign to discredit Gore and the IPCC by casting doubt on the validity of their research and conclusions and those of other major scientific bodies.

The 2007 IPCC report was based on an evaluation of more than 18,000 peer reviewed publications by 2,500 climate scientists and researchers from related fields. The 450 lead authors of the report took into account about 90,000 comments by reviewers of draft versions of the report. The final report was nearly 3,000 pages long.

In 2010, reviewers of the report found an incorrect statement about the projected rate of melting of Himalayan glaciers. They also found that the IPCC had used a report on the effects of fire on the Amazon rainforest that was not peer reviewed, although is was partly based on a number of peer-reviewed articles. And reviewers alleged that the projected effect of climate change on crop yields in Africa had been exaggerated.

Some scientists argue that it is remarkable that so few problems were found in this 3,000-page report written by a team of 450 authors. And none of these problems diminished the major findings of the study, which were backed by massive evidence. However, climate change skeptics and industries opposing any regulation of greenhouse gases broadly publicized these three problems and used them to cast doubt on all of the work of the IPCC. At the other end of the spectrum, the IPCC has been criticized by a number of climate scientists for *underestimating* the projected disruption of the world's climate during this century.

The IPCC acknowledged and corrected the identified problems. In 2010, the world's leading scientific organizations appointed a panel of highly distinguished scientists to evaluate the procedures used by the IPCC and to make recommendations for working to prevent any future errors or oversights within the IPCC's ongoing scientific studies.

Critical Thinking

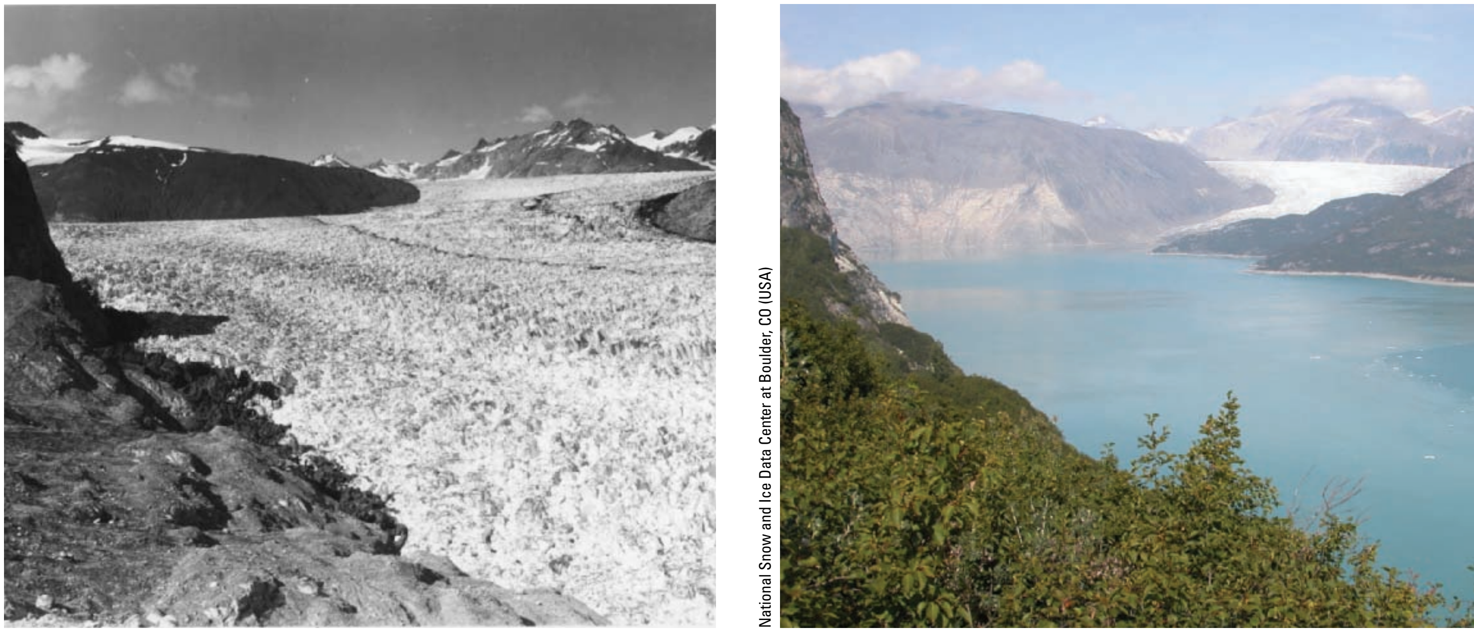
Some critics argue that the hypothesis that the earth's atmosphere has warmed and that humans have played a role in this warming is a scientific hoax. Explain why you agree or disagree with this argument.

- During the 20th century, the world's average sea level rose by 19 centimeters (7 inches), mostly because of runoff from melting land-based ice and the expansion of ocean water as its temperature increased. By comparison, sea levels rose about 2 centimeters (3/4 of an inch) in the 18th century and 6 centimeters (2 inches) in the 19th century.

On one hand, for almost two decades, scientists and skeptics have been evaluating cilmate data, statistical techniques, and the results of computer climate models (Science Focus, p. 500) related to past and projected climate change. On the other hand, there is now ample and growing evidence of a more visible and obvious nature regarding the warming of the atmosphere and oceans. For example, glaciers are melting (Figures 19-1 and 19-6) and sea ice is shrinking (Figure 19-7).

The decline in polar bear populations (see Chapter 9 Core Case Study, p. 190) is one result of the melting of polar ice—the major part of the polar bears' habitat—due to a warmer atmosphere and warmer ocean waters. In recent years, scientists have also observed the migration of populations of various plant and animal species up mountainsides and to other cooler areas to escape higher temperatures.

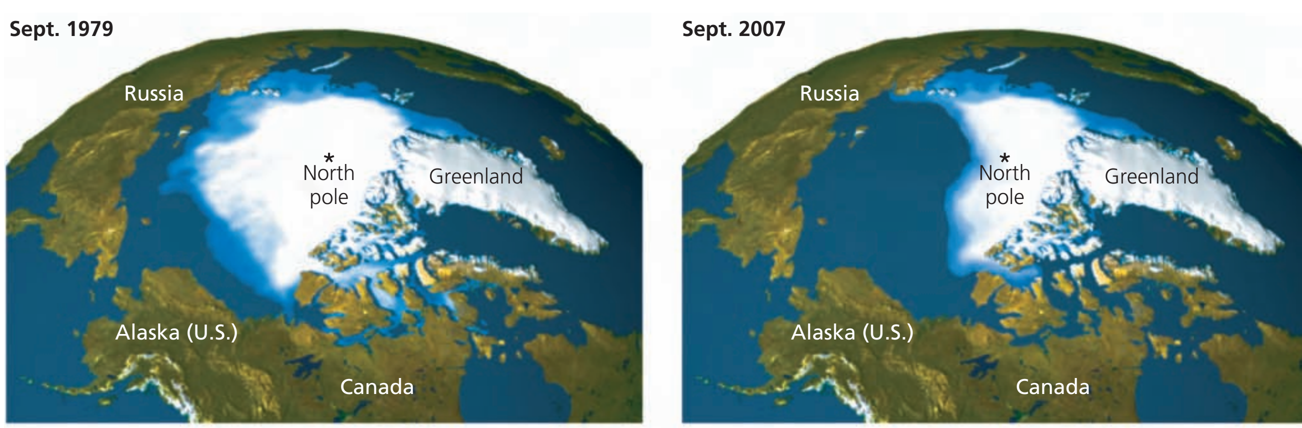
IPCC scientists have identified several natural and human-influenced factors that might *amplify* (give positive feedback to) or *dampen* (give negative feedback to) the projected changes in the average atmospheric temperature. We now examine some of those factors.



National Snow and Ice Data Center at Boulder, CO (USA)

National Snow and Ice Data Center at Boulder, CO (USA)

Figure 19-6 Much of Alaska's Muir Glacier in the popular Glacier Bay National Park and Preserve melted between 1948 and 2004. Mountain glaciers are now slowly melting throughout much of the world. **Question:** How might melting glaciers in Alaska and other parts of the world affect your life?



NASA Earth Observatory

Figure 19-7 *The big melt:* Each summer, some of the floating ice in the Arctic Sea melts and then refreezes during winter. But in most recent years, rising average atmospheric and ocean temperatures have caused more and more ice to melt during the summer months. Satellite data show a 39% drop in the average cover of summer arctic sea ice between 1979 and 2007. In 2007 alone, the sea ice shrank by an area that was 6 times that of California, much more than in any year since 1979 when scientists began taking satellite measurements. If this trend continues, this summer ice may be gone by 2040, according to researchers Muyin Wang and James Overland, and perhaps earlier, according to a 2007 estimate made by NASA climate scientist Jay Zwally. **Question:** Do you think that the increased melting of floating arctic sea ice is part of a positive or negative feedback loop (see Figure 2-18, p. 49 and Figure 2-19, p. 50)? Explain. (Data U.S. Goddard Space Flight Center, NASA, National Snow and Ice Data Center)

RESEARCH FRONTIER

Computer modeling of climate change; see **www.cengage.com/login**.

CO_2 Emissions Play an Important Role

The atmospheric concentration of CO_2, as part of the carbon cycle (see Figure 3-19, p. 70), plays an important role in determining the average temperature of the atmosphere. Other greenhouse gases and other factors that affect climate (see Chapter 7, pp. 148–151) also play roles. But much of the focus had been on CO_2 because there is considerable evidence that the burning of fossil fuels and forests, which adds CO_2 to the atmosphere, and the clearing of forests that help remove CO_2 from the atmosphere are altering the natural carbon cycle.

As we noted above, NOAA data show that the atmospheric concentration of CO_2 rose from 285 parts per million (ppm) in about 1850 at the start of the Industrial Revolution, to 389 ppm in 2010 (Figure 19-5).

SCIENCE FOCUS

Using Models to Project Future Changes in Atmospheric Temperatures

The most important question is not how the earth's atmospheric temperature has changed in the past (Figure 19-2) but how it is likely to change in the future because of a number of factors including the effects of increasing levels of greenhouse gases on average global temperatures. To make such projections, scientists develop complex *mathematical models*, which simulate interactions among the earth's sunlight, clouds, landmasses, oceans, ocean currents, concentrations of greenhouse gases and pollutants, and positive and negative feedback loops (see Figure 2-18, p. 49, and Figure 2-19, p. 50) within the earth's complex climate system. Then they run these continually improving models on supercomputers and compare the results to known past climate changes, from which they project future changes in the earth's average temperature. Figure 19-A gives a greatly simplified summary of some of the interactions in the global climate system.

Such models provide scenarios, or *projections*, of what is *likely* to happen to the average temperature of the lower atmosphere. Note that these are not *predictions*, in which the scientists would be stating what they believe *will* happen. How well these projections about what is likely to happen correspond to what actually happens in the real world depends on the validity of the assumptions and variables built into the models, and on the accuracy of the data used. Sometimes, scientists err in formulating their models by not including all the important variables or by weighing some variables too heavily or too lightly, and by not giving other scientists full access to their data to review them. But the relentless scientific process of discovery, reexamination, peer review, and reformulation of hypotheses (see Chapter 2, p. 34) is continually applied to the data fed into climate models and to the models themselves to make them more accurate.

In 1990, 1995, 2001, and 2007, the IPCC published reports on how global temperatures have changed in the past (Figure 19-2) and made projections of how they are likely to change during this century and how such changes can affect the earth's climate. According to the 2007 report, based on analyzing past climate data and the use of 19 climate models, it is very likely that human activities, especially the burning of fossil fuels, have played an important role in the observed atmospheric warming of the past 30 years (Figure 19-5). They base this on the fact that, after thousands of times running the models, the only way they can get the model results to match actual measurements is by including the human activities factor.

The 2007 IPCC report and more recent runs of the 19 climate models suggest that it is very likely that the earth's mean surface temperature will increase by 2–4.5C° (3.6–8.1F°) between 2005 and 2100 (Figure 19-B), with about 3C° (5.4F°) being the most likely rise, unless the world halts deforestation and makes drastic cuts in greenhouse gas emissions from fossil fuel–burning power plants, factories, and cars. The lower temperature in this range is likely only if global

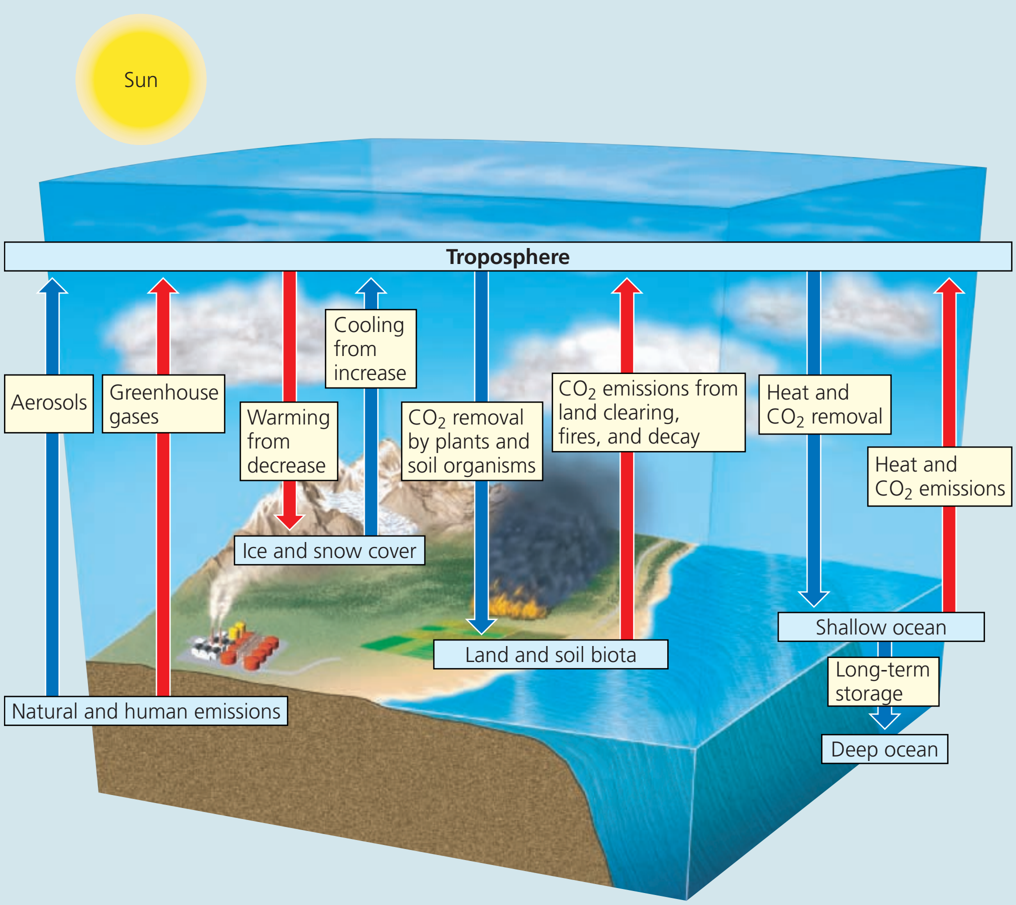


Figure 19-A **Science:** This is a simplified model of some major processes that interact to determine the average temperature and greenhouse gas content of the lower atmosphere and thus the earth's climate. Red arrows show processes that warm the atmosphere and blue arrows show those that cool it. **Question:** Why do you think a decrease in snow and ice cover is adding to the warming of the atmosphere?

greenhouse gas emissions fall 50–85% below 2000 levels by 2050.

These models, like all scientific models, are not perfect. In any scientific model, there is always some degree of uncertainty, as indicated by the fairly wide range of projected temperature changes in Figure 19-B. Climate experts are working hard to improve these models and to narrow the projected range of temperatures. Also, current climate models are better at projecting likely general changes in climate factors at the global level than they are at making such projections for particular areas. Despite such limitations, these models are the best tools that we have for estimating likely overall climate change in coming decades.

Critical Thinking

If projected temperature increases in Figure 19-B take place, what are three major ways in which this will affect your lifestyle and that of any children or grandchildren you might have?

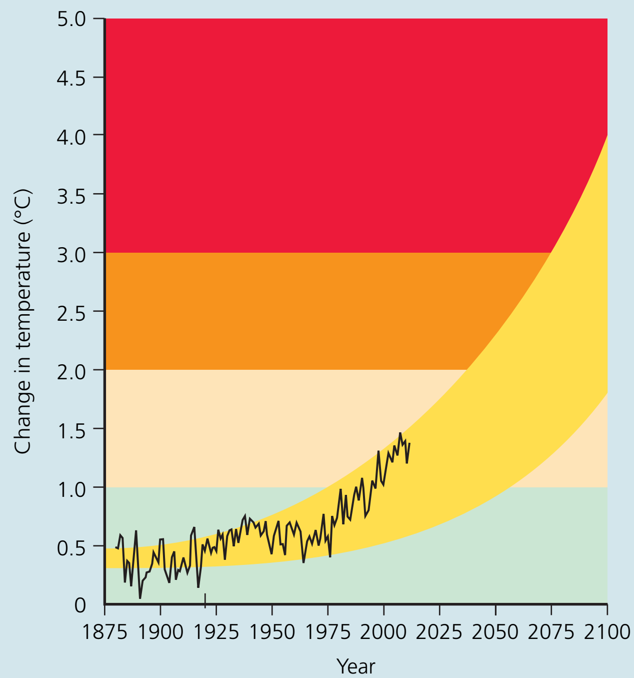


Figure 19-B **Science:** This figure shows estimated and measured changes in the average temperature of the atmosphere at the earth's surface between 1860 and 2008, and the projected range of temperature increase during the rest of this century (**Concept 19-1**). (Data from U.S. National Academy of Sciences, National Center for Atmospheric Research, Intergovernmental Panel on Climate Change, and Hadley Center for Climate Prediction and Research)

According to a 2007 study by scientists Christopher Field and Gregg Marland, if CO_2 emissions continue to increase at their current rate, levels in the atmosphere are likely to rise to 560 ppm by 2050 and could soar to 1,390 ppm by 2100. Climate models project that such dramatic increases would bring about significant changes in the earth's climate, which would likely cause major ecological and economic disruption in the latter half of this century.

A number of scientific studies and major climate models indicate that we need to prevent CO_2 levels from exceeding 450 ppm—an estimated threshold, or irreversible *tipping point*, that could set into motion large-scale climate changes for hundreds to thousands of years. According to NASA climate scientist James Hansen (Individuals Matter, p. 502), we need to bring CO_2 levels down to 350 ppm, the level we had in 1990, to maintain a climate similar to that in which our civilizations developed over the last 10,000 years.

In 2009, the largest CO_2 emitters were, in order, China, the United States, the European Union (with 27 countries), Indonesia, Russia, Japan, and India. China and the United States together are now the sources of nearly half of the world's annual greenhouse gas emissions. Scientific studies indicate that the United States has been responsible for three times more of the world's cumulative CO_2 emissions between 1900 and 2005 than China (see Figure 15, p. S63, in Supplement 9). But a 2008 study by the U.S.-based Energy Foundation and the World Wildlife Fund warned that by 2050, if China continues to burn fossil fuels, especially coal, at its present rate, its CO_2 emissions could triple and account for 60% of the world's CO_2 emissions.

It is also important to compare the per capita emissions of CO_2 emitted by various countries. Although China's total CO_2 emissions are the world's highest and are growing rapidly, its per capita emissions are low because of its huge population, most of them too poor to use large amounts of fossil fuels and other resources. The United States emits about five times more CO_2 per person than China emits and almost 200 times more CO_2 per person than the poorest countries emit. In 2009, the countries with the highest CO_2 emissions per person were, in order, Australia, the United States, Canada, the Netherlands, and Saudi Arabia.

Waste Heat Also Plays a Role in Climate Disruption

Because of the second law of thermodynamics (see Chapter 2, p. 47), burning any fuel automatically releases low-temperature waste heat into the environment. Thus, our use of carbon-containing fossil fuels, wood, and biofuels packs a double punch: burning them produces the greenhouse gas carbon dioxide and also adds waste heat directly to the atmosphere.

Our societies depend on a variety of very inefficient technologies such as the incandescent lightbulb, the internal combustion engine, the nuclear fuel cycle,

INDIVIDUALS MATTER

Sounding the Alarm—James Hansen

In 1988, American climate scientist James Hansen (Figure 19-C) appeared before a U.S. Congressional committee and stated he was 99% certain that atmospheric warming was a grave threat made worse every day by large and growing emissions of carbon dioxide and other greenhouse gases resulting from human activities. With that, he kicked off the public debate over what most climate scientists believe is our greatest environmental challenge. He also helped to promote the idea of creating the Intergovernmental Panel on Climate Change (IPCC) in 1988 to organize climate experts with the goals of studying this issue and reporting their findings to the world.

Hansen has used his decades of experience as a climate scientist and head of NASA's Goddard Institute for Space Studies to help develop several climate models (Science Focus, p. 500).

Hansen is well respected by his peers and is also known for his willingness to speak out despite some skepticism about projected climate disruption. This is unusual because most scientists prefer to stay out of the political arena where the rules of evidence and debate are quite different and much more lax than they are in the scientific arena. However, throughout the history of science, there have been scientists who have felt ethically obligated to speak out about issues they thought were important, based on their research.

Bruce Gilbert/Courtesy of NASA Goddard Institute for Space Studies

Figure 19-C James C. Hansen has been head of NASA's Goddard Institute for Space Studies since 1981. As one of the world's most respected climate scientists and climate modelers, he has made many important contributions to the science of atmospheric warming and projected climate disruption.

Hansen's message is that, based on what he has learned by studying climate and climate change for many decades, rising levels of greenhouse gases will likely lead to catastrophic climate disruption during this century unless those levels are drastically reduced. He has stated repeatedly that what motivates him is his concern for future generations. "The difficulty of this problem," Hansen said, "is that its main impacts will be felt by our children and by our grandchildren."

For his outspokenness, he has been threatened and harassed by some industry and government representatives. In 2005, the White House directed NASA to stop Hansen from speaking publicly about climate change. News reporters took this story of attempted censorship and ran with it, and Hansen's warnings consequently got more media coverage throughout the world. He has refused to yield to pressure from his powerful critics.

In 2006, he received the American Association for the Advancement of Science Award for Scientific Freedom and Responsibility. He was also listed by *Time* magazine as one of the world's 100 most influential people in 2006. In 2009, Hansen received the American Meteorological Society's highest award for his "outstanding contributions to climate modeling, understanding climate change, and for clear communication of climate science in the public arena."

In addition to sounding the alarm, Hansen uses his knowledge and experience to inspire some hope about the future. For example, using the climate models that he helped to develop, he evaluates and makes projections about possible solutions to projected problems related to climate disruption.

and coal burning power plants, all of which add large amounts of waste heat to the environment. We cannot recycle any of this waste heat into high-quality energy, because of the second law of thermodynamics (see Chapter 2, p. 47). Thus, improving the energy efficiency of these and other devices is a vital part of any strategy for reducing this unnecessary addition of heat to the atmosphere and thus for helping to reduce the threat of projected climate disruption.

The waste-heat problem also applies to low-carbon energy alternatives such as solar cells (which waste about 80–90% of the solar energy that reaches them) and wind turbines (which do better than most energy-conversion devices, wasting about 50–60% of the energy they extract from the wind). Thus, a key component of any strategy to reduce the threat of projected climate disruption must be a global energy efficiency revolution (see Chapter 16, pp. 398–408) in which the world's scientists and engineers work to make every energy conversion device as energy efficient as possible. **GREEN CAREER:** energy efficiency expert

What Role Does the Sun Play?

The energy output of the sun plays the key role in the earth's temperature and this output has varied over millions of years. However, in 2007 climate researchers Claus Froelich, Mike Lockwood, and Ben Santer all concluded in separate studies that most of the rise in global average atmospheric temperatures since 1980 (Figure 19-2, top right, and Figure 19-5) could not be the result of increased solar output. Instead, they determined that the energy output of sun has decreased for several decades.

These researchers noted that, according to satellite and weather balloon measurements, since 1975 the lower atmosphere, or troposphere, has warmed while the stratosphere has cooled. This is the opposite of what a hotter sun would do. According to Santer, "If you increase output from the sun, you increase the amount of energy that arrives at the top of the Earth's atmosphere and get heating throughout the atmosphere."

Instead, the data show that the atmosphere is now heating from the bottom up, which indicates that inputs at the earth's surface (most likely from human activities) play an important role. Other studies show that since the mid-1970s, the sun's output has remained about the same and thus cannot account for the rise in temperature since 1975.

What Role Do Oceans Play in Projected Climate Disruption?

The world's oceans absorb CO_2 from the atmosphere as part of the carbon cycle and thus help to moderate the earth's average surface temperature and its climate. It is estimated that the oceans remove about 25–30% of the CO_2 pumped into the lower atmosphere by human activities. The oceans also absorb heat from the lower atmosphere. Then, partly driven by this heat, ocean currents slowly transfer some CO_2 to the deep ocean (see Figure 7-5, p. 150), where it is buried in carbon compounds in bottom sediments for several hundred million years. However, a 2007 study by Ken Buesseler and other scientists at the Woods Hole Oceanographic Institution in Massachusetts (USA) found that much of the CO_2 currently absorbed by the oceans never reaches the deep ocean.

In 2009, the world's oceans were the warmest in 130 years of record keeping. The ability of the oceans to absorb CO_2 also decreases when water temperatures increase. As the oceans warm up, some of their dissolved CO_2 is released into the lower atmosphere, like CO_2 bubbling out of a warm carbonated soft drink. According to scientific measurements from a 2007 study, the upper portion of the oceans warmed by an average of 0.32–0.67C° (0.6–1.2F°) during the last century—an astounding increase considering the huge volume of water involved—most likely due to increasing atmospheric temperatures.

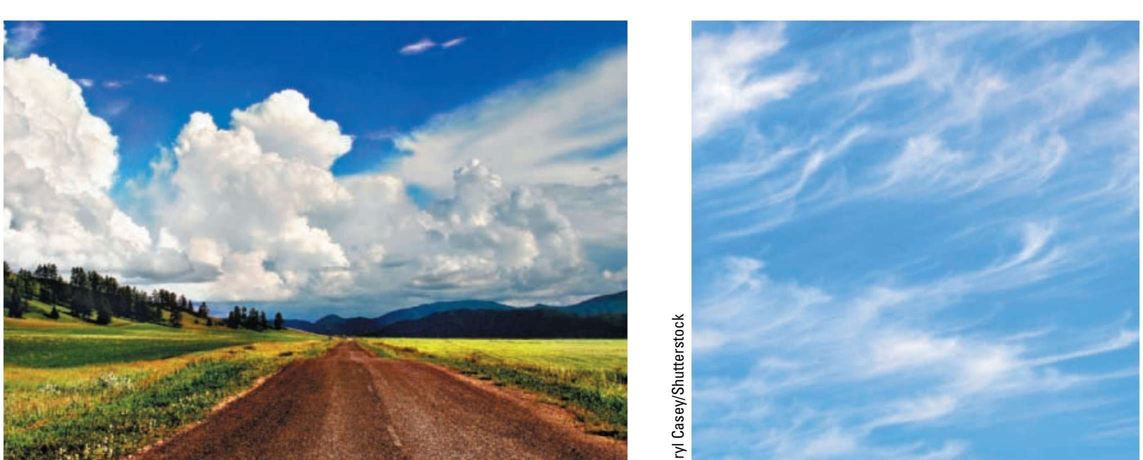
According to a 2005 report by the United Kingdom's Royal Society and a 2010 report by the U.S. National Academy of Sciences, increasing levels of CO_2 in the ocean have increased the *acidity* of its surface by 30% during the past 200 years, and ocean acidity could reach dangerous levels before 2050. This is happening because much of the CO_2 absorbed by the ocean reacts with water to produce carbonic acid (H_2CO_3)—the same weak acid found in carbonated drinks. The increased acidity threatens corals and other organisms with shells and body structures composed of calcium carbonate that dissolve when acidity reaches a certain level. This further reduces the ability of the oceans to absorb CO_2 and can accelerate climate change in another positive feedback loop.

Another problem is that increased acidity has been shown to decrease populations of phytoplankton that are the primary producer species of ocean food webs and that also remove CO_2 from the atmosphere. In 2010, ocean scientist William G. Sunda warned that ocean acidification might also reduce the ocean water's levels of iron needed by marine phytoplankton for photosynthesis. This could decrease the ocean's ability to absorb more carbon dioxide.

If these preliminary research results are correct, increasing ocean acidity could disrupt ocean food webs and global food supplies. It could also result in much less CO_2 being removed from the atmosphere, which would speed up projected climate disruption in yet another positive feedback loop.

There Is Uncertainty about the Effects of Cloud Cover on Atmospheric Warming

The role played by clouds in the warming of the atmosphere is a major unknown in global climate models and a key reason why there is such a wide range of projected future temperatures (Figure 19-B). Warmer temperatures increase evaporation of surface water and create more clouds, which can cool or warm the atmosphere. An increase in thick and continuous *cumulus clouds* at low altitudes (Figure 19-8, left) could decrease surface warming by reflecting more sunlight back into space. But an increase in thin, wispy *cirrus clouds* at high altitudes (Figure 19-8, right) could increase the warming of the lower atmosphere by preventing more heat from escaping into space. Climate modelers have not



Tatiana Grozetskaya/Shutterstock

Cheryl Casey/Shutterstock

Figure 19-8 Cumulus clouds (left) are thick, relatively low-lying clouds that tend to decrease surface warming by reflecting some incoming solar radiation back into space. Cirrus clouds (right) are thin and float at high altitudes; they tend to warm the earth's surface by preventing some heat from flowing into space.

been able to show which of these effects is the most important and are working hard to understand more about the role of clouds in their climate models.

CONNECTIONS

Air Travel and Atmospheric Warming

Infrared satellite images indicate that wispy condensation trails (contrails) left behind by jet planes expand and turn into large cirrus clouds (Figure 19-8, right), which tend to heat the atmosphere. If these preliminary results are confirmed, we may find that emissions from jet planes are responsible for as much as half of the warming of the lower atmosphere in the northern hemisphere where much of the world's air travel is concentrated.

Outdoor Air Pollution Can Temporarily Slow Atmospheric Warming

There is considerable evidence that human activities play a role in atmospheric warming. There is also evidence that aerosol air pollution from human activities has slowed the rate of atmospheric warming. Aerosols (suspended microscopic droplets and solid particles) of various air pollutants are released or formed in the troposphere by volcanic eruptions and human activities (see Figure 18-5, p. 469). They can warm or cool the air as well as hinder or enhance cloud formation, depending on factors such as their size and reflectivity.

Most aerosols, such as light-colored sulfate particles produced by fossil fuel combustion, tend to reflect incoming sunlight and cool the lower atmosphere. Sulfate particles also cool the lower atmosphere by serving as condensation nuclei that form cooling clouds. Scientists estimate that sulfate particles played a roll in slowing atmospheric warming between 1880 and 1970. However, a 2008 study by atmospheric scientist V. Ramanathan and his colleagues found that soot, the black carbon particulate matter emitted into the air by coal burning, diesel exhaust, open cooking fires, and the burning of forests has a warming effect on the atmosphere four times greater than was estimated earlier. These findings were supported by another study reported in 2009 by meteorologist Gunnar Myhre.

Climate scientists do not expect aerosols and soot pollutants to counteract or enhance projected climate change very much in the next 50 years for two reasons. *First,* aerosols and soot fall back to the earth or are washed out of the lower atmosphere within weeks or months, whereas CO_2 remains in the lower atmosphere for 80–120 years. *Second,* aerosol and soot inputs into the lower atmosphere are being reduced—especially in more-developed countries—because of their harmful impacts on plants and human health.

According to the IPCC, the resulting decline in atmospheric sulfate concentrations since 1970 has played a role in the warming of the atmosphere, especially since 1990, and this affect will grow as sulfate concentrations drop further due to improved air pollution regulations. We could probably slow down projected climate disruption by increasing outdoor air pollution. But since such pollution kills more than 800,000 people a year (60,000 to 70,000 people in the United States), this would not be a desirable or ethically acceptable way to try to deal with projected climate disruption.

HOW WOULD YOU VOTE? ✓

Do you think that we will experience significant atmospheric warming and climate disruption during this century? Cast your vote online at **www.cengage.com/login**.

19-2 What Are Some Possible Effects of a Warmer Atmosphere?

▶ **CONCEPT 19-2 The projected rapid change in the atmosphere's temperature could have severe and long-lasting consequences, including increased drought and flooding, rising sea levels, and shifts in the locations of croplands and wildlife habitats.**

Enhanced Atmospheric Warming Could Have Serious Consequences

So what is the big deal? Why should we worry about the projected rise of a few degrees in the earth's average atmospheric temperature? We often have that much change between May and July, or between yesterday and today. The key distinction is that we are not considering normal swings in *local weather*, but a projected *rapid global change in climate*—weather measurements averaged over a period of several decades (**Concept 19-2**).

Climate scientists are concerned not only about how much the temperature might change, but also about how rapidly the change occurs. Most historic changes in the temperature of the lower atmosphere took place over thousands of years (Figure 19-2, top left and bottom left). What makes the current problem urgent is that we face *a rapid projected increase in the average temperature of the lower atmosphere during this century* (Figure 19-B). This in turn is very likely to rapidly change the fairly mild climate that we have had for the past 10,000 years. Thus, what we are facing is *climate disruption*, or very rapid climate change.

Climate models indicate that such changes will determine where we can grow food and how much of it we can grow; which areas will suffer from increased drought and which will experience increased flooding; and in what areas people and many forms of wildlife can live. If the models are correct, we will have to deal with these disruptive effects within this century—an incredibly short time span in terms of the earth's overall climate history (Figure 19-2).

A 2003 U.S. National Academy of Sciences report laid out a nightmarish *worst-case scenario* in which human activities, alone or in combination with natural factors, trigger new and abrupt climate and ecological changes that could last for thousands of years. The report describes ecosystems collapsing, floods in low-lying coastal cities, forests consumed in vast wildfires, and grasslands, dried out from prolonged drought, turning into dust bowls. It warns of rivers drying up—and with them, drinking water and irrigation water supplies—as the mountain glaciers that feed them melt. It also describes premature extinction of up to half of the world's species, prolonged heat waves and droughts, more destructive storms, and some tropical infectious diseases spreading beyond their current ranges.

These possibilities were supported by a 2003 analysis carried out for the U.S. Department of Defense by Peter Schwartz and Doug Randall. They concluded that projected climate disruption "must be viewed as a serious threat to global stability and should be elevated to a U.S. national security concern."

Let us look more closely at some of the current signs, and projected effects, of such climate disruption.

Severe Drought Is Likely to Increase

Recall that *drought* occurs when evaporation from increased temperatures greatly exceeds precipitation for a prolonged period. According to a 2005 study by NASA climate scientist Aiguo Dai and his colleagues, severe and prolonged drought now affects at least 30% of the earth's land (excluding Antarctica)—an area the size of Asia.

For example, southern Australia has been in the grips of a severe drought for a decade, and the western United States is experiencing its worst drought in 500 years. According to a 2007 study by climate researchers at NASA's Goddard Institute for Space Studies, by 2059, up to 45% of the world's land area could be experiencing extreme drought.

Droughts caused by decreased rainfall are related to changes in weather patterns such as high pressure systems and jet streams (see Figure 2, p. S00, in Supplement 7). Droughts in some parts of the world are also related to shifts every few years in trade winds known as *El Niño–Southern Oscillations (ENSO)*. These weather (not climate) events typically alter Pacific Ocean currents (see Figure 4, p. S27, in Supplement 7) for about a year or two. This temporarily increases droughts and alters other weather conditions over much of the globe (see Figure 5, p. S28, in Supplement 7).

As droughts increase and spread, the growth of trees and other plants declines, which reduces the removal of CO_2 from the atmosphere. As forests and grasslands also dry out, wildfires increase in frequency, and this adds CO_2 to the atmosphere. Climate scientists project that these combined effects from the projected increase of prolonged droughts are likely to accelerate atmospheric warming in a positive feedback loop.

Other effects of this browning of the land include declining stream flows and less available surface water; falling water tables with more evaporation, worsened by farmers irrigating more to make up for drier conditions; shrinking lakes, reservoirs, and inland seas; dwindling rivers; water shortages for 1–3 billion people; declining biodiversity; and expansion of dry climate biomes, such as savannas, chaparral, and deserts. Note that some of these effects of prolonged droughts create conditions that, through positive feedback, are likely to accelerate atmospheric warming and lead to even more drought.

More Ice and Snow Are Likely to Melt

Climate models project that climate change will be the most severe in the world's polar regions—the Arctic and Antarctica. Light-colored ice and snow in these regions help to cool the earth by reflecting incoming solar energy. The melting of such ice and snow exposes much darker land and sea areas, which reflect much less sunlight and absorb more solar energy. This causes the atmosphere above the poles to warm faster than it does at lower latitudes, as projected by all major climate models. This in turn can cause more ice and snow to melt, which would lead to more atmospheric warming and an escalating positive feedback loop (see Figure 2-18, p. 49).

According to the 2007 IPCC report, arctic temperatures have risen almost twice as fast as average temperatures in the rest of the world during the past 50 years. Also, soot generated by North American, European, and Asian industries is darkening arctic ice and lessening its ability to reflect sunlight. Mostly as a result of these two factors, summer sea ice in the Arctic is disappearing faster than scientists thought only a few years ago (Figure 19-7). Because of changes in short-term weather conditions, summer sea ice coverage is likely to fluctuate. But the overall projected long-term trend is for the average summer coverage to decrease steadily and to be gone by 2040 or much earlier, according to a 2009 study by scientists Muyin Wang and James Overland.

Mountain glaciers are affected by two climatic factors: average snowfall, which adds to their mass during the winter, and average warm temperatures, which spur their melting during the summer. During the past 25 years, many of the world's mountain glaciers have been slowly melting and shrinking (Figure 19-6). For example, climate models project that by 2070, Glacier National Park in the U.S. state of Montana will have no glaciers for the first time in at least 7,000 years. The U.S. Geological Survey reported in 2009 that 99% of Alaska's glaciers are also shrinking (Figure 19-9).

Mountain glaciers play a vital role in the water cycle (see Figure 3-16, p. 68) by storing water as ice during cold wet seasons and releasing it slowly to streams during warmer dry seasons. These high-elevation reservoirs, such as those of the Himalayan Mountains in Asia, are a major source of water for large rivers such as the Ganges, which provides water for 407 million people in India and Bangladesh, and the Yangtze and Yellow Rivers in China. Water shortages could threaten billions of people in Asia as mountain glaciers in the Himalaya and Tibetan Plateau slowly melt over the next century or two. In 2009, Swiss scientists reported that Himalayan glaciers as well as glaciers in Europe's Alps shrank farther and faster in the last decade than they had in 150 years.

Thomas Schrantz

Figure 19-9 This photo shows the melting and retreat of the Athabasca Glacier in the Canadian province of Alberta between 1992 and 2005.

About 80% of the mountain glaciers in South America's Andes range are also slowly shrinking. If this continues, sometime during the next one or two centuries, millions of people in countries such as Bolivia, Peru, and Ecuador who rely on meltwater from the glaciers for irrigation and hydropower, could face severe water, power, and food shortages. In 2010, geophysicist Carolina Pagli warned that melting ice caps could lead to larger or more frequent volcanic eruptions in parts of Iceland and other areas where ice-capped volcanoes exist. This is because melting of thick ice would remove a huge weight and could free up molten rock (magma) in the earth's interior.

Permafrost Is Likely to Melt: Another Dangerous Scenario

The amount of carbon locked up as methane (CH_4) in permafrost soils is 50–60 times the amount emitted as carbon dioxide from burning fossil fuels each year. If the permafrost in soil and in lake bottoms in parts of the rapidly warming Arctic melts, significant amounts of CH_4 and CO_2 will be released into the atmosphere, and this will accelerate projected climate disruption.

According to the 2004 Arctic Climate Impact Assessment, 10–20% of the Arctic's current permafrost might thaw during this century, decreasing the total area of arctic tundra (Figure 19-10). The resulting increase in CH_4 and CO_2 emissions would cause more warming, which would in turn melt more permafrost in yet another positive feedback loop.

Current research indicates that the amount of carbon stored as CH_4 and CO_2 in permafrost is more than twice the amount estimated by the IPCC in 2007. Some scientists are concerned about another methane source—a layer of permafrost on the Arctic Sea floor. In 2009, Natalia Shakhova and other researchers found this source to be leaking bubbles of methane. Some scientists refer to such sources as "methane time bombs." They could eventually release amounts of CH_4 and CO_2 that would raise atmospheric concentrations of these gases to many times the current levels, resulting in rapid and probably catastrophic climate change—another positive feedback loop. More research is needed to study this potentially serious threat.

Sea Levels Are Rising

Sea levels are rising faster than IPCC scientists had reported in 2007, according to newer studies. For example, a 2008 U.S. Geological Survey report concluded that the world's average sea level will most likely rise 0.8–2 meters (3–6.5 feet) by the end of this century—3 to 5 times the increase estimated in the 2007 IPCC report—and will probably keep rising for centuries. This rise is due to the expansion of seawater as it warms, and to the melting of land-based ice.

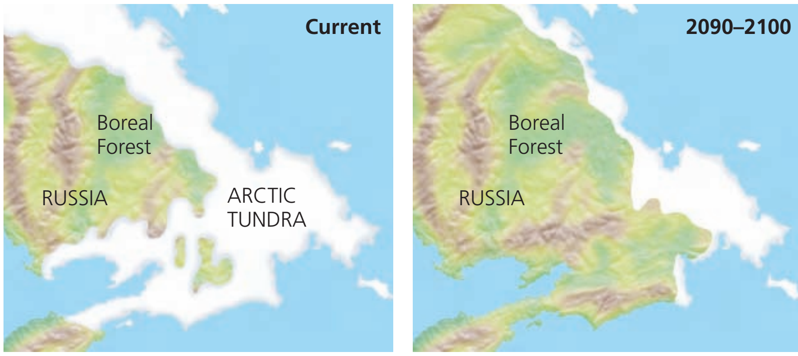


Figure 19-10 This figure shows a projected decrease in arctic tundra (see Figure 7-11, bottom, p. 157) in portions of eastern Russia between 2004 and 2100 as a result of atmospheric warming. The melting of permafrost in such tundra soils could release the greenhouse gases CH_4 and CO_2, and accelerate projected climate disruption, which would melt more tundra. This loss of arctic tundra could reduce grazing lands for caribou and breeding areas for a number of tundra-dwelling bird species. (Data from Intergovernmental Panel on Climate Change and 2004 Arctic Climate Impact Assessment)

Such a rise in sea level would be more dramatic if the vast land-based glaciers in Greenland (**Core Case Study**) and western Antarctica as well as many of the world's mountaintop glaciers continue melting at their current, or higher, rates as the atmosphere warms. A 2009 study by British climate scientist Jonathan Bamber estimated that a loss of just 15% of Greenland's ice sheet (Figure 19-1) would cause a 1-meter (3.3-foot) rise in sea level.

Severe reductions in greenhouse gas emissions might prevent such a rapid and catastrophic rise in sea level, but scientists project that even with such reductions, the world's average sea level (Figure 19-4, bottom) is still likely to rise by at least 1 meter (3.3 feet) by 2100. According to the IPCC, this projected rise in sea levels during this century (excluding the additional effects of storm surges) could cause the following serious effects:

- Degradation or destruction of at least one-third of the world's coastal estuaries, wetlands, and coral reefs.
- Disruption of many of the world's coastal fisheries.
- Flooding and erosion of low-lying barrier islands and gently sloping coastlines, especially in U.S. coastal states such as Texas, Louisiana, North and South Carolina, and Florida (Figure 19-11).
- Flooding of agricultural lowlands and deltas in coastal areas where much of the world's rice is grown. This is already happening on parts of the east coast of India and in Bangladesh. For example, a sea level rise of 1 meter (3.3 feet) would flood half of the rice paddies in low-lying Bangladesh and displace tens of millions of people.
- Saltwater contamination of freshwater coastal aquifers and decreased supplies of groundwater.
- Submersion of low-lying islands in the Indian Ocean (Figure 19-12, p. 508), the Pacific Ocean, and the Caribbean Sea, which are home to 1 of every 20 of the world's people.
- Flooding of some of the world's largest coastal cities, including Calcutta (India), Mumbai (India), Dhaka (Bangladesh), Guangzhou (China), Ho Chi Minh City (Vietnam), Shanghai (China), Bangkok (Thailand), Rangoon (Myanmar), Haiphong (Vietnam), and the U.S. cities of New York, New York and Miami, Florida (Figure 19-11), and displacement of at least 100 million people. A 2007 study by the Organization for Economic Cooperation and Development estimated that, by 2070, coastal flooding from a sea level rise of 0.5 meter (1.6 feet) would affect 150 million people. (See *The Habitable Planet*, Video 5, at **www.learner.org/resources/series209.html** for a discussion of the effects of rising sea levels on densely populated coastal areas in Vietnam, and on New York City.)

A 2009 study by University of Maryland scientists projected that the northeast coast of the United States is likely to see the biggest sea level rise in the world. Boston, Massachusetts would be one of the hardest hit cities, according to this study.

Such changes are unlikely to take place soon. However, climate scientists warn that they are very likely to begin occurring during the latter half of this century, unless the world takes immediate emergency action to slow projected climate disruption.

Figure 19-11 If the average sea level rises by 1 meter (3.3 feet), the areas shown here in red in the U.S. state of Florida will be flooded. (Data from Jonathan Overpeck and Jeremy Weiss based on U.S. Geological Survey Data)

Massimo Broche/Bruce Coleman, USA

Figure 19-12 For a low-lying island nation like the Maldives in the Indian Ocean, even a small rise in sea level could spell disaster for most of its 295,000 people. About 80% of the 1,192 small islands making up this country lie less than 1 meter (3.2 feet) above sea level. Rising sea levels and higher storm surges during this century could flood most of these islands and their coral reefs.

Extreme Weather Is Likely to Increase in Some Areas

According to the IPCC, atmospheric warming will increase the incidence of extreme weather events such as severe droughts and heat waves in some areas, which could kill large numbers of people, reduce crop production, and expand deserts. At the same time, because a warmer atmosphere can hold more moisture, other areas will experience increased flooding from heavy and prolonged snow or rainfall.

There is controversy among scientists over whether projected atmospheric warming will increase the frequency and intensity of tropical storms and hurricanes. In 2008, climatologists Mark Saunders and Adam Lea analyzed data collected since 1950 and found that for every increase of about 0.8 C° (1 F°) in the water temperature of the Atlantic Ocean, the overall number of hurricanes and tropical storms increased by about a third, and the number of intense hurricanes (with winds over 177 kilometers (110 miles) per hour) increased by 45%. A 2005 statistical analysis by MIT climatologist Kerry Emmanuel and six other peer-reviewed studies published in 2006 also indicated that atmospheric warming, on average, could increase the size and strength of Atlantic storms and hurricanes and their storm surges due to the warming of the ocean's surface water.

However, some researchers blame the ups and downs in the intensity of tropical Atlantic hurricanes on natural climate cycles that can change ocean circulation patterns. In 2010, a World Meteorological Organization panel of experts on hurricanes and climate change from both sides of this scientific debate reached the following consensus view: projected atmospheric warming is likely lead to fewer but stronger hurricanes that could cause more damage.

RESEARCH FRONTIER

Effects of climate change on tropical storms; see **www.cengage.com/login**.

Climate Disruption Is a Threat to Biodiversity

According to the 2007 IPCC report, projected climate disruption is likely to upset ecosystems, decrease biodiversity, and degrade ecosystem services (see Figure 1-4, p. 9) in areas of every continent. For example, the Amazon rain forest could be devastated, even by moderate warming. According to a 2009 British study led by Chris Jones, up to 85% of this forest could be lost if atmospheric warming is not curbed. The scientists noted that this would involve extensive losses in biodiversity and other ecosystem services as the rain forest dries out and becomes more prone to burning and the resulting conversion to tropical savanna (see Chapter 10, p. 229).

According to the 1997 IPCC study, approximately 30% of the land-based plant and animal species assessed so far could disappear if the average global temperature change exceeds 1.5–2.5ºC (2.7–4.5ºF). This percentage could grow to 70% if the temperature change exceeds 3.5ºC (6.3ºF) (**Concept 19-2**). The hardest hit will be plant and animal species in colder climates such as the polar bear in the Arctic and penguins in Antarctica; species that live at higher elevations; plant and animal species with limited ranges such as some amphibians (see Chapter 4 Case Study, p. 97); and those with limited tolerance for temperature change.

Coral reefs are the ecosystems most likely to suffer disruption and species loss from climate change, mostly due coral bleaching (see Chapter 8 Core Case Study, p. 168). A 2007 study by Ken Calderia and 16 other scientists warned that warmer and more acidic oceans threaten to destroy much of the world's ecologically important coral reef ecosystems before the end of this century. This would expose more people to coastal flooding, increase coastal erosion, reduce yields and revenues for reef-based fisheries and tourism, and greatly decrease aquatic biodiversity.

Other ecosystems especially vulnerable to climate disruption are polar seas, coastal wetlands, high-elevation mountaintops, and alpine and arctic tundra (Figure 19-11). Some types of forests unable to migrate fast enough to keep up with climate shifts will decline and others, such as U.S. oak–pine and oak–hickory forests, may expand northward. Primarily because of drier conditions, forest fires might increase in some areas such as the southeastern and western United States.

This would severely degrade some forest ecosystems, add more CO_2 to the atmosphere, reduce total CO_2 uptake by trees and plants, and help accelerate projected climate disruption through still another positive feedback loop.

A warmer climate can also greatly increase populations of insects and fungi that damage trees. In the Canadian province of British Columbia, for example, warmer winters have led to surges in mountain pine beetle populations that have infected huge areas of lodgepole pine forests, which are now dying (Figure 19-13). Since 2000, pine beetles have also damaged about 60% of the lodgepole pines in the U.S. state of Colorado, which has been experiencing warmer winters that are more favorable to the beetles. Large numbers of dry and dead trees can increase the risk of forest fires and further threaten biodiversity.

Shifts in regional climate would also threaten many existing state and national parks, wildlife reserves, wilderness areas, and wetlands, along with much of the biodiversity they contain. In other words, slowing the rate of projected climate change would help to sustain the earth's biodiversity, which in turn supports us and our economies. On the other hand, the populations of plant and animal species that thrive in warmer climates could grow.

Natural Resources Canada, Canadian Forest Service

Figure 19-13 With warmer winters, exploding populations of mountain pine beetles have munched their way through large areas of lodgepole pine forest (orange-colored trees) in the Canadian province of British Columbia. Foresters are trying to reduce this threat by planting a mix of trees less susceptible to the pest—an example of applying the biodiversity principle of sustainability.

Agriculture Could Face an Overall Decline

Modern industrialized food production runs on fossil fuels, and many forests have been cleared for growing crops. According to a 2006 report by the U.N. Food and Agriculture Organization, modern agriculture likely accounts for about one-third of the atmospheric warming that has taken place since 1960.

Farming, probably more than any other human activity, depends on a stable climate. Thus, farmers will face dramatic changes due to shifting climates and a faster hydrologic cycle, if the earth warms as projected (Figure 19-B). In a warmer world, agricultural productivity will drop in some areas. This decrease is likely to be worse in areas where farmers depend on monocultures of plants bred to thrive at certain temperatures and with certain levels of rainfall.

On the other hand, crop productivity will likely increase in some areas. According to the 2007 IPCC report, crop productivity is projected to increase slightly at middle to high latitudes with moderate warming, but decrease if warming goes too far. For example, moderately warmer temperatures and increased precipitation in parts of mid-western Canada, as well as in Russia and Ukraine, could lead to higher productivity there. But this effect may be limited because soils generally are more lacking in sufficient plant nutrients in these northern regions.

Climate change models predict a decline in agricultural productivity in tropical and subtropical regions, especially in Southeast Asia and Central America, where many of the world's poorest people live. In addition, flooding of river deltas due to rising sea levels could reduce crop production in these areas and fish production in nearby coastal aquaculture ponds. Food production could also decrease in farm regions that are dependent on rivers fed by snow and glacial melt and in any arid and semiarid areas where droughts become more prolonged. This could also be a problem in humid areas of Southeast Asia that are vulnerable to increased seasonal rainfall and devastating storms, which could bring heavier flooding.

According to the IPCC, food will be plentiful for a while because of the longer growing season in northern regions. But the scientists warn that by 2050, some 200–600 million of the world's poorest and most vulnerable people could face starvation and malnutrition due to the effects of projected climate disruption.

A Warmer World Is Likely to Threaten the Health of Many People

According to IPCC and other reports, more frequent and prolonged heat waves in some areas will increase numbers of deaths and illnesses, especially among older people, people in poor health, and the urban poor who cannot afford air conditioning.

On the other hand, in a warmer world, fewer people will die from cold weather. But a 2007 study led by Mercedes Medina-Ramon of the Harvard University School of Public Health suggests that increased numbers of heat-related deaths will be greater than the projected drop in cold-related deaths. In addition, hunger and malnutrition will increase in areas where agricultural production drops.

A warmer, CO_2-rich world will be a great place for rapidly multiplying insects, microbes, toxic molds, and fungi that make us sick, and for plants that produce pollens that cause allergies and asthma attacks. Longer and more intense pollen seasons will mean more itchy eyes, runny noses, and asthma attacks. Insect pests and weeds will likely multiply, spread, and reduce crop yields.

In a warmer world, microbes that cause tropical infectious diseases such as dengue fever and yellow fever are likely to expand their ranges and numbers if mosquitoes that carry them spread to warmer temperate and higher elevation areas as they have begun to do (Figure 19-14).

Higher atmospheric temperatures and higher levels of water vapor in urban areas will also increase some forms of air pollution. The greatest effect will be to speed up the rate of the chemical reactions that produce ozone and other harmful chemicals in photochemical smog in urban areas (see Figure 18-11, p. 475). This in turn will likely cause more pollution-related deaths from heart ailments and respiratory problems.

Projected climate disruption will also force many millions of people to move, in search of better conditions. Environmental scientist Norman Myers estimates that projected climate change during this century could produce at least 150 million, and perhaps 250 million, environmental refugees who will be forced to migrate by increasing hunger, flooding, and drought. (See Myers's Guest Essay on this topic at **www.cengage.com/login**.)

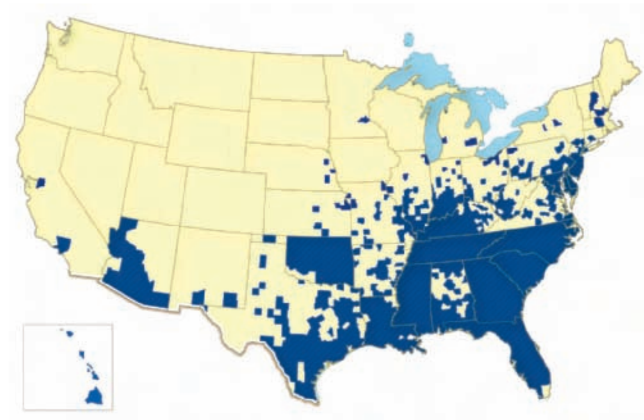


Figure 19-14 Areas in blue show counties in 28 U.S. states where one or both species of mosquitoes that transmit dengue fever have been found as of 2005. This supports the claim by some scientists that projected climate disruption will expand the range of mosquitoes that carry dengue fever, a debilitating and potentially deadly disease.

A 2009 study by a research institute led by former UN Secretary General Kofi Annan estimated that climate disruption already contributes to the premature deaths of more than 300,000 people—an average of 822 people a day. The report estimated that 325 million people—a number greater than the U.S. population—are now seriously affected by accelerating climate change through natural disasters and environmental degradation.

19-3 What Can We Do to Slow Projected Climate Disruption?

CONCEPT 19-3 To slow the projected rate of atmospheric warming and climate disruption, we can increase energy efficiency, sharply reduce greenhouse gas emissions, rely more on renewable energy resources, and slow population growth.

Dealing with Climate Disruption Is Difficult

Many scientists argue that our most urgent priority is *to do all we can to avoid any and all* ***climate tipping points*** —thresholds beyond which natural systems can change irrversibly. Once we reach such a point, there is no going back. Figure 19-15 summarizes some of the tipping points that scientists are most concerned about.

Partly because of these possibilities, many analysts believe that addressing climate change is one of the most urgent scientific, political, economic, and ethical issues that humanity faces. But the following characteristics of this complex problem make it difficult to tackle:

- *The problem is global.* Dealing with this threat will require unprecedented and prolonged international cooperation.
- *The problem is a long-term political issue.* Voters and elected officials generally respond better to short-term problems than to long-term threats. Most of the people who could suffer the most serious harm from projected climate disruption during the latter half of this century have not been born.
- *The projected harmful and beneficial impacts of climate disruption are not spread evenly.* For example, higher latitude nations such as Canada, Russia, and New Zealand could have higher crop yields, fewer deaths

in winter, and lower heating bills. Other nations such as Bangladesh could see more flooding and higher death tolls.

- *Many proposed solutions, such as sharply reducing or phasing out the use of fossil fuels, are controversial* because they could disrupt economies and lifestyles and threaten the profits of economically and politically powerful oil and coal companies (Science Focus, below). But waiting too long to slow climate change would also disrupt those same economies and lifestyles, probably to an even greater extent, according to a 2008 study by the Organization for Economic Cooperation and Development.

- Atmospheric carbon level of 450 ppm
- Melting of all Arctic summer sea ice
- Collapse and melting of the Greenland ice sheet
- Severe ocean acidification, collapse of phytoplankton populations, and a sharp drop in the ability of the oceans to absorb CO_2
- Massive release of methane from thawing Arctic permafrost
- Collapse and melting of most of the western Antarctic ice sheet
- Severe shrinkage or collapse of Amazon rainforest

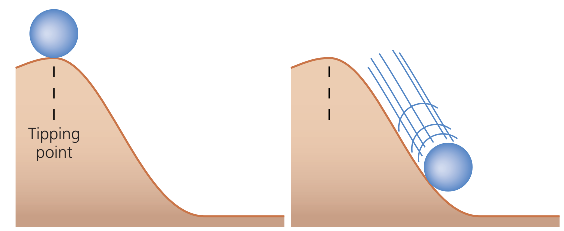


Figure 19-15 Environmental scientists have come up with this list of possible climate change tipping points. They urge us to focus on avoiding these thresholds beyond which large-scale, irreversible, and possibly catastrophic climate changes can occur. The problem is that we do not know how close we are to such tipping points.

SCIENCE FOCUS

Science, Politics, and Climate

After more than 20 years of research, most IPCC and other climate scientists reached an unprecedented general agreement about the earth's past and projected future atmospheric temperatures and their likely effects on the earth's climate during this century (see Science Focus boxes, pp. 498 and 500). However, between 2006 and 2010, public opinion polls showed that the percentage of the U.S. public who believed that the seriousness of atmospheric warming had been exaggerated increased from 30% to 48%. How did this happen?

To many analysts, the answer lies in the deliberate politicizing of the climate change issue by certain parties that sought to create doubt about the reliability of the scientific research and to accuse climate scientists of exaggerating the seriousness of the issue. A corporation's primary goal and fiscal responsibility is to maximize profits for its owners and stockholders. Thus, it is understandable that for more than two decades, the leaders of financially and politically powerful oil, coal, and related industries have mounted a highly effective campaign to cast doubt on climate change arguments. Their goal has been to protect their profits by preventing any government taxation or regulation of the immense amounts of CO_2 and other greenhouse gases that these industries add to the atmosphere.

So far, it has worked. These industries employed the same tactics that the U.S. tobacco industry used to cast doubt about the overwhelming scientific evidence and agreement among scientists that tobacco can be harmful and highly addictive (see Case Study, pp. 458–460). The tobacco industry was able to delay any serious government regulation of smoking for more than 40 years.

One tactic used in the political campaign against greenhouse gas regulation has played on the general public's lack of knowledge about how science works. The idea is to argue that scientists have not provided absolute proof that projected climate disruption is real, threatening, or caused mostly by human activities. Such a statement is correct but misleading and irrelevant, because science cannot absolutely prove anything. Instead, scientists provide varying degrees of certainty about the results of their peer-evaluated research (see Chapter 2, pp. 32–38). And the estimated degree of certainty about projected climate disruption is quite high by scientific standards—ranging from *likely* (60–89% certain) to *very likely* (at least 90% certain).

A second tactic plays on the general lack of knowledge about the difference between weather and climate. Most people know a lot about weather because they experience it every day and listen to weather forecasts. But consumers, along with most weather forecasters and many scientists in a variety of fields, know very little about the much more complex science of climatology.

For example, weather in much of the United States during the month of January 2010 was cold with many snowstorms. Climate change skeptics and some members of the U.S. congress had a snowman built in front of the U.S. capital in Washington, DC. Then they used it as a media ploy to argue publicly that climate change ideas had been debunked and that the findings of the IPCC and other major scientific bodies should be ignored.

Organizers of this media event implied falsely that the weather during a week, a month, a year, or even a decade or two can tell us something useful about climate change. They overlooked the fact that any climate change projection requires an analysis of weather data spanning at least 30 and preferably hundreds of years.

By 2010, the use of these two tactics had planted doubt about the seriousness of projected climate disruption in the minds of almost half of the U.S. public. Many climate scientists therefore put a high priority on informing the public and its government representatives about this issue (Individuals Matter, p. 502).

Critical Thinking

Do you believe that warnings about atmospheric warming and its projected harmful effects on the earth's climate during this century are generally exaggerated, about right, or understated? Explain. Compare your answer with those of your classmates.

- *A growing number of social scientists contend that humans are not "hardwired" to respond to long-term threats*. Scientists and educators are frustrated by how difficult it is to convince the public that projected climate disruption could pose a great threat to many people living on earth today, and even more so to their children, grandchildren, and great grandchildren. Some are trying new approaches to this challenge (Individuals Matter, below).

What Are Our Options?

There are three basic approaches to dealing with the projected harmful effects of global climate disruption: act to slow it, try to reduce some of its harmful effects (adaptation), or suffer. Climate scientist James Hansen (Individuals Matter, p. 502) and other prominent climate scientists have urged policy makers and business leaders to mount an unprecedented crash program to cut global carbon dioxide emissions by 50–85% by 2050 in an effort to slow down or avoid the projected harmful effects of climate disruption.

In 2009, investors who collectively manage more than $13 trillion of the world's financial assets issued a joint call for U.S. and international policy makers to come up with an effective international agreement on climate change. They warned that climate disruption poses a threat to the global economy, and they projected that moving to a low-carbon world is an enormous global investment opportunity.

In 2010, Bill Gates—one of the world's most successful businessmen and a leading philanthropist—stated his belief that dealing with climate change is the most

INDIVIDUALS MATTER

John Sterman's Bathtub Model

Professor John Sterman teaches system dynamics to graduate students at the Massachusetts Institute of Technology's Sloan School of Management. He found that his already highly educated students had difficulty in grasping the basic problem of how various levels of CO_2 emissions affect the atmosphere. That is, until he lit upon the simple but profound analogy of the bathtub.

Sterman likens the atmosphere to a bathtub (Figure 19-D) that gets inputs of chemicals such as CO_2, which eventually drain from the tub into the oceans and continents. Before the Industrial Revolution, the system was receiving CO_2 inputs at about the same rate as it was draining them. With the explosive increase in human-generated CO_2 emissions, however, the bathtub is filling much faster than it can drain.

Sterman's students now have a better understanding of something they had trouble grasping before he used this visual analogy. It explains why, even if we stop increasing CO_2 emissions and keep them at current rates, CO_2 levels in the atmosphere will still increase to dangerous levels and the tub will eventually overflow. Draining the bathtub will require a sharp cut in emissions. That is because it will take hundreds to thousands of years for nature to drain the CO_2 that is now in the tub—into plants and soil, the oceans, and sediments and rocks—to the point where it is not overflowing or at least is not too full to avoid catastrophic climate disruption.

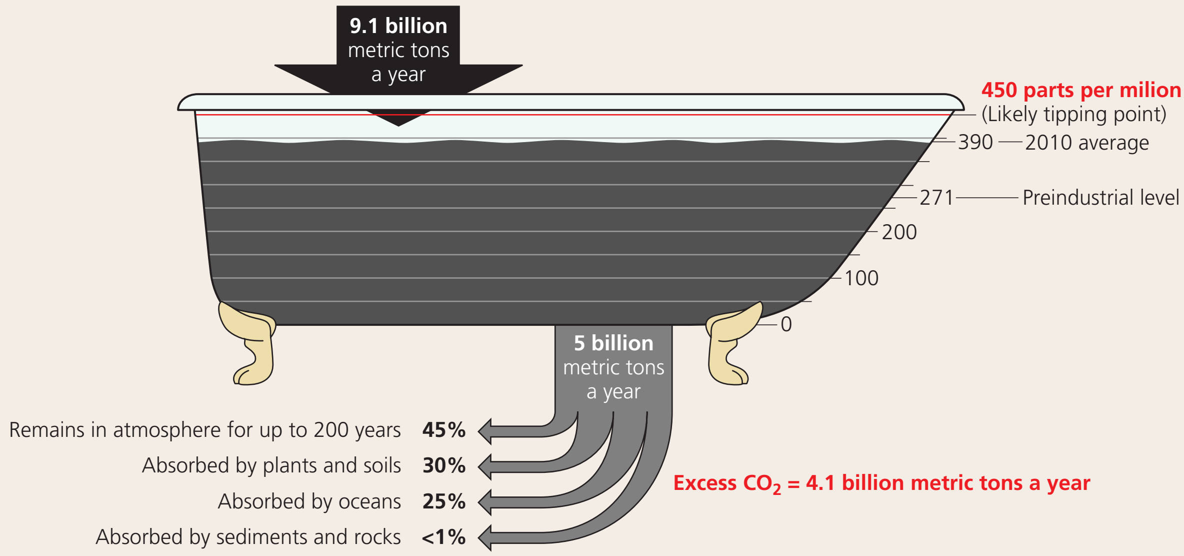


Figure 19-D The bathtub represents the atmosphere. Inputs of CO_2 have increased dramatically since the mid-1700s and are now entering the bathtub at nearly twice the rate at which the tub can drain. The tub drains into three major reservoirs: plants and soil, which absorb about 30% of daily outputs; the oceans, which take 25%; and sediments and rocks, which absorb less than 1%. Together, these reservoirs can absorb only about 55% of what is put into the tub every day by human activities. The other 45% is added to the tub, which is steadily filling—at a rate that some scientists say is beyond the level that is safe for most of life on earth.

important challenge we face. He argued that the only sensible goal is to eliminate all net emissions of greenhouse gases, primarily by shifting to renewable, low-carbon energy resources. Gates and others have suggested that such a shift will lead us into a new era of economic growth and prosperity.

HOW WOULD YOU VOTE?

Should we take serious action now to help slow projected climate disruption as a result of human actions? Cast your vote online at **www.cengage.com/login**.

Prevent and Reduce Greenhouse Gas Emissions

GOOD NEWS

Figure 19-16 lists a number of ways to slow the rate and degree of atmospheric warming and the resulting climate disruption caused by our activities. Among these solutions are four major *prevention* strategies that, by 2050, could reduce human greenhouse gas emissions by the 57–83% called for in a 2010 study by the U.S. National Academy of Sciences:

1. Improve energy efficiency to reduce fossil fuel use, especially use of coal. According to climate scientist James Hansen, phasing out coal use is "80% of the solution to the global warming crisis."
2. Shift from nonrenewable carbon-based fossil fuels to a mix of low-carbon renewable energy resources based on local and regional availability.
3. Stop cutting down tropical forests and plant trees to help remove more CO_2 from the atmosphere.
4. Shift to more sustainable and climate-friendly agriculture (Figure 12-34, p. 310).

THINKING ABOUT
Climate Disruption Prevention Strategies

How are each of the four strategies listed above related to one or more of the **principles of sustainability** (see back cover)?

Solutions

Slowing Climate Disruption

Prevention	Cleanup
Cut fossil fuel use (especially coal)	Remove CO_2 from smokestack and vehicle emissions
Shift from coal to natural gas	Store (sequester) CO_2 by planting trees
Improve energy efficiency	Sequester CO_2 in soil by using no-till cultivation and taking cropland out of production
Shift to renewable energy resources	Sequester CO_2 deep underground (with no leaks allowed)
Transfer energy efficiency and renewable energy technologies to developing countries	Sequester CO_2 in the deep ocean (with no leaks allowed)
Reduce deforestation	Repair leaky natural gas pipelines and facilities
Use more sustainable agriculture and forestry	Use animal feeds that reduce CH_4 emissions from cows (belching)
Put a price on greenhouse gas emissions	
Reduce poverty	
Slow population growth	

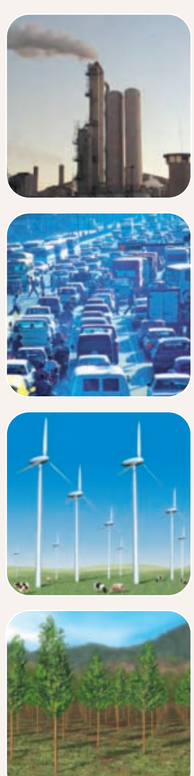


Figure 19-16 These are some ways to slow atmospheric warming and the resulting projected climate disruption during this century (**Concept 19-3**). **Questions:** Which five of these solutions do you think are the most important? Why?

Collect Greenhouse Gas Emissions and Stash Them Somewhere

The solutions listed on the right side of Figure 19-16 are *output*, or *cleanup*, strategies, which focus on dealing with CO_2 after it has been produced. In earlier chapters, we looked at several ways to prevent or reduce the release of greenhouse gases to the atmosphere in order to slow projected climate disruption. These have involved energy efficiency and the use of renewable energy (Chapter 16), sharply reducing tropical deforestation (Chapter 10), and shifting to more sustainable agriculture (Chapter 12). Let us now look more closely at some proposed output solutions—strategies for removing some of the CO_2 from the atmosphere or from smokestacks and storing (sequestering) it in other parts of the environment.

One way to increase the uptake of CO_2 is by implementing, on an emergency basis, a massive, global tree-planting program, especially on degraded land in the tropics (see Chapter 10 Core Case Study, p. 217). A similar approach is to restore wetlands where they have been drained for farming. Wetlands are very efficient at taking up CO_2, and they provide other valuable natural services as well (see Chapter 8, p. 186).

A third cleanup approach is to plant large areas of degraded land with fast-growing perennial plants such as switchgrass (see Figure 16-29, p. 423), which remove CO_2 from the air and store it in the soil. We can also harvest these plants to produce biofuels such as ethanol. To be sustainable, this approach could not involve clearing forests. (See *The Habitable Planet*, Video 10, at **www.learner.org/resources/series209.html** for a discussion of how scientists are using a grassland as a laboratory to measure the carbon uptake of plants.)

Along these lines, a measure that is getting more attention among scientists is the use of *biochar*. Scientists have rediscovered this fertilizer that Amazon Basin natives used for growing crops several centuries ago. Producing biochar involves burning biomass such as chicken waste or wood in a low-oxygen environment to make a charcoal-like material—a process that produces no smoke and no odor. The resulting carbon-rich biochar makes an excellent organic fertilizer that helps to keep carbon in the soil for as long as 1,000 years. While making biochar does release CO_2, burying it stores considerably more CO_2 in the soil. Farmers could plant fast-growing trees on degraded land and use them to make biochar. They could then make money selling some of it as fertilizer.

A fourth cleanup approach is to help the natural uptake and storage of carbon by preserving and restoring natural forests. In 2007, biologist Renton Righelato and climate scientist Dominick Spracklen concluded that the amount of carbon that we could sequester by protecting and restoring forests is greater than the amount of carbon in CO_2 emissions that we would avoid by using biofuels such as biodiesel and ethanol (see Chapter 16 Case Studies, p. 421).

GOOD NEWS

Fifth, some scientists propose seeding the oceans with iron to promote the growth of more marine algae and other phytoplankton, which absorb huge amounts of CO_2 from the atmosphere as they grow. When they die, they sink to the sea floor, carrying the carbon with them. The proposal is controversial because the long-term effects of adding large amounts of iron to ocean ecosystems are unknown. In addition, it was found in 2009 that shrimp-like animals called copepods had quickly devoured a large swarm of algae produced by seeding a test sight in the Atlantic Ocean with iron. If this were to happen regularly, more carbon would move up the food chain and eventually be released as CO_2, thus adding to the CO_2 problem. In addition, a 2009 study by oceanographer Richard Saunders found that even when it works, this scheme does not sequester large amounts of carbon.

A sixth approach that is receiving a lot of attention is to remove CO_2 from the smokestacks of coal-burning power and industrial plants and to store it somewhere. This approach is generally referred to as **carbon capture and storage**, or **CCS** (Science Focus, at right).

Some Promote Geoengineering Schemes to Deal with Climate Change

Some scientists and engineers want to use prevention strategies that fall under the umbrella of *geoengineering*, or trying to manipulate certain natural conditions to help counter an enhanced greenhouse effect. In recent years, some of these scientists have become discouraged by the slow response of governments to what they see as the global emergency of projected climate disruption with its potentially serious harmful effects. They suggest that we look at the implications and costs of using large-scale geoengineering schemes as a last resort, if humanity fails to deal with the world's projected climate change emergency soon enough.

For example, some scientists have studied the 1991 eruption of Mount Pinatubo in the Philippines and the fact that the average global atmospheric temperature cooled for about 15 months after the eruption. (**Explore More:** See a Case Study at **www.cengage.com/login** to learn more about these studies.) The volcano pumped massive amounts of SO_2 into the atmosphere where chemical reactions converted the SO_2 to sulfate particles, which were thought to have reflected some incoming sunlight into space, thus cooling the troposphere. These scientists have suggested using balloons, large jet planes, or giant cannons to inject sulfate particles into the stratosphere to get the same effect. Other scientists have called for placing a series of giant mirrors in orbit above the earth to reflect incoming sunlight for the same purpose.

Some scientists reject the idea of launching sulfates into the stratosphere as being too risky because of our limited knowledge about possible unknown effects. They note that huge amounts of sulfates would have to be injected into the stratosphere about every 2 years. And a 2008 study by atmospheric scientist Simone Tilmes suggests that chlorine released by reactions involved in this scheme could speed up the thinning of the earth's vital ozone layer (which we discuss in the next section of this chapter).

Even if it worked, this short-term technological fix would allow CO_2 levels in the lower atmosphere to continue rising and adding to climate disruption. It would also increase the acidity of the oceans, thereby decreasing their ability to absorb CO_2. Some scientists would deal with this ocean acidity problem by building a global network of thousands of chemical plants that would remove acid from seawater to reduce its acidity. But this would be quite costly and also could have unpredictable and possibly harmful ecological effects on ocean ecosystems.

THINKING ABOUT
Tinkering with the Stratosphere

Do you think the projected benefits of injecting large quantities of sulfate particles into the stratosphere every 2 years to help cool the troposphere would outweigh any projected negative results? Explain.

Another geoengineering idea, proposed by scientist James Lovelock, is to anchor huge vertical pipes in the oceans as part of a system that would allow wave motion to pump nutrient-rich water up from the deep ocean layer to fertilize algae on the ocean surface. Lovelock contends that the resulting algal blooms would remove CO_2 from the atmosphere and emit dimethyl sulfide (see Figure 3-22, p. 74), which would contribute to the formation of low clouds that would reflect sunlight.

SCIENCE FOCUS

Is Capturing and Storing CO_2 the Answer?

Figure 19-E shows several techniques for removing some of the CO_2 from the atmosphere and from smokestacks, and storing (sequestering) it in other parts of the environment.

Some researchers are studying ways to remove CO_2 from the exhaust coming out of smokestacks at coal-burning power and industrial plants. They hope to pump it deep underground into abandoned coal beds and oil and gas fields or to liquefy it and inject it into sediments under the sea floor (Figure 19-E). Another idea is to turn the collected CO_2 into charcoal or into carbonate rock. These schemes are generally referred to as *carbon capture and storage (CCS)*. (See *The Habitable Planet*, Video 10, at **www.learner.org/resources/series209.html**.)

However, it is becoming clear to scientists that stored CO_2 would have to remain sealed from the atmosphere forever. Any large-scale leaks caused by earthquakes or other shocks, as well as any number of smaller continuous leaks from CO_2 storage sites around the world, could dramatically increase atmospheric warming and climate disruption in a very short time. Some scientists doubt that we can develop the technology to guarantee that all such stored CO_2 would remain safely sequestered without some of it leaking out.

There are other serious problems. Removing all or most of the CO_2 from smokestack emissions and transporting and storing it takes a lot of energy. This would greatly reduce the net energy yield and significantly raise the cost of burning coal to supply electricity. Also, these measures would do nothing to reduce the massive amounts of CO_2 and other greenhouse gases emitted by using fossil fuels to propel motor vehicles and grow food. Nor would they do anything to curb land use changes that add to CO_2 levels in the atmosphere, such as the cutting and burning of forests. Most worrisome of all to some scientists, CCS promotes the increased use of coal, the world's most environmentally harmful fuel (see Figure 15-18, right, p. 384).

Environmental scientists such as Peter Montague argue that CCS is a costly and extremely risky *output* solution to a serious problem that can be dealt with by using a variety of cheaper, quicker, and safer *input*, or *prevention*, approaches (Figure 19-16, left). They point out that coal is mostly carbon that is already sequestered in the ground and they argue for leaving it there and producing the electricity we need by using low-carbon energy resources such as energy efficiency, solar cells, and wind power. To these scientists, when we face a problem such as CO_2 coming out of a smokestack or exhaust pipe, the most important question to ask is not *What do we do with it?* but, *How do we avoid producing the CO_2 in the first place?*

Critical Thinking

Do you think that a government-supported crash program to build coal-burning power plants with CCS components would be a good investment of taxpayer dollars? Explain.

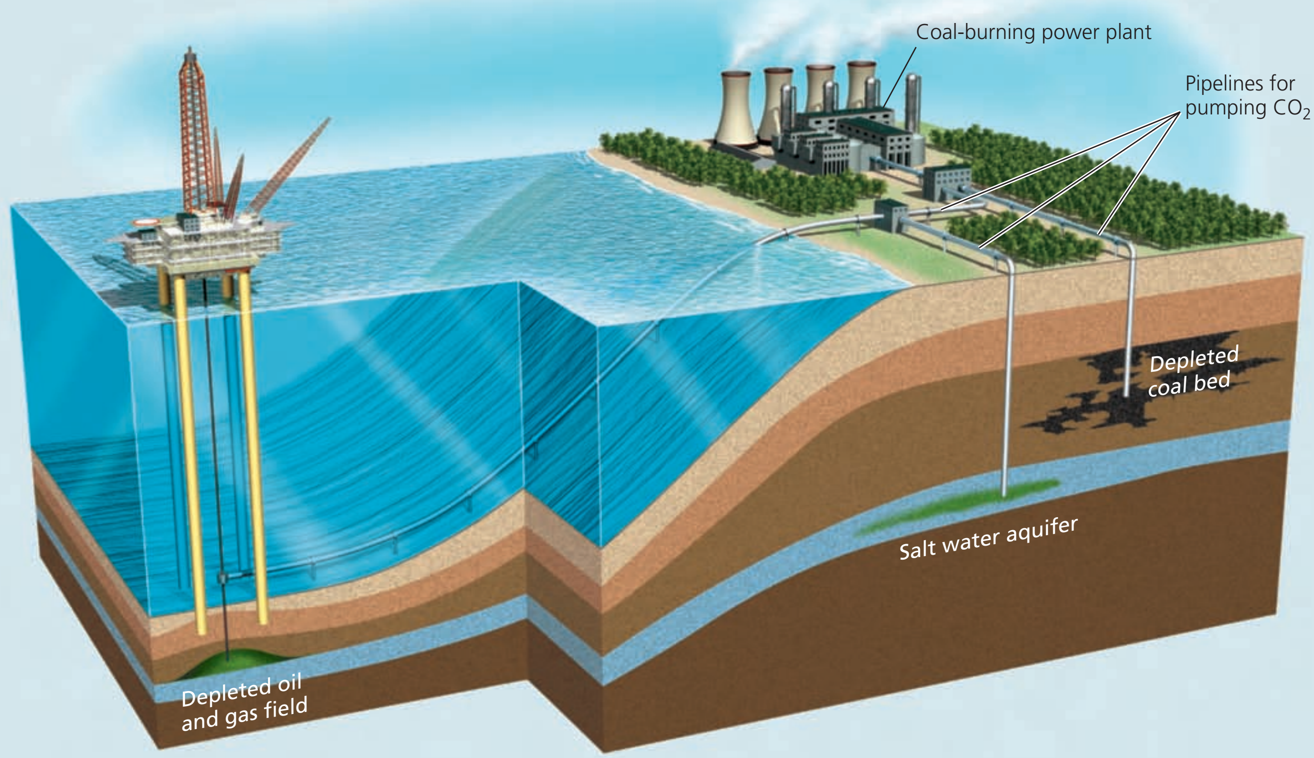


Figure 19-E **Solutions:** There are several proposed *output* methods for removing carbon dioxide from the atmosphere or from smokestacks and storing it in soil, plants, and deep underground reservoirs, as well as in sediments beneath the ocean floor. **Questions:** Which two of these solutions do you think would work best? Which two would be the least effective? Why?

According to skeptical scientists, one major problem with most of these technological fixes and with some carbon capture and storage schemes (Science Focus, p. 515) is that they require huge investments of energy and materials, and there is no guarantee that they will work. Geoengineering schemes all depend on complex machinery running constantly, flawlessly, and essentially forever, primarily to pump something from one place to another in the environment. If we rely on these systems and continue emitting greenhouse gases, and if the systems then fail, atmospheric temperatures will likely soar at a rapid rate and greatly increase the threat of projected climate disruption.

Critics of large-scale geoengineering schemes argue for slowing climate change by using prevention approaches, such as improving energy efficiency, replacing fossil fuels with already available renewable energy resources, and drastically reducing tropical deforestation. They say this is a better investment of limited resources than gambling on large-scale, costly changes to the global environment that could have unknown and potentially long-lasting harmful effects. A nightmare for many climate scientists and ecologists is that the world might not act quickly and boldly enough to slow greenhouse gas emissions. Then, if the projected severe effects of climate disruption occur, many people and government leaders might panic and support a variety of band-aid geoengineering proposals that are likely to make matters much worse in the long run.

Governments Can Help to Reduce the Threat of Climate Disruption

Governments can use six major methods to promote the solutions listed in Figure 19-16 (**Concept 19-3**). One is to *strictly regulate carbon dioxide and methane as air pollutants*. In 2009, the U.S. Environmental Protection Agency found that CO_2, CH_4, N_2O, and three other greenhouse gases are a danger to public health and welfare and will be listed as pollutants under the Clean Air Act (Science Focus at right). But politically and economically powerful coal, oil, and utility companies that make their money by burning carbon-containing fuels have successfully opposed regulating carbon dioxide for more than two decades and hope to overturn or greatly weaken any government efforts to regulate carbon dioxide emissions (Science Focus, p. 511).

Second, governments could reduce greenhouse gas emissions by phasing in *carbon taxes* or *fees* on each unit of CO_2 or CH_4 emitted by fossil fuel use, or they could levy *energy taxes* or *fees* on each unit of fossil fuel that is burned (Figure 19-7). This has the effect of putting a price on carbon emissions. Decreasing taxes on income, wages, and profits to offset such taxes could help to make such a strategy more politically acceptable, and it might also stimulate the economy. In other words, *tax pollution, not payrolls and profits*. Some European countries are gradually phasing in such a tax shift.

Trade-Offs

Carbon and Energy Taxes

Advantages

- Simple to administer
- Clear price on carbon
- Covers all emitters
- Predictable revenues

Disadvantages

- Tax laws can get complex
- Vulnerable to loopholes
- Doesn't guarantee lower emissions
- Politically unpopular

Figure 19-17 Using carbon and energy taxes or fees to help reduce greenhouse gas emissions has advantages and disadvantages. **Question:** Which two advantages and which two disadvantages do you think are the most important and why?

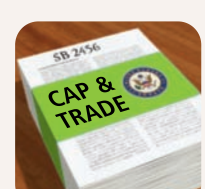
A third approach for governments is to *place a cap on total human-generated CO_2 and CH_4 emissions* in a country or region, issue permits to emit these pollutants, and then let polluters trade their permits in the marketplace. This *cap-and-trade* or *pollution reduction approach* (Figure 19-18) has a political advantage over taxes, but it is difficult to manage because there are so many different emitters of greenhouse gases. In addition, this approach works only if the original caps are set low enough to encourage a serious reduction in greenhouse gas emissions and are lowered on a regular basis to promote further cuts. A related and more politically acceptable approach is to use a *cap-and-rebate* scheme in which all money made by any trades would go straight back to the public in the form of cash payments.

Trade-Offs

Cap and Trade Policies

Advantages

- Clear legal limit on emissions
- Rewards cuts in emissions
- Record of success
- Low expense for consumers



Disadvantages

- Revenues not predictable
- Vulnerable to cheating
- Rich polluters can keep polluting
- Puts variable price on carbon

Figure 19-18 Using a cap-and-trade policy to help reduce greenhouse gas emissions has advantages and disadvantages. **Question:** Which two advantages and which two disadvantages do you think are the most important and why?

SCIENCE FOCUS

What Is a Pollutant?

Some people have a poor understanding of what makes a chemical a pollutant. In Chapter 1, we defined a pollutant as a chemical or other agent such as noise or heat in the environment that proves harmful to the health, survival, or activities of humans or other organisms.

Carbon dioxide is now classified as a pollutant. But some people wonder how CO_2 can possibly be classified as such, because it is a natural and important part of the carbon cycle (see Figure 3-19, p. 70). Humans and most animal life forms constantly emit CO_2 into the atmosphere, while plants remove it and use it for photosynthesis.

In fact, the characteristic of any chemical that determines whether or not it should be classified as a pollutant is its *concentration* in the atmosphere, soil, water, or plant or animal tissues. At a high enough concentration, essentially any chemical can cause enough harm to be classified as a pollutant.

For example, if we were to fill up a room with CO_2, everyone there would die very quickly from lack of oxygen. Similarly, when we add CO_2 to the atmosphere faster than the carbon cycle can remove it (Figure 19-E, p. 512), we help to warm the atmosphere and contribute to climate change that can cause considerable long-term harm to us, our economies, and many other forms of life. At some point in that process (at some atmospheric concentration), CO_2 becomes a pollutant. This is why the U.S. Environmental Protection Agency declared in 2009 that excessive concentrations of CO_2 and five other greenhouse gases in the atmosphere can cause harm and thus need to be regulated as air pollutants.

Similarly, nitrate ions (NO_3^-) and phosphate ions (PO_4^{3-}) are important chemicals in the nitrogen cycle (see Figure 3-20, p. 71) and phosphorous cycle (see Figure 3-21, p. 73), respectively. But add too much of these normally harmless and useful chemicals to bodies of water and they become pollutants that can disrupt these aquatic systems and cause cultural eutrophication (see Figure 8-17, right, p. 182).

Critical Thinking

What is another chemical that is normally useful or harmless that can become a pollutant?

Environmental economists argue that, regardless of whether governments use taxes or a cap-and-trade or cap-and-rebate policy, the most critical goal is to put a price on carbon emissions to get all emitters to come as close as possible to paying all of the estimated harmful environmental and health costs of their carbon emissions. Economist Gary Yohe and others contend that the resulting higher costs for fossil fuels will spur innovation in finding ways to reduce carbon emissions, improve energy efficiency, and phase in a mix of low-carbon renewable energy alternatives.

A fourth strategy is to *level the economic playing field* by greatly increasing government subsidies to businesses and individuals to encourage their use of energy-efficiency technologies, low-carbon renewable energy sources, and more sustainable agriculture. This would also include phasing out or sharply reducing subsidies and tax breaks that encourage the use of fossil fuels and nuclear power, unsustainable agriculture, and the clearing of forests. In other words, we could shift from environmentally degrading to environmentally sustaining subsidies and tax breaks.

The fifth strategy focuses on *technology transfer*. Governments of more-developed countries could help to fund the transfer of the latest green technologies to less-developed countries so that they could bypass older, energy-wasting and polluting technologies. Some analysts argue that helping poorer countries to deal with the harmful effects of projected climate disruption would make sense, because many of these countries will suffer the most from such effects, which have been caused mostly by more-developed countries. Increasing the current tax on each international currency transaction by a quarter of a penny could finance this technology transfer, which would then generate wealth for less-developed countries and help to stimulate a more environmentally sustainable global economy.

Finally, the sixth strategy that governments can employ to promote the solutions listed in Figure 19-17 is to create programs that will help to curb population growth (see Chapter 6, pp. 139–142).

Governments Can Enter into International Climate Negotiations

In December 1997, more than 2,200 delegates from 161 nations met in Kyoto, Japan, to negotiate a treaty to slow global warming and the resulting projected climate disruption. The first phase of the resulting *Kyoto Protocol* went into effect in February 2005 with 187 of the world's 194 countries (not including the United States) ratifying the agreement by late 2009.

This agreement requires the 36 participating more-developed countries to cut their emissions of CO_2, CH_4, and N_2O to an average of at least 5.2% below their 1990 levels by 2012, when the treaty expires. Less-developed countries were excluded from this requirement in this first phase, because such reductions would curb their economic growth. In 2005, participating countries began negotiating a second phase, which is supposed to go into effect after 2012. But these negotiations ended up with only a general agreement by the nations that produce most of the current and projected future emissions of greenhouse gases to talk more about the problem in the future. A 2009 U.N. conference in

Copenhagen, Denmark, ended in a similarly general nonbinding agreement.

Some analysts see current and proposed international climate agreements as weak and slow responses to an urgent global problem, pointing out that atmospheric carbon dioxide levels have increased 35% faster than was expected under the Kyoto agreement. Many have also concluded that a top-down international agreement will be too slow and ineffective. Some call for the nations that produce most of the world's greenhouse gas emissions—especially the United States, China, India, Brazil, and the European Union nations—to get together and work out an agreement to sharply lower their emissions.

Some Governments Are Leading the Way

Some nations are leading others in facing the challenges of projected climate disruption. Costa Rica aims to be the first country to become *carbon neutral* by cutting its net carbon emissions to zero by 2030. The country generates 78% of its electricity with renewable hydroelectric power and another 18% from renewable wind and geothermal energy.

GOOD NEWS

Some analysts are urging rapidly developing countries such as China and India to shift toward more sustainable, low-carbon economic development by leapfrogging over the traditional forms of economic development that have led to the climate change problem. If China and India continue their extensive coal burning and other high-carbon activities, the world will not be able to avoid the projected harmful effects of climate disruption.

China needs no encouragement. It has the most intensive energy efficiency program in the world, according to ClimateWorks, a global energy-consulting firm. Chinese automobile fuel-efficiency standards are higher than U.S. standards but enforcement of the standards is still weak. China's government is working with the country's top 1,000 industries to implement tough energy efficiency goals. China is also rapidly becoming the world's leader in developing and selling solar cells, solar water heaters, wind turbines, advanced batteries, and plug-in hybrid electric cars. China's leaders are planning for their country to become the world leader in developing and selling these low-carbon technologies, and thus receiving most of the immense profits to be made from phasing in these technologies during this century. At the same time, each year, China emits more CO_2 into the atmosphere than any other country.

By 2009, 30 U.S. states had set goals for reducing greenhouse gas emissions. California plans to get 33% of its electricity from low-carbon renewable energy sources by 2030. (**Explore More:** See a Case Study at **www.cengage.com/login** to learn more about California's leading role in reducing greenhouse gas emissions.) Since 1990, local governments in more than 650 cities around the world (including more than 450 U.S. cities) have established programs to reduce their greenhouse gas emissions.

The first major U.S. city to do this was Portland, Oregon. Between 1993 and 2005, the city cut its greenhouse gas emissions back to 1990 levels, while national levels rose by 16%. The city promotes energy-efficient buildings and the use of electricity from wind and solar sources. It has also built bicycle trails and has greatly expanded its mass transit system. Far from hurting Portland's economy, these strategies have produced an economic boom and have saved the city $2 million a year on its energy bills.

Some Companies and Schools Are Reducing Their Carbon Footprints

A growing number of major global companies, including Alcoa, DuPont, IBM, Toyota, General Electric, and British Petroleum (BP), have set goals for seriously reducing their greenhouse gas emissions, mostly because this will save them money. Between 1990 and 2006, DuPont slashed its energy usage and cut its greenhouse gas emissions by 72% and saved $3 billion, while the company increased its business by almost a third. Wal-Mart has become the world's largest seller of energy-saving compact fluorescent lightbulbs, and it saves $12 million a year using energy-efficient LED bulbs in its refrigeration units.

Leaders of these and many other major companies see an enormous profit opportunity in developing or using energy-efficient and cleaner-energy technologies, such as fuel-efficient cars, wind turbines, and solar cells. Like the leaders of China, they understand that there is gold in going green.

Some colleges and universities are also taking action. Students and faculty at Oberlin College in the U.S. state of Ohio have asked their board of trustees to reduce the college's CO_2 emissions to zero by 2020 by buying or producing renewable energy. In the U.S. state of Pennsylvania, 25 colleges have joined to purchase wind power and other forms of low-carbon renewable energy. In 2005, the president of Yale University committed the school to cutting its considerable greenhouse gas emissions by 44% by 2020. (You can find out more about how to help your school cut its CO_2 emissions by viewing the 2008 National Wildlife Federation report on this topic at **www.nwf.org/campusecology/BusinessCase/index.cfm**.)

THINKING ABOUT
What Your School Can Do

What are three steps that you think your school should take to help reduce its CO_2 emissions?

Individual Choices Make a Difference

Each of us plays a part in the acceleration of atmospheric warming. Whenever we use energy generated by fossil fuels, for example, we add a certain amount of CO_2 to the atmosphere. The total weight of all the CO_2 that the world's people dump into the atmosphere every day is roughly equal to combined weight of 53 million mid-sized cars.

Each use of energy adds to an individual's *carbon footprint*. To calculate your carbon footprint, the amount of carbon dioxide generated by your lifestyle, you can go to several websites, including the following:

nature.org/climatecalculator

epa.gov/climatechange/emissions/ind_calculator.html

carbonfootprint.com

climatecrisis.net/calculate-your-impact.php

coolclimate.berkeley.edu

worldwildlife.org/carboncalculator

Some of these websites suggest ways for you to reduce, or *offset*, some of your carbon dioxide emissions by helping to fund or participate in projects such as forest restoration and renewable energy development. But buyers need to do their homework because some carbon-offset programs are not real and do not actually produce emissions cuts. For evaluations of carbon offset providers go to **www.cleanair-coolplanet.org** and **www.tufts.edu/tie/tci/carbonoffsets**. The nonprofit Consumers Union also has a website (**www.GreenerChoices.org/calculators.cfm**) to help consumers evaluate conflicting claims of travel agencies over the greenest way to travel.

Critics of such carbon-offset schemes say that most of them primarily offer a way for consumers to ease their guilt. Some critics also argue that such programs can encourage people to continue producing greenhouse gases instead of making carbon-cutting lifestyle changes, such as driving less, using public transit, and consuming less electricity. Some of these offset schemes have also been found to be scams.

Figure 19-19 lists some ways in which you can cut your CO_2 emissions. One person taking each of these steps makes a small contribution to reducing global greenhouse gas emissions. But when millions of people take such steps, the cumulative result is quite large. A 2009 study by human ecologist Thomas Dietz estimated that if individual Americans took steps such as those listed in Figure 19-19, the cumulative impact of such individual actions could cut U.S. emissions of CO_2 by more than 7% within a decade. Also when people make environmentally beneficial changes in their lifestyles, they are more likely to become politically active and effective people.

What Can You Do?

Reducing CO_2 Emissions

- Calculate your carbon footprint (see websites listed at left)
- Drive a fuel-efficient car, walk, bike, carpool, and use mass transit
- Reduce garbage by recycling and reusing more items
- Use energy-efficient appliances and compact fluorescent or LED lightbulbs
- Wash laundry in warm or cold water
- Dry clothes on a rack or line
- Use a low-flow showerhead
- Eat less meat or no meat
- Heavily insulate your house and seal all air leaks
- Use energy-efficient windows
- Insulate your hot water heater and set it no higher than 49ºC (120ºF)
- Plant trees to shade your house during summer
- Buy from businesses working to reduce their emissions

Figure 19-19 **Individuals matter:** You can reduce your annual emissions of CO_2. **Question:** Which of these steps, if any, do you take now or plan to take in the future?

We Can Prepare for Climate Disruption

According to global climate models, the world needs to make a 50–85% cut in emissions of greenhouse gases by 2050 to stabilize concentrations of these gases in the atmosphere. This would help to prevent the planet from heating up by more than 2ºC (3.6ºF) and to head off rapid changes in the world's climate and the projected harmful effects, as discussed in Section 19-2.

However, because of the difficulty of making such large reductions, many analysts believe that while we work to slash emissions, we should also begin to prepare for the projected harmful effects of projected climate disruption. Figure 19-20 (p. 520) shows some ways to do so.

Relief organizations, including the International Red Cross and Oxfam, are turning their attention to projects such as expanding mangrove forests as buffers against storm surges, building shelters on high ground, and planting trees on slopes to help prevent landslides. Seawall design and construction will be a major growth industry. And low-lying countries such as Bangladesh are trying to figure out what to do with millions of environmental refuges who will be flooded out by rising sea levels. Some cities plan to establish cooling centers to shelter residents during increasingly intense heat waves.

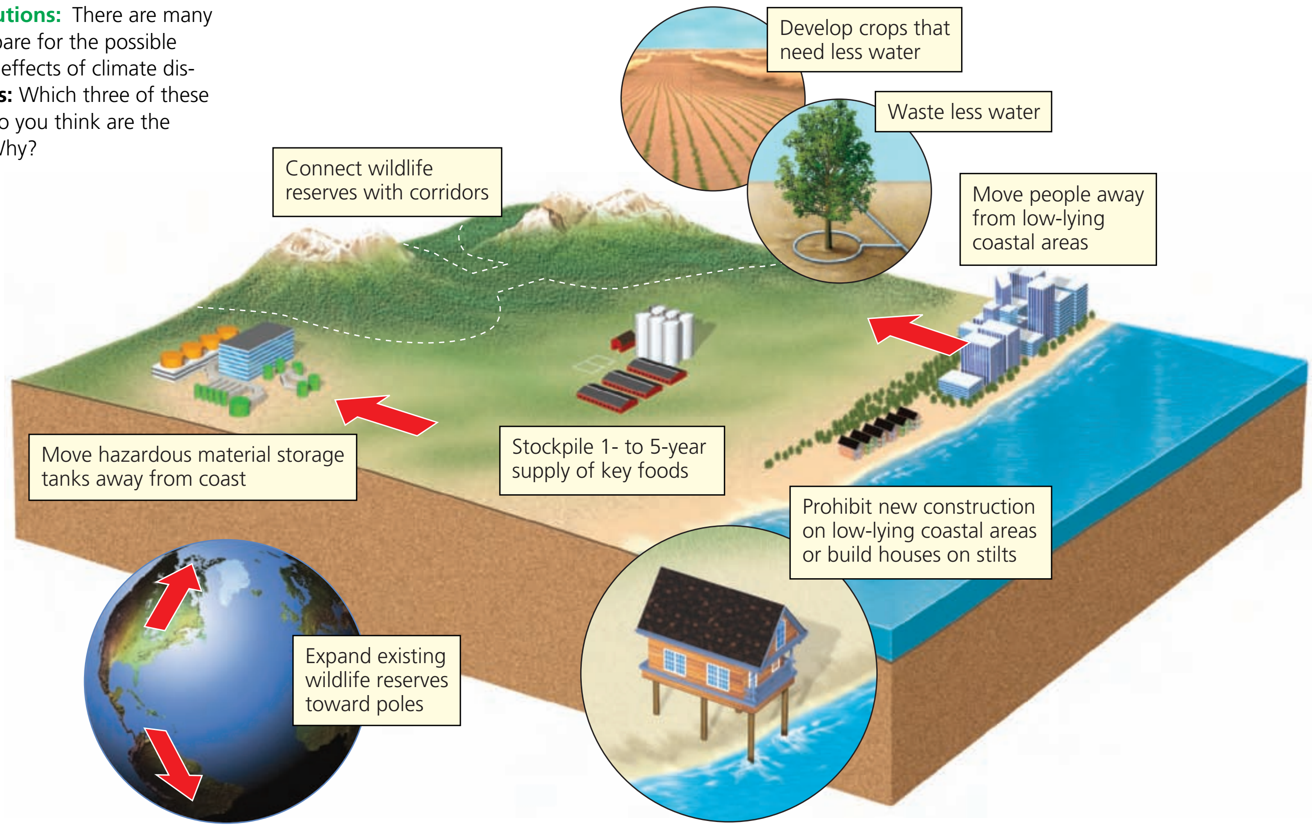


Figure 19-20 **Solutions:** There are many ways for us to prepare for the possible long-term harmful effects of climate disruption. **Questions:** Which three of these adaptation plans do you think are the most important? Why?

Some U.S. cities, including New York City, and Seattle, Washington, have developed adaptation plans, as have some states, including California, Alaska, Maryland, Washington, and Oregon. Alaska has plans to relocate coastal villages at risk from rising sea levels and storm surges. California is beefing up its forest firefighting capabilities and is proposing desalination plants to help relieve projected water shortages, which will worsen as some of its mountain glaciers melt. In addition, some coastal communities in the United States now require that new houses and other new construction be built high enough off of the ground to survive projected higher storm surges; others are prohibiting new construction in especially vulnerable areas.

Some people fear that emphasizing these adaptation approaches will distract us from the more urgent need to reduce greenhouse gas emissions. However, to some analysts, projected climate change is already such a serious threat that we have no alternative but to implement both prevention and adaptation strategies, and we have no time to lose in doing this on an emergency basis.

A No-Regrets Strategy

The threat of climate disruption pushes us to look for preventive solutions such as those listed in Figure 19-16. But suppose we had the ability to look into the future and, in doing so, we found that the climate models were wrong and that climate change was not a serious threat after all. Should we then return to the present and abandon the search for preventive solutions?

A number of climate and environmental scientists and economists say *no* to this question, and they call for us to begin implementing such changes now as a *no-regrets strategy*. They argue that actions such as those listed in Figure 19-16 lead to other very important environmental, health, and economic benefits.

For example, improving energy efficiency has numerous economic and environmental advantages (see Figure 16-3, p. 399). Burning fossil fuels, especially coal, also causes a great deal of air and water pollution. Thus, a sharp decrease in the use of fossil fuels will greatly reduce such pollution, which now harms or kills large numbers of people. Cutting coal use will also greatly reduce land disruption resulting from surface mining.

Because of such reductions in pollution, public health scientists argue that shifting from carbon-containing fossil fuels to a mix of low-carbon, cleaner renewable energy resources will make us healthier, overall. Also, countries that rely more on renewable domestic energy resources will cut their dependence on imports of fossil fuels and improve their national security.

In addition, sharply decreasing or halting the destruction of tropical forests would help to preserve the earth's increasingly threatened biodiversity. Ultimately, the world's ecosystems, our economies, and our personal well being depend on the biodiversity that makes up an important part of the earth's vital natural capital (see Figure 1-4, p. 9). Thus, leaving out any concerns about climate disruption, there are plenty of reasons for implementing a no-regrets strategy for sharply reducing carbon outputs on an urgent basis.

19-4 How Have We Depleted Ozone in the Stratosphere and What Can We Do about It?

▶ **CONCEPT 19-4A Our widespread use of certain chemicals has reduced ozone levels in the stratosphere, which has allowed more harmful ultraviolet radiation to reach the earth's surface.**

▶ **CONCEPT 19-4B To reverse ozone depletion, we must stop producing ozone-depleting chemicals and adhere to the international treaties that ban such chemicals.**

Our Use of Certain Chemicals Threatens the Ozone Layer

A layer of ozone in the lower stratosphere keeps about 95% of the sun's harmful ultraviolet (UV-A and UV-B) radiation from reaching the earth's surface (see Figure 18-3, p. 467). However, measurements taken by meteorologists show a considerable seasonal depletion (thinning) of ozone concentrations in the stratosphere above Antarctica and the Arctic. Similar measurements reveal a lower overall ozone thinning everywhere except over the tropics.

In 1984, researchers analyzing satellite data unexpectedly discovered that each year, 40–50% of the ozone in the upper stratosphere over Antarctica (100% in some places) disappears during October and November. This observed loss of ozone has been called an *ozone hole*. A more accurate term is *ozone thinning* because the ozone depletion varies with altitude and location. Figure 19-21 shows a colorized satellite image of ozone thinning over Antarctica in 2009.

When the seasonal thinning ends each year, huge masses of ozone-depleted air above Antarctica flow northward, and these masses linger for a few weeks over parts of Australia, New Zealand, South America, and South Africa. This raises biologically damaging UV-B levels in these areas by 3–10%, and in some years, by as much as 20%.

In 1988, scientists discovered that similar but usually less severe ozone thinning occurs over the Arctic from February to June, resulting in a typical ozone loss of 11–38% (compared to a typical 50% loss above Antarctica). When this mass of air above the Arctic breaks up each year, large masses of ozone-depleted air flow south to linger over parts of Europe, North America, and Asia.

Based on these measurements as well as mathematical and chemical models, the overwhelming consensus of researchers in this field is that ozone depletion in the stratosphere poses a serious threat to humans, other animals, and some primary producers (mostly plants) that use sunlight to support the earth's food webs (**Concept 19-4A**).

This problem began with the discovery of the first chlorofluorocarbon (CFC) in 1930. Chemists soon developed similar compounds to create a family of highly useful CFCs, known by their trade name of Freons. These chemically unreactive, odorless, nonflammable, nontoxic, and noncorrosive compounds seemed to be dream chemicals. Inexpensive to manufacture, they became popular as coolants in air conditioners and refrigerators, propellants in aerosol spray cans, cleaners for electronic parts such as computer chips, fumigants for granaries and ships' cargo holds, and as gases used to make insulation and packaging.

It turned out that CFCs were too good to be true. Starting in 1974 with the work of chemists Sherwood Rowland and Mario Molina (Individuals Matter, p. 522), scientists demonstrated that CFCs are persistent chemicals that destroy protective ozone in the stratosphere. Measurements and models indicate that 75–85% of the observed ozone losses in the stratosphere since 1976 resulted from people releasing CFCs and other ozone-

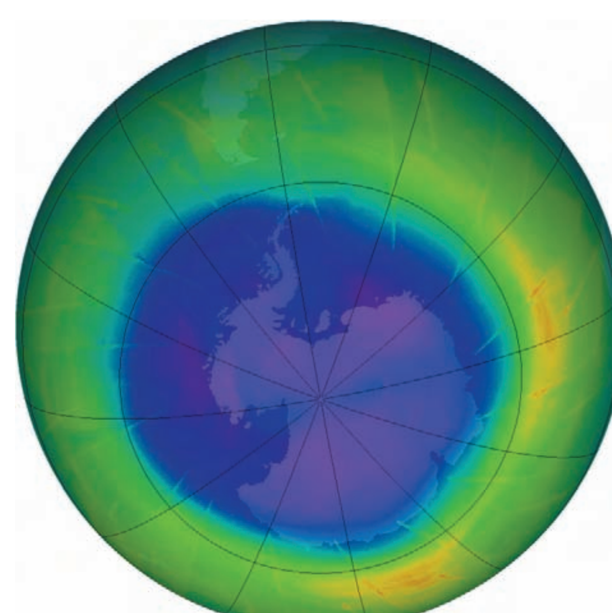


Figure 19-21 Natural capital degradation: This colorized satellite image shows massive ozone thinning over Antarctica during several months in 2009. The center of this image shows a large area where the concentration of ozone has decreased by 50% or more. (Data from NASA)

INDIVIDUALS MATTER

Sherwood Rowland and Mario Molina—A Scientific Story of Expertise, Courage, and Persistence

In 1974, calculations by chemists Sherwood Rowland and Mario Molina of the University of California–Irvine indicated that chlorofluorocarbons (CFCs) were lowering the average concentration of ozone in the stratosphere. Instead of remaining safely in their laboratories, these scientists decided that they had an ethical obligation to go public with the results of their research. They shocked both the scientific community and the \$28-billion-per-year CFC industry by calling for an immediate ban of CFCs in spray cans, for which substitutes were available.

The research done by these two scientists led them to four major conclusions. *First*, once injected into the atmosphere, these persistent CFCs remain there.

Second, over 11–20 years, these compounds rise into the stratosphere through convection, random drift, and the turbulent mixing of air in the lower atmosphere.

Third, once they reach the stratosphere, the CFC molecules break down under the influence of high-energy UV radiation. This releases highly reactive chlorine atoms (Cl), as well as atoms of fluorine (F) and bromine (Br), all of which accelerate the breakdown of ozone (O_3) into O_2 and O in a cyclic chain of chemical reactions. As a consequence, ozone is destroyed faster than it forms in some parts of the stratosphere.

Fourth, each CFC molecule can last in the stratosphere for 65–385 years, depending on its type. During that time, each chlorine atom released during the breakdown of CFC can convert hundreds of O_3 molecules to O_2.

The CFC industry (led by DuPont) was a powerful, well-funded adversary with a lot of profits and jobs at stake. It attacked Rowland's and Molina's calculations and conclusions. But the two researchers held their ground, expanded their research, and explained their results to other scientists, elected officials, and the media. After 14 years of delaying tactics, DuPont officials acknowledged in 1988 that CFCs were depleting the ozone layer, and they agreed to stop producing them and to sell higher-priced alternatives that their chemists had developed.

In 1995, Rowland and Molina received the Nobel Prize in chemistry for their work on CFCs. In awarding the prize, the Royal Swedish Academy of Sciences said that these two scientists contributed to "our salvation from a global environmental problem that could have had catastrophic consequences."

depleting chemicals into the atmosphere, beginning in the 1950s.

CFCs are not the only ozone-depleting chemicals. Others are *halons* and *hydrobromoflurocarbons* (*HBFCs*) (used in fire extinguishers), *methyl bromide* (a widely used fumigant), *hydrogen chloride* (emitted into the stratosphere by the U.S. space shuttles), and cleaning solvents such as *carbon tetrachloride, methyl chloroform, n-propyl bromide*, and *hexachlorobutadiene*.

Models indicate that the Arctic is unlikely to develop the large-scale ozone thinning found over the Antarctic. They also project that ozone depletion over the Antarctic and Arctic will be at its worst between 2010 and 2019.

Why Should We Worry about Ozone Depletion?

Why is ozone depletion something that should concern us? Figure 19-22 lists some of the expected effects of decreased ozone levels in the stratosphere. One effect is

Natural Capital Degradation

Effects of Ozone Depletion

Human Health

- Worse sunburns
- More eye cataracts and skin cancers
- Immune system suppression

Food and Forests

- Reduced yields for some crops
- Reduced seafood supplies from reduced phytoplankton
- Decreased forest productivity for UV-sensitive tree species

Climate Change

- While in troposphere, CFCs act as greenhouse gases

Wildlife

- Increased eye cataracts in some species
- Decreased populations of aquatic species sensitive to UV radiation
- Reduced populations of surface phytoplankton
- Disrupted aquatic food webs from reduced phytoplankton

Air Pollution and Materials

- Increased acid deposition
- Increased photochemical smog
- Degradation of outdoor paints and plastics

Figure 19-22 Decreased levels of ozone in the stratosphere can have a number of harmful effects. (**Concept 19-4A**). **Questions:** Which three of these effects do you think are the most threatening? Why?

What Can You Do?

Reducing Exposure to UV Radiation

- Stay out of the sun, especially between 10 A.M. and 3 P.M.
- Do not use tanning parlors or sunlamps.
- When in the sun, wear protective clothing and sunglasses that protect against UV-A and UV-B radiation.
- Be aware that overcast skies do not protect you.
- Do not expose yourself to the sun if you are taking antibiotics or birth control pills.
- When in the sun, use a sunscreen with a protection factor of at least 15.
- Examine your skin and scalp at least once a month for moles or warts that change in size, shape, or color and sores that do not heal. If you observe any of these signs, consult a doctor immediately.

Figure 19-23 **Individuals matter:** You can reduce your exposure to harmful UV radiation. **Question:** Which of these precautions do you already take?

that more biologically damaging UV-A and UV-B radiation will reach the earth's surface (**Concept 19-4A**). This will cause more eye cataracts, worse sunburns, and more skin cancers. **Explore More:** See a *Science Focus* at **www.cengage.com/login** to learn about skin cancers and their relationship to UV radiation.

GOOD NEWS

Figure 19-23 lists ways in which you can protect yourself from harmful UV radiation.

Another serious threat from ozone depletion is that the resulting increase in UV radiation could impair or destroy phytoplankton, especially in Antarctic waters (see Figure 3-13, p. 64). These tiny marine plants play a key role in removing CO_2 from the atmosphere. They also form the base of ocean food webs. Destroying them would eliminate the vital ecological services they provide. This could also accelerate projected atmospheric warming by reducing the ability of the oceans to remove CO_2 from the atmosphere—another example of disruption of the carbon cycle (Figure 3-19, p. 70). Projected climate change could make this problem worse by slowing down the upwelling of nutrients from deep ocean waters that feed these populations of phytoplankton. This in turn would accelerate climate change and lead to another runaway positive feedback loop (Figure 2-18, p. 49).

We Can Reverse Stratospheric Ozone Depletion

According to researchers in this field, we should immediately stop producing all ozone-depleting chemicals (**Concept 19-4B**). However, models indicate that even with immediate and sustained action, it will take about 60 years for the earth's ozone layer to recover the levels of ozone it had in 1980, and it could take about 100 years for recovery to pre-1950 levels.

CONNECTIONS

Atmospheric Warming and Repair of the Ozone Layer

Scientists from Johns Hopkins University reported in 2009 on their discovery that warming of the troposphere makes the stratosphere cooler, which slows down its rate of ozone repair. Thus, as the planet warms, ozone levels may take much longer to return to where they were before ozone thinning began, or they may never recover completely.

In 1987, representatives of 36 nations met in Montreal, Canada, and developed the *Montreal Protocol*. This treaty's goal was to cut emissions of CFCs (but not other ozone-depleting chemicals) by about 35% between 1989 and 2000. After hearing more bad news about seasonal ozone thinning above Antarctica in 1989, representatives of 93 countries had more meetings and in 1992 adopted the *Copenhagen Protocol*, an amendment that accelerated the phase-out of key ozone-depleting chemicals.

GOOD NEWS

The ozone protocols set an important precedent by using *prevention* to solve a serious environmental problem. Nations and companies agreed to work together to solve this global problem for three reasons. *First*, there was convincing and dramatic scientific evidence of a serious problem. *Second*, CFCs were produced by a small number of international companies and this meant there was less corporate resistance to finding a solution. *Third*, the certainty that CFC sales would decline over a period of years because of government bans unleashed the economic and creative resources of the private sector to find even more profitable substitute chemicals.

Substitutes are available for most uses of CFCs, and others are being developed. However, the most widely used substitutes are hydrofluorocarbons (HFCs), which act as greenhouse gases. An HFC molecule can be up to 10,000 times more potent in warming the atmosphere than a molecule of CO_2 is. Currently, HFCs account for only 2% of all greenhouse gas emissions, but the IPCC has warned that global use of HFCs is growing rapidly. In 2009, the U.S. government asked the UN to enact mandatory reductions in HFC emissions through the Montreal Protocol.

In addition, there is growing concern that the Montreal Protocol should also be used to regulate the greenhouse gas nitrous oxide (N_2O), which is released from fertilizers and livestock manure. It remains in the troposphere for about 100 years and then migrates to the stratosphere where it can also destroy ozone.

The landmark international agreements on stratospheric ozone, now signed by all 196 of the world's countries, are important examples of global cooperation in response to a serious global environmental problem. If nations continue to follow these agreements, ozone levels should return to 1980 levels by 2068 (18 years later than originally projected) and to 1950 levels by 2108 (**Concept 19-4B**).

Here are this chapter's *three big ideas:*

- Considerable scientific evidence indicates that the earth's atmosphere is warming, mostly because of human activities, and that this is likely to lead to significant climate disruption during this century that could have severe and long-lasting harmful consequences.
- Reducing the projected harmful effects of rapid climate disruption during this century requires emergency action to increase energy efficiency, sharply reduce greenhouse gas emissions, rely more on renewable energy resources, and slow population growth.
- We need to continue phasing out the use of chemicals that have reduced ozone levels in the stratosphere and allowed more harmful ultraviolet radiation to reach the earth's surface.

REVISITING Melting Ice in Greenland and Sustainability

CORE CASE STUDY

SUSTAINABILITY

In this chapter, we have seen that human activities such as the burning of fossil fuels and the widespread clearing and burning of forests for planting crops have contributed to higher levels of greenhouse gases in the atmosphere. This has added to increased atmospheric warming, which in turn is projected to result in climate disruption during this century. The effects of this disruption include rapid and increased melting of land-based ice (**Core Case Study**) and sea ice, worsening drought, rising sea levels, and declining biodiversity. Many of these effects become part of positive feedback loops, which further accelerate climate disruption. We have also seen how the widespread use of certain chemicals has thinned the stratospheric ozone layer, which has led to plant and animal health problems.

We can apply the three **principles of sustainability** (see back cover) to help reduce the harmful effects of projected climate disruption and stratospheric ozone depletion. We can reduce inputs of greenhouse gases and ozone-depleting chemicals into the atmosphere by relying more on direct and indirect forms of solar energy than on fossils fuels; reducing the waste of matter and energy resources and recycling and reusing matter resources; and mimicking biodiversity by using a variety of low-carbon renewable energy resources in place of fossil fuels. We can enhance these strategies by finding substitutes for ozone-depleting chemicals, emphasizing pollution prevention, and reducing human population growth.

People who say it cannot be done should not interrupt those who are doing it.

GEORGE BERNARD SHAW

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 493. Describe how Greenland's melting glaciers (**Core Case Study**) provide evidence that climate disruption is occurring as projected, according to most climate scientists. CORE CASE STUDY

2. Explain why weather and climate are not the same. What are the differences between them? Describe atmospheric warming and cooling over the past 900,000 years and during the last century. How do scientists get information about past temperatures and climates? What is the greenhouse effect and why is it so important to life on the earth? How have human activities affected atmospheric greenhouse gas levels during the last 275 years and especially in the last 30 years? List the major human activities that add CO_2, CH_4 and N_2O to the atmosphere.

3. After studying past climate change and the nature of the earth's climate system for almost three decades, what two general conclusions did most of the world's climate scientists agree on about atmospheric warming over the past 30 years? How did scientists arrive at these two general conclusions, and why was this such a rare event? How do scientists use models to make projections about future temperature changes? What do a number of climate models project about temperature changes during this century? How can positive feedback loops affect future temperature changes and thus global climate? Give two examples of such loops. Describe the roles that climate scientist James Hansen has played in improving our understanding of climate and projected climate disruption. Describe the contribution of waste heat from energy-conversion devices to projected climate disruption.

4. Describe how each of the following might contribute to projected atmospheric warming and resulting global climate disruption: **(a)** CO_2 emissions, **(b)** a hotter sun, **(c)** the oceans, **(d)** cloud cover, and **(e)** air pollution. What are three effects of increasing atmospheric CO_2 levels on the oceans?

5. Briefly describe how projected climate disruption is likely to affect: **(a)** drought, **(b)** ice cover, **(c)** permafrost, **(d)** sea levels, **(e)** extreme weather, **(f)** biodiversity, **(g)** crop yields, and **(h)** human health during this century. Pick three of these factors and describe how each can become part of a positive feedback loop leading to climate disruption.

6. List seven examples of **climate tipping points** that we could be approaching. What are five factors that make it difficult to deal with the problem of projected climate disruption? Describe the interactions among science, politics, and climate. Describe John Sterman's bathtub analogy as it applies to CO_2 emissions. What are three major prevention strategies and three major cleanup strategies for dealing with projected climate disruption? What is **carbon capture and storage (CCS)**? Describe three problems associated with capturing and storing carbon dioxide emissions. What are geoengineering schemes (give two examples) and what is the major problem with most of them?

7. List six steps that governments could take to help slow projected climate disruption. What is a pollutant and why is CO_2 being classified as a pollutant? What are the advantages and disadvantages of using taxes on carbon emissions or energy use to help reduce greenhouse gas emissions? What is cap-and-trade and what are the advantages and disadvantages of using it to help reduce greenhouse gas emissions? What are the pros and cons of developing an international treaty to help deal with the threat of projected climate disruption? What is the U.S. city of Portland, Oregon, doing to help reduce its greenhouse gas emissions? What is China doing to help reduce its contribution to the climate disruption? What is the United Sates doing to help reduce its contribution to this problem?

8. Give two examples of what some major corporations have done and two examples of what some schools have done to reduce their carbon footprints. List five ways in which you can reduce your carbon footprint. List five ways in which we can prepare for the possible long-term harmful effects of climate disruption. Describe the no-regrets strategy for dealing with the problems associated with energy waste and fossil fuel use, regardless of climate change.

9. Describe how human activities have depleted ozone in the stratosphere, and list five harmful effects of such depletion. How did scientists Sherwood Roland and Mario Molina help to awaken the world to this threat? What has the world done to reduce the threat from ozone depletion in the stratosphere? How are the problems of atmospheric warming and ozone depletion connected?

10. What are this chapter's *three big ideas?* Describe how we can apply the three **principles of sustainability** to the problems of projected climate disruption (**Core Case Study**) and ozone depletion.

SUSTAINABILITY

CORE CASE STUDY

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. If you had convincing evidence that at least half of Greenland's glaciers (**Core Case Study**) were sure to melt during this century, would you argue for taking serious actions now to slow projected climate disruption? If so, summarize the arguments you would use. If not, explain why you would be opposed to such actions.

CORE CASE STUDY

2. A top U.S. economic adviser to the president once gave a speech in Williamsburg, Virginia (USA), to representatives of governments from a number of countries. He told his audience not to worry about atmospheric warming because the average global temperature increases predicted by scientists were much less than the temperature increase he had experienced that day in traveling from Washington, DC, to nearby Williamsburg. What was the flaw in his reasoning? Write an argument that you could use to counter his claim.

3. How might the earth's climate change if the land area of the planet were larger than its ocean area?

4. List three ways in which you could apply **Concept 19-3** to making your lifestyle more environmentally sustainable.

5. Explain why you would support or oppose each of the strategies listed in Figure 19-16 for slowing projected climate disruption caused by atmospheric warming.

6. What changes might occur in **(a)** the global hydrologic cycle (see Figure 3-16, p. 67) and **(b)** the global carbon cycle (see Figure 3-19, p. 70) if the atmosphere experiences significant warming? Explain.

7. One way to slow the rate of CO_2 emissions is to reduce the clearing of forests—especially in less-developed tropical countries where intense deforestation is taking place. Should the United States and other more-developed countries pay poorer countries to stop cutting their forests? Explain.

8. What are three consumption patterns or other aspects of your lifestyle that directly add greenhouse gases to the

atmosphere? Which, if any, of these habits would you be willing to give up in order to help slow projected climate disruption?

9. Congratulations! You are in charge of the world. List your three most important strategies for dealing with the problems of **(a)** climate disruption due to atmospheric warming caused mostly by human activities, and **(b)** depletion of ozone in the stratosphere.

10. List two questions that you would like to have answered as a result of reading this chapter.

ECOLOGICAL FOOTPRINT ANALYSIS

Largely because of the intense use of fossil fuels, per capita CO_2 emissions for the United States are more than four times the world average. According to a recent report from the International Energy Agency, the average American is responsible for adding 19.6 metric tons (21.6 tons) of CO_2 per year to the atmosphere, compared with a world average of 4.23 metric tons (4.65 tons). The table below is designed to help you understand the sources of your personal inputs of CO_2 into the atmosphere and how you can reduce them. You will be making calculations to fill in the blanks in this table.

Some typical numbers are provided in the "Typical Quantity per Year" column of the table. However, your calculations will be more accurate if, in place of those typical values, you can substitute information based on your own personal lifestyle, which you can enter in the blank "Personal Quantity" column. For example, you could add up your monthly utility bills for a year and divide the total by the number of persons in your household to determine your own utility use, and you could analyze your driving habits to determine how much fuel you use in your vehicle if you own one. When you are finished with this exercise, you can check your results against those you would get by using the greenhouse gas emissions calculator provided on the Web by the EPA at **www.epa.gov/climatechange/emissions/ind_calculator.html**. Also, compare your results with those of your classmates.

	Units per Year	Personal Quantity per Year	Typical Quantity per Year	Multiplier	Emissions per Year (lbs. CO_2)
Residential Utilities					
Electricity	kwh		4,500	1.5	
Heating oil	gallons		37	22	
Natural gas	hundreds of cubic feet (ccf)		400	12	
Propane	gallons		8	13	
Coal	tons		–	4,200	
Transportation					
Automobiles	gallons		600	19	
Air travel	miles		2,000	0.6	
Bus, urban	miles		12	0.07	
Bus, intercity	miles		0	0.2	
Rail or subway	miles		28	0.6	
Taxi or limousine	miles		2	1	
Other motor fuel	gallons		9	22	
Household Waste					
Trash	pounds		780	0.75	
Recycled Items	pounds		337	–2	
				Total (pounds)	
				Total (tons)	
				Total (kilograms)	
				Total (metric tons)	

Source: Thomas B. Cobb at Ohio's Bowling Green State University developed this CO_2 calculator.

1. Calculate your carbon footprint. To calculate your emissions, first complete the blank "Personal Quantity" column as described above. If your information is not available, use the data listed in the "Typical Quantity per Year" column. Then, for each activity, calculate your annual consumption (using the units specified in the "Units per Year" column), and multiply your annual consumption by the associated number in the "Multiplier" column to obtain an estimate of the pounds of CO_2 resulting from that activity, which you will enter in the "Emissions per Year" column. Finally, add the numbers in that column to find your carbon footprint, and express the final CO_2 result in both pounds and tons (1 ton = 2,000 lbs) and in kilograms and metric tons (1 kilogram = 2.2 pounds; 1 metric ton = 1.1 tons).
2. Compare your emissions with those of your classmates and with the per capita U.S. average of 19.6 metric tons (21.6 tons) of CO_2 per person per year. (Actually, your answer should be considerably less—roughly about half the per capita value—because this computation only accounts for direct emissions. For instance, CO_2 resulting from driving a car is included, but the CO_2 emitted in manufacturing or disposing of the car is not.)
3. Consider and list actions you could take to reduce your carbon footprint by 20%.

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengagebrain.com/shop/ISBN/0538735341** and choose Chapter 19 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

For students with access to premium online resources, log on to **www.cengage.com/login**.

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20 Water Pollution

CORE CASE STUDY Lake Washington

The U.S. city of Seattle, Washington, was founded on the western shore of Puget Sound (Figure 20-1). In the early 20th century, it grew and expanded eastward toward Lake Washington, a freshwater lake that became a popular recreation site for its citizens.

The lake also became attractive to growing suburban municipal governments as a place to dispose of wastewater. By the mid-1950s, Seattle's suburbs surrounded the lake, and ten sewage treatment plants were operating near its shores, dumping huge amounts of treated wastewater into the lake every day. In 1955, researchers working with the late Dr. W.T. Edmondson of the University of Washington discovered the presence in the lake of a species of cyanobacteria, commonly called *blue-green algae*.

Masses of these algae quickly grew and darkened the lake's waters. Dead algae accumulated on the lakeshores where they rotted and fouled the air. The water became cloudy and populations of desirable fish species declined. Edmondson, who spent decades studying the biochemistry of Lake Washington, hypothesized that the chief nutrient feeding the algae was phosphorus coming from the area's sewage treatment plants.

Edmondson and his colleagues wrote a technical paper for sewage treatment plant managers to read but did not get much attention from these officials. So Edmondson and his team wrote letters and articles to educate the general public about the nature of Lake Washington's pollution and its likely sources.

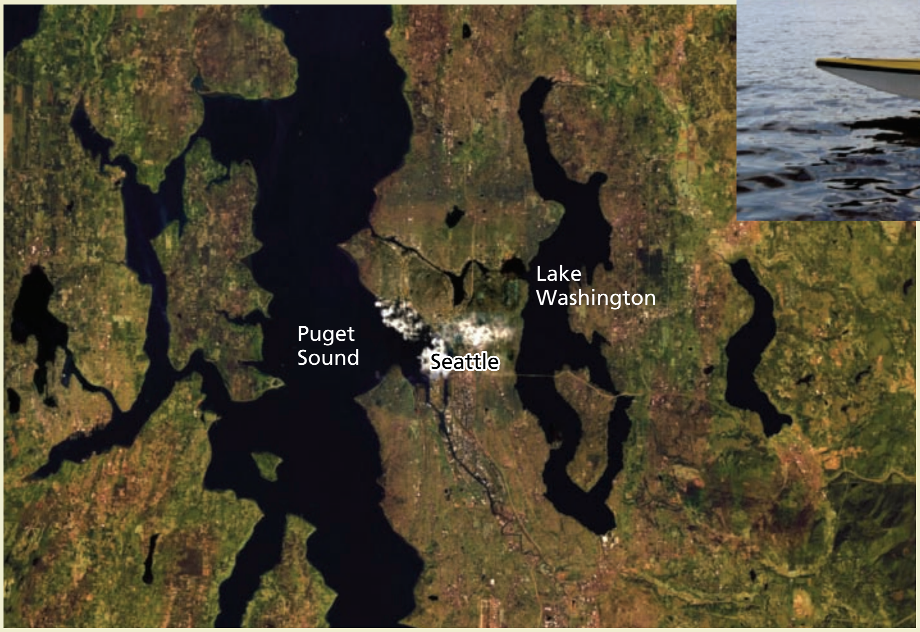
GOOD NEWS

The researchers' public education efforts paid off. Within 3 years, citizen pressure on elected officials led to the development of a scheme to divert nutrient-rich effluents from Seattle's sewage treatment plants into the nearby Puget Sound (Figure 20-1), where tides would mix and dilute them with ocean water. This diversion was completed by 1968, and by 1976, the blue-green algae were virtually gone from Lake Washington. The clarity of the lake water improved dramatically, fish populations in the lake recovered, and recreationists returned to the lake (Figure 20-2).

However, with the increasing popularity of the Seattle area, the human population has steadily grown. This is posing new challenges to the lake and to the sound, as we discuss throughout this chapter.

Lee Foster/Bruce Coleman USA

Figure 20-2 With the city of Seattle in the background, this kayaker enjoys the waters of Lake Washington. The once badly polluted lake has recovered, but population pressures and the resulting wastes are threatening it again.



NASA

Figure 20-1 The U.S. city of Seattle, Washington, was founded on the shore of Puget Sound and quickly expanded eastward toward Lake Washington.

Key Questions and Concepts

20-1 What are the causes and effects of water pollution?

CONCEPT 20-1A Water pollution causes illness and death in humans and other species, and disrupts ecosystems.

CONCEPT 20-1B The chief sources of water pollution are agricultural activities, industrial facilities, and mining, but growth in population and resource use makes it increasingly worse.

20-2 What are the major water pollution problems in streams and lakes?

CONCEPT 20-2A Streams and rivers around the world are extensively polluted, but they can cleanse themselves of many pollutants if we do not overload them or reduce their flows.

CONCEPT 20-2B The addition of excessive nutrients to lakes resulting from human activities can disrupt their ecosystems, and prevention of such pollution is more effective and less costly than cleaning it up.

20-3 What are the major pollution problems affecting groundwater and other drinking water sources?

CONCEPT 20-3A Chemicals used in agriculture, industry, transportation, and homes can spill and leak into groundwater and make it undrinkable.

CONCEPT 20-3B There are both simple and complex ways to purify groundwater used as a source of drinking water, but protecting it through pollution prevention is the least expensive and most effective strategy.

20-4 What are the major water pollution problems affecting oceans?

CONCEPT 20-4A The great majority of ocean pollution originates on land and includes oil and other toxic chemicals as well as solid waste, which threaten fish and wildlife and disrupt marine ecosystems.

CONCEPT 20-4B The key to protecting the oceans is to reduce the flow of pollution from land and air and from streams emptying into ocean waters.

20-5 How can we best deal with water pollution?

CONCEPT 20-5 Reducing water pollution requires that we prevent it, work with nature to treat sewage, cut resource use and waste, reduce poverty, and slow population growth.

Note: Supplements 2 (p. S3) and 6 (p. S20) can be used with this chapter.

Today everybody is downwind or downstream from somebody else.

WILLIAM RUCKELSHAUS

20-1 What Are the Causes and Effects of Water Pollution?

▶ **CONCEPT 20-1A Water pollution causes illness and death in humans and other species, and disrupts ecosystems.**

▶ **CONCEPT 20-1B The chief sources of water pollution are agricultural activities, industrial facilities, and mining, but growth in population and resource use makes it increasingly worse.**

Water Pollution Comes from Point and Nonpoint Sources

Water pollution is any change in water quality that can harm living organisms or make the water unfit for human uses such as irrigation and recreation. It usually involves contamination by one or more chemicals or excessive heat (thermal pollution).

Water pollution can come from a single (point) source, or from a larger, more dispersed (nonpoint) source. **Point sources** discharge pollutants into bodies of surface water at specific locations through drain pipes (Figure 20-3, p. 530), ditches, or sewer lines. Examples include factories, sewage treatment plants (which remove some, but not all, pollutants), underground mines, and oil tankers.

Because point sources are located at specific places, they are fairly easy to identify, monitor, and regulate. Most of the world's more-developed countries have laws that help control point-source discharges of harmful chemicals into aquatic systems. In most of the less-developed countries, there is little control of such discharges.

GOOD NEWS

Nonpoint sources are broad and diffuse areas, rather than points, from which pollutants enter bodies of surface water or air. Examples include runoff of

age fotostock/SuperStock

Figure 20-3 This point-source water pollution flows uncontrolled into a stream near Gargas, France.

chemicals and sediments from cropland (Figure 20-4), livestock feedlots, logged forests, urban streets, parking lots, lawns, and golf courses. We have made little progress in controlling water pollution from nonpoint sources because of the difficulty and expense of identifying and controlling discharges from so many diffuse sources.

Agricultural activities are by far the leading cause of water pollution. Sediment eroded from agricultural lands (Figure 20-4) is the most common pollutant. Other major agricultural pollutants include fertilizers and pesticides, bacteria from livestock and food-processing wastes, and excess salts from soils of irrigated cropland.

Industrial facilities, which emit a variety of harmful inorganic and organic chemicals, are a second major source of water pollution. A growing problem of great concern is that of coal ash, an indestructible waste created by the burning of coal in power plants. Some power utilities store the ash on land in slurry ponds that can leak and pollute nearby bodies of water (see Case Study, Chapter 15, p. 384). Other utilities dump the toxic ash and associated wastewater into nearby lakes and rivers. In addition, some oil and natural gas drilling operations inject large volumes of water at high pressure into shale rock deposits to release trapped natural gas or oil. This process can contaminate aquifers that are used as sources of drinking water with various chemicals.

CONNECTIONS

Cleaning Up the Air and Polluting the Water

Stricter air pollution control laws (see Chapter 18, pp. 485–486) have forced coal-burning power plants to remove many of the harmful gases and particulates from their smokestack emissions. But because of the law of conservation of matter (see Chapter 2, p. 43), we cannot create or destroy matter. All we can do is change it from one physical or chemical form to another or move it from one part of the environment to another, as we do when we take ash and wastewater from coal burning and place them in slurry ponds. Thus, the problem of coal ash illustrates one way in which air and water pollution are connected.

Tim McCabe/Natural Resources Conservation Service

Figure 20-4 Nonpoint sediment pollution eroded from farmland flows into streams and sometimes changes their courses or dams them up. As measured by weight, it is the largest source of water pollution. **Question:** What do you think the owner of this farm could have done to prevent such sediment pollution?

Mining is the third biggest source of water pollution. Surface mining disturbs the land (Figure 14-16, p. 358 and Figure 14-17, p. 359), creating major erosion of sediments and runoff of toxic chemicals. (See *The Habitable Planet*, Video 6 at **www.learner.org/resources/series209.html** for a discussion of how scientists measure water pollution from toxic heavy metals found in mining wastes and abandoned underground mines.) Wastes from existing and abandoned mines can also pollute streams and lakes (Figure 20-5).

Another form of water pollution is caused by the widespread use of human-made materials such as plastics that make up millions of products, all of which eventually end up in the environment. The polymers that make up the plastics break down very slowly and, in the process, pollute many waterways and the oceans where they have been improperly discarded (Figure 20-6). Plastic products can also harm various forms of wildlife (see Figure 11-6, p. 256).

Jose AS Reyes/Shutterstock

Figure 20-5 The water in this lake is polluted with mining wastes.

CONNECTIONS

Atmospheric Warming and Water Pollution

Projected climate disruption from atmospheric warming will likely contribute to water pollution in some areas of the globe. In a warmer world, some regions will get more precipitation and other areas will get less. More intense downpours will flush more harmful chemicals, plant nutrients, and microorganisms into waterways. Prolonged drought will reduce river flows that dilute wastes.

Major Water Pollutants Have Harmful Effects

Table 20-1 (p. 532) lists the major types of water pollutants along with examples of each and their harmful effects and sources (**Concept 20-1A**). The Science Focus on page 533 describes some methods that scientists and public health officials use to test water for pollutants.

Stéphane Bidouze/Shutterstock

Figure 20-6 Plastics and other forms of waste pollute this mountain lake as well as many bodies of water around the world, and can release harmful chemicals into the water.

Table 20-1 Major Water Pollutants and Their Sources

Type/*Effects*	Examples	Major Sources
Infectious agents (pathogens) *Cause diseases*	Bacteria, viruses, protozoa, parasites	Human and animal wastes
Oxygen-demanding wastes *Deplete dissolved oxygen needed by aquatic species*	Biodegradable animal wastes and plant debris	Sewage, animal feedlots, food-processing facilities, paper mills
Plant nutrients *Cause excessive growth of algae and other species*	Nitrates (NO_3^-) and phosphates (PO_4^{3-})	Sewage, animal wastes, inorganic fertilizers
Organic chemicals *Add toxins to aquatic systems*	Oil, gasoline, plastics, pesticides, fertilizers, cleaning solvents	Industry, farms, households, mining sites, runoff from streets and parking lots
Inorganic chemicals *Add toxins to aquatic systems*	Acids, bases, salts, metal compounds	Industry, households, mining sites, runoff from streets and parking lots
Sediments *Disrupt photosynthesis, food webs, other processes*	Soil, silt	Land erosion from farms and construction and mining sites
Heavy metals *Cause cancer, disrupt immune and endocrine systems*	Lead, mercury, arsenic	Unlined landfills, household chemicals, mining refuse, industrial discharges
Thermal *Make some species vulnerable to disease*	Heat	Electric power and industrial plants

One of the major water pollution problems that we face is exposure to infectious disease organisms through drinking water contaminated with human and animal wastes. Table 20-2 lists some common diseases that can be transmitted to humans through contaminated drinking water (**Concept 20-1A**). Cleaning up water supplies has helped to control some of these diseases.

In 2010, the United Nations reported that each year, unsafe water kills more people than war and all other forms of violence combined. The World Health Organization (WHO) estimates that almost 1 billion people—almost one of every seven in the world—do not have access to clean drinking water. As a result, the WHO has estimated, more than 1.6 million people die every year from largely preventable waterborne infectious diseases that they get by drinking contaminated water or by not having enough clean water for adequate hygiene. This adds up to an average of nearly 4,400 premature deaths a day, 90% of them in children younger than age 5. Diarrhea alone, caused mostly by exposure to polluted water, kills a child under the age of 5 every 18 seconds, on average.

Table 20-2 Common Diseases Transmitted to Humans through Contaminated Drinking Water

Type of Organism	Disease	Effects
Bacteria	Typhoid fever	Diarrhea, severe vomiting, enlarged spleen, inflamed intestine; often fatal if untreated
	Cholera	Diarrhea, severe vomiting, dehydration; often fatal if untreated
	Bacterial dysentery	Diarrhea, bleeding; rarely fatal except in infants without proper treatment
	Enteritis	Severe stomach pain, nausea, vomiting; rarely fatal
Viruses	Infectious hepatitis (Type B)	Fever, severe headache, loss of appetite, abdominal pain, jaundice, enlarged liver; rarely fatal but may cause permanent liver damage
	Poliomyelitis	Fever, diarrhea, backache, sore throat, aches in limbs; can infect spinal chord and cause paralysis and muscle weakness
Parasitic protozoa	Amoebic dysentery	Severe diarrhea, headache, abdominal pain, chills, fever; if not treated can cause liver abscess, bowel perforation, and death
	Giardiasis	Diarrhea, abdominal cramps, flatulence, belching, fatigue
	Cryptosporidium	Severe diarrhea, cramps for up to 3 weeks, and possible death for people with weakened immune systems
Parasitic worms	Schistosomiasis	Abdominal pain, skin rash, anemia, chronic fatigue, and chronic general ill health
	Ancylostomiasis	Severe anemia and possible symptoms of bronchial infection

SCIENCE FOCUS

Testing Water for Pollutants

Scientists use a variety of methods to measure water quality. For example, Dr. Edmondson and his students tested samples of water from Lake Washington (**Core Case Study**) for the presence of various infectious agents such as certain strains of the coliform bacteria *Escherichia coli*, or *E. coli*, which live in the colons and intestines of humans and other animals and thus are present in their fecal wastes. Although most strains of coliform bacteria do not cause disease, their presence indicates that sampled water has been contaminated by human or animal wastes that are likely to contain disease-causing agents.

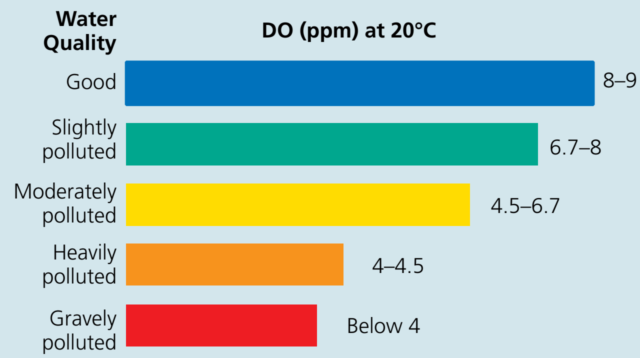


Figure 20-A Scientists measure dissolved oxygen (DO) content in parts per million (ppm) at 20°C (68°F) as an indicator of water quality. Only a few fish species can survive in water with less than 4 ppm of dissolved oxygen at this temperature. Some warm-water species have evolved ways to tolerate low DO levels better than most cold-water species can. **Question:** Would you expect the dissolved oxygen content of polluted water to increase or decrease if the water is heated? Explain.

To be considered safe for drinking, a 100-milliliter (about 1/2 cup) sample of water should contain no colonies of coliform bacteria. To be considered safe for swimming, such a water sample should contain no more than 200 colonies of coliform bacteria. By contrast, a similar sample of raw sewage may contain several million coliform bacterial colonies.

Another indicator of water quality is its *level of dissolved oxygen* (DO). Excessive inputs of oxygen-demanding wastes can deplete DO levels in water. Figure 20-A shows the relationship between dissolved oxygen content and water quality.

Scientists can use *chemical analysis* to determine the presence and concentrations of specific organic chemicals in polluted water. They can also monitor water pollution by using living organisms as *indicator species.* For example, they remove aquatic plants such as cattails from areas contaminated with fuels, solvents, and other organic chemicals, and analyze them to determine the exact pollutants contained in their tissues. Scientists also determine water quality by analyzing bottom-dwelling species such as mussels, which feed by filtering water through their bodies.

Genetic engineers are working to develop bacteria and yeasts (single-celled fungi) that glow in the presence of specific pollutants such as toxic heavy metals in the ocean, toxins in the air, and carcinogens in food.

Scientists measure the amount of sediment in polluted water by evaporating the water in a sample and weighing the resulting sediment. They also use instruments called colorimeters, which measure specific wavelengths of light shined through a water sample to determine the concentrations of pollutants in the water, and turbidimeters to measure the *turbidity*, or cloudiness, of water samples containing sediment.

The technology for testing waters is evolving. For example, in 2010, researchers in Spain used five robot fish, each one about as long as a seal, to detect potentially hazardous pollutants in a river.

Critical Thinking

Runoff of fertilizer into a lake such as Lake Washington (**Core Case Study**) from farmland, lawns, and sewage treatment plants can overload the water with nitrogen and phosphorus—plant nutrients that can cause algae population explosions. How could this lower the dissolved oxygen level of the water and lead to fish kills?

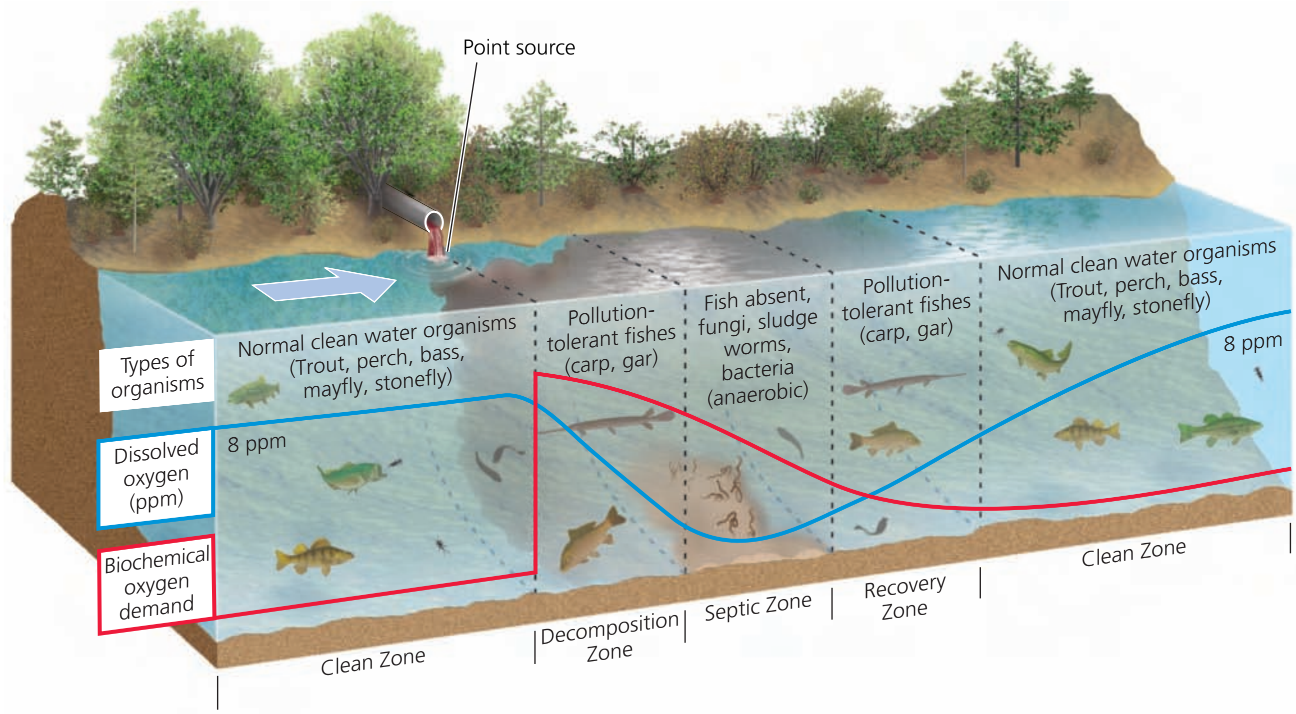
20-2 What Are the Major Water Pollution Problems in Streams and Lakes?

▶ **CONCEPT 20-2A Streams and rivers around the world are extensively polluted, but they can cleanse themselves of many pollutants if we do not overload them or reduce their flows.**

▶ **CONCEPT 20-2B The addition of excessive nutrients to lakes resulting from human activities can disrupt their ecosystems, and prevention of such pollution is more effective and less costly than cleaning it up.**

Streams Can Cleanse Themselves, If We Do Not Overload Them

Flowing rivers and streams can recover rapidly from moderate levels of degradable, oxygen-demanding wastes through a combination of dilution and bacterial breakdown of such wastes. But this process does not work when streams become overloaded with such pollutants or when drought, damming, or water diversion reduce their flows (**Concept 20-2A**). While this process can remove biodegradable wastes, it does not eliminate slowly degrading or nondegradable wastes.



CENGAGENOW™ **Active Figure 20-7** **Natural capital:** A stream can dilute and decay degradable, oxygen-demanding wastes, and it can also dilute heated water. This figure shows the oxygen sag curve (blue) and the curve of oxygen demand (red). Depending on flow rates and the amount of biodegradable pollutants, streams recover from oxygen-demanding wastes and from the injection of heated water if they are given enough time and are not overloaded (**Concept 20-2A**). *See an animation based on this figure at* CengageNOW™. **Question:** What would be the effect of putting another discharge pipe emitting biodegradable waste to the right of the one in this picture?

In a flowing stream, the breakdown of biodegradable wastes by bacteria depletes dissolved oxygen and creates an *oxygen sag curve* (Figure 20-7). This reduces or eliminates populations of organisms with high oxygen requirements until the stream is cleansed of oxygen-demanding wastes. We can plot a similar oxygen sag curve when heated water from an industrial or power plant is discharged into a stream, because heating water decreases its level of dissolved oxygen.

CENGAGENOW™ Learn more about how pollution affects the water in a stream and the creatures living there at CengageNOW.

Stream Pollution in More Developed Countries

Laws enacted in the 1970s to control water pollution have greatly increased the number and quality of wastewater treatment plants in the United States and in most other more-developed countries. Such laws also require industries to reduce or eliminate their point-source discharges of harmful chemicals into surface waters. This has enabled the United States to hold the line against increased pollution by disease-causing agents and oxygen-demanding wastes in most of its streams. This is an impressive accomplishment given the country's increased economic activity, resource consumption, and population growth since passage of these laws.

GOOD NEWS

One success story is the cleanup of the U.S. state of Ohio's Cuyahoga River. It was so polluted that it caught fire several times and, in 1969, was photographed while burning as it flowed through the city of Cleveland toward Lake Erie, one of the Great Lakes. The highly publicized image of this combustible river prompted elected officials to enact laws that limited the discharge of industrial wastes into the river and into local sewage systems, and provided funds to upgrade sewage treatment facilities. Today, the river is cleaner, no longer flammable, and is widely used by boaters and anglers. This accomplishment illustrates the power of bottom-up pressure by citizens, who prodded elected officials to change a severely polluted river into an economically and ecologically valuable public resource.

GOOD NEWS

Another spectacular cleanup occurred in Great Britain. In the 1950s, the Thames River was little more than a flowing, smelly sewer. Now, after 50 years of effort and large inputs of money from British taxpayers and private industry, the Thames has made a remarkable recovery. Commercial fishing is thriving and the number of fish species in the river has increased 20-fold since 1960. In addition, many species of waterfowl and wading birds have returned to their former feeding grounds along the banks of the Thames.

Fish kills and drinking water contamination still occur occasionally in some of the rivers and lakes of more-developed countries. Some of these problems are caused by the accidental or deliberate release of toxic inorganic or organic chemicals by industries and mining operations (see Figure 14-1, p. 346, and Figure 20-5). Another cause is malfunctioning sewage treatment plants. A third cause is nonpoint runoff of pesticides and excess plant nutrients from cropland and animal feedlots.

However, streams can recover from some forms of pollution if given the chance (**Concept 20-2A**). *Stream restoration*, or recovery aided by cleanup efforts, can be done on a large scale, as in the cases of the Cuyahoga and the Thames, or on a smaller scale, as in the case of Hamm Creek (Individuals Matter, below).

Global Outlook: Stream Pollution in Less-Developed Countries

In most less-developed countries, stream pollution from discharges of untreated sewage and industrial wastes is a serious and growing problem.

According to the World Commission on Water in the 21st Century, half of the world's 500 major rivers are heavily polluted, and most of these polluted waterways run through less-developed countries. A majority of these countries cannot afford to build waste treatment plants and do not have, or do not enforce, laws for controlling water pollution. According to the Global Water Policy Project, most cities in less-developed countries discharge 80–90% of their untreated sewage directly into rivers, streams, and lakes whose waters are then used for drinking, bathing, and washing clothes.

Industrial wastes and sewage pollute more than two-thirds of India's water resources and 54 of the 78 rivers and streams monitored in China (Figure 20-8). According to a 2007 report by Chinese officials, more than half of China's 1.3 billion people live without any form of sewage treatment. In addition, 300 million Chinese do not have access to clean drinking water. In Latin America and Africa, most streams passing through

Zhao Weiming/UNEP/Peter Arnold, Inc.

Figure 20-8 **Natural capital degradation:** This highly polluted river in central China has been turned greenish-black by uncontrolled pollution from thousands of factories. In some parts of China, river water is too toxic to touch, much less drink. The cleanup and modernization of Chinese cities such as Beijing and Shanghai are forcing polluting refineries and factories to move to rural areas where two-thirds of China's population resides. Liver and stomach cancers, linked in some cases to water pollution, are among the leading causes of death in the countryside. Farmers too poor to buy bottled water must often drink polluted well water.

INDIVIDUALS MATTER

John Beal Planted Trees to Restore a Stream

In 1980, John Beal, an engineer with the Boeing Company, was told that he had only a few months to live because of severe heart problems. To help prolong his life, he began taking daily walks. His strolls took him by Hamm Creek, a small stream that flows from the hills southwest of Seattle, Washington (USA), into the Duwamish River, which empties into Puget Sound (Figure 20-1). CORE CASE STUDY He remembered when the stream was a spawning ground for salmon and when evergreen trees lined its banks. By 1980, the polluted stream had no fish and the trees were gone.

Beal decided to spend his last days doing something good by helping to clean up Hamm Creek. He persuaded some companies to stop polluting the creek, and he hauled out many truckloads of trash, including items such as discarded washing machines and truck tires. Then he began a 15-year project of planting thousands of trees along the stream's banks. He also restored natural waterfalls and ponds that had served as salmon spawning beds.

At first, he worked alone and many people thought he was crazy. But word spread and volunteers began to join him. Television news reports and newspaper articles about the restoration project brought hundreds of volunteers and schoolchildren.

The creek's water now runs clear, its vegetation has been restored, and salmon have returned to spawn. Until his death in 2006—27 years after doctors gave him only months to live—his reward was the personal satisfaction he felt about making a difference for Hamm Creek and his community. He also won more than 40 awards for his restoration work. His dedication to making the world a better place is an inspiring example of *stewardship* based on the idea that *all sustainability is local*.

©Paul Dix/Visuals Unlimited

Figure 20-9 *Global outlook:* This garbage truck is dumping trash into a river in Peru.

Lilac Mountain/Shutterstock

Figure 20-10 Water pollution has killed the fish in this lake.

urban or industrial areas suffer from severe pollution. Garbage dumped into rivers is also a problem in some less-developed nations (Figure 20-9). **Explore More:** See a Case Study at **www.cengage.com/login** to learn about pollution of India's Ganges River.

Too Little Mixing and Low Water Flow Make Lakes and Reservoirs Vulnerable to Water Pollution

Lakes and reservoirs are generally less effective at diluting pollutants than streams are, for two reasons. *First,* lakes and reservoirs often contain stratified layers (see Figure 8-16, p. 182) that undergo little vertical mixing. *Second,* they have little or no flow. The flushing and changing of water in lakes and large artificial reservoirs can take from 1 to 100 years, compared with several days to several weeks for streams.

As a result, lakes and reservoirs are more vulnerable than streams are to contamination by runoff or discharge of plant nutrients, oil, pesticides, and nondegradable toxic substances, such as lead and mercury. These contaminants can kill bottom-dwelling organisms and fish (Figure 20-10), as well as birds that feed on contaminated aquatic organisms. Many toxic chemicals and acids also enter lakes and reservoirs from the atmosphere (see Figure 18-14, p. 477).

Due to the stratified layers and reduced flows in lakes and reservoirs, the concentrations of some harmful chemicals are biologically magnified as they pass through food webs in these waters. Examples include DDT (see Figure 9-15, p. 203), PCBs (see Chapter 17 Case Study, p. 446), some radioactive isotopes, and some mercury compounds.

Cultural Eutrophication Is Too Much of a Good Thing

Eutrophication is the name given to the natural nutrient enrichment of a shallow lake, estuary, or slow-moving stream. It is caused mostly by runoff of plant nutrients such as nitrates and phosphates from surrounding land. In the case of Lake Washington (**Core Case Study**), the major nutrient was phosphorous in treated wastewater that was dumped into the lake from the suburban areas adjacent to it. CORE CASE STUDY

An *oligotrophic lake* is low in nutrients and its water is clear (see Figure 8-17, left, p. 182). Over time, some lakes become more eutrophic (see Figure 8-17, right) as nutrients are added from natural and human sources in the surrounding watersheds. Near urban or agricultural areas, human activities can greatly accelerate the input of plant nutrients to a lake—a process called **cultural eutrophication**. Such inputs involve mostly nitrate- and phosphate-containing effluents from various sources, including farms, feedlots, streets and parking lots, chemically fertilized lawns, mining sites, and sewage treatment plants. Some nitrogen also drops into lakes from the atmosphere.

During hot weather or drought, this nutrient overload produces dense growths, or "blooms," of organisms such as algae and cyanobacteria (see Figure 8-17, right, p. 182), and thick growths of water hyacinth, duckweed, and other aquatic plants. These dense colonies of plant life can reduce lake productivity and fish growth by decreasing the input of solar energy needed for photosynthesis by the phytoplankton that support fish populations (**Concept 20-2B**).

When the algae die, they are decomposed by swelling populations of aerobic bacteria, which deplete dissolved oxygen in the surface layer of water near the shore as well as in the bottom layer of a lake. This can kill fish and other aerobic aquatic animals; it is what happened to Lake Washington (Figure 20-1) before scientists and citizens worked together to clean the lake up (**Core Case Study**). If excess nutrients continue to flow into a lake, anaerobic bacteria take over and produce gaseous products such as smelly, highly toxic hydrogen sulfide and flammable methane.

According to the U.S. Environmental Protection Agency (EPA), about one-third of the 100,000 medium to large lakes and 85% of the large lakes near major U.S. population centers have some degree of cultural eutrophication. Also, the International Water Association estimates that more than half of the lakes in China suffer from cultural eutrophication (Figure 20-11).

There are several ways to *prevent* or *reduce* cultural eutrophication. We can use advanced (but expensive) waste treatment systems to remove nitrates and phosphates before wastewater enters lakes. This approach was used to help reduce eutrophication in Lake Washington (**Core Case Study**). We can also use a preventive approach by banning or limiting the use of phosphates in household detergents and other cleaning agents, and by employing soil conservation (see Chapter 12, pp. 304–307) and land-use control to reduce nutrient runoff (**Concept 20-2B**).

There are several ways to *clean up* lakes suffering from cultural eutrophication. They include mechanically removing excess weeds, controlling undesirable plant growth with herbicides and algaecides, and pumping air into lakes and reservoirs to prevent oxygen depletion, all of which are expensive and energy-intensive methods.

As usual, pollution prevention is more effective and quite often cheaper in the long run than cleanup. Lakes are likely to recover from cultural eutrophication, if excessive inputs of plant nutrients are stopped.

Revisiting Lake Washington and Puget Sound

We can learn two lessons from the story of Lake Washington (**Core Case Study**), both related to themes we explore throughout this book. *First*, we can reverse severe water pollution in a fairly short time, if we sharply reduce pollutant inputs. *Second*, citizen action combined with scientific research works.

However, recall that the wastewater treatment plant effluents that had been flowing into Lake Washington were diverted to the Puget Sound (Figure 20-1). Today, mostly because of continued population and economic growth in the Seattle area, the sound is becoming overloaded with these effluents. There is also growing concern about overflows of raw sewage and urban storm water from wastewater treatment systems during heavy rains, and the resulting large inputs of toxic materials into the sound.

Despite the ecological and political success story of Lake Washington, the relentless growth of population, resource use, and urbanization are again overwhelming

Peter Arnold, Inc.

Figure 20-11 *Global outlook:* Severe cultural eutrophication has covered this lake near the Chinese city of Haozhou with algae.

the lake, as well as the sound. This provides us with a third lesson from the Lake Washington story: Even good solutions to environmental problems cannot work indefinitely if we keep overwhelming the natural systems involved. Ultimately, sustainability (see back cover) requires reducing population growth and resource use.

In 2007, the legislature in Washington State created the Puget Sound Partnership. This state agency brings together communities, businesses, and scientists to evaluate the condition of the sound and to develop strategies for meeting the state's goal of having a healthy Puget Sound by 2020.

CASE STUDY

Pollution in the Great Lakes

The five interconnected Great Lakes of North America (Figure 20-12) contain about 95% of the fresh surface water in the United States and one-fifth of the world's fresh surface water. At least 38 million people in the United States and Canada obtain their drinking water from these lakes.

Despite their enormous size, these lakes are vulnerable to pollution from point and nonpoint sources. One reason is that each year, less than 1% of the water entering the lakes flows east into the St. Lawrence River and then out to the Atlantic Ocean, meaning that pollutants can take as long as 100 years to be flushed out to sea.

By the 1960s, many areas of the Great Lakes were suffering from severe cultural eutrophication, huge fish kills, and contamination from bacteria and a variety of toxic industrial wastes. The impact on Lake Erie was particularly intense because it is the shallowest of the Great Lakes and has the highest concentrations of people and industrial activity along its shores.

In 1972, the United States and Canada signed the Great Lakes Water Quality Agreement, which is considered a model of international cooperation. They agreed to spend more than $20 billion to maintain and restore the chemical, physical, and biological integrity of the Great Lakes basin ecosystem. This program has decreased algal blooms, increased dissolved oxygen levels, boosted sport and commercial fishing catches in Lake Erie, and allowed most swimming beaches to reopen—making this one of the nations' greatest environmental success stories. These improvements occurred mainly because of new or upgraded sewage treatment plants, better treatment of industrial wastes, and bans on the use of detergents, household cleaners, and water conditioners that contain phosphates—all instituted mostly because of bottom-up citizen pressure.

GOOD NEWS

Despite this important progress, many problems remain. In 2006, Canadian scientists reported that cities around the lakes were releasing the equivalent of more than 100 Olympic-size swimming pools full of raw sew-

Figure 20-12 The five Great Lakes of North America make up the world's largest freshwater system. Dozens of major cities in the United States and Canada are located on their shores, and water pollution in the lakes is a growing problem.

age into the lakes each day. This is because dozens of municipal sewage systems combine storm water with wastewater and allow emergency overflows into the lakes. According to the scientists, these systems overflow far too easily and too often.

Increasing nonpoint runoff of pesticides and fertilizers resulting from urban sprawl, fueled by population growth, now surpasses industrial pollution as the greatest threat to the lakes. Bottom sediments in 26 toxic hot spots remain heavily polluted. In addition, *biological pollution* in the form of growing populations of zebra mussels (Figure 11-14, p. 271) and more than 180 other invasive species (see Figure 11-15, p. 272) threaten some native aquatic species and cause at least $200 million a year in damages (see Chapter 11 Case Study, p. 270).

Air quality over the Great Lakes has improved according to the 2007 State of the Lakes report. But about half of the toxic compounds entering the lakes still come from atmospheric deposition of pesticides, mercury from coal-burning plants, and other toxic chemicals from as far away as Mexico and Russia. In a survey done by Wisconsin biologists, one of every four fish taken from the Great Lakes was unsafe for human consumption.

Despite ongoing pollution problems, EPA funding for cleanup of the Great Lakes dropped 80% between 1992 and 2009. In 2010, Congress increased funding for this long-term project. The major goals are to help clean up contaminated rivers that flow into the lakes, reduce erosion and runoff, protect and restore wetlands, restore wildlife habitat, clean up toxic hotspots, and reduce the number of invasive species entering the lakes.

Some environmental and health scientists also call for taking a prevention approach and banning the use of toxic chlorine compounds, such as bleach used in the pulp and paper industry, which is prominent around the Great Lakes. They would also ban new waste incinerators, which can release toxic chemicals into the atmosphere, and they would stop the discharge into the lakes of 70 toxic chemicals that threaten human health and wildlife. So far, officials in the industries involved have successfully opposed such bans.

THINKING ABOUT
Pollution in the Great Lakes
What are three steps you would take to sharply reduce pollution in the Great Lakes?

20-3 What Are the Major Pollution Problems Affecting Groundwater and Other Drinking Water Sources?

CONCEPT 20-3A Chemicals used in agriculture, industry, transportation, and homes can spill and leak into groundwater and make it undrinkable.

CONCEPT 20-3B There are both simple and complex ways to purify groundwater used as a source of drinking water, but protecting it through pollution prevention is the least expensive and most effective strategy.

Groundwater Cannot Cleanse Itself Very Well

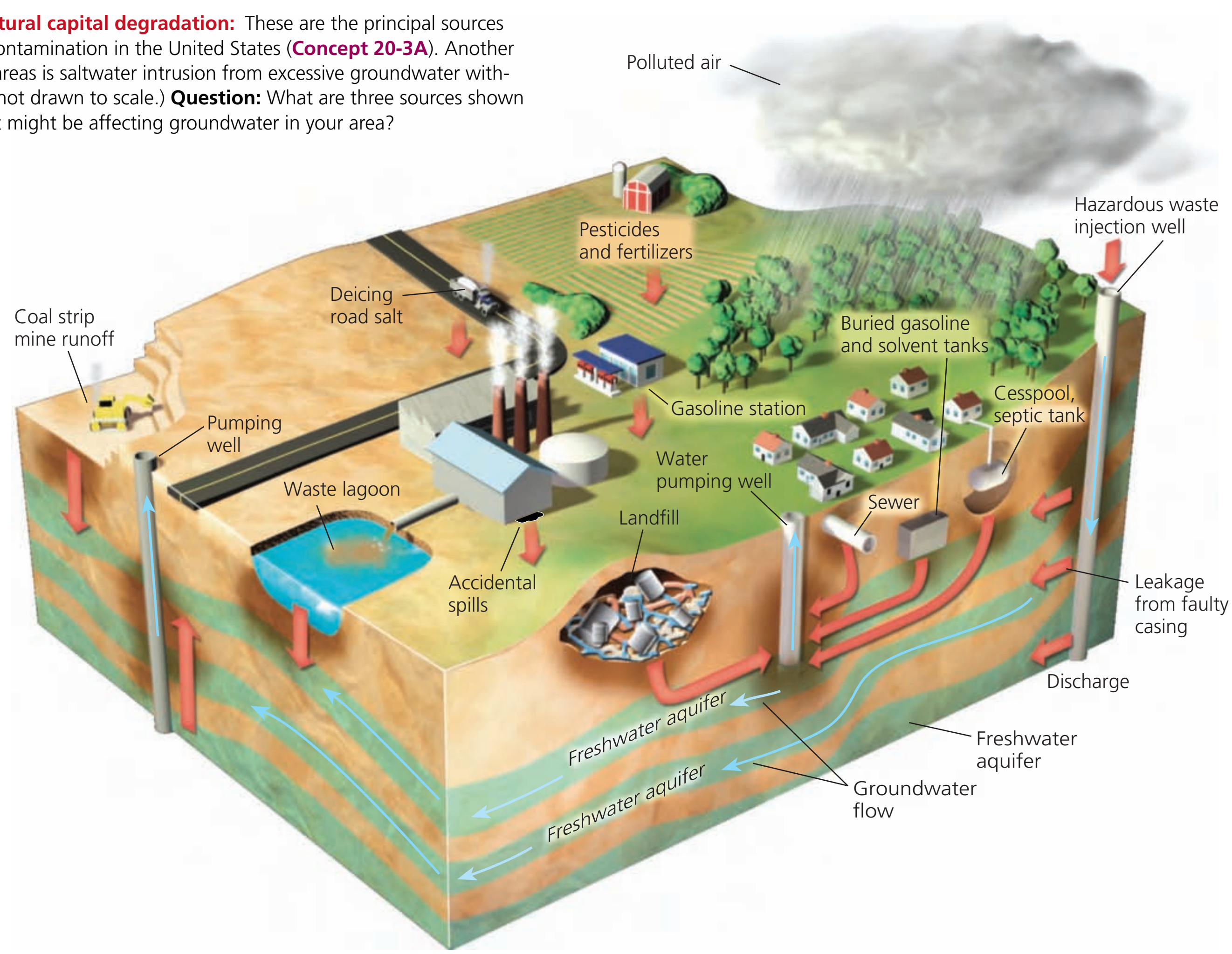
Drinking water for about half of the U.S. population and 95% of Americans who live in rural areas comes from groundwater aquifers. According to many scientists, groundwater pollution is a serious threat to human health.

Common pollutants such as fertilizers, pesticides, gasoline, and organic solvents can seep into groundwater from numerous sources (Figure 20-13, p. 540). People who dump or spill gasoline, oil, and paint thinners and other organic solvents onto the ground also contaminate groundwater (**Concept 20-3A**).

Once a pollutant from a leaking underground storage tank or other source contaminates groundwater, it fills the aquifer's porous layers of sand, gravel, or bedrock like water saturates a sponge. This makes removal of the contaminant difficult and costly. The slowly flowing groundwater disperses the pollutant in a widening *plume* of contaminated water. If the plume reaches a well used to extract groundwater, the toxic pollutants can get into drinking water and into water used to irrigate crops.

When groundwater becomes contaminated, it cannot cleanse itself of degradable wastes as quickly as flowing surface water can. Groundwater flows so slowly—usually less than 0.3 meter (1 foot) per day—that contaminants are not diluted and dispersed effectively. In addition, groundwater usually has much lower concentrations of dissolved oxygen (which helps decompose many contaminants) and smaller populations of decomposing bacteria. The usually cold temperatures of groundwater also slow down chemical reactions that decompose wastes.

Figure 20-13 **Natural capital degradation:** These are the principal sources of groundwater contamination in the United States (**Concept 20-3A**). Another source in coastal areas is saltwater intrusion from excessive groundwater withdrawal. (Figure is not drawn to scale.) **Question:** What are three sources shown in this picture that might be affecting groundwater in your area?



Groundwater Pollution Is a Serious Hidden Threat in Some Areas

On a global scale, we do not know much about groundwater pollution because few countries go to the great expense of locating, tracking, and testing aquifers. But the results of scientific studies in scattered parts of the world are alarming.

Groundwater provides about 70% of China's drinking water. In 2006, the Chinese government reported that aquifers in about nine of every ten Chinese cities were polluted or overexploited, and could take hundreds of years to recover.

In the United States, an EPA survey of 26,000 industrial waste ponds and lagoons found that one-third of them had no liners to prevent toxic liquid wastes from seeping into aquifers. One-third of these sites are within 1.6 kilometers (1 mile) of a drinking water well. In addition, almost two-thirds of America's liquid hazardous wastes are injected into the ground in disposal wells, some of which leak water into aquifers used as sources of drinking water (Figure 20-13).

By 2008, the EPA had completed the cleanup of about 357,000 of the more than 479,000 underground tanks in the United States that were leaking gasoline, diesel fuel, home heating oil, or toxic solvents into groundwater. During this century, scientists expect many of the millions of such tanks, which have been installed around the world, to become corroded and leaky, possibly contaminating groundwater and becoming a major global health problem. Determining the extent of a leak from a single underground tank can cost $25,000–250,000, and cleanup costs range from $10,000 to more than $250,000. If the chemical reaches an aquifer, effective cleanup is often not possible or is too costly.

Groundwater used as a source of drinking water can also be contaminated with *nitrate ions* (NO_3^-), especially in agricultural areas where nitrates in fertilizer can leach into groundwater. Nitrite ions (NO_2^-) in the stomach, colon, and bladder can convert some of the nitrate ions in drinking water to organic compounds that have been shown in tests to cause cancer in more than 40 animal species. Also, the conversion of nitrates in tap water to nitrites in infants under 6 months old can cause a potentially fatal condition known as "blue baby syndrome," in which blood lacks the ability to carry sufficient oxygen to body cells.

Another problem is toxic *arsenic*, which contaminates drinking water when a well is drilled into aquifers where soils and rock are naturally rich in arsenic, or when human activities such as mining and ore processing release arsenic into drinking water supplies. Some rivers used for drinking water also are contaminated naturally, having originated in springs that have high levels of arsenic. According to a 2007 study by the WHO, more than 140 million people in 70 countries are drinking water with arsenic concentrations of 5–100 times the accepted safe level of 10 parts per billion (ppb). Scientists from the WHO and other organizations warn that even the 10 ppb standard is not safe. Levels are especially high in Bangladesh, China, India's state of West Bengal, and parts of northern Chile. The WHO estimates that long-term exposure to nondegradable arsenic in drinking water is likely to cause hundreds of thousands of premature deaths from cancer of the skin, bladder, and lung.

There is also concern over arsenic levels in drinking water in parts of the United States. According to the EPA, some 13 million people in several thousand communities, mostly in the western half of the country, are exposed to arsenic levels of 3–10 ppb in their drinking water.

In 2006, researchers from Rice University in Houston, Texas (USA) reported that suspending nanoparticles of rust in arsenic-contaminated water, and then drawing them out with hand-held magnets, removed enough arsenic from the water to make it safe to drink. This could greatly reduce the threat of arsenic in drinking water for many families at a cost of a few cents a day. Stay tuned while scientists evaluate this process.

Pollution Prevention Is the Only Effective Way to Protect Groundwater

It can take decades to thousands of years for contaminated groundwater to cleanse itself of *slowly degradable wastes* (such as DDT). On a human time scale, *nondegradable wastes* (such as toxic lead and arsenic) remain in the water permanently. Although there are ways to clean up contaminated groundwater (Figure 20-14, right) such methods are very expensive. Thus, preventing groundwater contamination (Figure 20-14, left) is the only effective way to deal with this serious water pollution problem.

There Are Many Ways to Purify Drinking Water

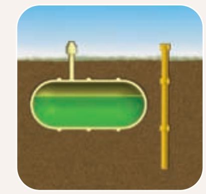
Most of the more-developed countries have laws establishing drinking water standards. But most of the less-developed countries do not have such laws or, if they do have them, they do not enforce them. There are simple ways and complex ways to purify drinking water

Solutions

Groundwater Pollution

Prevention

- Find substitutes for toxic chemicals
- Keep toxic chemicals out of the environment
- Install monitoring wells near landfills and underground tanks
- Require leak detectors on underground tanks
- Ban hazardous waste disposal in landfills and injection wells
- Store harmful liquids in aboveground tanks with leak detection and collection systems



Cleanup

- Pump to surface, clean, and return to aquifer (very expensive)
- Inject microorganisms to clean up contamination (less expensive but still costly)
- Pump nanoparticles of inorganic compounds to remove pollutants (still being developed)

Figure 20-14 There are ways to prevent and ways to clean up contamination of groundwater but prevention is the only effective approach (**Concept 20-3B**). **Questions:** Which two of these preventive solutions do you think are the most important? Why?

obtained from surface and groundwater sources (**Concept 20-3B**).

In more-developed countries, wherever people depend on surface water sources, it is usually stored in a reservoir for several days. This improves clarity and taste by increasing dissolved oxygen content and allowing suspended matter to settle. The water is then pumped to a purification plant and treated to meet government drinking water standards. In areas with very pure groundwater or surface water sources, little treatment is necessary. Some cities have found that protecting watersheds that supply their drinking water is a lot cheaper than building water purification plants (see the Case Study that follows).

Japan and several other countries are beginning to develop plants that process sewer water into drinking water. El Paso, Texas (USA), gets 40% of its drinking water from recycling and purifying wastewater. In 2007, Orange County, California (USA), completed the world's largest plant devoted to making sewer water as pure as distilled water. It will be used to supply drinking water and to recharge aquifers.

We have the technology to convert sewer water into pure drinking water. But reclaiming wastewater is expensive and it faces opposition from citizens and from some health officials who are unaware of the advances in this technology. In a world where we will face increasing shortages of drinking water, companies such as General Electric and several Chinese companies see the development and sales of wastewater purification technologies as a major growth business.

We can also use simpler measures to purify drinking water. In tropical countries that lack centralized water treatment systems, the WHO urges people to purify drinking water by exposing a clear plastic bottle filled with contaminated water to intense sunlight. The sun's heat and UV rays can kill infectious microbes in as little as 3 hours. Painting one side of the bottle black can improve heat absorption in this simple solar disinfection method, which applies the solar energy **principle of sustainability**. Where this measure has been used, incidence of dangerous childhood diarrhea has decreased by 30–40%.

In 2007, the Danish company Vestergaard Frandsen developed the LifeStraw™, an inexpensive, portable water filter that eliminates many viruses and parasites from water that is drawn into it (Figure 20-15). This filter has been particularly useful in Africa, where aid agencies are distributing it.

Another product that could be of help to the 1 billion people who do not have access to safe drinking water is PUR, a powder containing chlorine and iron sulfate, made by the U.S. company Proctor and Gamble. The company sells it at cost to nongovernmental agencies that then distribute the powder to people in need of it throughout the world. A user empties a packet of PUR into a large container of dirty water, then stirs the mixture and lets it sit for about 20 minutes. After the water is poured through a piece of clean cloth, it is ready to drink.

CASE STUDY

Protecting Watersheds Instead of Building Water Purification Plants

Several major U.S. cities have avoided building expensive water treatment facilities by investing in protection of the forests and wetlands in the watersheds that provide their water supplies (**Concept 20-3B**). Examples are the U.S. cities of New York, New York; Boston, Massachusetts; Seattle, Washington; and Portland, Oregon.

New York's drinking water is known for its purity. The city gets 90% of the drinking water for its 9 million residents from reservoirs in New York State's Catskill Mountains. Forests cover more than three-fourths of this watershed. Underground tunnels transport the water to the city.

To continue providing quality drinking water for its citizens, New York City faced spending $6 billion to build water purification facilities. Instead, the city decided to negotiate an agreement with the state as well as with towns, farmers, and other parties with interests in the Catskills watershed. The city agreed to pay this diverse group of governments and private citizens $1.5 billion over 10 years in exchange for their promise to protect and, in some cases, to restore the forests, wetlands, and streams in the watershed.

The money that New York spent on watershed protection saved the city the $6 billion cost of building water purification facilities plus $300 million a year in filtration costs. This is an excellent example of how people can cooperate and work with nature to provide a more sustainable supply of clean drinking water.

THINKING ABOUT
Protecting the Sources of Drinking Water

Where does the community in which you live get its drinking water? Could it save money and help to preserve biodiversity by finding ways to protect its watershed or the aquifers that supply this water?

Using Laws to Protect Drinking Water Quality

About 54 countries, most of them in North America and Europe, have standards for safe drinking water. The U.S. Safe Drinking Water Act of 1974 requires the EPA

Vestergaard Frandsen

Figure 20-15 The *LifeStraw*™, designed by Torben Vestergaard Frandsen, is a personal water purification device that gives many poor people access to safe drinking water. Here, four young men in Uganda demonstrate its use. **Question:** Do you think the development of such devices should make prevention of water pollution less of a priority? Explain.

to establish national drinking water standards, called *maximum contaminant levels,* for any pollutants that may have adverse effects on human health. Currently, this act strictly limits levels of 91 pollutants or contaminants in U.S. tap water. But in most of the less-developed countries, such laws do not exist or are not enforced.

Health scientists call for strengthening the U.S. Safe Drinking Water Act in several ways. Here are three of their recommendations:

- Combine many of the drinking water treatment systems that serve fewer than 3,300 people with nearby larger systems to make it cheaper for small systems to meet federal standards.
- Strengthen and enforce public notification requirements about violations of drinking water standards.
- Ban the use of any toxic lead in new plumbing pipes, faucets, and fixtures. Current law allows for fixtures with up to 10% lead content to be sold as lead-free.

According to the Natural Resources Defense Council (NRDC), making these three improvements would cost U.S. taxpayers an average of about $30 a year per household.

However, water-polluting industries are pressuring elected officials to weaken the Safe Drinking Water Act. One proposal is to eliminate national testing of drinking water and requirements for public notification about violations of drinking water standards. Another such proposal would allow states to give providers of drinking water a permanent right to violate the standard for a given contaminant if they claim they cannot afford to comply with it. Finally, some critics call for greatly reducing the EPA's already low budget for enforcing the U.S. Safe Drinking Water Act.

HOW WOULD YOU VOTE? ✓

Should the U.S. Safe Drinking Water Act be strengthened? Cast your vote online at **www.cengage.com/login**.

CASE STUDY
Is Bottled Water a Good Option?

Despite some problems, experts say the United States has some of the world's cleanest drinking water. Municipal water systems in the United States are required to test their water regularly for a number of pollutants and to make the results available to citizens.

Yet about half of all Americans worry about getting sick from tap water contaminants, and many drink high-priced bottled water or install expensive water purification systems. Americans are the world's largest consumers of bottled water, followed by Mexico, China, and Brazil. In 2009, Americans spent more than $11 billion to buy billions of plastic bottles filled with water and each year, they drink more bottled water than they do beer, coffee, or milk. That is enough to meet the annual drinking water needs of the roughly 1 billion people in the world who routinely lack access to safe and clean drinking water.

Studies by the NRDC and water expert Peter Gleick reveal that in the United States, a bottle of water costs between 240 and 10,000 times as much as the same volume of tap water and uses 100 to 2,000 times more energy to produce from start to finish. In 2008, Gleick estimated that more than 40% of the expensive bottled water that Americans drink is really just bottled tap water. And a 4-year study by the NRDC found bacteria and synthetic organic chemicals in one-third of the bottles tested. Neither the EPA nor the FDA certifies bottled water. However, the International Bottled Water Association and the nonprofit National Sanitation Foundation International certify bottled water companies that meet their standards. Cautious buyers use only bottled water that is certified by such organizations.

Use of bottled water also causes environmental problems, according to a 2007 study by the Worldwatch Institute and a 2008 study by water experts Peter Gleick and Heather Cooley. Every second, about 1,500 plastic water bottles are thrown away. Each year, the number of water bottles thrown away, if lined up end-to-end, would circle the earth's equator eight times. Water bottles are made up of recyclable polyethylene terephthalate (PET) plastic, but in the United States, only about 14% of these bottles get recycled. The rest end up in landfills or in lakes (Figure 20-6) and in the ocean.

Manufacturing the bottles and transporting them throughout the world uses huge amounts of energy, primarily from oil and coal. The consumer and environmental group Food & Water Watch estimates that each year, more than 17 million barrels of oil are used to produce the plastic water bottles sold in the United States. This is enough to fuel about 1 million cars a year. Toxic gases and liquids are released during the manufacture of plastic water bottles and greenhouse gases and other air pollutants are emitted by the fossil fuels burned to make them and to deliver bottled water to suppliers. In addition, withdrawing water for bottling is helping to deplete some aquifers, although most are used sustainably.

Every week, ships, trains, and trucks move about 1 billion bottles of water into and around the United States. Some bottled water is shipped from as far away as Fiji (8,800 kilometers, or 5,500 miles). There, an automated factory produces more than a million bottles a day for the U.S. market using plastic shipped to Fiji from China. The corporation that produces Fiji water has a 99-year lease that gives it access to an enormous aquifer on the island. But while Americans and Europeans are drinking this very expensive bottled Fiji water, half of the people in Fiji do not have access to safe, reliable drinking water.

Because of these harmful environmental impacts and the high cost of bottled water, there is a growing *back-to-the-tap* movement based on boycotting bottled water. Its motto is "*Think globally, drink locally*." From San Francisco to New York to Paris, city governments, restaurants, schools, religious groups, and many consumers are refusing to buy bottled water as this trend picks up steam. Individuals are also refilling portable bottles with tap water and using simple filters to improve the taste and color of water where necessary.

Health officials suggest that before drinking expensive bottled water or buying costly home water purifiers, consumers have their water tested by local health departments or private labs (but not by companies trying to sell water purification equipment). Independent experts contend that unless tests show otherwise, for most U.S. urban and suburban residents served by large municipal drinking water systems, home water treatment systems are not worth their cost, and drinking expensive and environmentally harmful bottled water is unnecessary.

HOW WOULD YOU VOTE?

Should pollution standards for bottled water be as strict as those for water from public systems? Cast your vote online at **www.cengage.com/login**.

20-4 What Are the Major Water Pollution Problems Affecting Oceans?

CONCEPT 20-4A The great majority of ocean pollution originates on land and includes oil and other toxic chemicals as well as solid waste, which threaten fish and wildlife and disrupt marine ecosystems.

CONCEPT 20-4B The key to protecting the oceans is to reduce the flow of pollution from land and air and from streams emptying into ocean waters.

Ocean Pollution Is a Growing and Poorly Understood Problem

Coastal areas—especially wetlands, estuaries, coral reefs, and mangrove swamps—bear the brunt of our enormous inputs of pollutants and wastes into the ocean (**Concept 20-4A** and Figure 20-16). This is not surprising because about 40% of the world's population (53% in the United States) lives on or near coastlines, and coastal populations are projected to double by 2050. (See *The Habitable Planet*, Video 5 at **www.learner.org/resources/series209.html** to learn how scientists are studying the effects of population growth and development on nitrogen pollution of coastal aquatic systems in Cape Cod, Massachusetts [USA].)

According to a 2006 *State of the Marine Environment* study by the UN Environment Programme (UNEP), an estimated 80% of marine pollution originates on land (**Concept 20-4A**), and this percentage could rise significantly by 2050 if coastal populations double as projected. The report says that 80–90% of the municipal sewage from most coastal areas of less-developed countries, and in some such areas of more-developed countries, is dumped into oceans without treatment. This often overwhelms the ability of the coastal ecosystems to break down these biodegradable wastes. The coastline of China, for example, is so choked with algae growing on the nutrients provided by sewage that some scientists believe large areas of China's coastal waters can no longer sustain marine ecosystems.

In deeper waters, the oceans can dilute, disperse, and degrade large amounts of raw sewage and other types of degradable pollutants. Some scientists suggest that it is safer to dump sewage sludge, toxic mining wastes, and most other harmful wastes into the deep ocean than to bury them on land or burn them in incinerators. Other scientists disagree, pointing out that we know less about the deep ocean than we do about the moon. They add that dumping harmful wastes into the ocean would delay urgently needed pollution prevention measures and promote further degradation of this vital part of the earth's life-support system.

THINKING ABOUT
Ocean Pollution

Should we dump sewage sludge, toxic mining wastes, and other harmful pollutants into the deep ocean? Explain. If you oppose such dumping, what would you do with these wastes?

Recent studies of some U.S. coastal waters have found vast colonies of viruses thriving in raw sewage and in effluents from sewage treatment plants (which do not remove viruses) and leaking septic tanks. According to one study, one-fourth of the people using coastal beaches in the United States develop ear infections, sore throats, eye irritations, respiratory disease, or gastrointestinal disease from swimming in seawater containing infectious viruses and bacteria.

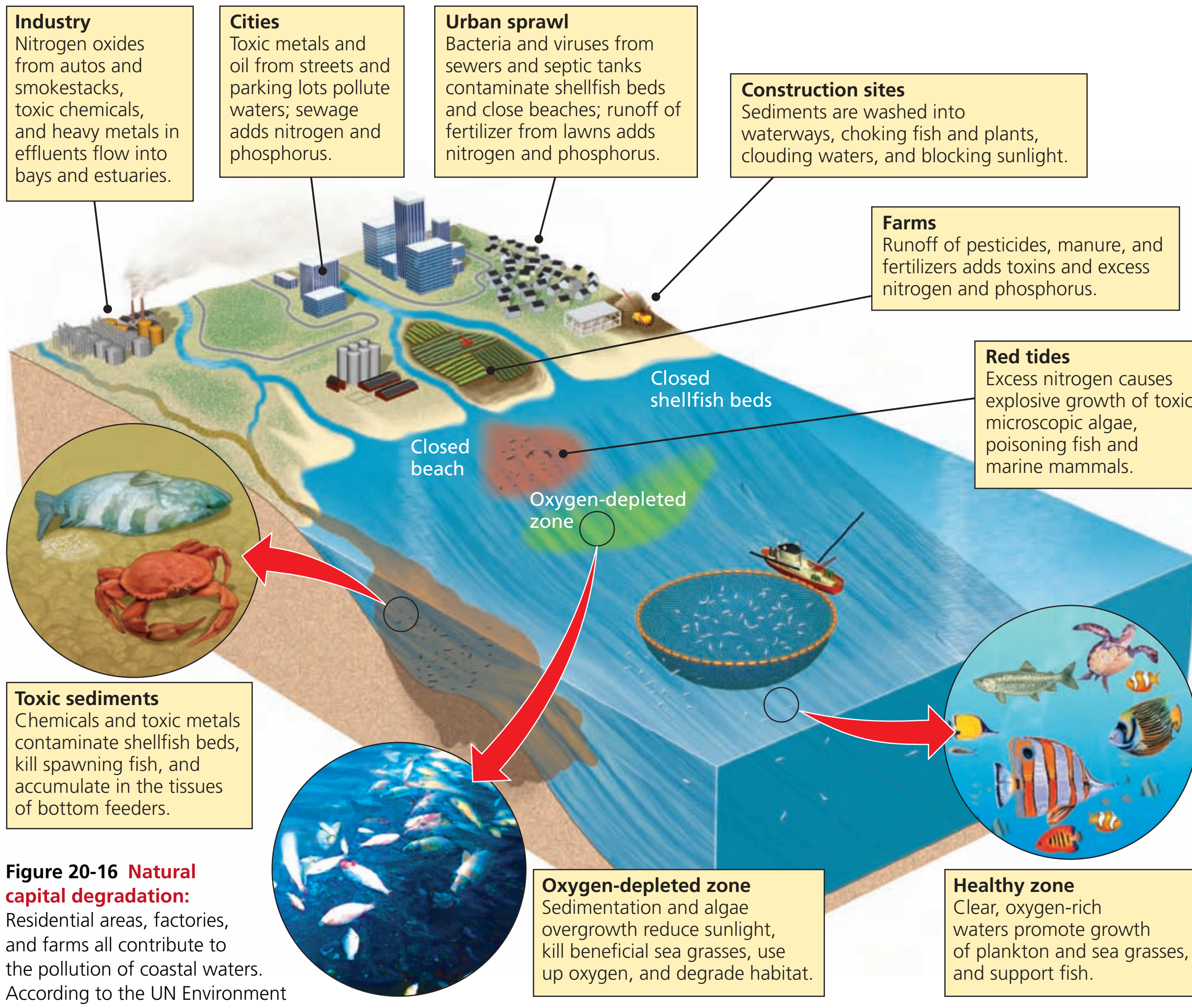


Figure 20-16 **Natural capital degradation:** Residential areas, factories, and farms all contribute to the pollution of coastal waters. According to the UN Environment Programme, coastal water pollution costs the world more than $30,000 a minute, primarily for health problems and premature deaths. **Questions:** What do you think are the three worst pollution problems shown here? For each one, how does it affect two or more of the ecological and economic services listed in Figure 8-5 (p. 172)?

Scientists also point to the underreported problem of pollution from cruise ships. A cruise liner can carry as many as 3,600 passengers and 1,500 crewmembers, and it can generate as much waste (toxic chemicals, garbage, sewage, and waste oil) as a small city. Many cruise ships dump these wastes at sea. In U.S. waters, such dumping is illegal, but some ships continue dumping secretively, usually at night. Some environmentally aware vacationers are refusing to go on cruise ships that do not have sophisticated systems for dealing with the wastes they produce.

Runoffs of sewage and agricultural wastes into coastal waters introduce large quantities of nitrate (NO_3^-) and phosphate (PO_4^{3-}) plant nutrients, which can cause explosive growths of harmful algae. These *harmful algal blooms* are called red, brown, or green toxic tides (Figure 20-16, middle). They can release waterborne and airborne toxins that poison seafood, damage fisheries, kill some fish-eating birds, and reduce tourism. Each year, harmful algal blooms lead to the poisoning of about 60,000 Americans who eat shellfish contaminated by the algae.

Because of harmful algal blooms, at least 400 *oxygen-depleted zones* form in coastal waters around the world every year, according to a 2008 study by marine scientists Robert Diaz and Rutger Rosenberg. They occur mostly in temperate coastal waters and in large bodies of water with restricted outflows, such as the Baltic and Black seas. About 43 of these zones occur in U.S. waters (Science Focus, p. 546). A 2008 study by Luan Weixin, of China's Dalain Maritime University, found that water pollutants such as nitrates and phosphates seriously contaminated about half of China's shallow coastal waters.

These zones are incorrectly called *dead zones*. Because of low oxygen levels (hypoxia), they contain few oxygen-consuming fish and bottom-dwelling organisms, but they abound with decomposing bacteria. The

SCIENCE FOCUS

Oxygen Depletion in the Northern Gulf of Mexico

The world's third largest oxygen-depleted zone (after those in the Baltic Sea and the northwestern Black Sea) forms every spring and summer in a narrow stretch of the northern Gulf of Mexico off the mouth of the Mississippi River. This area includes the coastal waters of the U.S. states of Texas, Louisiana, and Mississippi (Figure 20-B). The low oxygen levels suffocate fish, crabs, and shrimp that cannot move to less polluted areas. Thus, these oxygen-depleted zones threaten aquatic biodiversity and whole ecosystems.

Scientists believe the gulf's oxygen-depleted zone forms as a result of oxygen-depleting algal blooms. Evidence indicates that it is created mostly by huge inputs of nitrate (NO_3^-) plant nutrients from farms, cities, factories, and sewage treatment plants located in the vast Mississippi River basin (Figure 20-B).

The Mississippi River and its tributaries drain all or part of 31 U.S. states and two Canadian provinces. This watershed contains almost two-thirds of the continental U.S. land area and more than half of all U.S. croplands; it is one of the world's most productive agricultural regions. Yet the northern Gulf of Mexico's oxygen-depleted zone, which in recent years has covered an area almost as large as the U.S. state of New Jersey, greatly disrupts its fisheries. Thus, growing crops in the Mississippi River basin reduces food production from these fisheries at a cost of about $3 billion per year.

Some scientists who have studied this problem fear that it could reach a tipping point beyond which the ecosystem could collapse. This would be the point at which most of organisms living in this part of the Gulf of Mexico simply can no longer move far enough or fast enough to find oxygen-rich waters. Their populations might then decline to the point where they could not recover.

Because of the size and agricultural importance of the Mississippi River basin, there are no easy solutions to the problem of severe cultural eutrophication of the gulf, and the same is true of other overfertilized coastal zones around the world. Preventive measures include applying less fertilizer on farms upstream, injecting fertilizer below the soil surface, and using controlled-release fertilizers. Using no-till cultivation (see Chapter 12, p. 306) on the farms would help to reduce soil erosion. Farmers or conservation agencies could also plant strips of forests and grasslands along waterways to soak up excess nitrogen, and they could restore and create wetlands between crop fields and streams emptying into the Mississippi River for the same purpose.

Other measures involve improving flood control to prevent the release of nitrogen from floodplains during major floods, and upgrading sewage treatment systems to reduce discharges of nitrates into waterways. In addition, deposition of nitrogen compounds from the atmosphere could be reduced by requiring lower emissions of nitrogen oxides from motor vehicles and phasing in forms of renewable energy to replace the burning of fossil fuels.

Critical Thinking

How do you think each of the preventive measures described above would help to prevent pollution in the Gulf of Mexico? Can you think of other possible preventive solutions?

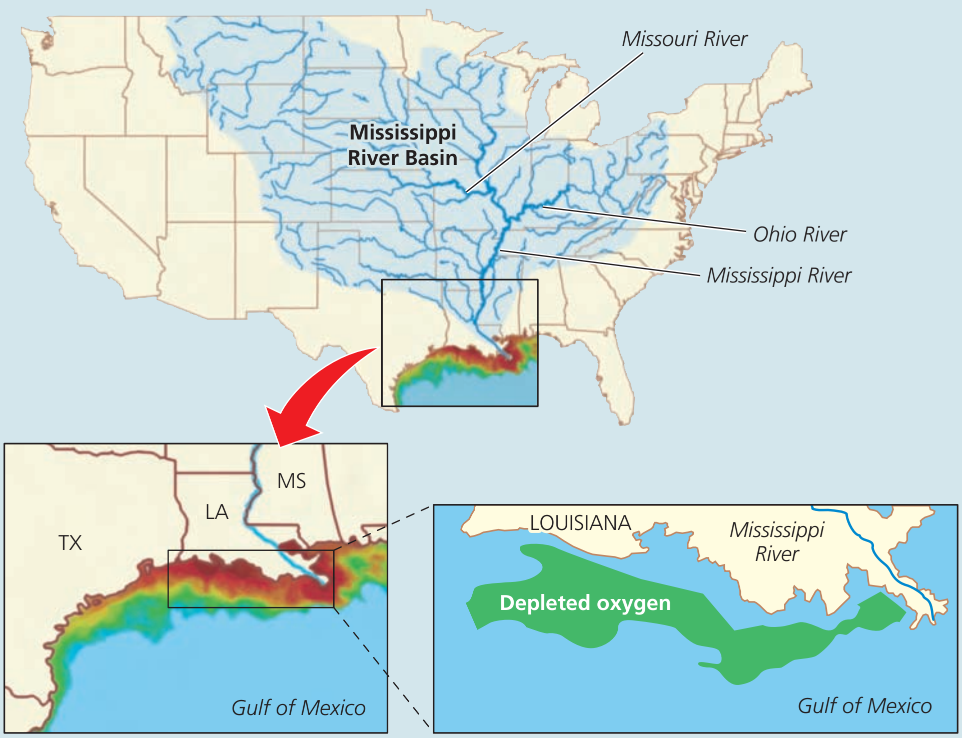


Figure 20-B **Natural capital degradation:** A large zone of oxygen-depleted water (containing less than 2 ppm dissolved oxygen) forms each year in the Gulf of Mexico (lower right drawing) as a result of oxygen-depleting algal blooms caused primarily by high inputs of plant nutrients from the Mississippi River basin (top). The drawing (bottom left), based on a satellite image, shows how these inputs spread along the coast during the summer of 2008. In the image, reds and greens represent high concentrations of phytoplankton and river sediment. This problem is worsened by loss of wetlands, which would have filtered some of these plant nutrients. **Question:** Can you think of a product you used today that was directly connected to this sort of pollution? (Data from NASA)

low oxygen levels are caused by the rapid growth of algae in nutrient-rich waters, which are decomposed by colonies of oxygen-consuming bacteria. Evidence indicates that oxygen-depleted zones are caused mostly by excessive inputs of nitrates and phosphates from runoff of fertilizers and animal wastes and by deposition of nitrogen compounds from the atmosphere.

In 1997 ocean researchers discovered a huge swirling mass of plastic wastes in the North Pacific Ocean, between California and Hawaii. This oceanic stew of plastic bags, bottles, jugs, nets, and tiny pieces of plastic is twice the size of the U.S. state of Texas. This long-lasting monument to the human throwaway mentality is now called the Great Pacific Garbage Patch. In 2010, scientists discovered another huge floating mass of plastic debris in the Atlantic Ocean, known as the Great Atlantic Garbage Patch. According to ocean researcher Charles Moore, who discovered the Pacific Garbage Patch in 1997, "Humanity's plastic footprint is probably more dangerous than its carbon footprint."

Figure 20-17 lists ways to prevent and reduce pollution of coastal waters. GOOD NEWS

The key to protecting the oceans is to reduce the flow of pollution from land and air and from streams emptying into these waters (**Concept 20-4B**). Thus, ocean pollution control must be linked with land-use and air pollution control policies, which in turn are linked to energy policies (see Figure 16-37, p. 431) and climate policies (see Figure 19-16, p. 513).

Ocean Pollution from Oil

Crude petroleum (oil as it comes out of the ground) and *refined petroleum* (fuel oil, diesel, gasoline, and other processed petroleum products) reach the ocean from a number of sources and become highly disruptive pollutants (**Concept 20-4A**).

U.S. Coast Guard

Figure 20-18 On April 20, 2010 oil and natural gas escaping from an oil-well borehole ignited and caused an explosion on the British Petroleum (BP) *Deepwater Horizon* drilling platform in the Gulf of Mexico. The accident sank the rig and killed 11 of its crewmembers. The ruptured wellhead released massive amounts of crude oil that contaminated ecologically vital coastal marshes (Figure 8-8, p. 174), mangroves (Figure 8-10, p. 175), sea-grass beds (Figure 8-9, p. 174) and deep ocean aquatic life. It also disrupted the livelihoods of people depending on the gulf's coastal fisheries and caused large economic losses for the gulf's tourism business. This disaster was caused by a combination of equipment failure, human error, failure by BP to prepare for a major oil release, and inadequate government regulation of oil drilling in the Gulf of Mexico.

Figure 20-17 There are a number of methods for preventing or cleaning up excessive pollution of coastal waters (**Concept 20-4B**). **Questions:** Which two of these solutions do you think are the most important? Why?

Tanker accidents (see the Case Study that follows) and blowouts at offshore drilling rigs (when oil and natural gas escape under high pressure from a borehole in the ocean floor) get most of the publicity because of their high visibility. In April of 2010, such a blowout occurred in the Gulf of Mexico (Figure 20-18). But *studies show that the largest source of ocean pollution from oil is urban and industrial runoff from land,* much of it from leaks in pipelines and oil-handling facilities.

At least 37% of the oil reaching the oceans is waste oil, dumped, spilled, or leaked onto the land or into sewers by cities and industries, as well as by people changing their own motor oil. However, according to a 2006 UNEP study, since the mid-1980s, the amount of oil entering the marine environment from oil tanker accidents has decreased 75% and oil leaks from industry and cities have dropped by nearly 90%. GOOD NEWS

Volatile organic hydrocarbons in oil kill many aquatic organisms immediately upon contact. Other chemicals in oil form tarlike globs that float on the surface and coat the feathers of seabirds (see Figure 15-7, p. 377) and the fur of marine mammals. This oil coating destroys their natural heat insulation and buoyancy, causing many of them to drown or die of exposure from loss of body heat.

Heavy oil components that sink to the ocean floor or wash into estuaries can smother bottom-dwelling organisms such as crabs, oysters, mussels, and clams, or make them unfit for human consumption. Some oil spills have killed coral reefs.

Research shows that populations of many forms of marine life recover from exposure to large amounts of *crude oil* in warm waters with fairly rapid currents within about 3 years. But in cold and calm waters, full recovery can take decades. And, recovery from exposure to *refined oil,* especially in estuaries and salt marshes, can take 10–20 years or longer. Oil slicks that wash onto beaches can have a serious economic impact on coastal residents, who lose income normally gained from fishing and tourist activities.

If they are not too large, oil spills can be partially cleaned up by mechanical means including floating booms, skimmer boats, and absorbent devices such as large pillows filled with feathers or hair. But scientists estimate that current cleanup methods can recover no more than 15% of the oil from a major spill. Thus, *preventing* oil pollution is the most effective and, in the long run, the least costly approach (**Concept 20-4B**).

CASE STUDY

The Exxon Valdez Oil Spill

In 1989, the *Exxon Valdez* oil tanker went off course, hit Bligh Reef, and released 41 million liters (11 million gallons) of crude oil into Alaska's Prince William Sound. The oil spill—the largest ever in U.S. waters—blackened 5,200 kilometers (3,200 miles) of pristine and biologically rich Alaskan coastline. (The 2010 BP oil rig blowout in the Gulf of Mexico released many times more crude oil than the Exxon Valdez spill did, but it was technically defined as a blowout, not an oil spill.)

The oil from this spill killed about 250,000 seabirds and large numbers of fish, fish eggs, shellfish, sea otters, orcas (killer whales), and harbor seals. The accident also disrupted the culture and livelihoods of 32,000 coastal residents of Alaska and caused an estimated $15 billion in damages.

Exxon Mobil paid $3.8 billion in damages and clean-up costs but recovered much of this money in tax credits and insurance payments. In 1994, a jury awarded 11,000 Alaskan fishers, cannery workers, and landowners $5 billion in punitive damages. Exxon Mobil refused to pay, and after 14 years of court appeals, Exxon lawyers persuaded the U.S. Supreme Court in 2008 to reduce the punitive damages by 90% to $510 million. That same year, Exxon Mobil had profits of $42.5 billion—the largest in history for any U.S. company at that time.

In 2009, the year of the twentieth anniversary of the accident, Exxon Mobil representatives said that there had been no long-term ecological damage to the Prince William Sound ecosystem. However, The Exxon Valdez Oil Spill Trustee Council, made up of three state and three federal appointees, disputed this claim. They said that significant amounts of toxic oil remain beneath certain sections of the shoreline, that it still threatens some types of wildlife, and that it will "take decades and possibly centuries to disappear." The council also found that populations of 17 of 27 monitored species still had not recovered and that high-pressure hoses used to scrub the beaches did more harm than good.

This tragic and costly accident did lead to improvements in oil tanker safety and cleanup strategies. In 1990, the U.S Congress passed the Oil Pollution Act, which banned single-hulled oil tankers in U.S. waters after 2010, but the oil industry got this ban delayed until 2015. After a series of tanker accidents in European waters, the International Maritime Organization also acted to phase out single-hulled tankers by 2015. In 2010, about 300 single-hulled tankers still remained in service, including the Exxon Valdez, which was repaired and given a new name.

Now tugboats escort oil tankers into and out of the port of Valdez and the U.S. Coast Guard has a sophisticated system for tracking ships in Prince William Sound. In addition, well-trained oil-spill cleanup teams with pre-positioned equipment are available to help deal with small spills that might occur.

THINKING ABOUT
The Exxon Valdez Accident

What are two lessons we can learn from the Exxon Valdez oil spill?

20-5 How Can We Best Deal with Water Pollution?

CONCEPT 20-5 Reducing water pollution requires that we prevent it, work with nature to treat sewage, cut resource use and waste, reduce poverty, and slow population growth.

Reducing Surface Water Pollution from Nonpoint Sources

GOOD NEWS

There are a number of ways to reduce nonpoint sources of water pollution, most of which come from agricultural practices. Farmers can reduce soil erosion by keeping cropland covered with vegetation and using other soil conservation methods (see Chapter 12, pp. 304–307). They can also reduce the amount of fertilizer that runs off into surface waters by using slow-release fertilizer, using no fertilizer on steeply sloped land, and planting buffer zones of vegetation between cultivated fields and nearby surface waters. (See *The Habitable Planet*, Video 7 at **www.learner.org/resources/series209.html** to learn how scientists have reduced excessive nitrogen runoff from fertilizer.)

Organic farming (see Chapter 12 Core Case Study, p. 277) can also help to prevent water pollution caused by nutrient overload because it does not use commercial inorganic fertilizers and pesticides. By applying pesticides only when needed and relying more on integrated pest management (see Chapter 12, p. 302) farmers can also reduce pesticide runoff. In addition, they can control runoff and infiltration of manure from animal feedlots by planting buffer zones and by locating feedlots, pastures, and animal waste storage sites away from steeply sloped land, surface water, and flood zones.

HOW WOULD YOU VOTE?

Should we greatly increase efforts to reduce water pollution from nonpoint sources even though this could be quite costly? Cast your vote online at **www.cengage.com/login**.

Laws Can Help Reduce Water Pollution from Point Sources

The Federal Water Pollution Control Act of 1972 (renamed the Clean Water Act when it was amended in 1977) and the 1987 Water Quality Act form the basis of U.S. efforts to control pollution of the country's surface waters. The Clean Water Act sets standards for allowed levels of 100 key water pollutants and requires polluters to get permits that limit how much of these various pollutants they can discharge into aquatic systems. See **www.epa.gov/safewater/mcl.html** for the EPA standards for tap water.

The EPA has been experimenting with a *discharge trading policy*, which uses market forces to reduce water pollution as has been done with sulfur dioxide for air pollution control (see Chapter 18, pp. 486–487) in the United States. Under this program, a permit holder can pollute at higher levels than allowed in its permit if it buys credits from permit holders who are polluting below their allowed levels.

Environmental scientists warn that the effectiveness of such a system depends on how low the cap on total pollution levels in any given area is set, and on how regularly the cap is lowered. They also warn that discharge trading could allow water pollutants to build up to dangerous levels in areas where credits are bought. They call for careful scrutiny of the cap levels and for the gradual lowering of the caps to encourage prevention of water pollution and development of better pollution control technology. Neither of these strategies is a part of the current EPA discharge trading system. In addition, recent studies show the EPA has been lax in enforcing water pollution permits and in collecting fines for permit violations.

CASE STUDY

The U.S. Experience with Reducing Point-Source Pollution

According to the EPA, the Clean Water Act of 1972 led to numerous improvements in U.S. water quality. These are some of the encouraging developments that took place between 1972 and 2002 (the latest figures available):

GOOD NEWS

- The percentage of Americans served by community water systems that met federal health standards increased from 79% to 94%.
- The percentage of U.S. stream lengths found to be fishable and swimmable increased from 36% to 60% of those tested.
- The proportion of the U.S. population served by sewage treatment plants increased from 32% to 74%.
- Annual wetland losses decreased by 80%.

These are impressive achievements given the increases in the U.S. population and its per capita consumption of water and other resources since 1972. But there is more work to be done. In 2006, the EPA found that 45% of the country's lakes and 40% of the streams surveyed were still too polluted for swimming or fishing. It also found that runoff of animal wastes from hog, poultry, and cattle feedlots and meat processing facilities pollutes seven of every ten U.S. rivers.

Even where sewage treatment plants are in place, treated wastewater can contain nutrients that feed algal blooms, as was the case in Lake Washington (**Core Case Study**). Population growth and increasing levels of resource use and waste can overwhelm these sewage treatment systems.

CORE CASE STUDY

There are other problems. A 2007 government study found that tens of thousands of gasoline storage tanks in 43 states are leaking. In addition, according to a 2007 study by the U.S. Public Interest Research Group, more than half of the country's industrial and wastewater facilities exceeded the limits of their Clean Water Act pollution permits at least once in 2005. The average facility discharged close to four times its legal limit of water pollutants.

In 2009, the *New York Times* used the Freedom of Information Act to cite water pollution violations of the Clean Water Act and the Safe Drinking Water Act in every U.S. state. It found that one in five U.S. water treatment systems violated the Safe Drinking Water Act between 2003 and 2008, releasing sewage and chemicals such as arsenic and radioactive uranium. Such illegal discharges have affected more than 49 million Americans. You can view an interactive version of this database to find out about any violations in your community by visiting **www.nytimes.com/toxicwaters**.

In 2010, a study by *New York Times* reporters Charles Duhigg and Janet Roberts found that thousands of the country's largest water polluters (about 45% of them) have declared that the Clean Water Act no longer applies to waters that they are polluting. This results from a U.S. Supreme Court decision that created uncertainty over which waterways are protected by the law. As a result, many companies are currently violating the act and are not being prosecuted by the EPA, and water pollution levels are rising in some areas. About 117 million Americans get their drinking water from sources that are being polluted in this way. Many environmental and health scientists consider this a giant and dangerous step backward.

Toxic coal ash (see Chapter 15 Case Study, p. 384) is another problem that is difficult to deal with through the Clean Water Act. There are no U.S. federal regulations that specifically govern the disposal of coal ash. Some state regulators have used the Clean Water Act to combat such pollution, but the law was not designed to deal with this problem. According to a 2009 *New York Times* study of EPA records, 93% of the 313 coal-burning power plants that had violated the Clean Water Act between 2004 and 2009 had also avoided fines or other penalties by federal or state regulators. Other violators have managed to pay only small fines as well. For example, one plant in Pennsylvania, considered one of the country's dirtiest coal plants, was fined \$26,000 for 33 violations of the Clean Water Act during 2006 at a time when the plant's parent company earned \$1.1 billion.

Some environmental scientists call for strengthening the Clean Water Act. Suggested improvements include shifting the focus of the law to water pollution prevention instead of focusing mostly on end-of-pipe removal of specific pollutants; greatly increased monitoring for violations of the law and much larger mandatory fines for violators; and regulating irrigation water quality (for which there is no federal regulation).

Another suggestion is to expand the rights of citizens to bring lawsuits to ensure that water pollution laws are enforced. Still another suggestion is to rewrite the Clean Water Act to clarify that it covers all waterways (as Congress originally intended). This would eliminate confusion about which waterways are covered and stop major polluters from using this confusion to keep polluting in many areas.

Many people oppose these proposals, contending that the Clean Water Act's regulations are already too restrictive and costly. Some state and local officials argue that in many communities, it is unnecessary and too expensive to test all the water for pollutants as required by federal law.

HOW WOULD YOU VOTE? ✓

Should the U.S. Clean Water Act be strengthened? Cast your vote online at **www.cengage.com/login**.

Sewage Treatment Reduces Water Pollution

In rural and suburban areas with suitable soils, sewage from each house usually is discharged into a **septic tank** with a large drainage field (Figure 20-19). In this system, household sewage and wastewater is pumped into a settling tank, where grease and oil rise to the top and solids fall to the bottom and are decomposed by bacteria. The partially treated wastewater that results is discharged in a large drainage (absorption) field through small holes in perforated pipes embedded in porous gravel or crushed stone just below the soil's surface. As these wastes drain from the pipes and percolate downward, the soil filters out some potential pollutants and soil bacteria decompose biodegradable materials.

If these systems are not installed correctly and maintained properly, they can cause sewage to backup into homes or to pollute nearby groundwater and surface

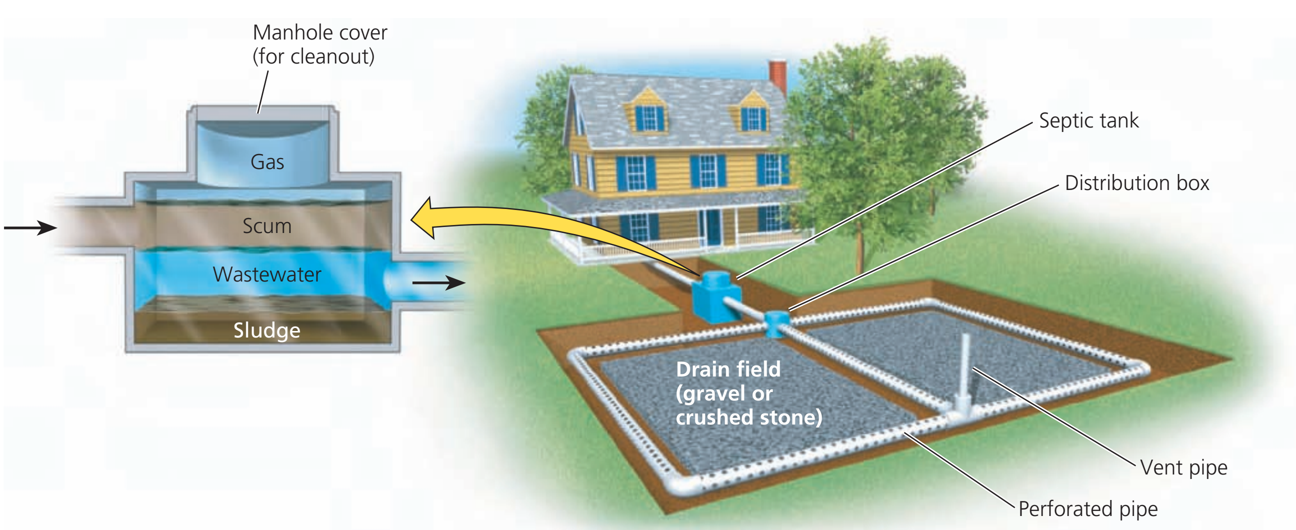


Figure 20-19 **Solutions:** *Septic tank systems* are often used for disposal of domestic sewage and wastewater in rural and suburban areas.

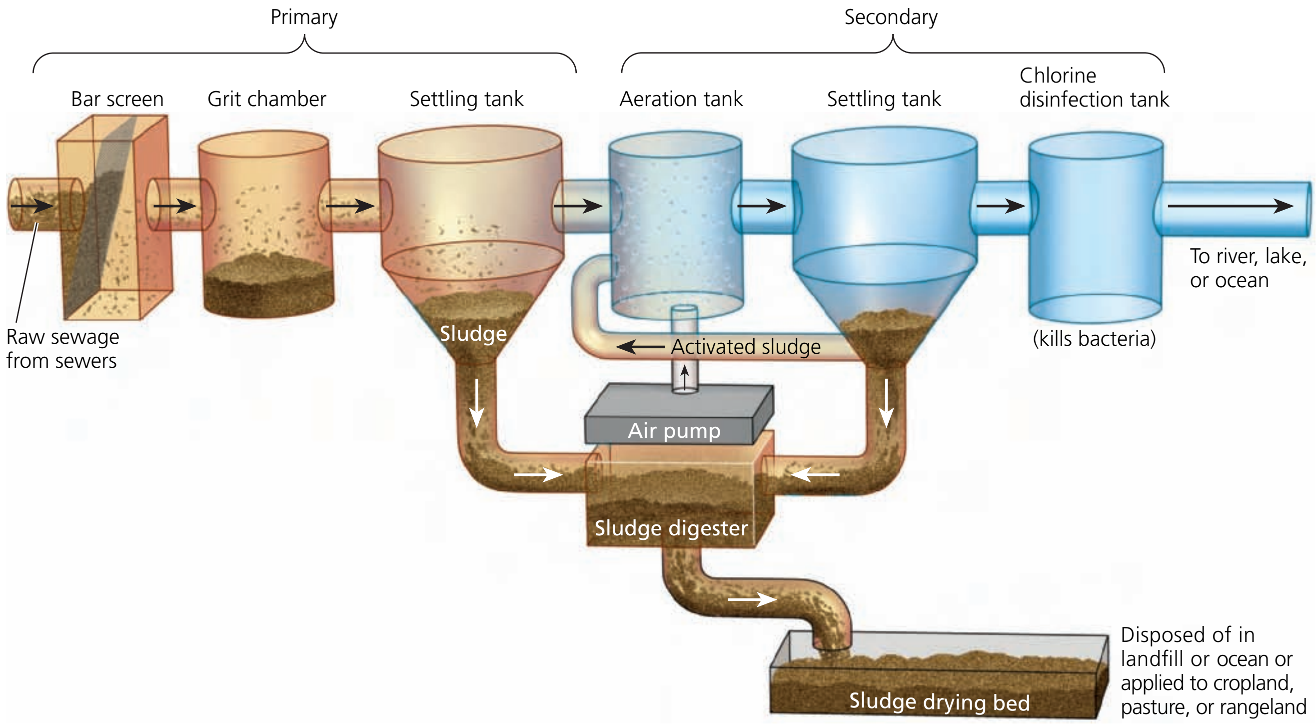


Figure 20-20 **Solutions:** Primary and secondary sewage treatment systems help to reduce water pollution. **Question:** What do you think should be done with the sludge produced by sewage treatment plants?

water. Chlorine bleaches, drain cleaners, and antibacterial soaps should not be used in these systems, because they can kill the bacteria that decompose the wastes. Kitchen sink garbage disposals should not be used either, because they can overload septic systems.

In urban areas in the United States and other more-developed countries, most waterborne wastes from homes, businesses, and storm runoff flow through a network of sewer pipes to *wastewater* or *sewage treatment plants.* Raw sewage reaching a treatment plant typically undergoes one or two levels of wastewater treatment. The first is **primary sewage treatment—**a *physical* process that uses screens and a grit tank to remove large floating objects and to allow solids such as sand and rock to settle out (Figure 20-20, left). Then the waste stream flows into a primary settling tank where suspended solids settle out as sludge. By itself, primary treatment removes about 60% of the suspended solids and 30–40% of the oxygen-demanding organic wastes from sewage. It removes no pathogens, phosphates, nitrates, salts, radioisotopes, trace amounts of medications, or pesticides.

The second level is **secondary sewage treatment**—a *biological* process in which aerobic bacteria remove as much as 90% of dissolved and biodegradable, oxygen-demanding organic wastes (Figure 20-20, right). A combination of primary and secondary treatment removes 95–97% of the suspended solids and oxygen-demanding organic wastes, 70% of most toxic metal compounds and nonpersistent synthetic organic chemicals, 70% of the phosphorus, and 50% of the nitrogen. But this process removes only a tiny fraction of persistent organic substances such as some pesticides and pharmaceuticals, and it does not kill pathogens.

A third level of cleanup, *advanced* or *tertiary sewage treatment*, uses a series of specialized chemical and physical processes to remove specific pollutants left in the water after primary and secondary treatment. In its most common form, advanced sewage treatment uses special filters to remove phosphates and nitrates from wastewater before it is discharged into surface waters. This third stage would help a great deal in reducing nutrient overload from nitrates and phosphates, but because of its high costs, it is not widely used.

Before discharge, water from sewage treatment plants usually undergoes *bleaching*, to remove water coloration, and *disinfection* to kill disease-carrying bacteria and some (but not all) viruses. The usual method for accomplishing this is *chlorination.* But chlorine can react with organic materials in water to form small amounts of chlorinated hydrocarbons. Some of these chemicals cause cancers in test animals, can increase the risk of miscarriages, and can damage the human nervous, immune, and endocrine systems. Use of other disinfectants, such as ozone and ultraviolet light, is increasing, but they cost more and their effects do not last as long as those of chlorination.

Federal law in the United States requires primary and secondary treatment for all municipal sewage treatment plants, but exemptions from secondary treatment are possible when the cost of installing such treatment poses an excessive financial burden on towns and cities. In addition, according to the EPA, at least two-thirds of the country's sewage treatment plants have sometimes violated water pollution regulations. Five hundred U.S. cities have also failed to meet federal standards for sewage treatment plants, and 34 East Coast cities simply screen out large floating objects from their sewage before discharging it into the coastal waters of the Atlantic Ocean.

Some cities have two separate networks of pipes, one for carrying storm-water runoff from streets and parking lots, and the other for carrying sewage. But 1,200 U.S. cities have combined these two systems into one set of pipes because it is cheaper. Heavy rains or a high volume of sewage from too many users hooked up to such combined systems can cause them to overflow and discharge untreated sewage directly into surface waters such as the Great Lakes (see Case Study, p. 538). According to the EPA, at least 40,000 such overflows occur each year in the United States, and about 7.1 million people get sick every year from swimming in waters contaminated by overflows that contain sewage. The best way to deal with this overflow problem is to prevent it by using separate systems to carry storm water and sewage (**Concept 20-5**).

We Can Improve Conventional Sewage Treatment

Environmental scientist Peter Montague calls for redesigning the conventional sewage treatment system shown in Figure 20-20. The idea is to prevent toxic and hazardous chemicals from reaching sewage treatment plants and thus from getting into sludge and water discharged from such plants.

Montague suggests several ways to do this. One is to require industries and businesses to remove toxic and hazardous wastes from water sent to municipal sewage treatment plants. Another is to encourage industries to reduce or eliminate their use and waste of toxic chemicals.

HOW WOULD YOU VOTE?

Should we ban the discharge of toxic chemicals into pipes leading to sewage treatment plants? Cast your vote online at **www.cengage.com/login**.

Another suggestion is to require or encourage more households, apartment buildings, and offices to eliminate sewage outputs by switching to waterless, odorless *composting toilet systems*, to be installed, maintained, and managed by professionals. These systems, pioneered several decades ago in Sweden, convert nutrient-rich human fecal matter into a soil-like humus that can be used as a fertilizer supplement. About once or twice a year, vendors collect the humus and sell it as a soil conditioner. This process returns plant nutrients in human waste to the soil and thus mimics the natural chemical cycling **principle of sustainability** (see back cover). They also reduce the need for energy-intensive and water-polluting commercial fertilizers. The downside is that the initial cost for homeowners is much higher than that of conventional toilets.

On a larger scale, such systems would be cheaper to install and maintain than current sewage systems are, because they do not require vast systems of underground pipes connected to centralized sewage treatment plants. They also save large amounts of water, reduce water bills, and decrease the amount of energy used to pump and purify water. The U.S. EPA lists several brands of dry composting toilets approved for use in the United States. One of the authors of this book (Miller) used a compositing toilet for over a decade with no problems in his office-home facility. This more environmentally sustainable replacement for the conventional toilet is now being used in more than a dozen countries, including China, India, Mexico, Syria, and South Africa.

Many communities are using unconventional, but highly effective, *wetland-based sewage treatment systems*, which work with nature (Science Focus at right). Wetland-based sewage treatment systems would be ideal in some less-developed countries where water is short and disease is rampant. They would also be useful in areas where valuable wetlands have been destroyed, such as along the U.S. Gulf Coast. Using such systems can be less costly for taxpayers, and in building them, people would be restoring devastated coastal marshlands, which are economically and ecologically vital natural resources.

There Are Sustainable Ways to Reduce and Prevent Water Pollution

It is encouraging that since 1970, most of the world's more-developed countries have enacted laws and regulations that have significantly reduced point-source water pollution. These improvements were largely the result of *bottom-up* political pressure on elected officials by individuals and groups.

On the other hand, little has been done to reduce water pollution in most of the less-developed countries. However, by 2020, China plans to provide all of its cities with small sewage treatment plants that will make wastewater clean enough to be recycled back into the urban water supply systems. If China is successful in this ambitious plan, it could become a world leader in developing ways to tackle both water pollution and water scarcity through systems that recycle water, in keeping with the chemical cycling **principle of sustainability**.

To environmental and health scientists, the next step is to increase efforts to reduce and prevent water pollution in both more- and less-developed coun-

SCIENCE FOCUS

Treating Sewage by Working with Nature

Some communities and individuals are seeking better ways to purify sewage by working with nature (**Concept 20-5**). Biologist John Todd has developed an ecological approach to treating sewage, which he calls *living machines* (Figure 20-C).

This purification process begins when sewage flows into a passive solar greenhouse or outdoor site containing rows of large open tanks populated by an increasingly complex series of organisms. In the first set of tanks, algae and microorganisms decompose organic wastes, with sunlight speeding up the process. Water hyacinths, cattails, bulrushes, and other aquatic plants growing in the tanks take up the resulting nutrients.

After flowing though several of these natural purification tanks, the water passes through an artificial marsh made of sand, gravel, and bulrushes, which filters out algae and remaining organic waste. Some of the plants also absorb, or *sequester*, toxic metals such as lead and mercury and secrete natural antibiotic compounds that kill pathogens.

Next, the water flows into aquarium tanks, where snails and zooplankton consume microorganisms and are in turn consumed by crayfish, tilapia, and other fish that can be eaten or sold as bait. After 10 days, the clear water flows into a second artificial marsh for final filtering and cleansing. The water can be made pure enough to drink by treating it with ultraviolet light or by passing the water through an ozone generator, usually immersed out of sight in an attractive pond or wetland habitat. Operating costs are about the same as those of a conventional sewage treatment plant.


Ocean Arks International

Figure 20-C Solutions: This is an ecological wastewater purification system called a *living machine*. This Solar Sewage Treatment Plant is in the U.S. city of Providence, Rhode Island. Biologist John Todd is demonstrating this ecological process he invented for purifying wastewater by using the sun and a series of tanks containing living organisms. Todd and others are conducting research to perfect such solar–aquatic sewage treatment systems based on working with nature.

More than 800 cities and towns around the world (150 in the United States, including West Palm Beach, Florida, and Phoenix, Arizona) use natural or artificially created wetlands to treat sewage as a lower-cost alternative to expensive waste treatment plants. For example, Arcata, California—a coastal town of 16,000 people—created some 65 hectares (160 acres) of wetlands between the town and the adjacent Humboldt Bay. The marshes and ponds, developed on land that was once a dump, act as a natural waste treatment plant. The project cost was less than half the estimated price of a conventional treatment plant.

This system returns purified water to Humboldt Bay, and the sludge that is removed is processed for use as fertilizer. The marshes and ponds also serve as an Audubon Society bird sanctuary, which provides habitats for thousands of seabirds, otters, and other marine animals. The town even celebrates its natural sewage treatment system with an annual "Flush with Pride" festival.

This approach and the living machine system developed by John Todd apply all three **principles of sustainability:** using solar energy, employing natural processes to remove and recycle nutrients and other chemicals, and relying on a diversity of organisms and natural processes.

Critical Thinking

Can you think of any disadvantages of using such a nature-based system instead of a conventional sewage treatment plant? Do you think any such disadvantages outweigh the advantages? Why or why not?

tries. They would begin by asking the question: *How can we avoid producing water pollutants in the first place?* (**Concept 20-5**). Figure 20-21 lists ways to achieve this goal over the next several decades.

This shift to pollution prevention will not take place unless citizens put political pressure on elected officials and also take actions to reduce their own daily contributions to water pollution. Figure 20-22 (p. 554) lists some actions you can take to help reduce water pollution.

Solutions

Water Pollution

- Prevent groundwater contamination
- Reduce nonpoint runoff
- Reuse treated wastewater for drinking and irrigation
- Find substitutes for toxic pollutants
- Work with nature to treat sewage
- Practice the three R's of resource use (reduce, reuse, recycle)
- Reduce air pollution
- Reduce poverty
- Slow population growth

Figure 20-21 There are a number of ways to prevent and reduce water pollution (**Concept 20-5**). **Questions:** Which two of these solutions do you think are the most important? Why?

Figure 20-22 **Individuals matter:** You can help reduce water pollution. **Questions:** Which three of these actions do you think are the most important? Why?

What Can You Do?

Reducing Water Pollution

- Fertilize garden and yard plants with manure or compost instead of commercial inorganic fertilizer
- Minimize your use of pesticides, especially near bodies of water
- Prevent yard wastes from entering storm drains
- Do not use water fresheners in toilets
- Do not flush unwanted medicines down the toilet
- Do not pour pesticides, paints, solvents, oil, antifreeze, or other products containing harmful chemicals down the drain or onto the ground

Here are this chapter's *three big ideas*:

- There are a number of ways to purify drinking water, but the most effective and cheapest strategy is pollution prevention.
- The key to protecting the oceans is to reduce the flow of pollution from land and air, and from streams emptying into ocean waters.
- Reducing water pollution requires that we prevent it, work with nature in treating sewage, cut resource use and waste, reduce poverty, and slow population growth.

REVISITING Lake Washington and Sustainability

CORE CASE STUDY

SUSTAINABILITY

The story of Lake Washington (**Core Case Study**) is an example of people loving a natural resource and abusing it at the same time. For many years, Seattle residents assumed the lake could easily absorb their treated sewage and still remain a good place for swimming and boating. Eventually, with the help of scientific inquiry and investigation, they learned that the numbers of people using the lake could overwhelm its natural systems. A technical solution was found for dealing with sewage treatment effluent, but now continually increasing pressures due to a growing population are again overwhelming the natural systems of Lake Washington and the Puget Sound.

This story is instructive for dealing with pollution problems in other more-developed countries and in rapidly growing less-developed countries. Pollution control for the good of the world's water supplies is within our reach. But even more hopeful is the possibility of shifting our emphasis from cleaning up water pollution to reducing and preventing it.

The three **principles of sustainability** (back cover) can guide us in reducing and preventing pollution. We can use solar energy to purify the water we use. Recycling more water will help us to reduce water waste, and we can use natural nutrient cycles to treat our waste in wetland-based sewage treatment systems (Science Focus, p. 553). Preserving biodiversity by avoiding the disruption of aquatic systems and their bordering terrestrial systems, which in turn helps to reduce pollution, is a key factor in maintaining water supplies and water quality. Controlling human population growth and levels of resource use and waste is also fundamental to maintaining water quality.

It is a hard truth to swallow, but nature does not care if we live or die. We cannot survive without the oceans, for example, but they can do just fine without us.

ROGER ROSENBLATT

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 529. Describe the cleanup of Lake Washington near Seattle (**Core Case Study**) and list the three lessons learned from this process. CORE CASE STUDY
2. What is **water pollution**? Distinguish between **point sources** and **nonpoint sources** of water pollution, and give an example of each. List nine major types of water pollutants and give an example of each. List three diseases transmitted to humans by polluted water. Describe chemical and biological methods that scientists use to measure water quality.
3. Describe how streams can cleanse themselves of some pollutants and how these cleansing processes can be overwhelmed. Describe the state of stream pollution in more- and less-developed countries.
4. Give two reasons why lakes cannot cleanse themselves as readily as streams can. Distinguish between **eutrophication** and **cultural eutrophication**. List ways to prevent

or reduce cultural eutrophication. Describe the pollution of the Great Lakes and the progress made in reducing it.

5. Explain why groundwater cannot cleanse itself very well. What are the major sources of groundwater contamination in the United States? Describe the threat from arsenic in groundwater. List ways to prevent or clean up groundwater contamination. Describe three ways to provide safe drinking water in poor countries.

6. Describe U.S. laws for protecting drinking water quality. Describe the environmental problems caused by the widespread use of bottled water.

7. How are coastal waters and deeper ocean waters polluted? What causes harmful algal blooms and what are their negative effects? Describe oxygen depletion in the northern Gulf of Mexico. How serious is oil pollution of the oceans, what are its effects, and what can be done to reduce such pollution? Describe the damage caused by the 2010 oil well blowout in the U.S. Gulf Coast. Describe the effects of the 1989 Exxon Valdez oil spill in Alaskan waters.

8. List ways to reduce water pollution from **(a)** nonpoint sources and **(b)** point sources. Describe the U.S. experience with reducing point-source water pollution. What is a **septic tank** and how does it work? Describe how **primary sewage treatment** and **secondary sewage treatment** are used to help purify water. What are the options for dealing with sewage sludge?

9. How would Peter Montague improve conventional sewage treatment? What is a composting toilet system? Describe how we can use wetlands to treat sewage. Describe John Todd's use of living machines to treat sewage. List six ways to prevent or reduce water pollution. List five things you can do to reduce water pollution.

10. Describe the connections between the cleanup of Lake Washington (**Core Case Study**) and the three **principles of sustainability**. CORE CASE STUDY SUSTAINABILITY

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. What were two important roles played by the scientists who studied Lake Washington as discussed in the **Core Case Study** that opens this chapter? Explain how the story might have been different if the scientists had not fulfilled each role. CORE CASE STUDY

2. Lake Washington and the Puget Sound now face new problems similar to those of the past, as suggested in the **Core Case Study**. Describe the nature of those problems and suggest possible solutions. CORE CASE STUDY

3. A large number of dead fish are found floating in a lake. How would you determine whether they died from cultural eutrophication or from exposure to toxic chemicals?

4. If you were a regulator charged with drawing up plans for controlling water pollution, briefly describe one idea for controlling water pollution from each of the following sources: **(a)** a pipe from a factory discharging effluent into a stream, **(b)** a parking lot at a shopping mall bordered by a stream, and **(c)** a farmer's field on a slope next to a stream.

5. What role does population growth play in the problems of **(a)** groundwater pollution and **(b)** coastal water pollution?

6. When you flush your toilet, where does the wastewater go? Trace the actual flow of this water in your community from your toilet through sewers to a wastewater treatment plant and from there to the environment. Try to visit a local sewage treatment plant to see what it does with your wastewater. Compare the processes it uses with those shown in Figure 20-20. What happens to the sludge produced by this plant? What improvements, if any, would you suggest for this plant?

7. In your community,

a. what are the principal nonpoint sources of contamination of surface water and groundwater?
b. what is the source of drinking water?
c. how is drinking water treated?
d. how many times during each of the past 5 years have levels of tested contaminants violated federal standards? Were violations reported to the public?
e. what problems related to drinking water, if any, have arisen in your community? What actions, if any, has your local government taken to solve them?
f. is groundwater contamination a problem? If so, where, and what has been done about the problem?
g. is there a vulnerable aquifer or critical recharge zone that needs protection to ensure the quality of groundwater? Is your local government aware of this? What action (if any) has it taken?

8. List three ways in which you could apply **Concept 20-5** to making your lifestyle more environmentally sustainable.

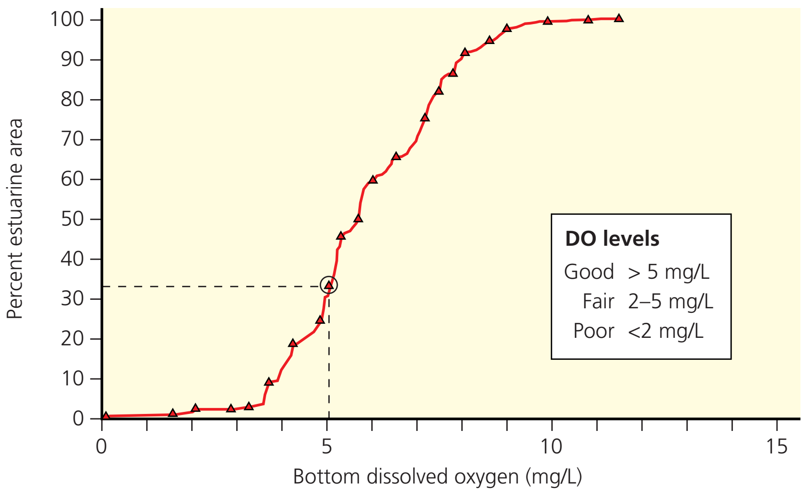
9. Congratulations! You are in charge of the world. What are three actions you would take to **(a)** sharply reduce point-source water pollution in more-developed countries, **(b)** sharply reduce nonpoint-source water pollution throughout the world, **(c)** sharply reduce groundwater pollution throughout the world, and **(d)** provide safe drinking water for the poor and for other people in less-developed countries?

10. List two questions that you would like to have answered as a result of reading this chapter.

DATA ANALYSIS

In 2006, scientists assessed the overall condition of the estuaries on the western coasts of the U.S. states of Oregon and Washington. To do so, they took measurements of various characteristics of the water, including dissolved oxygen (DO), in selected locations within the estuaries. The concentration of DO for each site was measured in terms of milligrams (mg) of oxygen per liter (L) of water sampled. The scientists used the following DO concentration ranges and quality categories to rate their water samples: water with greater than 5 mg/L of DO was considered *good* for supporting aquatic life; water with 2 to 5 mg/L of DO was rated as *fair*; and water with less than 2mg/L of DO was rated as *poor*.

The following graph shows measurements taken in bottom water at 242 locations. Each triangle mark represents one or more measurements. The x-axis on this graph represents DO concentrations in mg/L. The y-axis represents percentages of the total area of estuaries studied (estuarine area).



Concentrations of dissolved oxygen in bottom waters of estuaries in Washington and Oregon.

To read this graph, pick one of the triangles and observe the values on the x- and y-axes. For example, note that the circled triangle lines up approximately with the 5-mg/L mark on the x-axis and with a value of about 34% on the y-axis. This means that waters at this particular measurement station (or stations), along with about 34% of the total area being studied, are estimated to have a 5% or lower DO concentration.

Use this information, along with the graph to answer the following questions:

1. Half of the estuarine area has waters falling below a certain DO concentration level, and the other half has waters above that level. What is that level, in mg/L?
2. Give your estimate of the highest DO concentration measured and your estimate of the lowest concentration.
3. Approximately what percentage of the estuarine area studied is considered to have poor DO levels? About what percentage has fair DO levels, and about what percentage has good DO levels?

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Solid and Hazardous Waste

21

E-waste—An Exploding Problem

CORE CASE STUDY

Electronic waste, or *e-waste*, consists of discarded television sets, cell phones, computers, and other electronic devices (Figure 21-1). It is the fastest-growing solid waste problem in the United States and in the world. Each year, Americans discard an estimated 155 million cell phones, 48 million personal computers, and many more millions of television sets, iPods, Blackberries, FAX machines, printers, and other electronic products. In 2009, an estimated 100 million additional television sets, made obsolete as the United States shifted to digital TV, were discarded.

Most e-waste ends up in landfills and incinerators, even though 80% of the components in these devices contain materials that can be recycled or reused. These wasted resources include high-quality plastics and valuable metals such as aluminum, copper, platinum, silver, and gold. E-waste is also a source of toxic and hazardous pollutants, including polyvinylchloride (PVC), brominated flame retardants, lead, and mercury. These chemicals can contaminate air, water, and soil, and cause serious health problems and early death for e-waste workers.

Fotopic/Miles Simmons/PhototakeUSA

Figure 21-1 *Rapidly growing electronic waste* (e-waste) from discarded computers and other electronic devices consumes resources and pollutes the air, water, and land with harmful compounds. **Questions:** Have you disposed of an electronic device lately? If so, how did you dispose of it?

Much of the e-waste in the United States that is not buried or incinerated is shipped to Asia (mostly China and India) and poor African nations for dangerous low-tech recycling. Labor is cheap in these countries and environmental regulations are weak. Workers there—many of them children—dismantle, burn, and treat e-waste products with acids to recover valuable metals and reusable parts. As they do this, they are exposed to toxic metals and other harmful chemicals. The remaining scrap is dumped into waterways and fields or burned in open fires, exposing many people to highly toxic chemicals called dioxins. This practice is a dark and dangerous side of recycling.

Transfer of such hazardous waste from more-developed to less-developed countries was banned by the International Basel Convention, a treaty now signed by 172 countries to reduce and control the movement of hazardous waste across international borders. Despite such a ban, much of the world's e-waste is not officially classified as hazardous waste or is illegally smuggled from some European Union countries into countries such as China and India. The United States can export this hazardous e-waste legally because it is the only industrialized nation that has not ratified the Basel Convention.

The European Union (EU) has led the way in dealing with e-waste. A *cradle-to-grave* approach requires manufacturers to take back electronic products at the end of their useful lives and repair, remanufacture, or recycle them, and e-waste is banned from landfills and incinerators. To cover the cost, consumers pay a recycling tax on electronic products. Japan is also adopting cradle-to-grave standards for electronic devices and appliances. But because of the high costs involved in complying with these laws, much of this waste that is supposed to be recycled domestically is shipped illegally to China, India, and various African countries for unregulated recycling, which we discuss further in this chapter.

But recycling probably will not keep up with the explosive growth of e-waste, and there is money to be made from illegally sending such materials to other countries. According to Jim Puckett, coordinator of the Basel Action Network, a charitable organization working to stem the international trade in toxic waste, the only real long-term solution is a *prevention* approach. With this approach, electronic products would be designed and manufactured without the use of toxic materials and could be easily repaired and recycled. Electronic waste is just one of many types of solid and hazardous wastes discussed in this chapter.

Key Questions and Concepts

21-1 What are solid waste and hazardous waste, and why are they problems?

CONCEPT 21-1 Solid waste contributes to pollution and represents the unnecessary consumption of resources; hazardous waste contributes to pollution as well as natural capital degradation, health problems, and premature deaths.

21-2 How should we deal with solid waste?

CONCEPT 21-2 A sustainable approach to solid waste is first to reduce it, then to reuse or recycle it, and finally to safely dispose of what is left.

21-3 Why is reusing and recycling materials so important?

CONCEPT 21-3 Reusing items decreases the consumption of matter and energy resources, and reduces pollution and natural capital degradation; recycling does so to a lesser degree.

21-4 What are the advantages and disadvantages of burning or burying solid waste?

CONCEPT 21-4 Technologies for burning and burying solid wastes are well developed, but burning contributes to air and water pollution and greenhouse gas emissions, and buried wastes eventually contribute to the pollution and degradation of land and water resources.

21-5 How should we deal with hazardous waste?

CONCEPT 21-5 A sustainable approach to hazardous waste is first to produce less of it, then to reuse or recycle it, then to convert it to less hazardous materials, and finally to safely store what is left.

21-6 How can we make the transition to a more sustainable low-waste society?

CONCEPT 21-6 Shifting to a low-waste society requires individuals and businesses to reduce resource use and to reuse and recycle wastes at local, national, and global levels.

Note: Supplements 2 (p. S3), 4 (p. S11), and 9 (p. S57) can be used with this chapter.

Solid wastes are only raw materials we're too stupid to use.

ARTHUR C. CLARKE

21-1 What Are Solid Waste and Hazardous Waste, and Why Are They Problems?

CONCEPT 21-1 Solid waste contributes to pollution and represents the unnecessary consumption of resources; hazardous waste contributes to pollution as well as to natural capital degradation, health problems, and premature deaths.

We Throw Away Huge Amounts of Useful Things and Hazardous Materials

In the natural world, wherever humans are not dominant, there is essentially no waste because the wastes of one organism become nutrients for others (see Figure 3-12, p. 63). In other words, wastes equal nutrients. This natural recycling of nutrients follows one of the three **principles of sustainability**.

On the other hand, modern humans produce huge amounts of waste material that go unused and pollute the environment. Because of the law of conservation of matter (see Chapter 2, p. 43) and the nature of human lifestyles, we will always produce some waste. But studies indicate that we could reduce this waste of potential resources and the resulting environmental harm it causes by as much as 90%.

One major category of waste is **solid waste**—any unwanted or discarded material we produce that is not a liquid or a gas. Solid waste can be divided into two types. One type is **industrial solid waste** produced by mines, farms, and industries that supply people with goods and services. The other is **municipal solid waste (MSW)**, often called *garbage* or *trash*, which consists of the combined solid waste produced by homes and workplaces

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. GOOD NEWS refers to good news about the environmental challenges we face.

other than factories. Examples include paper and cardboard, food wastes, cans, bottles, yard wastes, plastics, metals, glass, and e-waste (**Core Case Study**). Much of this waste ends up in rivers (see Figure 1-11, p. 14, and Figure 20-9, p. 536), lakes (Figure 20-6, p. 531), and open trash dumps.

In more-developed countries, most MSW is buried in landfills or burned in incinerators. In many less-developed countries, much of it ends up in open dumps, where poor people eke out a living finding items they can sell for reuse or recycling (see Figure 1-19, p. 22). In 2008, the Organization for Economic Cooperation and Development projected that between 2005 and 2030, the world's output of MSW will almost double.

China has undergone very rapid industrialization and economic growth. Its factories are turning out massive quantities of goods for sale domestically and all over the world. As a result, several hundred million of the country's people are now able to buy more things. This has led to mountains of MSW being trucked out of China's rapidly growing cities to rural areas, where it is polluting the air, water, and soil.

Another major category of waste is **hazardous**, or **toxic, waste**, which threatens human health or the environment because it is poisonous, dangerously chemically reactive, corrosive, or flammable. Examples include industrial solvents, hospital medical waste, car batteries (containing lead and acids), household pesticide products, dry-cell batteries (containing mercury and cadmium), and incinerator ash. Figure 21-2 lists some of the harmful chemicals found in many homes. The two largest classes of hazardous wastes are *organic compounds* (such as various solvents, pesticides, PCBs, and dioxins) and nondegradable *toxic heavy metals* (such as lead, mercury, and arsenic).

Another form of extremely hazardous waste is highly radioactive waste produced by nuclear power plants and nuclear weapons facilities (see Chapter 16, pp. 390–391). Such wastes must be stored safely for 10,000 to 240,000 years depending on what radioactive isotopes are present in them. But after 60 years of research, scientists and governments have not found a scientific and politically acceptable way to safely isolate these dangerous wastes for periods of time that, in some cases, will be longer than the 200,000 years that our species has been around.

According to the UN Environment Programme (UNEP), more-developed countries produce 80–90% of the world's hazardous wastes, and the United States is the largest producer. In order, the top three U.S. producers of hazardous waste are the military, the chemical industry, and the mining industry. As China continues to industrialize, largely without adequate pollution controls, it may take over the number one spot.

There are two reasons for sharply reducing the amount of solid and hazardous wastes we produce. One reason is that at least three-fourths of these materials represent an unnecessary consumption of the earth's resources and thus violate the chemical cycling **sustainability principle**. Studies show that we could reuse and recycle up to 90% of the MSW we produce and thus reduce our resource use dramatically (see the quote on p. 558).

What Harmful Chemicals Are in Your Home?

Cleaning
- Disinfectants
- Drain, toilet, and window cleaners
- Spot removers
- Septic tank cleaners

Paint Products
- Paints, stains, varnishes, and lacquers
- Paint thinners, solvents, and strippers
- Wood preservatives
- Artist paints and inks

General
- Dry-cell batteries (mercury and cadmium)
- Glues and cements


Gardening
- Pesticides
- Weed killers
- Ant and rodent killers
- Flea powders

Automotive
- Gasoline
- Used motor oil
- Antifreeze
- Battery acid
- Brake and transmission fluid

Figure 21-2 Harmful chemicals are found in many homes. The U.S. Congress has exempted disposal of these materials from government regulation. For more details on hazardous chemicals in household products see www.HealthyStuff.org and the Cancer Prevention Coalition website at www.preventcancer.com. **Question:** Which of these chemicals are in your home?

A second reason to reduce wastes is that the manufacturing of the products we use and often discard creates huge amounts of air pollution, greenhouse gases, water pollution (Figure 21-3, p. 560), land degradation, and ocean pollution (see Figure 20-16, p. 545). According to a 2009 report by the U.S.-based Ocean Conservancy, a tidal wave of solid and hazardous wastes is threatening the world's ocean ecosystems and seafood supplies (**Concept 21-1**).

Solid Waste in the United States

The United States leads the world in total solid waste production and in solid waste per person. With only 4.6% of the world's population, the United States produces about one-third of the world's solid waste. About 98.5% of all solid waste produced in the United States is industrial solid waste from mining (76%), agriculture (13%), and industry (9.5%).

Suppose you buy a desktop computer. You may not know that manufacturing it required 700 or more different materials obtained from mines, oil wells, and chemical factories all over the world. You may also

Lineair Fotochief/Peter Arnold, Inc.

Figure 21-3 **Natural capital degradation:** These solid wastes pollute a river in Jakarta, Indonesia, a city of more than 11 million people. The man in the boat is looking for items to salvage or sell.

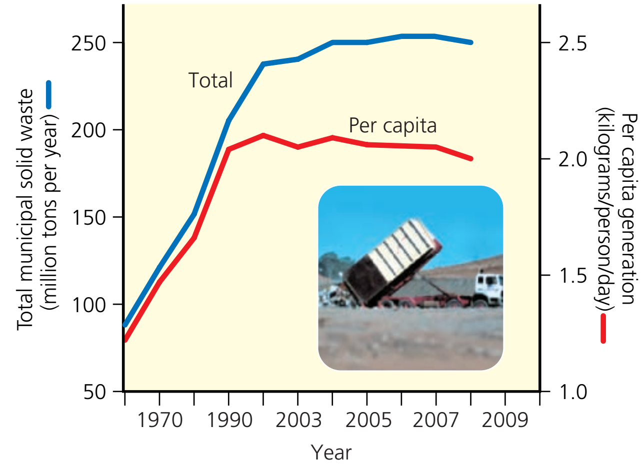


Figure 21-4 This graph shows the total and per capita production of municipal solid waste in the United States, 1960–2008. (Data from the U.S. Environmental Protection Agency)

be unaware that for every 0.5 kilogram (1 pound) of electronics it contains, approximately 3,600 kilograms (8,000 pounds) of solid and liquid waste were created—an amount roughly equal to the weight of a very large pickup truck. The manufacturing of a single semiconductor computer chip generates about 630 times its weight in solid and hazardous wastes.

Extracting resources and using them to make your computer also required large amounts of energy produced mostly by burning fossil fuels, which emitted CO_2 and numerous other pollutants into the atmosphere. If you consider all the computers and other products made, you can see how industrial solid waste and hazardous waste mount up.

Besides industrial waste, the remaining 1.5% of U.S. solid waste is municipal solid waste (MSW). In 2008, the largest categories of all MSW (before recycling) were paper and cardboard (31%), yard waste (13%), food waste (13%), plastics (12%), and metals (8%). This 1.5% of the overall U.S. solid waste problem is still huge (Figure 21-4).

Every year, the United States generates enough MSW to fill a bumper-to-bumper convoy of garbage trucks encircling the globe almost eight times! About 67% of it is dumped in landfills (54%) or incinerated (13%), but much of it ends up as litter.

Consider some of the solid wastes that consumers throw away in the high-waste economy of the United States:

- Enough tires each year to encircle the planet almost three times (Figure 21-5).
- An amount of disposable diapers every year that, if linked end to end, would reach to the moon and back seven times.
- Enough carpet each year to cover the U.S. state of Delaware.
- About 24 million rolls of toilet paper a day, which if laid end-to-end, would stretch from New York City to London.
- About 2.5 million nonreturnable plastic bottles *every hour*. If laid end-to-end, the number of these bottles produced each year would reach from the earth to the moon and back about 6 times.
- About 274 million plastic shopping bags per day, an average of about 3,200 every second.
- About 25 million metric tons (27 million tons) of edible food per year that is roughly equal to the combined weight of 8 million Hummer (H2) motor vehicles.
- Enough office paper each year to build a wall 3.5 meters (11 feet) high across the country from New York City to San Francisco, California.
- Some 186 billion pieces of junk mail (an average of 660 pieces per American) every year, about 45% of which are thrown in the trash unopened.

Most of these wastes break down very slowly, if at all. Lead, mercury, glass, plastic foam, and most plastic bottles essentially take forever to break down; an aluminum can takes 500 years; plastic bags, 400 to 1,000 years, and a plastic six-pack holder, 100 years.

Jim Wark/Peter Arnold, Inc.

Figure 21-5 Hundreds of millions of discarded tires have accumulated in this massive tire dump in Midway, Colorado (USA). Lehigh Technologies has developed a recycling method that uses liquid nitrogen to freeze the scrap tires, making them brittle. The rubber is then pulverized into a fine powder, which can be used in a variety of products such as paints, sealants, and coatings. A preventive approach to managing this waste would be to double the average lifetime of tires in order to reduce the number thrown away each year.

Some encouraging news is that since 1990, the average weight of MSW per American has leveled off (Figure 21-4), mostly because of increased recycling and the use of lighter-weight products such as cans, thinner plastic packaging, and high-strength plastics to replace the use of some metals. (See p. S10 in Supplement 3 for a surprising story about the history of trash production and waste recycling in New York City [USA].)

GOOD NEWS

21-2 How Should We Deal with Solid Waste?

▶ **CONCEPT 21-2 A sustainable approach to solid waste is first to reduce it, then to reuse or recycle it, and finally to safely dispose of what is left.**

We Can Burn or Bury Solid Waste or Produce Less of It

We can deal with the solid wastes we create in two ways. One method is **waste management**, in which we attempt to control wastes in ways that reduce their environmental harm without seriously trying to reduce the amount of waste produced. This output approach begins with the question, "What do we do with solid waste?" It typically involves mixing wastes together and then transferring them from one part of the environment to another, usually by burying them, burning them, or shipping them to another location.

The second approach is **waste reduction**, in which we produce much less waste and pollution, and the wastes we do produce are considered to be potential resources that we can reuse, recycle, or compost (**Concept 16-2**). It begins with the question, "How can we avoid producing so much solid waste?" With this prevention approach, we could think of trash cans and garbage trucks as resource containers that carry materials to recycling or composting facilities, rather than to landfills and incinerators.

There is no single solution to the solid waste problem. Most analysts call for using **integrated waste management**—a variety of coordinated strategies for both waste disposal and waste reduction (Figure 21-6, p. 562). Environmental scientists call for much greater emphasis on waste reduction (Figure 21-7, p. 562) rather than on waste disposal. In 2008, the EPA reported

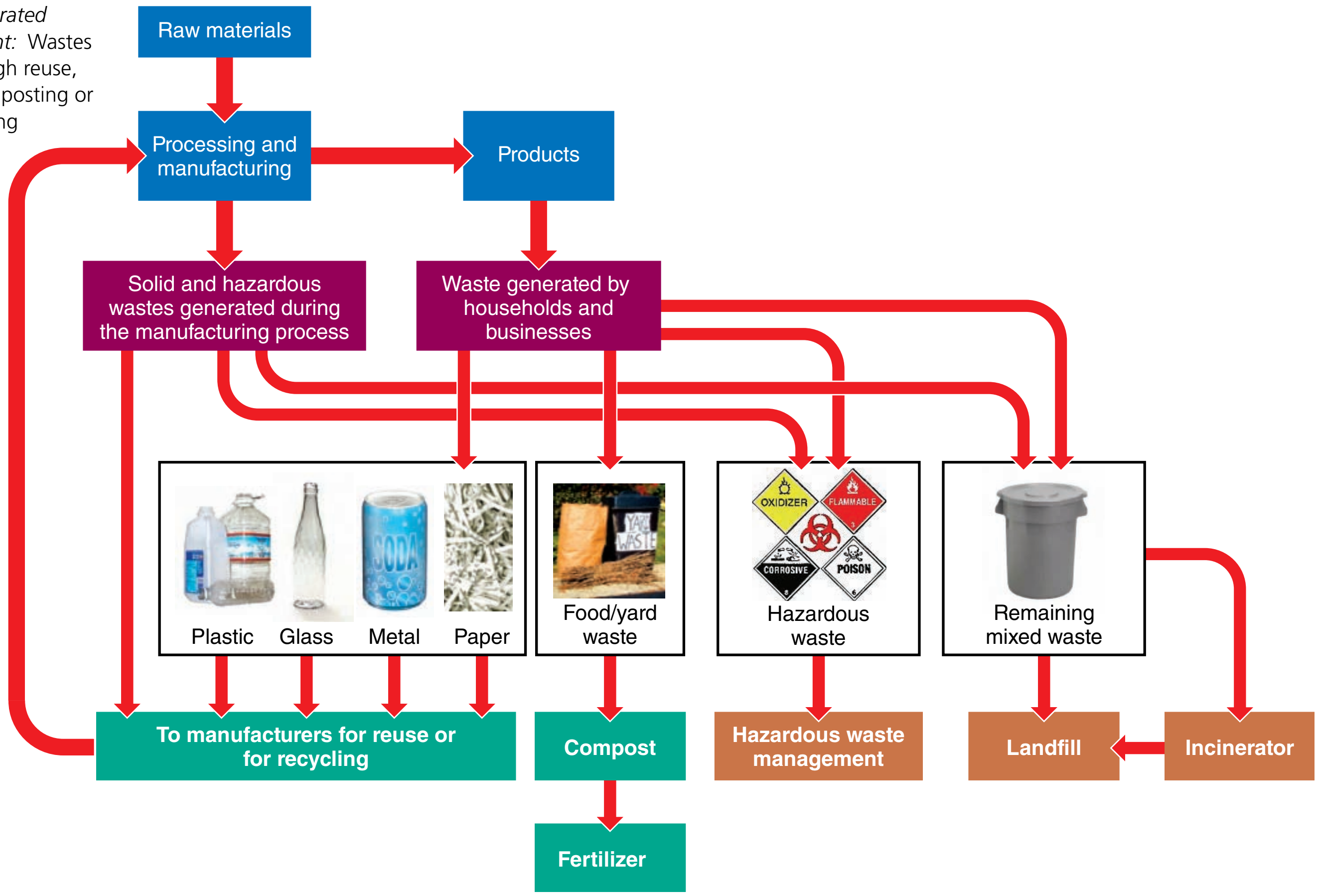


Figure 21-6 *Integrated waste management:* Wastes are *reduced* through reuse, recycling, and composting or *managed* by burying them in landfills or incinerating them. Most countries rely primarily on burial and incineration. **Question:** What happens to the solid waste you produce?

that 54% of the MSW produced in the United States was buried in landfills (Science Focus at right) and 13% was incinerated. About 33% was either recycled (25%) or composted (8%)—up from 16% in 1990.

Some scientists and economists estimate that 75–90% of the solid waste we produce could be eliminated by a combination of the strategies shown in Figure 21-7. Let us look more closely at these options in the order of priorities suggested by scientists.

We Can Cut Solid Wastes by Reducing, Reusing, and Recycling

Waste reduction (**Concept 21-2**) is based on three Rs:

- **Reduce:** consume less and live a simpler lifestyle.
- **Reuse:** rely more on items that we can use repeatedly instead of on throwaway items, and buy necessary items secondhand or borrow or rent them.

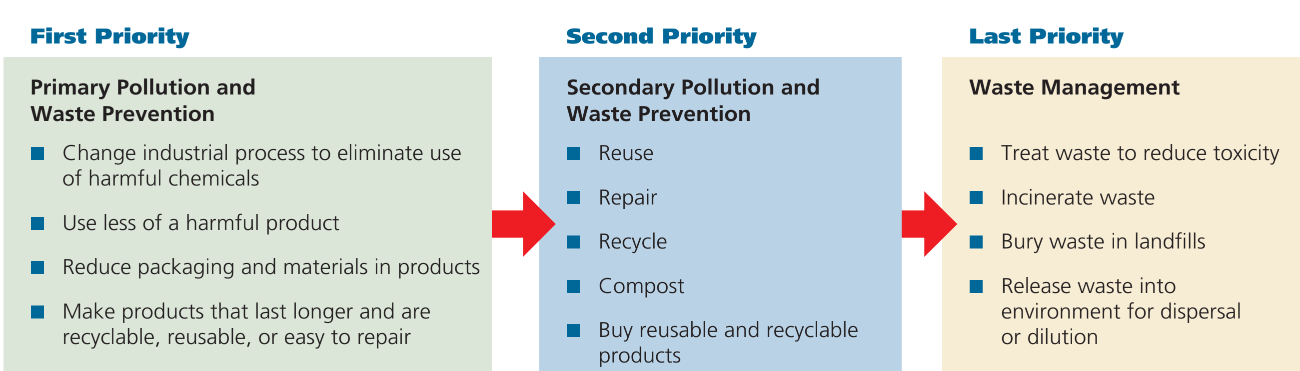


Figure 21-7 *Integrated waste management:* The U.S. National Academy of Sciences suggests these priorities for dealing with solid waste. To date, these waste-reduction priorities have not been followed in the United States or in most other countries. Instead, most efforts are devoted to waste management through disposal (bury it, burn it, or send it somewhere else). **Question:** Why do you think most countries do not follow these priorities, even though they are based on reliable science? (Data from U.S. Environmental Protection Agency and U.S. National Academy of Sciences)

Garbology and Tracking Trash

How do we know about the composition of trash in landfills? Much of that information comes from research by *garbologists* such as William Rathje, an anthropologist who pioneered the field of garbology in the 1970s at the University of Arizona (USA). These scientists work in the fashion of archaeologists, training their students to sort, weigh, and itemize people's trash, and to bore holes in garbage dumps and analyze what they find.

Many people think of landfills as huge compost piles where biodegradable wastes are decomposed within a few months. But garbologists looking at the contents of landfills found 50-year-old newspapers that were still readable and hot dogs and pork chops buried for decades that still looked edible. In landfills (as opposed to open dumps), trash can resist decomposition for perhaps centuries because it is tightly packed and protected from sunlight, water, and air, and from the bacteria that could digest and decompose much of these wastes in keeping with the sustainability principle of chemical cycling.

In 2009, a team of researchers, led by Carlo Riatti, at the Massachusetts Institute of Technology (MIT) conducted a project called "Trash Track." The project's goals were to find out where urban trash goes and to help New York City increase its recycling rate from the current 30% to 100% by 2030.

The researchers attached wireless transmitters about the size of a matchbook to several thousand different items of trash produced by volunteer participants in New York City, Seattle, Washington, and London, England. They are now using these battery-operated electronic tags to track the trash items and show their real-time movements online. They hope to determine where each piece of trash ends up, be it at a recycling plant, a landfill, or an incinerator, and how long each step in the process takes. To view some of the results see **http://senseable.mit.edu/trashtrack**.

Critical Thinking

Should landfills be exposed to more air and water to hasten decomposition of their wastes? Explain.

- **Recycle:** separate and recycle paper, glass, cans, plastics, metal, and other items, and buy products made from recycled materials.

From an environmental standpoint, the first two Rs are preferred because they are *input*, or *prevention*, approaches that tackle the problem of waste production at the front end—before it occurs. When we reduce and reuse, we also save matter and energy resources, reduce pollution (including greenhouse gas emissions), help protect biodiversity, and save money. Recycling is very important, but it deals with wastes after they have been produced.

Figure 21-8 lists some ways in which you can use the three Rs of waste reduction to reduce your output of solid waste. GOOD NEWS

Here are six strategies that industries and communities can use to reduce resource use, waste, and pollution.

First, *redesign manufacturing processes and products to use less material and energy*. For example, the weight of a typical car has been reduced by about one-fourth since the 1960s through use of lighter steel and lightweight plastics and composite materials. We can still do much better.

Second, *develop products that are easy to repair, reuse, remanufacture, compost, or recycle*. A Xerox photocopier made of reusable or recyclable parts that allow for easy remanufacturing could eventually save the company $1 billion in manufacturing costs.

RESEARCH FRONTIER

Inventing less wasteful and less polluting manufacturing processes and products; see **www.cengage.com/login**.

Third, *eliminate or reduce unnecessary packaging*. Use the following hierarchy for product packaging: no packaging, reusable packaging, and recyclable packaging. The 37 European Union countries require the recycling of 55–80% of all packaging waste.

Fourth, *use fee-per-bag waste collection systems* that charge consumers for the amount of waste they throw

What Can You Do?

Solid Waste

- Follow the three Rs of resource use: Reduce, Reuse, and Recycle
- Ask yourself whether you really need a particular item, and refuse packaging where possible
- Rent, borrow, or barter goods and services when you can, buy secondhand, and donate or sell unused items
- Buy things that are reusable, recyclable, or compostable, and be sure to reuse, recycle, and compost them
- Avoid disposables and do not use throwaway paper and plastic plates, cups, eating utensils, and other disposable items when reusable or refillable versions are available
- Use e-mail or text-messaging in place of conventional paper mail
- Read newspapers and magazines online and read e-books
- Buy products in bulk or concentrated form whenever possible

Figure 21-8 Individuals matter: You can save resources by reducing your output of solid waste and pollution. **Questions:** Which three of these actions do you think are the most important? Why? Which of these things do you do?

away but provide free pickup of recyclable and reusable items.

Five, *establish cradle-to-grave responsibility laws* that require companies to take back various consumer products such as electronic equipment (**Core Case Study**), appliances, and motor vehicles, as Japan and many European countries do.

CORE CASE STUDY

Six, *restructure urban transportation systems* to rely more on mass transit and bicycles than on cars. An urban bus can replace about 60 cars and greatly reduce the amounts of material used and wastes produced. Using a bicycle also represents a small fraction of the resource use and solid waste involved with the manufacture and use of a motor vehicle.

21-3 Why Are Reusing and Recycling Materials So Important?

CONCEPT 21-3 Reusing items decreases the consumption of matter and energy resources, and reduces pollution and natural capital degradation; recycling does so to a lesser degree.

Reuse Is an Important Way to Reduce Solid Waste and Pollution, and to Save Money

In today's modern societies, we have increasingly substituted throwaway items for reusable ones, which has resulted in growing masses of solid waste. For example, if the 1 billion throwaway paper coffee cups used by one famous chain of donut shops each year were lined up end-to-end, they would encircle the earth two times. Rewarding customers who bring their own refillable coffee mugs by discounting the price of their coffee helps to reduce this waste.

Reuse involves cleaning and using material items over and over, and thus increasing the typical life span of a product (see the Case Study that follows). This form of waste reduction decreases the use of matter and energy resources, cuts waste and pollution (including greenhouse gases), creates local jobs, and saves money (**Concept 21-3**).

Reuse is alive and well in many less-developed countries (see Figure 1-7, p. 11). In northeast Thailand, for example, 19 Buddhist temples have been built from millions of beer bottles. The colorful bottles were free and allow light into the temple interiors. Caps from the bottles were used to make decorative mosaics. But reuse has a downside. The poor who scavenge in open dumps (see Figure 1-19, p. 22) for food scraps and items that they can reuse or sell are often exposed to toxins and infectious diseases.

Reuse strategies in more-developed countries include yard sales, flea markets, secondhand stores, and online sites such as eBay and craigslist. An international website at **www.freecycle.org** links people who want to give away household belongings to people who want or need them. This network's nearly 7 million members reuse an average of 640 metric tons (700 tons) of items every day, on average, which is about the amount of sold waste that arrives at a mid-size landfill every day.

Technology allows for reuse of many items, including batteries. The latest rechargeable batteries come fully charged, can hold a charge for up to 2 years when they are not used, can be recharged in about 15 minutes, and greatly reduce toxic waste when used in place of discarded conventional batteries.

GOOD NEWS

CASE STUDY
We Can Use Refillable Containers

Two examples of reusable items are refillable glass beverage bottles and refillable soft drink bottles made of polyethylene terephthalate (PET) plastic. Typically, such bottles make 15 round-trips before they become too damaged for reuse and are then recycled. Reusing these containers saves energy while reducing CO_2 emissions, air pollution, water pollution, and solid wastes, and it stimulates local economies by creating local jobs related to the containers' collection and refilling.

But big companies still make more money by producing and shipping throwaway beverage and food containers from centralized facilities. This shift to single-use containers contributed to the demise of many small, local bottling companies, breweries, and dairies that had collected and reused most of their containers, and it hurt local economies. However, some U.S. dairies now deliver milk to their customers in refillable glass or plastic acrylic bottles that can be reused 50 to 100 times. A few breweries have also switched back to refillable bottles.

Some Canadian provinces and ten U.S. states have bottle laws that place a deposit fee on all beverage containers, which consumers can get back when they return the bottle. Retailers must accept the used containers and pass them on for recycling or reuse. Large beverage industries have used their political and financial clout to keep most U.S. states from passing bottle laws, arguing that such laws lead to a loss of jobs and higher beverage costs for consumers. But experience in Canada and U.S. states with bottle bills shows that more jobs are gained than lost, consumers' costs have not risen, resources are saved, and both roadside litter and the amount of solid waste arriving at landfills decreases. Some analysts call for a national bottle bill in the United States, while others would ban all beverage containers that cannot be reused.

Reuse is on the rise. Denmark, Finland, and the Canadian province of Prince Edward Island have banned all beverage containers that cannot be reused. In Finland, 95% of the soft drink, beer, wine, and spirits containers are refillable.

GOOD NEWS

HOW WOULD YOU VOTE?

Do you support banning all beverage containers that cannot be reused as Denmark has done? Cast your vote online at **www.cengage.com/login**.

Instead of using throwaway paper or plastic bags to carry home groceries and other items we purchase, we can switch to reusable cloth bags. Both paper and plastic bags are environmentally harmful, and the question of which is more damaging has no clear-cut answer.

According to Vincent Cobb, founder of reusablebags.com, each year an estimated 500 billion to 1 trillion plastic bags are used and usually discarded throughout the world. Producing them requires large amounts of oil because most are made from ethylene, a petroleum byproduct. In addition, each discarded bag can take from 400 to 1,000 years to break down. Less than 1% of the estimated 100 billion plastic bags used each year in the United States are recycled.

In a number of African countries, the landscape is littered with billions of plastic bags. In addition to being an eyesore and a waste of resources, the bags block drains and sewage systems, and can kill wildlife and livestock that eat them. They also kill plants and spread malaria by holding mini-pools of warm water where mosquitoes can breed. And plastic bags that end up in the ocean kill many marine animals that ingest them.

There is a growing backlash against plastic shopping bags. To encourage people to carry reusable bags, the governments of Ireland, Taiwan, and the Netherlands tax plastic shopping bags. In Ireland, a tax of about 25¢ per bag helped to cut plastic bag litter by 90% as people switched to reusable bags. Bangladesh, Bhutan, parts of India, Taiwan, Kenya, Rwanda, South Africa, Uganda, China, Australia, France, Italy, and the U.S. city of San Francisco have banned the use of all or most types of plastic shopping bags.

Understandably, plastics industry officials have mounted a massive advertising and political campaign to prevent such bans. So far such efforts have been successful in most countries.

What Can You Do?

Reuse

- Buy beverages in refillable glass containers instead of cans or throwaway bottles
- Use reusable plastic or metal lunchboxes
- Carry sandwiches and store refrigerated food in reusable containers instead of wrapping them in aluminum foil or plastic wrap
- Use rechargeable batteries and recycle them when their useful life is over
- When eating out, bring your own reusable silverware and napkin
- Bring your own reusable container for takeout food or restaurant meal leftovers
- Carry groceries and other items in a reusable basket or cloth bag
- Buy used furniture, computers, cars, and other items instead of buying new
- Give away or sell items you no longer use

Figure 21-9 **Individuals matter:** There are many ways to reuse the items we purchase. **Question:** Which of these suggestions have you tried and how did they work for you?

HOW WOULD YOU VOTE?

Should consumers have to pay for plastic or paper bags at grocery and other stores? Cast your vote online at **www.cengage.com/login**.

There are many other ways to reuse various items, some of which are listed in Figure 21-9.

GOOD NEWS

There Are Two Types of Recycling

Recycling involves reprocessing discarded solid materials into new, useful products. In addition to saving resources and reducing solid waste and pollution, recycling also reduces unsightly and environmentally harmful litter.

Households and workplaces produce five major types of materials that we can recycle: paper products, glass, aluminum, steel, and some plastics. We can reprocess such materials in two ways. In **primary**, or **closed-loop, recycling**, materials such as aluminum cans are recycled into new products of the same type. In **secondary recycling**, waste materials are converted into different products. For example, we can shred used tires and turn them into rubberized road surfacing material.

Scientists distinguish between two types of recyclable wastes: *preconsumer* or *internal waste* generated in a manufacturing process, and *postconsumer* or *external waste* generated by consumers' use of products. Preconsumer waste makes up more than three-fourths of the total.

Just about anything (except energy) is recyclable, but there are two key questions. *First*, do the items that are separated for recycling actually get recycled? *Second*, do businesses, governments, and individuals complete the recycling loop by buying products that are made from recycled materials?

The United States recycles about 33% of its MSW—up from 6.4% in 1960. This increase has received a boost from more than 8,600 curbside-pickup recycling programs that serve about half of the U.S. population. Recycling rates vary with different waste items and include 99% for lead-acid batteries, 88% for newsprint, 77% for corrugated boxes, 67% for major appliances, 48% for aluminum cans, 40% for magazines, 27% for PET plastic bottles and jars. Experts say that with education and proper incentives, the United States could recycle 60–75% of its MSW, in keeping with the chemical cycling **principle of sustainability**.

GOOD NEWS

SUSTAINABILITY

We Can Mix or Separate Household Solid Wastes for Recycling

One way to recycle is to send mixed household and business wastes to centralized *materials-recovery facilities* (MRFs or "murfs"). There, machines or workers separate the mixed waste to recover valuable materials for sale to manufacturers as raw materials (Figure 21-6). The remaining paper, plastics, and other combustible wastes are recycled or burned to produce steam or electricity, which is used to run the recovery plant or is sold to nearby industries or homes.

Such plants are expensive to build, operate, and maintain. If not operated properly, they can emit CO_2 and toxic air pollutants, and they produce a toxic ash that must be disposed of safely, usually in landfills. Because MRFs require a steady diet of garbage to make them financially successful, their owners have a vested interest in increasing the throughput of matter and energy resources. Thus, use of MRFs encourages people to produce more trash—the reverse of what many scientists believe we should be doing (Figure 21-7).

To many experts, it makes more environmental and economic sense for households and businesses to separate their trash into recyclable categories such as glass, paper, metals, certain types of plastics, and compostable materials. This *source separation* approach produces much less air and water pollution and costs less to implement than do MRFs. It also saves more energy, provides more jobs per unit of material, and yields cleaner and usually more valuable recyclables.

To promote separation of wastes for recycling, more than 4,000 communities in the United States use a *pay-as-you-throw* (PAUT) or *fee-per-bag* waste collection system. They charge households and businesses for the amount of mixed waste picked up, but do not charge for pickup of materials separated for recycling or reuse. When the U.S. city of Ft. Worth, Texas, instituted such a program, the proportion of households recycling their trash went from 21% to 85%. In addition, the city went from losing $600,000 in its recycling program to making $1 million a year because of increased sales of recycled materials to industries.

GOOD NEWS

HOW WOULD YOU VOTE?

Should households and businesses be charged for the amount of mixed waste they generate for pickup, but not for pickup of the materials they separate for recycling? Cast your vote online at **www.cengage.com/login**.

Composting is a form of recycling that mimics nature's recycling of nutrients—one of the three **principles of sustainability**. It involves using decomposer bacteria to recycle yard trimmings, vegetable food scraps, and other biodegradable organic wastes. The resulting organic material can be added to soil to supply plant nutrients, slow soil erosion, retain water, and improve crop yields. Homeowners can compost such wastes in simple backyard containers, in composting piles that must be turned over occasionally, or in small composting drums (Figure 21-10) that are rotated to mix the wastes and speed up the decomposition process. (For details on composting, see the website for this chapter.)

SUSTAINABILITY

Some cities in Canada and in many European Union countries collect and compost more than 85% of their biodegradable wastes in centralized community

Figure 21-10 Bacteria convert plant wastes into rich compost in this backyard kitchen composter drum. When the compost is ready, the device can be wheeled out and emptied into to vegetable and flower gardens.

Courtesy of Green Culture, Inc.

facilities. The United States has about 3,300 municipal composting programs that recycle about 37% of the country's yard wastes, amounting to about 8% of the total MSW. This is likely to rise as the number of states (now 20) that ban yard wastes from sanitary landfills increases. In 2009, San Francisco, California, became the first U.S. city to mandate composting as part of its goal to eliminate dumping any of its MSW in landfills by 2020. The resulting compost can be used as organic soil fertilizer, topsoil, or landfill cover. It can also be used to help restore eroded soil on hillsides and along highways, as well as on strip-mined land, overgrazed areas, and eroded cropland.

To be successful, a large-scale composting program must be located carefully and odors must be controlled, especially near residential areas. Sometimes, composting takes place in huge indoor buildings. In the Canadian city of Edmonton, Alberta, an indoor facility the size of eight football fields composts 50% of the city's organic solid waste. Composting programs must also exclude toxic materials that can contaminate the compost and make it unsafe for fertilizing crops and lawns.

■ **CASE STUDY**

Recycling Paper

About 55% of the world's industrial tree harvest is used to make paper. However, we could make tree-free paper from straw and other agricultural residues and from the fibers of rapidly growing plants such as kenaf (Figure 10-17, p. 231) and hemp, according to the U.S. Department of Agriculture.

The pulp and paper industry is the world's fifth largest energy consumer and uses more water to produce a metric ton of its product than any other industry. In both Canada and the United States, it is the third-largest industrial energy user and polluter, and paper is the dominant material in the MSW of both countries.

Paper (especially newspaper and cardboard) is easy to recycle. Recycling newspaper involves removing its ink, glue, and coating and then reconverting the paper to pulp, which is pressed into new paper. Making recycled paper uses 64% less energy and produces 35% less water pollution and 74% less air pollution than does making paper from wood pulp, and, of course, no trees are cut down.

In 2008, the United States recycled about 49% of its wastepaper of all types (up from 25% in 1989). At least 10 other countries recycle 50–97% of their wastepaper, and the global recycling rate is 43%. Paper recycling leaders are Denmark (97%), South Korea (77%) Germany (72%), and Sweden (55%).

Despite a 49% recycling rate, the amount of paper thrown away each year in the United States is more than all of the paper used in China. Also, about 95% of books and magazines produced in the United States are printed on virgin paper. In producing this textbook, the publisher strives to use paper with a high percentage of recycled fibers and to reduce paper waste (see a description of Cengage Learning's sustainability program on p. xxiv).

CONNECTIONS

Environmental Impact of Magazines

According to a 2009 study by Audubon magazine, fewer than 200 of the 17,000 magazines published in the United States contain any post-consumer recycled paper. As a result, producing each issue of most magazines requires, on average, roughly the equivalent of 2,100 trees along with enough energy to power 49 homes for a year and enough water to fill 41,300 bathtubs. It also produces about the same amount of carbon dioxide emissions as 78 cars would emit in a year.

In 2009, the Natural Resources Defense Council (NRDC) mounted a campaign to pressure paper companies to stop cutting down trees in some of North America's old-growth forests in order to make toilet paper. NRDC encourages consumers to use toilet paper made from recycled paper fibers. According to Allen Hershkowitz, a senior scientist with NRDC, "Using toilet paper made from virgin trees is the paper industry equivalent of driving a Hummer." The NRDC estimates that nearly 425,000 trees would be saved each year if every U.S. household used just one 500-sheet roll of toilet paper made from 100% recycled paper in place of a roll made from virgin timber.

One problem associated with making paper is the chlorine (Cl_2) and chlorine compounds (such as chlorine dioxide, ClO_2) used to bleach about 40% of the world's pulp for making paper. These compounds are corrosive to processing equipment, hazardous for workers, hard to recover and reuse, and harmful when released into the environment. A growing number of paper mills (mostly in the European Union) are replacing chlorine-based bleaching chemicals with chemicals such as hydrogen peroxide (H_2O_2) or oxygen (O_2).

■ **CASE STUDY**

Recycling Plastics

Plastics consist of various types of large polymers, or *resins*—organic molecules made by chemically linking organic chemicals produced mostly from oil and natural gas (see Figure 15-4, p. 375). About 46 different types of plastics are used in consumer products, and some products contain several kinds of plastic.

Many plastic containers and other items are thrown away and end up as litter on roadsides and beaches (Figure 21-11, p. 568). Each year, they threaten terrestrial animal species as well as millions of seabirds, marine mammals (see Figure 11-6, p. 256), and sea turtles, which can mistake a floating plastic sandwich bag for a jellyfish or get caught in discarded plastic nets (see Figure 11-10, p. 262). About 80% of the plastics in the ocean are blown or washed in from beaches,

UNEP/Peter Arnold, Inc.

Figure 21-11 Discarded solid waste litters beaches, poses a threat to beach users, and washes into the ocean and threatens marine animals.

rivers, storm drains, and other sources, and the rest get dumped into the ocean from ocean-going garbage barges, ships, and fishing boats.

Plastics discarded on beaches or dumped into the ocean from ships can disintegrate into very small particles that resemble the prey of a variety of organisms. These undigestible particles can fill the stomachs of birds and other sea creatures and cause dehydration, malnutrition, and eventually starvation. Because tiny plastic particles can accumulate as they move through food webs, some level of plastic is found in most of the seafood that people eat.

Currently, only about 4% by weight of all plastic wastes in the United States (and 13% of plastic containers and packaging) is recycled. These percentages are low because there are many different types of plastic resins, which are difficult to separate from products that contain them. American comedian Lily Tomlin observed, "We buy a wastebasket and take it home in a plastic bag. Then we take the wastebasket out of the bag, and put the bag in the wastebasket." But progress is being made in the recycling of plastics (Individuals Matter, below) and in the development of more degradable bioplastics (Science Focus, at right).

Recycling Has Advantages and Disadvantages

Figure 21-12 lists the advantages and disadvantages of recycling (**Concept 21-3**). Whether recycling makes economic sense depends on how you look at its economic and environmental benefits and costs.

Critics of recycling programs argue that recycling is costly and adds to the taxpayer burden in communities where recycling is funded through taxation. Proponents of recycling point to studies showing that the net economic, health, and environmental benefits of recycling (Figure 21-12, left) far outweigh the costs. For example, in 2008, the recycling and composting of 33% of all the MSW in the United States reduced CO_2 emissions by an amount equivalent to removing the emissions of 33 million passenger cars, according to the EPA.

Cities that make money by recycling and that have higher recycling rates tend to use a *single-pickup system* for both recyclable and nonrecyclable materials, instead of a more expensive dual-pickup system. Successful sys-

INDIVIDUALS MATTER

GOOD NEWS

Mike Biddle's Contribution to Recycling Plastics

In 1994, Mike Biddle, a former PhD engineer with Dow Chemical, and his business partner Trip Allen founded MBA Polymers, Inc. Their goal was to develop a commercial process for recycling high-value plastics from complex streams of manufactured goods such as computers, electronics, appliances, and automobiles. They succeeded by designing a 16-step automated process that separates plastics from nonplastic items in mixed waste streams, and then separates plastics from each other by type and grade. The process then converts them to pellets that can be used to make new products.

The pellets are cheaper than virgin plastics because the company's process uses 90% less energy than that needed to make a new plastic and because the raw material is discarded junk that is cheap or free. The environment also wins because greenhouse gas emissions from this process are much lower than those from the process of making virgin plastics. Also, recycling waste plastics reduces the need to incinerate them or bury them.

The company is considered a world leader in plastics recycling. It operates a large state-of-the-art research and recycling plant in Richmond, California (USA), and recently opened plastics recycling plants in China, England, and Austria. MBA Polymers has won many awards, and was selected by *Inc.* magazine as one of "America's Most Innovative Companies." Biddle views the world's mountains of plastic wastes, including e-wastes (**Core Case Study**), as "above-ground mines." His dream is to recycle e-waste on a mass scale, worldwide.

CORE CASE STUDY

Maybe you can be an environmental entrepreneur by using your brainpower to develop an environmentally beneficial and financially profitable process or business.

SCIENCE FOCUS

Bioplastics

Most of today's plastics are made from organic polymers produced from petroleum-based chemicals (petrochemicals, Figure 15-4, p. 375). This may change as scientists shift to developing plastics made from biologically based chemicals.

The search for biologically based plastics dates from 1913 when a French scientist and a British scientist each filed independently for patents on a soy-based plastic. At that time, there was intense competition between the petrochemical and agricultural industries to dominate the market for plastics made from organic polymers.

Henry Ford, who developed the first Ford motorcar, supported research on the development of a plastic made from corn and soybean oils. A 1914 photograph shows him using an ax to strike the body of a Model-T car made from soy and corn plastic to demonstrate its strength.

But as oil became widely available, petrochemical plastics took over the market. Now, with climate change and other environmental problems associated with the use of oil, chemists are stepping up efforts to make biodegradable and more environmentally sustainable plastics from a variety of green polymers. These *bioplastics* can be made from corn, soy, sugarcane, switchgrass (see Figure 16-29, p. 423), chicken feathers, and some components of garbage. Also, CO_2 extracted from coal-burning power plant emissions could be used in this process.

The key to making such biopolymers is to find chemicals called *catalysts*, which speed up the reactions that form polymers from biologically based chemicals without the use of high-temperature heat. Compared to conventional oil-based plastics, with proper design and mass production, bioplastics could be lighter, stronger, and cheaper, and the process of making them would require less energy and produce less pollution per unit of weight. But so far, the most promising bioplastics cost much more to make than conventional plastics cost.

Instead of being sent to landfills, packaging made from bioplastics could be composted to produce a soil conditioner, in keeping with the chemical recycling **principle of sustainability**.

Toyota Motor Corporation is investing heavily in a process that makes plastics from plants. By 2020, it expects to control two-thirds of the world's supply of bioplastics.

There are also efforts to find or genetically engineer microbes that could decompose conventional plastics such as those used in plastic bags. However, some scientists caution that relying more on *biodegradable conventional plastics* promotes throwing away instead of recycling such bags and can add potentially toxic products to the soil and water during the breakdown process. This happens when producers add tiny amounts of potentially hazardous metals such as cobalt, iron, or manganese to these plastics to speed up their degradation in the presence of air (oxygen) and sunlight.

Critical Thinking

What might be some other disadvantages of more rapidly degradable bioplastics? Do you think they outweigh the advantages?

tems also tend to use a *pay-as-you-throw* (PAUT) or *fee-per-bag* approach. San Francisco, California (USA), uses such a system to recycle, compost, or reuse 70% of its MSW and plans to increase this amount to 75%.

Trade-Offs

Recycling

Advantages	Disadvantages
Reduces energy and mineral use and air and water pollution	Can cost more than burying in areas with ample landfill space
Reduces greenhouse gas emissions	Reduces profits for landfill and incinerator owners
Reduces solid waste	Source separation inconvenient for some
Can save landfill space	

Figure 21-12 Recycling solid waste has advantages and disadvantages (**Concept 21-3**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

We Can Encourage Reuse and Recycling

Three factors hinder reuse and recycling. *First*, the market prices of almost all products do not include the harmful environmental and health costs associated with producing, using, and discarding them.

Second, the economic playing field is uneven, because in most countries, resource-extracting industries receive more government tax breaks and subsidies than reuse and recycling industries get.

Third, the demand and thus the price paid for recycled materials fluctuates, mostly because buying goods made with recycled materials is not a priority for most governments, businesses, and individuals.

How can we encourage reuse and recycling? Proponents say that leveling the economic playing field is the best way to start. Governments can *increase* subsidies and tax breaks for reusing and recycling materials (a positive incentive) and *decrease* subsidies and tax breaks for making items from virgin resources (a negative incentive).

Other strategies are to greatly increase use of the fee-per-bag waste collection system and to encourage or require government purchases of recycled products to help increase demand and lower prices of these products. Governments can also pass laws requiring companies to take back and recycle or reuse packaging and electronic waste discarded by consumers of their products (**Core Case Study**), as is done in Japan and in some European Union countries. But proponents call for strengthening such laws to require that the recycling of such material be done domestically. They argue that this will help to reduce the illegal shipping of hazardous waste materials to other countries for recycling under dangerous conditions.

CORE CASE STUDY

HOW WOULD YOU VOTE?

Should governments pass laws requiring manufacturers to take back and reuse or recycle all packaging waste, appliances, electronic equipment (**Core Case Study**), and motor vehicles at the end of their useful lives? Cast your vote online at **www.cengage.com/login**.

CORE CASE STUDY

Also, citizens can pressure governments to require product labeling that lists the total and post-consumer recycled content of products as well as the types and amounts of any hazardous materials they contain. This would help consumers make more informed choices about the environmental consequences of buying certain products. It would also help to expand the market for recycled materials.

One reason for the popularity of recycling is that it helps to soothe the consciences of people living in a throwaway society. Many people think that recycling their newspapers and aluminum cans is all they need do to meet their environmental responsibilities. Recycling is important, but reducing resource consumption and reusing resources are more effective *prevention* approaches to reducing the flow and waste of resources (**Concept 21-3**).

21-4 What Are the Advantages and Disadvantages of Burning or Burying Solid Waste?

CONCEPT 21-4 Technologies for burning and burying solid wastes are well developed, but burning contributes to air and water pollution and greenhouse gas emissions, and buried wastes eventually contribute to the pollution and degradation of land and water resources.

Burning Solid Waste Has Advantages and Disadvantages

Globally, MSW is burned in more than 600 large *waste-to-energy incinerators* (87 in the United States that burn 13% of the country's MSW), which use the heat generated to boil water and make steam for heating water or space, or for producing electricity. Trace the flow of materials through this process, as diagrammed in Figure 21-13.

Figure 21-14 lists the advantages and disadvantages of using incinerators to burn solid waste. Waste incineration has not caught on in the United States because of excessive air pollution from early incinerators, citizen opposition, and an abundance of cheaper landfills. However, studies show that modern waste-to-energy incinerators produce lower emissions of greenhouse gases and other air pollutants than modern landfills do.

About 15% of the MSW produced in China is incinerated under lax pollution control regulations. For example, regulations allow incinerators in China to emit ten times the levels of cancer-causing dioxins permitted in the United States.

HOW WOULD YOU VOTE?

Do the advantages of incinerating solid waste outweigh the disadvantages? Cast your vote online at **www.cengage.com/login**.

Burying Solid Waste Has Advantages and Disadvantages

About 54% by weight of the MSW in the United States is buried in sanitary landfills, compared to 80% in Canada, 15% in Japan, 12% in Switzerland, and 4% in Denmark.

There are two types of landfills. **Open dumps** are essentially fields or holes in the ground where garbage is deposited and sometimes burned. They are rare in more-developed countries, but are widely used near major cities in many less-developed countries (see Figure 1-19, p. 22) China disposes of about 85% of its rapidly growing mountains of solid waste mostly in rural open dumps or in poorly designed and regulated landfills with no lining or only a thin single lining instead of making much greater use of newer state-of-the-art landfills.

In newer landfills, called **sanitary landfills** (Figure 21-15, p. 572), solid wastes are spread out in thin layers, compacted, and covered daily with a fresh layer of clay or plastic foam, which helps to keep the material dry and reduces leakage of contaminated water (leachate) from the landfill. This covering also lessens the risk of fire, decreases odor, and reduces accessibility to vermin. The bottoms and sides of the landfills also have strong double liners and containment systems that collect liquid leaching from them. Some landfills also have

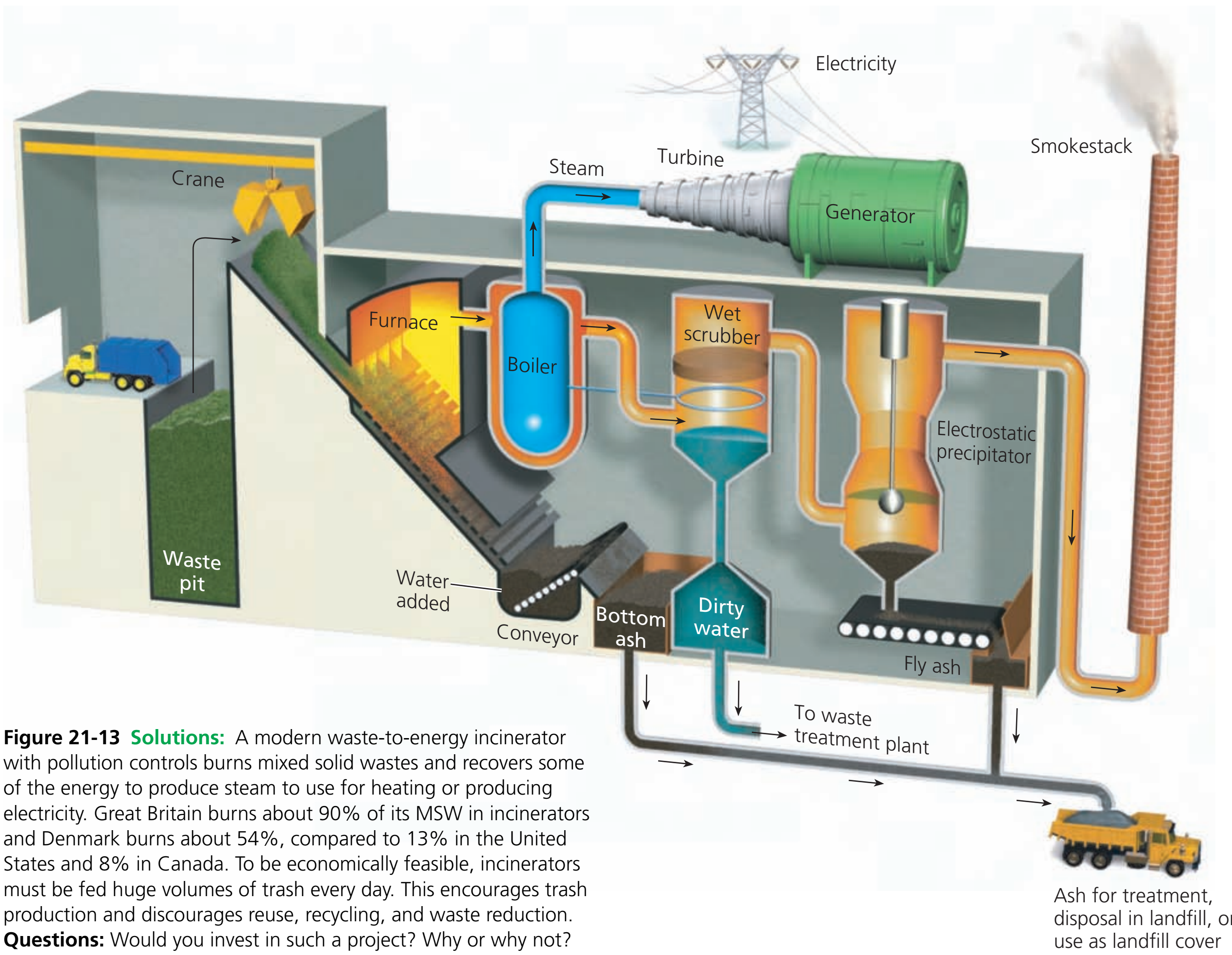


Figure 21-13 **Solutions:** A modern waste-to-energy incinerator with pollution controls burns mixed solid wastes and recovers some of the energy to produce steam to use for heating or producing electricity. Great Britain burns about 90% of its MSW in incinerators and Denmark burns about 54%, compared to 13% in the United States and 8% in Canada. To be economically feasible, incinerators must be fed huge volumes of trash every day. This encourages trash production and discourages reuse, recycling, and waste reduction. **Questions:** Would you invest in such a project? Why or why not?

systems for collecting and burning methane, the potent greenhouse gas produced when the wastes decompose in the absence of oxygen.

Trade-Offs

Waste-to-Energy Incineration

Advantages	Disadvantages
Reduces trash volume	Expensive to build
Produces energy	Produces a hazardous waste
Concentrates hazardous substances into ash for burial	Emits some CO_2 and other air pollutants
Sale of energy reduces cost	Encourages waste production

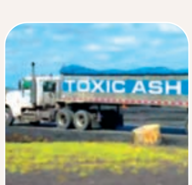


Figure 21-14 Waste-to-energy incineration of solid waste has advantages and disadvantages (**Concept 21-4**). These trade-offs also apply to the incineration of hazardous waste. Since 1985, more than 280 new incinerator projects have been delayed or canceled in the United States because of high costs, concern over air pollution, and intense citizen opposition. **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

Figure 21-16 (p. 572) lists the advantages and disadvantages of using sanitary landfills to dispose of solid waste. According to the EPA, all landfills eventually leak, passing both the effects of contamination and cleanup costs on to future generations.

Some analysts say we should think of landfills as future mines for metals, plastics, paper, and other useful materials that we throw away. But critics of this idea point out that because of the second law of thermodynamics (see Chapter 2, p. 47), digging up and separating the components of complex garbage mixtures uses significant amounts of energy and is expensive. It means that putting garbage in landfills has a low net energy

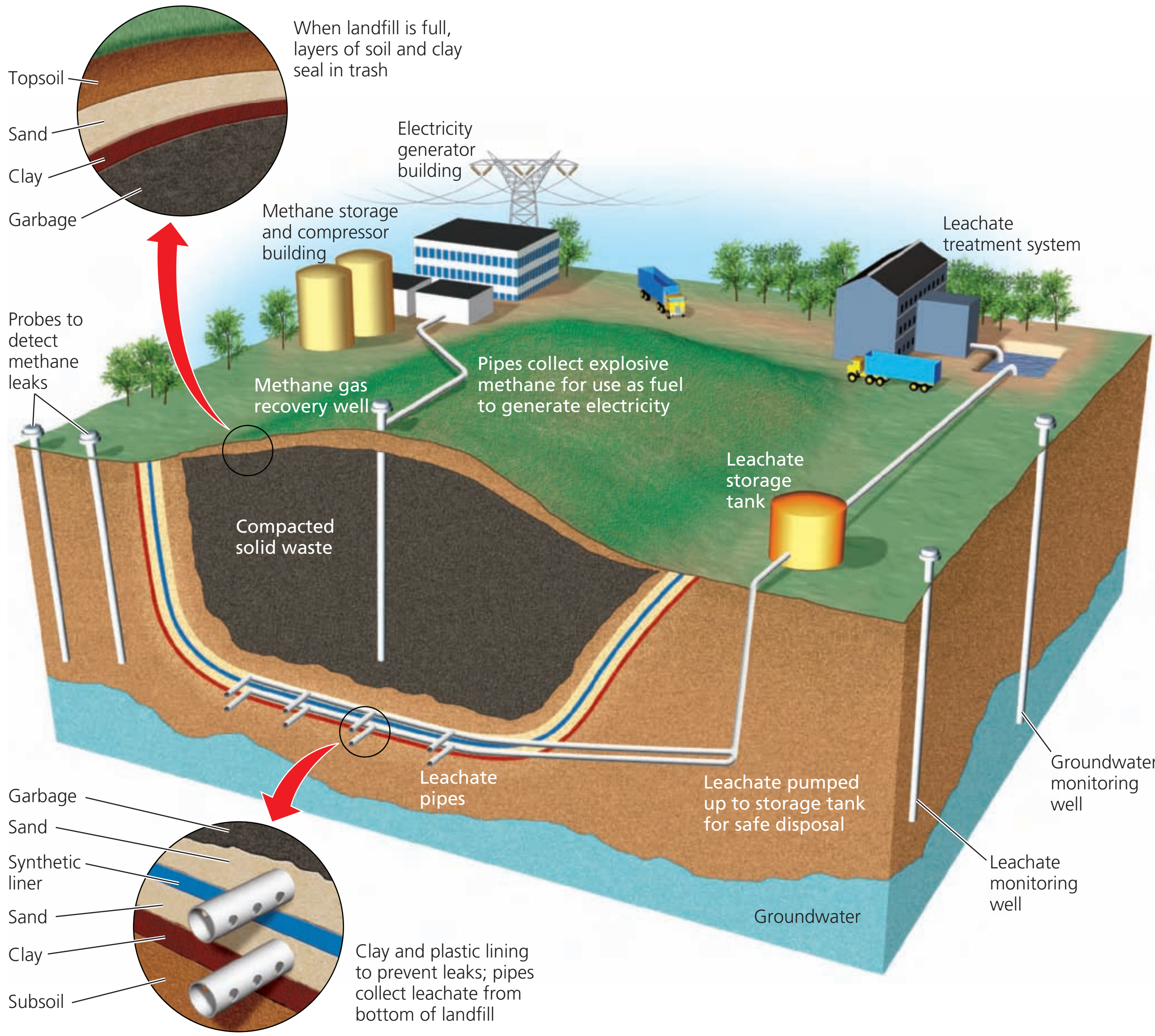


Figure 21-15 **Solutions:** A state-of-the-art *sanitary landfill* is designed to eliminate or minimize environmental problems that plague older landfills. Since 1997, only modern sanitary landfills have been permitted in the United States. As a result, many small, older landfills have been closed and replaced with larger local or regional landfills. **Question:** Some experts say that these landfills will eventually develop leaks and could emit toxic liquids. How do you think this could happen?

yield. One rule based on the second law of thermodynamics would be *never mix different types of waste that you may want to separate later.* This is also a scientific argument for using source separation of recyclable items instead of a MRF system (p. 566).

HOW WOULD YOU VOTE?

Do the advantages of burying solid waste in sanitary landfills outweigh the disadvantages? Cast your vote online at **www.cengage.com/login**.

Trade-Offs

Sanitary Landfills

Advantages	Disadvantages
Low operating costs	Noise, traffic, and dust
Can handle large amounts of waste	Releases greenhouse gases (methane and CO_2) unless they are collected
Filled land can be used for other purposes	Output approach that encourages waste production
No shortage of landfill space in many areas	Eventually leaks and can contaminate groundwater

Figure 21-16 Using sanitary landfills to dispose of solid waste has advantages and disadvantages (**Concept 16-4**). **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

21-5 How Should We Deal with Hazardous Waste?

▶ **CONCEPT 21-5 A sustainable approach to hazardous waste is first to produce less of it, then to reuse or recycle it, then to convert it to less hazardous materials, and finally to safely store what is left.**

We Can Use Integrated Management of Hazardous Waste

Figure 21-17 shows an integrated management approach suggested by the U.S. National Academy of Sciences that establishes three priority levels for dealing with hazardous waste: produce less; convert as much of it as possible to less hazardous substances; and put the rest in long-term, safe storage (**Concept 21-5**). Denmark follows these priorities, but most countries do not.

As with solid waste, the top priority should be pollution prevention and waste reduction. With this approach, industries try to find substitutes for toxic or hazardous materials, reuse or recycle the hazardous materials within industrial processes, or use them as raw materials for making other products. (See Case Study, p. 581 and the Guest Essays on this subject by Lois Gibbs and Peter Montague at CengageNOW.)

At least one-third of industrial hazardous wastes produced in the European Union are exchanged through clearinghouses where they are sold as raw materials for use by other industries. The producers of these wastes do not have to pay for their disposal and recipients get low-cost raw materials. About 10% of the hazardous waste in the United States is exchanged through such clearinghouses, a figure that could be raised significantly.

We could use integrated waste management more for dealing with postconsumer hazardous waste, but such waste is not well managed, globally. In fact, most e-waste recycling efforts (**Core Case Study**) create further hazards, especially for workers in some less-developed countries (see the Case Study that follows). In addition, producing cell phones and throwing them away as e-waste can even threaten gorillas in Africa (see Connections box that follows).

CONNECTIONS

Cell Phones and Endangered African Gorillas

Most cell phones (a component of e-waste, see **Core Case Study**) contain coltan, a mineral extracted from the deep forests of the Democratic Republic of the Congo in central Africa, which is the home to the last remaining endangered lowland gorillas. Coltan is a metallic ore that is refined to produce metallic tantalum, which can hold an electrical charge. In recent years, rapid expansion of both legal and illegal coltan mining in the Congo—which holds about 80% of the world's coltan reserves—has dramatically reduced the habitat of lowland gorillas and other species. It has also contributed to the killing of lowland gorillas for bush meat to feed the miners. An international outcry has helped to shift much of the coltan mining from Africa to areas such as western Australia, but the threat to gorillas remains. To help reduce this threat, some American zoos collect old cell phones for recycling, which could help to reduce the need to mine coltan to make new cell phones. Thus, by recycling your old cell phone, you might help to save the remaining population of lowland gorillas.

CASE STUDY

Recycling E-Waste

In some countries, workers in e-waste recycling operations—many of them children—are often exposed to toxic chemicals as they dismantle the electronic trash to extract its valuable metals or parts that can be sold for reuse or recycling (**Core Case Study**).

According to the United Nations, more than 70% of the world's e-waste ends up in China. A center for such waste is the small port city of Guiyu, where the air reeks of burning plastic and acid fumes. There, more than 5,500 small-scale e-waste businesses employ over 30,000 people (including some children) who work at very low wages in dangerous conditions

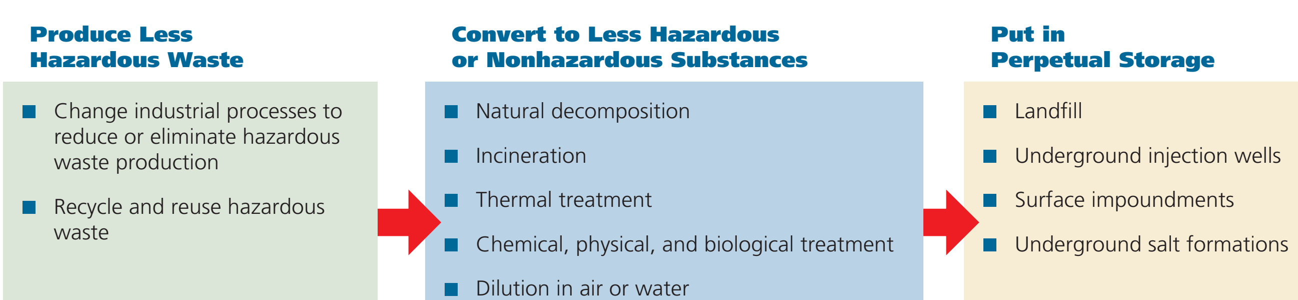


Figure 21-17 *Integrated hazardous waste management:* The U.S. National Academy of Sciences has suggested these priorities for dealing with hazardous waste (**Concept 21-5**). **Question:** Why do you think that most countries do not follow these priorities? (Data from U.S. National Academy of Sciences)

to extract valuable metals like gold and copper from millions of discarded computers, television sets, and cell phones.

These workers usually wear no masks or gloves, often work in rooms with no ventilation, and are usually exposed to a cocktail of toxic chemicals. They carry out dangerous activities such as smashing TV picture tubes with large hammers to recover glass and electronic parts—a method that releases large amounts of toxic lead dust into the air. They also burn computer wires to expose copper, melt circuit boards in metal pots over coal fires to extract lead and other metals, and douse the boards with strong acid to extract gold.

After the valuable metals are removed, some leftover parts are burned or dumped into rivers or onto the land. Atmospheric levels of deadly dioxin in Guiyu are as high as 86 times the WHO safety standards, and an estimated 82% of the area's children younger than age 6 suffer from lead poisoning.

In recent years, Hewlett Packard and Dell Inc., which together sell more than half of the personal computers in the United States, have reduced the use of toxic components and will take back their products for recycling when consumers discard them. Still, in 2008, only 18% of the e-waste in the United States was recycled, and up to 80% of that was shipped overseas to dismantling shops such as the one in Guiyu.

By contrast, in Canada and in European Union countries such as Belgium, smelters that melt and extract valuable metals from discarded electronic devices must meet strict environmental and health standards. But there are only five such e-scrap smelters in the world, none of which are located in the United States. Such high-tech recycling is also much more expensive than the low-tech and dangerous recycling of e-waste in China, India, and various African countries. Thus, much of the hazardous e-waste produced in Europe is shipped illegally to these countries.

People who are worried about this problem call for establishing e-waste recycling programs throughout the world. Some also suggest that consumers could resist their frequent upgrading of cell phones, computers, and other electronic equipment. When they do discard these devices, they could donate them to schools and small business for reuse, return them to manufacturers or stores that accept such items for recycling, or find a responsible recycler. If you live in the United States, see **www.electronicsrecycling.org**, **www.rbrc.org**, and **www.Earth911.com** to find out where to recycle electronic devices in your area; to find out how to donate your used computer, visit **www.recycle.org**.

THINKING ABOUT
E-Waste Recycling

Would you support a recycling fee on all electronic devices? Explain.

We Can Detoxify Hazardous Wastes

The first step in dealing with hazardous wastes is to collect them. In Denmark, all hazardous and toxic waste from industries and households is delivered to any of 21 transfer stations throughout the country. From there it is taken to a large processing facility, where three-fourths of the waste is detoxified by physical, chemical, and biological methods. The rest is buried in a carefully designed and monitored landfill.

Physical methods for detoxifying hazardous wastes include using charcoal or resins to filter out harmful solids, distilling liquid wastes to separate out harmful chemicals, and precipitating, or allowing natural processes to separate, such chemicals from solution. Especially deadly wastes can be encapsulated in glass, cement, or ceramics and then put in secure storage sites.

Chemical methods are used to convert hazardous chemicals to harmless or less harmful chemicals through chemical reactions. Currently, chemists are testing the use of *cyclodextrin*—a type of sugar made from cornstarch—to remove toxic materials such as solvents and pesticides from contaminated soil and groundwater. To clean up a site contaminated by hazardous chemicals, a solution of cyclodextrin is applied. After this molecular-spongelike material moves through the soil or groundwater, picking up various toxic chemicals, it is pumped out of the ground, stripped of its contaminants, and reused.

Another approach is the use of *nanomagnets*, magnetic nanoparticles coated with certain compounds that can remove various pollutants from water. For example, magnetic nanoparticles coated with chitosan, derived from the exoskeletons of shrimps and crabs, are used to remove oil and other organic pollutants from contaminated water. Magnetic fields are used to remove the pollutant-coated nanomagnets. The pollutants can then be separated out and disposed of or recycled, and the magnetic nanoparticles can be reused.

Some scientists and engineers consider *biological methods* for treatment of hazardous waste to be the wave of the future. One such approach is *bioremediation*, in which bacteria and enzymes help to destroy toxic or hazardous substances, or convert them to harmless compounds. In bioremediation, a contaminated site is inoculated with an army of microorganisms that breakdown specific hazardous chemicals, such as certain organic solvents, PCBs, pesticides, and oil, leaving behind harmless substances such as water and water-soluble chloride salts. So far, more than 1,000 different types of bacteria and fungi have been used to detoxify various types of hazardous waste. Bioremediation takes a little longer to work than most physical and chemical methods, but it costs much less. (See the Guest Essay by John Pichtel on this topic at CengageNOW.)

Another approach is *phytoremediation*, which involves using natural or genetically engineered plants to absorb, filter, and remove contaminants from polluted soil and water, as shown in Figure 21-18. Various plants have

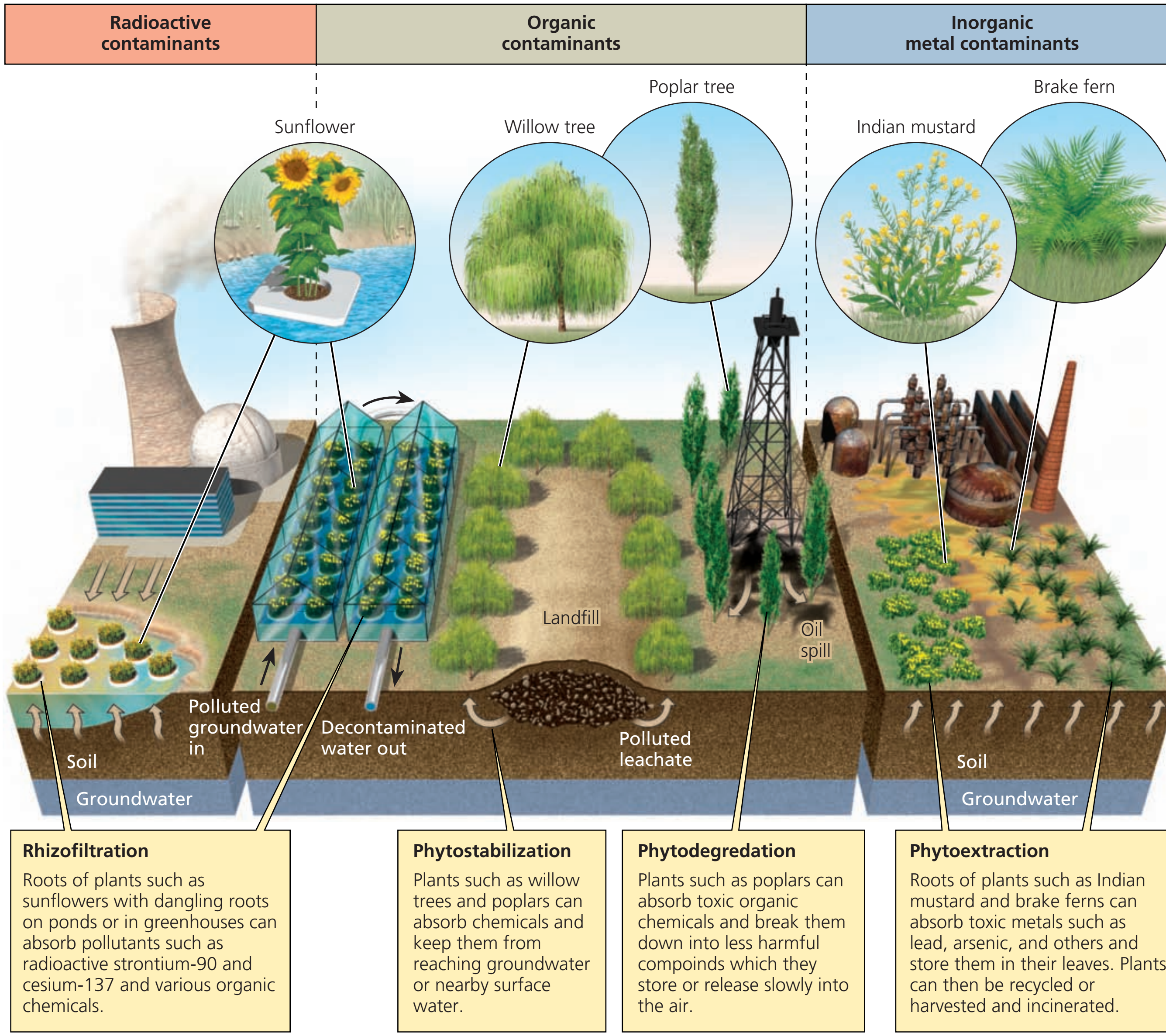


Figure 21-18 **Solutions:** Phytoremediation involves using various types of plants that function as pollution sponges to clean up contaminants such as radioactive substances (left), organic compounds (center), and toxic metals (right) from soil and water. (Data from American Society of Plant Physiologists, U.S. Environmental Protection Agency, and Edenspace)

been identified as "pollution sponges," which can help to clean up soil and water contaminated with chemicals such as pesticides, organic solvents, and radioactive or toxic metals. Phytoremediation is still being evaluated and is slow (can take several growing seasons) compared to other alternatives. However, it can be used to help clean up toxic hotspots.

We can incinerate hazardous wastes to break them down and convert them to harmless or less harmful chemicals such as carbon dioxide and water. This has the same combination of advantages and disadvantages as does burning solid wastes (Figure 21-14). But incinerating hazardous waste can release air pollutants such as highly toxic dioxins, and it produces a highly toxic ash that must be safely and permanently stored in a landfill or vault especially designed for this hazardous end product.

RESEARCH FRONTIER

Improving current methods and finding new ways to detoxify wastes; see **www.cengage.com/login**.

We can also detoxify hazardous wastes by using a *plasma arc torch*, which breaks them down at very high temperatures. Passing an electrical current through air or through an unreactive gas to generate an electric arc and very high temperatures creates *plasma*—an ionized gas made up of electrically conductive ions and electrons. The plasma (hotter than the surface of the sun)

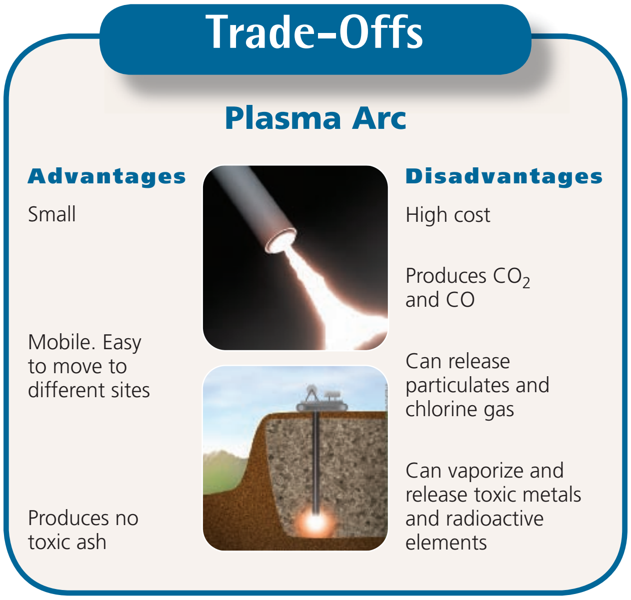


Figure 21-19 Using a *plasma arc torch* to detoxify hazardous wastes has advantages and disadvantages. **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

can decompose liquid or solid hazardous waste to gas consisting mostly of carbon monoxide (CO) and hydrogen (H_2) and a molten, glassy, solid material that can be used to encapsulate toxic metals and keep them from leaching into groundwater. Figure 21-19 lists the major advantages and disadvantages of using this process.

So why are we not making widespread use of the plasma arc torch to detoxify hazardous wastes? The main reason is its high cost. Plasma arc companies are working to bring the cost down.

HOW WOULD YOU VOTE?

Do the advantages of using a plasma arc torch to detoxify hazardous waste outweigh the disadvantages? Cast your vote online at **www.cengage.com/login**.

Regardless of the comparative costs of using plasma arc torches, incinerators, and sanitary landfills, scientists urge us to focus first on decreasing the amount of waste that we produce. They suggest we can reduce our waste output by as much as 80% by applying the 3 Rs—reduce, reuse, and recycle (Figures 21-7 and 21-17).

We Can Store Some Forms of Hazardous Waste

Ideally, we should use burial on land or long-term storage of hazardous and toxic wastes in secure vaults only as the third and last resort after the first two priorities have been exhausted (Figure 21-17 and **Concept 21-5**). But currently, burial on land is the most widely used method in the United States and in most countries.

The most common form of burial is *deep-well disposal*, in which liquid hazardous wastes are pumped under pressure through a pipe into dry, porous rock formations far beneath aquifers that are tapped for drinking and irrigation water (Figure 20-13, p. 540). Theoretically, these liquids soak into the porous rock material and are isolated from overlying groundwater by essentially impermeable layers of clay and rock.

However, this fairly cheap, out-of-sight and out-of-mind approach presents some problems. There are a limited number of such sites and limited space within them. Sometimes the wastes can leak into groundwater from the well shaft or migrate into groundwater in unexpected ways. In the United States, roughly 64% of liquid hazardous wastes are injected into deep disposal wells. Many scientists believe that current regulations for deep-well disposal in the United States are inadequate and should be improved. Figure 21-20 lists the advantages and disadvantages of deep-well disposal of liquid hazardous wastes.

HOW WOULD YOU VOTE?

Do the advantages of deep-well disposal of hazardous wastes outweigh the disadvantages? Cast your vote online at **www.cengage.com/login**.

Surface impoundments are lined ponds, pits, or lagoons in which liquid hazardous wastes are stored (Figure 21-21). As the water evaporates, the waste settles and becomes more concentrated. But using no liner, using leaking single liners, and failing to use double liners can allow such wastes to percolate into the groundwater, and because these impoundments are not covered, volatile harmful chemicals can evaporate into the air. Also, powerful storms can cause them to overflow. Figure 21-22 lists the advantages and disadvantages of this method.

EPA studies found that 70% of the storage ponds in the United States have no liners and could threaten

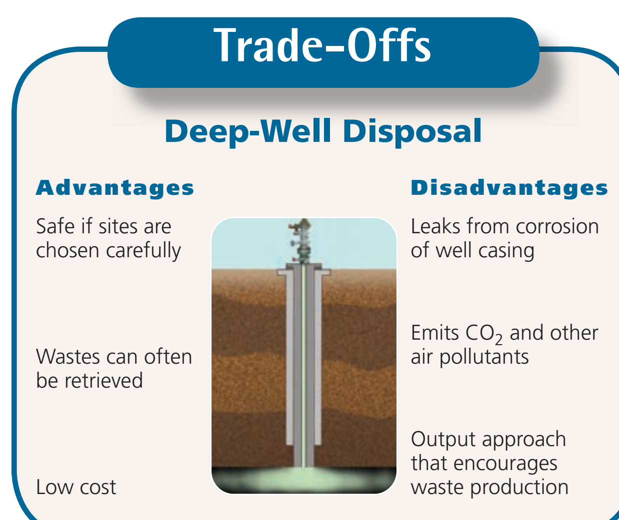


Figure 21-20 Injecting liquid hazardous wastes into deep underground wells has advantages and disadvantages. **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

Ken Sherman/Bruce Coleman USA, Inc.

Figure 21-21 This surface impoundment for storing liquid hazardous wastes is located in Niagara Falls, New York (USA). Such sites can pollute the air and nearby ground water and surface water.

groundwater supplies. According to the EPA, eventually all impoundment liners are likely to leak and could contaminate groundwater.

HOW WOULD YOU VOTE?

Do the advantages of storing hazardous wastes in surface impoundments outweigh the disadvantages? Cast your vote online at **www.cengage.com/login**.

There are some highly toxic materials (such as mercury; see Chapter 17, Science Focus, p. 448) that we cannot destroy, detoxify, or safely bury. The best way to deal with such materials is to prevent or reduce their use and to put what is produced in metal drums or other containers. These containers can be placed aboveground in especially designed storage buildings or underground in salt mines or bedrock caverns where they can be inspected on a regular basis and retrieved if necessary.

Sometimes both liquid and solid hazardous wastes are put into drums or other containers and buried in carefully designed and monitored *secure hazardous waste landfills* (Figure 21-23). This is the least-used method because of the expense involved.

Trade-Offs

Surface Impoundments

Advantages	Disadvantages
Low cost	Groundwater contamination from leaking liners (and overflow from flooding)
Wastes can often be retrieved	Air pollution from volatile organic compounds
Can store wastes indefinitely with secure double liners	Output approach that encourages waste production

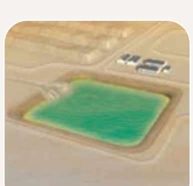


Figure 21-22 Storing liquid hazardous wastes in surface impoundments has advantages and disadvantages. **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

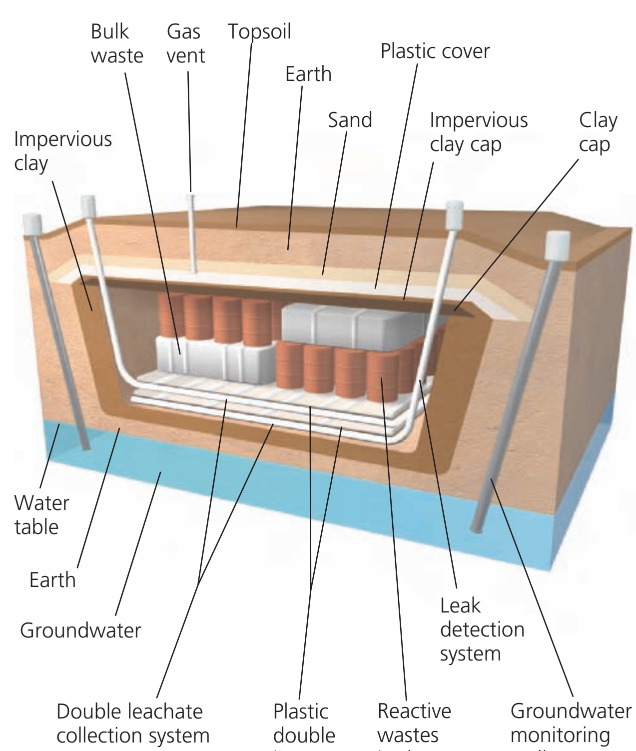


Figure 21-23 Solutions: This diagram shows how hazardous wastes can be isolated and stored in a secure hazardous waste landfill.

What Can You Do?

Hazardous Waste

- Avoid using pesticides and other hazardous chemicals, or use them in the smallest amounts possible
- Use less harmful and usually cheaper substances instead of commercial chemicals for most household cleaners. For example, use vinegar to polish metals, clean surfaces, and remove stains and mildew; baking soda to clean utensils and to deodorize and remove stains; and borax to remove stains and mildew.
- Do not dispose of pesticides, paints, solvents, oil, antifreeze, or other hazardous chemicals by flushing them down the toilet, pouring them down the drain, burying them, throwing them into the garbage, or dumping them down storm drains. Instead, use hazardous waste disposal services available in many cities.

Figure 21-24 **Individuals matter:** You can reduce your output of hazardous wastes (**Concept 21-5**). **Questions:** Which two of these measures do you think are the most important? Why?

Some more-developed countries are careless with their hazardous wastes. In the United Kingdom, most of these wastes are mixed with household garbage and stored in hundreds of conventional landfills throughout the country. Most less-developed countries do little to regulate and control what happens to their hazardous wastes.

GOOD NEWS

Figure 21-24 lists some ways in which you can reduce your output of hazardous waste—the first step in dealing with it.

■ CASE STUDY
Hazardous Waste Regulation in the United States

About 5% of all hazardous waste produced in the United States is regulated under the Resource Conservation and Recovery Act (RCRA, pronounced "RICK-ra"), passed by the U.S. Congress in 1976 and amended in 1984. Under this act, the EPA sets standards for the management of several types of hazardous waste and issues permits to companies that allow them to produce and dispose of a certain amount of those wastes by approved methods. Permit holders must use a *cradle-to-grave* system to keep track of waste they transfer from a point of generation (cradle) to an approved off-site disposal facility (grave), and they must submit proof of this disposal to the EPA.

RCRA is a good start, but only about 5% of the hazardous and toxic wastes, including e-waste, produced in the United States are regulated. In most other countries, especially less-developed countries, an even smaller amount of this waste is regulated.

THINKING ABOUT
Hazardous Waste

CORE CASE STUDY

Why is it that 95% of the hazardous waste, including the growing mounds of e-waste (**Core Case Study**) produced in the United States, is not regulated? Do you favor regulating such wastes? What do you think would be the economic consequences of doing so? How would this change the way producers of hazardous waste deal with it?

In 1980, the U.S. Congress passed the *Comprehensive Environmental Response, Compensation, and Liability Act,* commonly known as the *CERCLA* or *Superfund* program, supervised by the EPA. Its goals are to identify sites, commonly called Superfund sites, where hazardous wastes have contaminated the environment (Figure 21-25) and to clean them up on a priority basis. The worst sites—those that represent an immediate and severe threat to human health—are put on a *National Priorities List* and scheduled for cleanup using EPA-approved methods.

In 2010, there were about 1,300 sites on this list, and about 340 sites had been cleaned up and removed

Phototake, Inc.

Figure 21-25 These leaking barrels of toxic waste were found at a Superfund site in the United States that has since been cleaned up.

from the list. (To view any Superfund sites near where you live see **http://www.epa.gov/superfund/sites/index.htm**.) The Waste Management Research Institute estimates that at least 10,000 sites should be on the priority list and that cleanup of these sites would cost about $1.7 trillion, not including legal fees. This is a glaring example of the economic and environmental value of emphasizing waste reduction and pollution prevention over "end of the pipeline" cleanup.

In 1984, Congress amended the Superfund Act to give citizens the right to know what toxic chemicals are being stored or released in their communities. This required 23,800 large manufacturing facilities to report their annual releases into the environment of any of nearly 650 toxic chemicals. If you live in the United States, you can find out what toxic chemicals are being stored and released in your neighborhood by going to the EPA's *Toxic Release Inventory* website at **www.epa.gov/tri/**.

The Superfund Act, designed to make polluters pay for cleaning up abandoned hazardous waste sites, greatly reduced the number of illegal dumpsites (Figure 21-25) around the country. It also forced waste producers who were fearful of liability claims to reduce their production of such waste and to recycle or reuse much more of it. However, under pressure from polluters, the U.S. Congress refused to renew the tax on oil and chemical companies that had financed the Superfund legislation after it expired in 1995. The Superfund is now broke, and taxpayers, not polluters, are footing the bill for future cleanups when the responsible parties cannot be found. As a result, the pace of cleanup has slowed and taxpayers are now paying more than $1 billion a year on Superfund cleanups.

HOW WOULD YOU VOTE?

Should the U.S. Congress reinstate the polluter-pays principle by levying taxes on chemical, oil, mining, and smelting companies to reestablish a fund for cleaning up existing and new Superfund sites? Register your vote online at **www.cengage.com/login**.

The U.S. Congress and several state legislatures have also passed laws that encourage the cleanup of *brownfields*—abandoned industrial and commercial sites such as factories, junkyards, older landfills, and gas stations (see **http://www.epa.gov/brownfields/basic_info.htm**). In most cases, they are contaminated with hazardous wastes. Brownfields can be cleaned up and reborn as parks, nature reserves, athletic fields, ecoindustrial parks (see Case Study, p. 581), and residential neighborhoods. By 2009, more than 42,000 former brownfield sites had been redeveloped in the United States. According to the U.S. General Accounting Office, there are as many as 500,000 brownfield sites throughout the United States.

GOOD NEWS

Various other federal and state laws have done much to deal with hazardous waste on a prevention basis. One of the most successful was the 1976 law requiring that use of leaded gasoline be phased out completely in the United States by 1986 (see Chapter 18, Case Study, pp. 471–472).

21-6 How Can We Make the Transition to a More Sustainable Low-Waste Society?

CONCEPT 21-6 Shifting to a low-waste society requires individuals and businesses to reduce resource use and to reuse and recycle wastes at local, national, and global levels.

Grassroots Action Has Led to Better Solid and Hazardous Waste Management

In the United States, individuals have organized grassroots (bottom-up) citizen movements to prevent the construction of hundreds of incinerators, landfills, treatment plants for hazardous and radioactive wastes, and polluting chemical plants in or near their communities. Health risks from incinerators and landfills, when averaged over the entire country, are quite low, but the risks for people living near such facilities are much higher.

GOOD NEWS

Manufacturers and waste industry officials point out that something must be done with the toxic and hazardous wastes created in the production of certain goods and services. They contend that even if local citizens adopt a "not in my back yard" (NIMBY) approach, the waste will always end up in someone's back yard.

Many citizens do not accept this argument. To them, the best way to deal with most toxic and hazardous waste is to produce much less of it, as suggested by the U.S. National Academy of Sciences (Figure 21-17). For such materials, they believe that the goal should be "not in anyone's back yard" (NIABY) or "not on planet Earth" (NOPE), which calls for drastically reducing production of such wastes by emphasizing pollution prevention and using the *precautionary principle* (see Chapter 9, p. 213).

Providing Environmental Justice for Everyone Is an Important Goal

Environmental justice is an ideal whereby every person is entitled to protection from environmental hazards regardless of race, gender, age, national origin, income, social class, or any political factor. (See the Guest Essay on this subject by Robert Bullard on the website for this chapter.)

Studies have shown that a lopsided share of polluting factories, hazardous waste dumps, incinerators, and landfills in the United States are located in communities populated mostly by African Americans, Asian Americans, Latinos, and Native Americans. Studies have also shown that, in general, toxic waste sites in white communities have been cleaned up faster and more completely than similar sites in African American and Latino communities have.

Such environmental discrimination in the United States and in other parts of the world has led to a growing grassroots approach to this problem that is known as the *environmental justice movement*. Supporters of this group have pressured governments, businesses, and environmental organizations to become aware of environmental injustice and to act to prevent it. They have made some progress toward their goals, but have a long way to go.

THINKING ABOUT
Environmental Injustice

Have you or anyone in your family ever been a victim of environmental injustice? If so, what happened? What would you do to help prevent environmental injustice?

International Treaties Have Reduced Hazardous Waste

Environmental justice also applies at the international level. For decades, some more-developed countries had been shipping hazardous wastes to less-developed countries. Since 1992, an international treaty known as the Basel Convention has been in effect (**Core Case Study**). CORE CASE STUDY It banned the more-developed countries that participate in the treaty from shipping hazardous waste (including e-waste) to or through other countries without their permission. In 1995, the treaty was amended to outlaw all transfers of hazardous wastes from industrialized countries to less-developed countries. By 2009, this agreement had been signed by 175 countries and ratified (formally approved and implemented) by 172 countries. Those nations that signed but did not ratify the convention are the United States, Afghanistan, and Haiti.

This ban will help, but it will not wipe out the very profitable illegal shipping of hazardous wastes. Hazardous waste smugglers evade the laws by using an array of tactics, including bribes, false permits, and mislabeling of hazardous wastes as recyclable materials.

In 2000, delegates from 122 countries completed a global treaty known as the Stockholm Convention on Persistent Organic Pollutants (POPs). It regulated the use of 12 widely used persistent organic pollutants that can accumulate in the fatty tissues of humans and other organisms that occupy high trophic levels in food webs. There, they can reach levels hundreds of thousands of times higher than their levels in the general environment (see Figure 9-15, p. 203). Because they persist in the environment, POPs can also be transported long distances by wind and water.

The original list of 12 chemicals, called the *dirty dozen*, includes DDT and 8 other chlorine-containing persistent pesticides, PCBs (see Chapter 17, Case Study, pp. 446–447), dioxins, and furans. Using blood tests and statistical sampling, medical researchers at New York City's Mount Sinai School of Medicine (USA) found that it is likely that nearly every person on earth has detectable levels of POPs in their bodies. The long-term health effects of this involuntary global chemical experiment are largely unknown.

In 2009, 152 countries signed a strengthened version of the POPs treaty that seeks to ban or phase out use of these chemicals and to detoxify or isolate stockpiles of them. It does allow 25 countries to continue using DDT to combat malaria until safer alternatives are available. The United States has not yet ratified this treaty.

Environmental scientists consider the POPs treaty to be an important milestone in international environmental law and pollution prevention because it uses the precautionary principle to manage and reduce the threats from toxic chemicals. The list of POPs is expected to grow.

In 2000, the Swedish Parliament enacted a law that, by 2020, will ban all chemicals that are persistent in the environment and that can accumulate in living tissue. This law also requires industries to perform risk assessments on the chemicals they use and to show that these chemicals are safe to use, as opposed to requiring the government to show that they are dangerous. In other words, chemicals are assumed to be guilty until proven innocent—the reverse of the current policy in the United States and most other countries. There is strong opposition to this approach in the United States, especially from most of the industries that produce and use potentially dangerous chemicals.

We Can Make the Transition to Low-Waste Societies

According to physicist Albert Einstein, "A clever person solves a problem, a wise person avoids it." Many people are taking these words seriously. The gov- GOOD NEWS ernments of Norway, Austria, and the Netherlands have committed to reducing their resource waste by 75%. In a pilot study, residents of the U.S. city of East Hampton, New York, cut their solid waste production by 85%. Many school cafeterias, restaurants, national parks, and corporations are participating in a rapidly growing "zero waste" movement to reduce, reuse, and recycle in order to lower their waste outputs by up to 80%.

To prevent pollution and reduce waste, many environmental scientists argue that we can make a transition to a low-waste society by understanding and following some key principles:

- Everything is connected.
- There is no *away*, as in *to throw away*, for the wastes we produce.
- Polluters and producers should pay for the wastes they produce.
- We can mimic nature by reusing, recycling, composting, or exchanging most of the municipal solid wastes we produce (see the Case Study that follows).

CENGAGENOW™ Learn more about how shifting to a low-waste (low-throughput) economy would be the best long-term solution to environmental and resource problems at CengageNOW.

■ **CASE STUDY**

Industrial Ecosystems: Copying Nature

Biomimicry is the science and art of discovering and using natural principles to help solve human problems. For example, scientists have studied termite mounds to learn how to cool buildings naturally. And biomimicry is at the heart of the three **principles of sustainability** that we use as integrating themes in this book.

An important goal for a more sustainable society is to make its industrial manufacturing processes cleaner and more sustainable by redesigning them to mimic how nature deals with wastes. In nature, according to the chemical recycling **principle of sustainability**, the waste outputs of one organism become the nutrient inputs of another organism, so that all of the earth's nutrients are endlessly recycled. This explains why there is essentially no wasted matter in undisturbed ecosystems.

One way for industries to mimic nature is to reuse or recycle most of the minerals and chemicals they use, instead of burying or burning them or shipping them somewhere. Another way for industries to mimic nature would be to interact through *resource exchange webs* in which the wastes of one manufacturer become the raw materials for another—similar to food webs in natural ecosystems (see Figure 3-13, p. 64).

Such biomimicry is happening in Kalundborg, Denmark, where an electric power plant and nearby industries, farms, and homes are collaborating to save money and to reduce their outputs of waste and pollution, within what is called an *ecoindustrial park*, or *industrial ecosystem*. They exchange waste outputs and convert them into resources, as shown in Figure 21-26 (p. 582). This cuts pollution and waste and reduces the flow of nonrenewable mineral and energy resources through the local economy.

GOOD NEWS

Today, more than 40 ecoindustrial parks (18 of them in the United States) operate in various places around the world, and more are being built or planned—some of them on brownfield sites. A number of people who work in the rapidly growing field of industrial ecology are focusing on developing a global network of industrial ecosystems over the next few decades, and this could lead to an important *ecoindustrial revolution*. **GREEN CAREER:** industrial ecology

This and other industrial forms of biomimicry provide many economic benefits for businesses. By encouraging reuse, recycling, and pollution prevention, they reduce the costs of managing solid wastes, controlling pollution, and complying with pollution regulations. They also reduce a company's chances of being sued because of damages to people and to the environment caused by their actions. In addition, companies improve the health and safety of workers by reducing their exposure to toxic and hazardous materials, thereby reducing company health insurance costs.

Biomimicry also encourages companies to come up with new, environmentally beneficial, and less resource-intensive chemicals, processes, and products that they can sell worldwide. In addition, these companies convey a better image to consumers based on actual results rather than public relations campaigns.

Biomimicry involves two major steps. The first is to observe certain changes in nature and to study how natural systems have responded to such changing conditions over many millions of years. The second step is to try to copy or adapt these responses within human systems in order to help us deal with various environmental challenges. In the case of solid and hazardous wastes, the food web serves as a natural model for responding to the growing problem of these wastes. This is in keeping with the three **principles of sustainability** that nature has used for billions of years.

Here are this chapter's *three big ideas*:

- The order of priorities for dealing with solid waste should be to produce less of it, reuse and recycle as much of it as possible, and safely dispose of what is left.
- The order of priorities for dealing with hazardous waste should be to produce less of it, reuse or recycle it, convert it to less hazardous material, and safely store what is left.
- We need to view solid wastes as wasted resources and hazardous wastes as materials that we should not be producing in the first place.

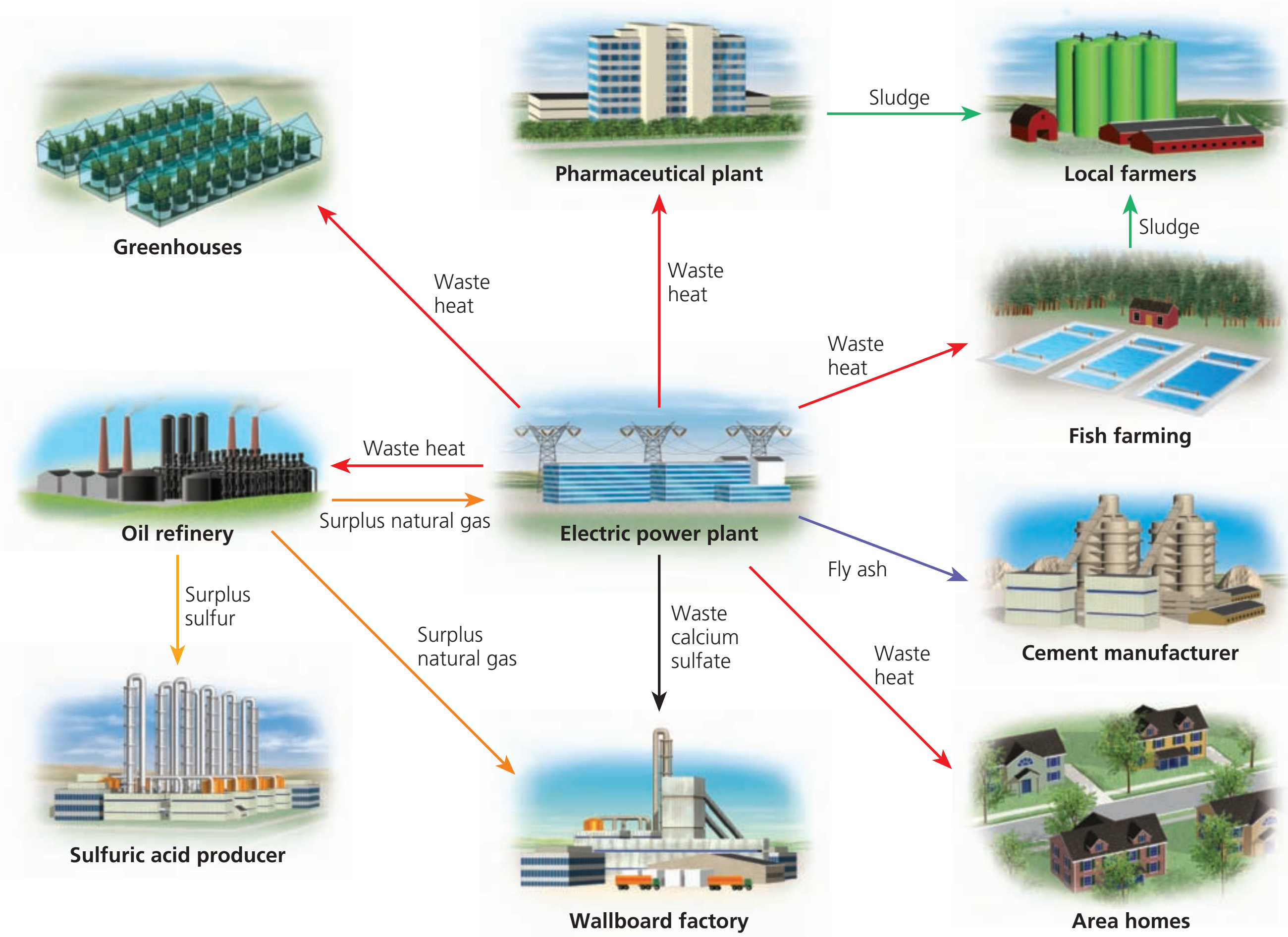


Figure 21-26 **Solutions:** This *industrial ecosystem* in Kalundborg, Denmark, reduces waste production by mimicking a natural ecosystem's food web. The wastes of one business become the raw materials for another, thus mimicking the way that nature recycles chemicals. **Question:** Is there an industrial ecosystem near where you live or go to school? If not, think about where and how such a system could be set up.

REVISITING E-Waste and Sustainability

One of the problems of maintaining a high-waste society is the growing mass of e-waste (**Core Case Study**) and other types of solid and hazardous waste discussed in this chapter. The challenge is to make the transition from an unsustainable high-waste, throwaway economy to a more sustainable low-waste, reducing–reusing–recycling economy as soon as possible.

Such a transition will require applying the three **principles of sustainability**. We can reduce our outputs of solid and hazardous waste by relying much less on fossil fuels and nuclear power (which produces long-lived, hazardous radioactive wastes) while relying much more on renewable energy from the sun, wind, and flowing water. We can mimic nature's chemical cycling processes by reusing and recycling materials that historically have become wastes. Integrated waste management, which uses a diversity of approaches and emphasizes waste reduction and pollution prevention, is a way to mimic nature's use of biodiversity. Slowing the growth of the human population and of levels of resource use per person would also decrease the demand for materials that eventually become solid and hazardous wastes.

The key to addressing the challenge of toxics use and wastes rests on a fairly straightforward principle: harness the innovation and technical ingenuity that has characterized the chemicals industry from its beginning and channel these qualities in a new direction that seeks to detoxify our economy.

ANNE PLATT MCGINN

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 558. Describe the problems associated with electronic waste (e-waste) (**Core Case Study**). CORE CASE STUDY
2. Distinguish among **solid waste**, **industrial solid waste**, **municipal solid waste (MSW)**, and **hazardous (toxic) waste**, and give an example of each. Give two reasons for sharply reducing the amount of solid and hazardous waste we produce. Describe the production of solid waste in the United States and what happens to it.
3. Distinguish among **waste management**, **waste reduction**, and **integrated waste management**. Describe the priorities that prominent scientists believe we should use for dealing with solid waste. What is garbology and how might it help us to deal with MSW? Distinguish among the 3 Rs—to **reduce**, **reuse**, and **recycle**—in dealing with the wastes we produce. Describe six ways in which industries and communities can reduce resource use, waste, and pollution.
4. Explain why reusing and recycling materials are so important and give two examples of each. Describe the importance of using refillable containers and list five other ways to reuse various items. Distinguish between **primary (closed-loop)** and **secondary recycling**, and give an example of each. Describe two approaches to recycling household solid wastes and evaluate each approach. What is a materials-recovery facility? What is composting?
5. Describe the recycling of paper and the problems involved. Describe the recycling of plastics and the problems involved. Describe the progress being made in the recycling of plastics. What are bioplastics? What are some possible problems with relying on biodegradable conventional plastics? What are the major advantages and disadvantages of recycling? What are three factors that discourage recycling? Describe three ways to encourage recycling and reuse. Explain why reduced resource use and reuse are more important than recycling for reducing wastes and pollution.
6. What are the major advantages and disadvantages of using incinerators to burn solid and hazardous waste? Distinguish between **open dumps** and **sanitary landfills**. What are the major advantages and disadvantages of burying solid waste in sanitary landfills? From a scientific standpoint, why is it not a good idea to mix wastes for burial?
7. What are the priorities that scientists believe we should use in dealing with hazardous waste? Explain the connection between cell phones and African lowland gorillas. Discuss the problems involved in sending e-wastes to some less-developed countries for recycling. What are some ways to do responsible e-waste recycling? Describe three ways to detoxify hazardous wastes. What is bioremediation? What is phytoremediation? What are the major advantages and disadvantages of incinerating hazardous wastes? What are the major advantages and disadvantages of using a plasma arc torch to detoxify hazardous wastes?
8. What are the major advantages and disadvantages of disposing of liquid hazardous wastes in **(a)** deep underground wells and **(b)** surface impoundments? What is a secure hazardous waste landfill? List three ways to reduce your output of hazardous waste. Describe the regulation of hazardous waste in the United States under the Resource Conservation and Recovery Act and the Comprehensive Environmental Response, Compensation, and Liability (or Superfund) Act. What is a brownfield?
9. How has grassroots action improved solid and hazardous waste management in the United States? What is **environmental justice** and how well has it been applied in locating and cleaning up hazardous waste sites in the United States? Describe regulation of hazardous wastes at the global level through the Basel Convention and the treaty to control persistent organic pollutants (POPs).
10. Define and give two examples of **biomimicry**. Describe the use of biomimicry in industrial ecosystems. What are this chapter's *three big ideas*? Describe the connections between the growing problem of e-waste (**Core Case Study**) and the three **principles of sustainability**. CORE CASE STUDY SUSTAINABILITY

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. Do you think that manufacturers of computers, television sets, and other forms of e-waste (**Core Case Study**) should be required to take their products back at the end of their useful lives for repair, remanufacture, or recycling in a manner that is both environmentally responsible and that does not threaten the health of recycling workers? Explain. Would you be willing to pay more for these products to cover the costs of such a take-back program? If so, what percent more per purchase would you be willing to pay for electronic products? CORE CASE STUDY
2. Find three items you regularly use once and then throw away. Are there other reusable items that you could use in place of these disposable items? Compare the cost of using the disposable option for a year versus the cost of using the alternatives.

3. Use the second law of thermodynamics (see Chapter 2, p. 47) to explain why a *properly designed* source-separation recycling program takes less energy and produces less pollution than a centralized program that collects mixed waste over a large area and hauls it to a central facility where workers or machinery separate the wastes for recycling.

4. Changing World Technologies has built a pilot plant to test a process it has developed for converting a mixture of computers, old tires, turkey bones and feathers, and other wastes into oil by mimicking and speeding up natural processes for converting biomass into oil. If this recycling process turns out to be technologically and economically feasible, explain why it could increase waste production.

5. Would you oppose having a hazardous waste landfill, waste treatment plant, deep-injection well, or waste incinerator in your community? For each of these facilities, explain your answer. If you oppose having such facilities in your community, how do you believe the hazardous waste generated in your community should be managed?

6. How does your school dispose of its solid and hazardous wastes? Does it have a recycling program? How well does it work? Does it have a hazardous waste collection system? If so, how does it work? List three ways to improve your school's waste reduction and management system.

7. Give your reasons for agreeing or disagreeing with each of the following proposals for dealing with hazardous waste:
   a. Reduce the production of hazardous waste and encourage recycling and reuse of hazardous materials by charging producers a tax or fee for each unit of waste generated.
   b. Ban all land disposal and incineration of hazardous waste to protect air, water, and soil from contamination, and to encourage reuse, recycling, and treatment of wastes to make them less hazardous.
   c. Provide low-interest loans, tax breaks, and other financial incentives to encourage industries that produce hazardous waste to reduce, reuse, recycle, treat, and decompose such waste.

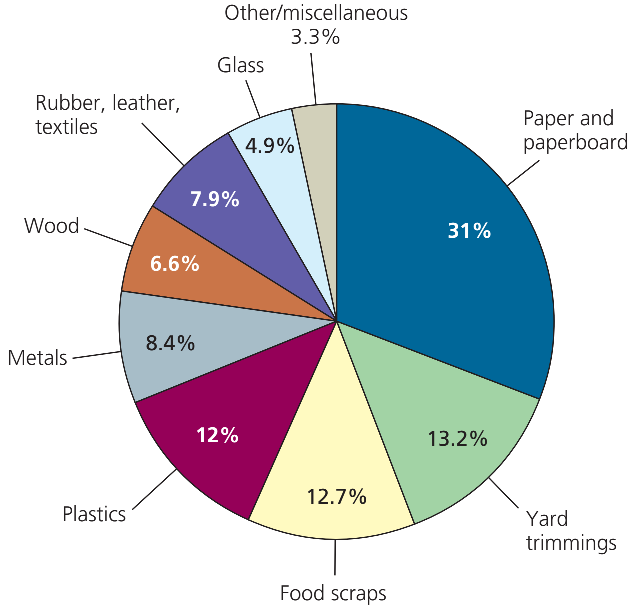
8. List three ways in which you could apply **Concept 21-6** to making your lifestyle more environmentally sustainable.

9. Congratulations! You are in charge of the world. List the three most important components of your strategy for dealing with **(a)** solid waste and **(b)** hazardous waste.

10. List two questions you would like to have answered as a result of reading this chapter.

ECOLOGICAL FOOTPRINT ANALYSIS

The average daily municipal solid waste production per person in the United States in 2008 was 2.04 kilograms (4.48 pounds). Use this information and the pie chart below to calculate the weight of waste generated in each category during 2008 by a typical American, in kilograms (and in pounds). (1 kilogram = 2.20 pounds)



This pie chart shows a typical composition of U.S. municipal solid waste (MSW) in 2008. (Data from U.S. Environmental Protection Agency, 2009)

Use the chart at right to enter your answers. Compare your answers with those of your classmates.

Waste category	Annual MSW footprint per person
Paper and paperboard	
Yard trimmings	
Food scraps	
Plastics	
Metals	
Wood	
Rubber, leather, and textiles	
Glass	
Other/miscellaneous	

LEARNING ONLINE

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22 Cities and Sustainability

CORE CASE STUDY The Ecocity Concept in Curitiba, Brazil

Urban planners envision large portions of the growing human population living in more environmentally sustainable cities, called *ecocities* or *green cities*. This is not just a futuristic dream. One such ecocity is Curitiba ("koor-i-TEE-ba"), a city of 3.2 million people known as the "ecological capital of Brazil."

In 1969, planners in this city decided to focus on creating an efficient mass transit system rather than on accomodating a growing number of cars. Curitiba now has the world's best bus system, in which clean and modern buses transport about 72% of all commuters every day throughout the city using express lanes dedicated to buses (Figure 22-1). Only high-rise apartment buildings are allowed near major bus routes, and each building must devote its bottom two floors to stores—a practice that reduces the need for residents to travel.

Cars are banned from 49 blocks in the center of the downtown area, which has a network of pedestrian walkways connected to bus stations, parks, and bicycle paths running throughout most of the city. Consequently, Curitiba uses less energy per person and has lower emissions of greenhouse gases and other air pollutants, as well as less traffic congestion than do most comparable cities.

The city transformed flood-prone areas along its six rivers into a series of interconnected parks. Volunteers have planted more than 1.5 million trees throughout the city, none of which can be cut down without a permit, which also requires that two trees must be planted for each one that is cut down.

Curitiba recycles roughly 70% of its paper and 60% of its metal, glass, and plastic, which is collected from households three times a week. Recovered materials are sold mostly to the city's more than 500 major industries, which must meet strict pollution standards. Most of these businesses are located in an industrial park outside the city limits. A major bus line runs to the park, but many of the workers live nearby and can walk or bike to work.

The poor receive free medical and dental care, child care, and job training, and 40 feeding centers are available for street children. Poor people can exchange filled garbage bags for surplus food, bus tokens, and school supplies. Also, the city has a *build-it-yourself* program that gives a poor family a plot of land, building materials, two trees, and an hour's consultation with an architect.

This internationally acclaimed model of urban planning and sustainability is the brainchild of architect and former college professor Jaime Lerner, who has served as the city's mayor three times since 1969. When its transformation began, Curitiba was no more well off than any other Brazilian city. In 1980, its per capita GDP was only 10% above the average for Brazil. By 1996, it was 65% above average. Its economy did well partly because companies were attracted to the city's pleasant environment, lack of congestion, and ease of commuting.

Curitiba now faces new challenges, as do all cities, mostly because of increasing population pressure. Throughout this chapter, we will examine these challenges and some possible solutions for Curitiba and other urban areas.

John Maier, Jr./Peter Arnold, Inc.

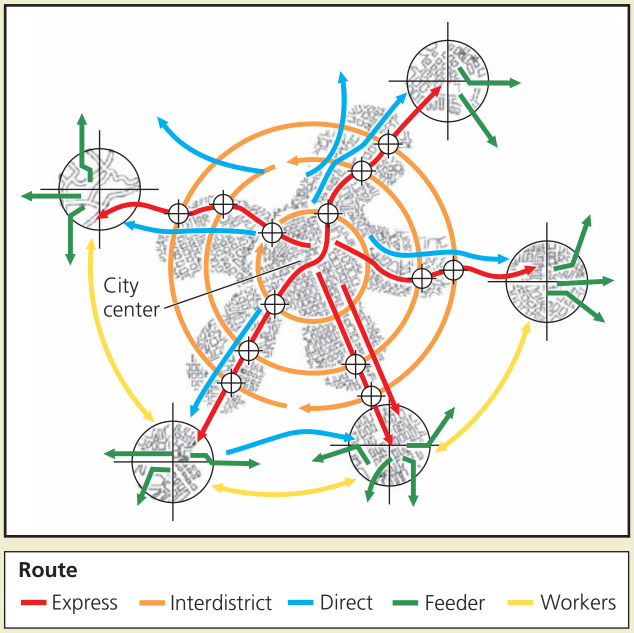

Figure 22-1 Solutions: This bus rapid transit (BRT) system in Curitiba, Brazil, moves large numbers of passengers around rapidly because each of the system's five major "spokes," connecting the city center with outlying districts, has two express lanes used only by buses. Double- and triple-length bus sections are coupled together as needed to carry up to 300 passengers. Boarding is speeded up by the use of extra-wide bus doors and boarding platforms under glass tubes where passengers can pay before getting on the bus (top left).

Key Questions and Concepts

22-1 What are the major population trends in urban areas?

CONCEPT 22-1 Urbanization continues to increase steadily and the numbers and sizes of urban areas are growing rapidly, especially in less-developed countries.

22-2 What are the major urban resource and environmental problems?

CONCEPT 22-2 Most cities are unsustainable because of high levels of resource use, waste, pollution, and poverty.

22-3 How does transportation affect urban environmental impacts?

CONCEPT 22-3 In some countries, many people live in dispersed urban areas and depend mostly on motor vehicles for their transportation, which greatly expands their ecological footprints.

22-4 How important is urban land–use planning?

CONCEPT 22-4 Urban land-use planning can help to reduce uncontrolled sprawl and slow the resulting degradation of air, water, land, biodiversity, and other natural resources.

22-5 How can cities become more sustainable and livable?

CONCEPT 22-5 An *ecocity* allows people to choose walking, biking, or mass transit for most transportation needs; to recycle or reuse most of their wastes; to grow much of their food; and to protect biodiversity by preserving surrounding land.

Note: Supplements 2 (p. S3), 3 (p. S6), 8 (p. S30), and 9 (p. S57) can be used with this chapter.

The city is not an ecological monstrosity. It is rather the place where both the problems and the opportunities of modern technological civilization are most potent and visible.

PETER SELF

22-1 What Are the Major Population Trends in Urban Areas?

CONCEPT 22-1 Urbanization continues to increase steadily and the numbers and sizes of urban areas are growing rapidly, especially in less-developed countries.

Half of the World's People Live in Urban Areas

People live in *urban areas*, or cities (Figure 22-2, top, p. 588), suburbs that spread out around city centers (Figure 22-2, middle), and rural areas or villages (Figure 22-2, bottom). **Urbanization** is the creation and growth of urban and suburban areas. It is measured as the percentage of the people in a country or in the world living in such areas. **Urban growth** is the *rate* of increase of urban populations.

The world's first cities emerged about 6,000 years ago. The first city to reach a population of 1 million was Rome, Italy, in 133 BC. Since then, the world has become increasingly urbanized. Today, half of the world's people, and 79% of Americans, live in urban areas.

Urban areas grow in two ways—by *natural increase* (more births than deaths) and by *immigration,* mostly from rural areas. Rural people are *pulled* to urban areas in search of jobs, food, housing, educational opportunities, better health care, and entertainment. Some are also *pushed* from rural to urban areas by factors such as poverty, lack of land for growing food, declining agricultural jobs, famine, war, and religious, racial, and political conflicts.

People are also pushed or pulled to cities by government policies that favor urban over rural areas. For example, less-developed countries tend to spend most of their budgets on economic development and job creation in urban areas. Some governments establish lower food prices in urban areas, which reward city dwellers, help to keep leaders in power, and attract the rural poor.

Four major trends in urban population dynamics have emerged, and they are important for understanding the problems and challenges of urban growth. First, *the proportion of the global population living in urban areas is increasing.* In 1900, the average population of the

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Figure 22-2 About half of the world's people live in urban areas, or cities, such as Shanghai, China (top), and their surrounding suburban areas such as this one in Southern California (middle). The other half live in rural areas—in villages such as this one in the southern African country of Malawi (bottom), in small towns, or in the countryside.

world's biggest 100 cities was about 700,000. By 2009, that average had climbed to 6 million.

Between 1850 and 2009, the percentage of people living in urban areas increased from 2% to 50%, and it could reach 66% by 2030. About 88% of this growth will occur in already overcrowded and economically stressed cities in less-developed countries, where four of every ten people live in urban areas (Figure 22-3). In each of the two largest of these countries, China and India, more than 25 million people move to cities each year.

Second, *the numbers and sizes of urban areas are mushrooming.* Every week, more than 1 million people are added to the world's urban areas. Between 2008 and 2015, the number of urban areas with a million or more people is projected to increase from 400 to 564. Demographers project that by 2025, China will add 60 new cities, each hosting 1.5 million to 5 million people. By comparison, the United States currently has just 9 cities of more than 1 million people. Between 2010 and 2030, China will add more city dwellers than the entire current population of the United States.

Currently, there are 18 *megacities* or *megalopolises*—cities with 10 million or more people—up from 8 in 1985. Fifteen of them are in less-developed countries (Figure 22-4). Such megacities will soon be eclipsed by *hypercities* each having more than 20 million people. Tokyo, Japan, is the leading city in this category, having 32 million people—more than the entire population of Canada. But according to UN projections, by 2015, Tokyo, Japan, Mumbai (formerly Bombay) and Delhi in India, Dhaka, Bangladesh, and São Paulo, Brazil, will be the top five most populated cities. All of them, along with Lagos, Nigeria, are projected to become hypercities by then.

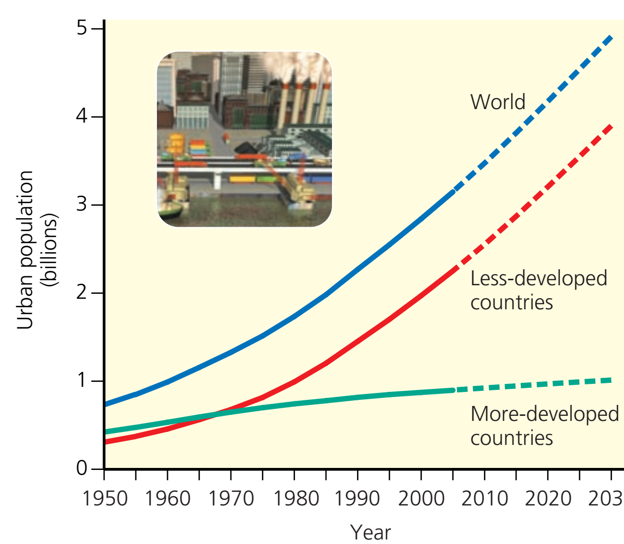


Figure 22-3 This graph tracks urban population growth for the world, as well as for less-developed countries and more-developed countries, 1950–2010, with projections to 2030. **Question:** Why do you think the growth in urban populations is much higher in less-developed countries than in more-developed countries? (Data from United Nations Population Division)

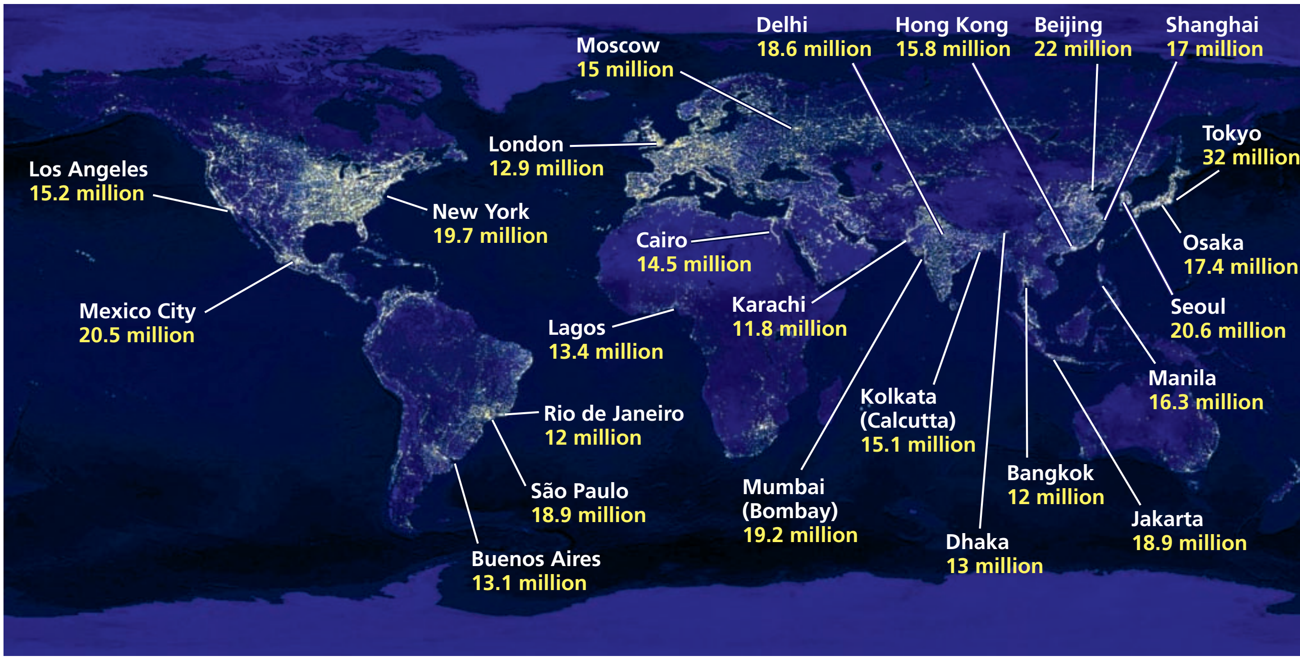


Figure 22-4 *Global outlook:* Major urban areas throughout the world are revealed in these satellite images of the earth at night, showing city lights. Currently, the 50% of the world's people who live in urban areas occupy about 2% of the earth's land area. Note that most of the urban areas are found along the continental coasts, which explains why most of Africa and much of the interior of South America, Asia, and Australia are dark at night. This figure also shows the populations of the world's 18 *megacities* (each with 10 million or more people) in 2010. All but three are located in less-developed countries. **Question:** In order, what were the world's five most populous cities in 2010? (Data from National Geophysics Data Center, National Oceanic and Atmospheric Administration, and United Nations)

Third, *urban growth is much slower in more-developed countries than in less-developed countries* (Figure 22-3). However, more-developed countries, now with 75% urbanization, are projected to reach 81% urbanization by 2030.

Fourth, *poverty is becoming increasingly urbanized, mostly in less-developed countries*. The United Nations estimates that at least 1 billion people in less-developed countries (more than three times the current U.S. population) live in crowded and unsanitary slums and shantytowns within most cities or on their outskirts; within 30 years this number may double.

THINKING ABOUT
Urban Trends

CORE CASE STUDY

If you could reverse one of the four urban trends discussed here, which one would it be? Which of these trends has Curitiba, Brazil, (**Core Case Study**) reversed?

If you visit a poor, over-crowded area of a large city in a less-developed country, your senses may be overwhelmed by a vibrant but chaotic crush of people, vehicles of all types, traffic jams (Figure 22-5), noise, and odors, including smoke from burning trash, as well as from wood and coal cooking fires, and raw sewage. Many people sleep on the streets or live in crowded, unsanitary, rickety, and unsafe slums and shantytowns with little or no access to safe drinking water or modern sanitation facilities.

Mark Edwards/Peter Arnold, Inc.

Figure 22-5 This is a typical daily traffic jam of people, carts, bicycle taxis, and other vehicles in an older section of Delhi, India—a city with 13 million people.

■ CASE STUDY

Urbanization in the United States

Between 1800 and 2008, the percentage of the U.S. population living in urban areas increased from 5% to 79%. This population shift has occurred in four phases.

First, *people migrated from rural areas to large central cities.* Currently, three-fourths of Americans live in cities with at least 50,000 people, and nearly half live in urban areas with 1 million or more residents (Figure 22-6).

Second, *many people migrated from large central cities to smaller cities and suburbs.* Currently, about half of urban Americans live in the suburbs (Figure 22-2, middle), nearly a third in central cities, and the rest in rural housing developments beyond suburbs.

Third, *many people migrated from the North and East to the South and West.* Since 1980, about 80% of the U.S. population increase has occurred in the South and West. Between 2009 and 2043, demographers project that the fastest growing U.S. states will continue to be Nevada, Arizona, and Florida, although increased drought and heat waves due to projected climate change may alter this trend. According to a 2006 study by the Center for Environment and Population, the South and West also contain many of the country's ecological hot spots (see Figure 27 on p. S55 in Supplement 8) where biodiversity is threatened.

Fourth, since the 1970s, and especially since 1990, *some people have fled both cities and suburbs, and migrated to developed areas outside of suburbs*. The result is rapid growth of *exurbs*—housing developments scattered over vast areas that lie beyond suburbs and have no socioeconomic centers.

Since 1920, many of the worst urban environmental problems in the United States have been reduced significantly (Figure 6-7, p. 132). Most people have better working and housing conditions, and air and water quality have improved. Better sanitation, clean public water supplies, and medical care have slashed death rates and incidences of sickness from infectious diseases. Concentrating most of the population in urban areas also has helped to protect the country's biodiversity by reducing the destruction and degradation of wildlife habitat.

Figure 22-6 The major urban areas in the United States are revealed in satellite images of the earth at night showing city lights (top). About eight of every ten Americans live in urban areas, which occupy a small but growing fraction of the country's land area. The cities identified in the image are the fastest-growing metropolitan areas. Nearly half (48%) of all Americans live in cities of 1 million or more people, most of which are projected to merge into huge urban areas shown as shaded sections in the bottom map. **Question:** Why are many of the largest urban areas located near water? (Data from National Geophysical Data Center/National Oceanic and Atmospheric Administration, U.S. Census Bureau)

However, a number of U.S. cities—especially older ones—have deteriorating services and aging *infrastructures* (streets, bridges, dams, power lines, schools, waste management, water supply pipes, and sewers). Indeed, according to a 2009 study by the American Society of Civil Engineers (ASCE), the United States has fallen $2.2 trillion behind in maintaining its vital public infrastructure of roads, bridges, sewer systems, dams, and schools. This amounts to more than $7,000 for each U.S. citizen.

The ASCE president warned that "crumbling infrastructure has a direct impact on personal and economic health." For example, the ASCE report found that aging sewer systems allow huge volumes of untreated wastewater to flow into U.S. waterways every year. This results in pollution of many urban streams and beaches, as well as the potential for contaminating groundwater and surface water.

At a time when there are urgent needs to upgrade rapidly deteriorating infrastructure, many U.S. cities face budget crises and the resulting cuts to public services, as businesses and people move to the suburbs and exurbs, and city revenues from property taxes decline. The economic recession beginning in 2008 has worsened this situation, as city and state budgets have suffered from declining tax revenues. In hard times, funds for maintaining infrastructure are usually the first to be cut.

Urban Sprawl Gobbles Up the Countryside

In the United States and some other countries, **urban sprawl**—the growth of low-density development on the edges of cities and towns—is eliminating surrounding agricultural and wild lands (Figure 22-7). It results in a far-flung hodgepodge of housing developments, (Figure 22-2, middle) shopping malls, parking lots, and office complexes that are loosely connected by multilane highways and freeways.

Five major factors promoted urban sprawl in the United States. *First,* ample land was available for most cities to spread outward. *Second,* low-cost gasoline combined with federal and state funding of highways encouraged automobile use and the development of outlying tracts of land. *Third,* starting around 1950, federal government home loan guarantees for World War II veterans stimulated the development of suburbs; since then, tax laws have encouraged home ownership. *Fourth,* most state and local zoning laws favored large residential lots and the separation of residential and commercial areas. *Fifth,* most urban areas consist of multiple local governments, which rarely work together to develop an overall plan for managing urban growth. Similar processes have occurred in other countries.

Image courtesy of the U.S. Geological Survey

1973

Image courtesy of the U.S. Geological Survey

2003

Figure 22-7 These satellite images show the growth of *urban sprawl* in and around the U.S. city of Las Vegas, Nevada, between 1973 and 2003—a process that continues. Between 1970 and 2009, the population of water-short Clark County, which includes Las Vegas, more than quadrupled from 463,000 to around 1.9 million, making it one of the nation's fastest-growing urban areas. **Question:** What might be a limiting factor on population growth in Las Vegas?

As they grow outward, separate urban areas sometimes merge to form a *megalopolis*. For example, the remaining open spaces between the U.S. cities of Boston, Massachusetts, New York, New York, and Washington, DC, are rapidly urbanizing (Figure 22-6, bottom). The result is an almost 800-kilometer-long (500-mile-long) urban area that contains about 35 million people and is often called *Bowash*. Other such megalopolises include the areas between Amsterdam, the Netherlands, and Paris, France, in Europe; Japan's Tokyo–Yokohama–Osaka–Kobe corridor known as Tokohama (with nearly 50 million people); and the Brazilian industrial triangle made up of São Paulo, Rio de Janeiro, and Belo Horizonte.

In a nutshell, urban sprawl is the product of affordable land, automobiles, cheap gasoline, and little or no urban planning. Many people prefer living in suburbs and exurbs. Compared to central cities, these areas provide lower-density living and access to larger lot sizes and single-family homes. Often these areas also have newer public schools and lower crime rates.

However, urban sprawl has caused or contributed to a number of environmental problems. Because of nonexistent or inadequate mass transportation in most such areas, sprawl forces people to drive everywhere, and in the process, their vehicles consume significant amounts of gasoline while emitting greenhouse gases and other forms of air pollution. Sprawl has decreased energy efficiency, increased traffic congestion, and destroyed prime cropland, forests, and wetlands.

Urban sprawl also has led to the economic deaths of many central cities, as people and businesses move out of these areas. In addition, a similar but new problem has arisen since 2000—the growing decay of suburban shopping centers. As cheap credit has dried up, making consumers less willing to use their credit cards, and as online shopping has replaced many car trips, numerous suburban shopping centers have closed. Some of these abandoned shopping centers are being recycled as apartment or office buildings and churches. Others will remain as crumbling eyesores or urban dinosaurs surrounded by vast empty parking lots on the outskirts of many cities.

Analysts at the Metropolitan Institute at Virginia Tech have suggested that this problem is deeper than an economic slump. They suggest that the suburban population of U.S. consumers is shrinking as the baby boomers (the large number of Americans born in the two decades after World War II) grow older. As a result, fewer suburban households have growing children, and many older Americans now prefer to live in more culturally diverse and interesting redeveloped central cities. These analysts project that the year 2025 will see a surplus of 22 million large-lot homes in U.S. suburbs and exurbs.

Figure 22-8 summarizes these and other undesirable consequences of urban sprawl.

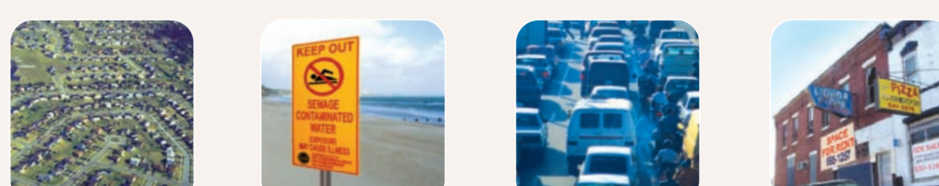
THINKING ABOUT
Urban Sprawl

Do you think the advantages of sprawl outweigh its disadvantages? What might happen to suburban and exurban areas as the prices of oil and gasoline rise sharply? How might this affect your lifestyle?

CENGAGE**NOW**™ Examine how the San Francisco Bay area in the U.S. state of California grew in population between 1900 and 1990 at CengageNow.

Natural Capital Degradation

Urban Sprawl



Land and Biodiversity	Water	Energy, Air, and Climate	Economic Effects
Loss of cropland	Increased use and pollution of surface water and groundwater	Increased energy use and waste	Decline of downtown business districts
Loss and fragmentation of forests, grasslands, wetlands, and wildlife habitat	Increased runoff and flooding	Increased emissions of carbon dioxide and other air pollutants	More unemployment in central cities

Figure 22-8 These are some of the undesirable impacts of urban sprawl or car-dependent development. **Question:** Which five of these effects do you think are the most harmful?

22-2 What Are the Major Urban Resource and Environmental Problems?

▶ **CONCEPT 22-2 Most cities are unsustainable because of high levels of resource use, waste, pollution, and poverty.**

Urbanization Has Advantages

Urbanization has many benefits. From an *economic standpoint*, cities are centers of economic development, innovation, education, technological advances, and jobs. They serve as centers of industry, commerce, and transportation.

GOOD NEWS

Urban residents in many parts of the world tend to live longer than do rural residents and to have lower infant mortality and fertility rates. They also have better access to medical care, family planning, education, and social services than do their rural counterparts. However, the health benefits of urban living are usually greater for the rich than for the poor.

Urban areas also have some environmental advantages. Recycling is more economically feasible because concentrations of recyclable materials and funding for recycling programs tend to be higher in urban areas. Concentrating people in cities helps to preserve biodiversity by reducing the stress on wildlife habitats. Central cities also can save energy if residents rely more on energy-efficient mass transportation, walking, and bicycling, as they do in Curitiba, Brazil (**Core Case Study**).

CORE CASE STUDY

Urbanization Has Disadvantages

Half of the world's 6.9 billion people live in urban areas and each year, about 63 million people—an average of nearly 7,200 per hour—are added to these areas. Such intense population pressure and high population densities (see Figure 6-1, p. 125) makes most of the world's cities more environmentally unsustainable every year (**Concept 22-2**).

Even in more sustainable cities such as Curitiba, Brazil, (**Core Case Study**) this pressure is taking its toll. The city's once clear streams are often overloaded with pollutants. The bus system is nearing capacity, and car ownership is on the rise. While the recycling rate is still among the highest in the world, the region's only landfill is now full. Architect Jorge Wilheim, who helped create Curitiba's master plan, points out that the city's population is now more than five times as large as it was in 1965 when the plan was drafted. With the metropolitan area's population at 3.2 million, Wilheim believes it is time to adjust the plan.

CORE CASE STUDY

We will touch on aspects of a possible new vision for Curitiba and similar solutions for other cities throughout this chapter. Here we take a closer look at some significant problems faced by cities.

Cities Have Huge Ecological Footprints. According to the Worldwatch Institute, although urban populations occupy only about 2% of the earth's land area, they consume about 75% of its resources and produce about 75% of the world's climate-changing CO_2 emissions from human activities. Because of this high resource input of food, water, and materials, and the resulting high waste output (Figure 22-9, p. 594), *most of the world's cities have huge ecological footprints and are not self-sustaining systems* (**Concept 22-2**).

While urbanization does help to preserve some of the earth's biodiversity, large areas of land must be disturbed and degraded to provide urban dwellers with food, water, energy, minerals, and other resources. This decreases and degrades biodiversity, overall.

Thus, urban areas have huge ecological footprints that extend far beyond their boundaries. If you live in a city, you can calculate its ecological footprint by going to the website **www.redefiningprogress.org/**. (Also, see the Guest Essay on this topic by Michael Cain at CengageNOW.)

> CONNECTIONS
>
> **Urban Living and Biodiversity Awareness**
>
> Recent studies reveal that most urban dwellers live most or all of their lives in an artificial environment that isolates them from forests, grasslands, streams, and other natural areas that make up the world's biodiversity. As a result, many urban residents tend to be uninformed about the importance of protecting not only the earth's increasingly threatened biodiversity but also its other forms of natural capital that support their lives and the cities in which they live.

Most Cities Lack Vegetation. In urban areas, most trees, shrubs, grasses, and other plants are destroyed to make way for buildings, roads, parking lots, and housing developments. Thus, most cities do not benefit from vegetation that would absorb air pollutants, give off oxygen, provide shade, reduce soil erosion, provide wildlife habitats, and offer aesthetic pleasure. As one observer remarked, "Cities are places where they cut down most of the trees and then name the streets after them."

Cities Often Have Water Problems. As cities grow and their water demands increase, expensive reservoirs

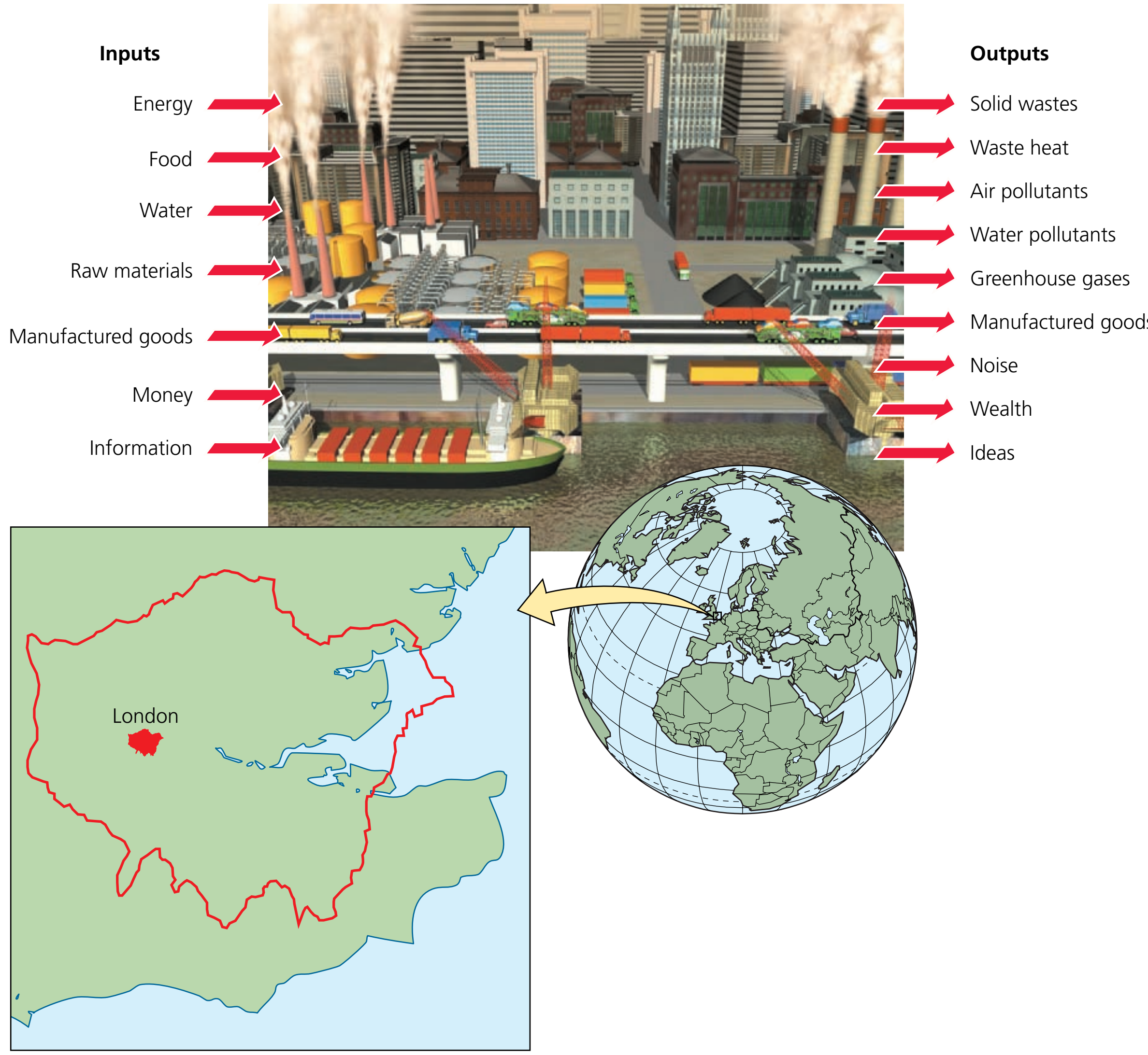


Figure 22-9 Natural capital degradation: Urban areas are rarely sustainable systems. The typical city depends on large nonurban areas for huge inputs of matter and energy resources, while it generates large outputs of waste matter and heat. According to an analysis by Mathis Wackernagel and William Rees, developers of the ecological footprint concept, London, England, requires an area 58 times as large as the city to supply its residents with resources (see area outlined in red on map below). They estimate that if all of the world's people used resources at the same rate as Londoners do, it would take at least three more planet Earths to meet their needs. **Question:** How would you apply the three **principles of sustainability** (see back cover) to lessen some of these impacts?

and canals must be built and deeper wells must be drilled. This can deprive rural and wild areas of surface water and can deplete underground water supplies.

Flooding also tends to be greater in some cities that are built on floodplains near rivers or along low-lying coastlines subject to natural flooding. In addition, covering land with buildings, asphalt, and concrete causes precipitation to run off quickly and overload storm drains. Further, urban development has often destroyed or degraded large areas of wetlands that have served as natural sponges to help absorb excess storm water. Many of the world's largest coastal cities (Figure 22-4) face a new threat of flooding some time in this century if sea levels rise as projected due to climate disruption (see Chapter 19, pp. 507–508).

For cities in arid areas that depend on water withdrawn from rivers and reservoirs that are fed by mountaintop glaciers, projected climate change will likely create another problem. Those cities will face severe water shortages as atmospheric warming melts these mountaintop glaciers.

For example, in some especially arid areas in the western United States (see Figure 13-5, p. 322) fed by the Colorado River (see Figure 13-1, p. 317) and California's water distribution system (see Figure 13-16, p. 331), irrigated agriculture may no longer be possible. For urban populations in some of these areas, this will lead to sharply rising food prices, because food will have to be shipped in from other areas. These urban dwellers will also face more water shortages, especially in areas where groundwater is being depleted (see Figure 13-9, p. 326).

The good news is that we have a variety of methods for reducing both groundwater depletion (see Figure 13-12, p. 327) and urban water use and waste (see Figure 13-23, p. 339).

Cities Concentrate Pollution and Health Problems. Because of their high population densities and high resource consumption, cities produce most of the world's air pollution, water pollution, and solid and hazardous wastes. Pollutant levels are generally higher because pollution is produced in a smaller area and cannot be dispersed and diluted as readily as pollution produced in rural areas can.

The concentration of transportation vehicles and industrial facilities in urban centers results in just over two-thirds of the world's emissions of CO_2 from human-related sources. This causes disruption of local and regional portions of the carbon cycle (see Figure 3-19, p. 70). High concentrations of urban air pollution also disrupt the nitrogen cycle (see Figure 3-20, p. 71) because of large quantities of nitrogen oxide emissions, which play a key role in the formation of photochemical smog. Also, nitric acid and nitrate emissions are major components of acid deposition in urban areas and beyond (see Figure 18-14, p. 477, and Figure 18-15, p. 478). Nitrogen nutrients in urban runoff and in discharges from urban sewage treatment plants can also disrupt the nitrogen cycle in nearby lakes and other bodies of water, and cause excessive eutrophication (see Figure 20-11, p, 537).

In addition, high population densities in urban areas can increase the spread of infectious diseases, especially if adequate drinking water and sewage systems are not available.

Cities Have Excessive Noise. Most urban dwellers are subjected to **noise pollution**: any unwanted, disturbing, or harmful sound that damages, impairs, or interferes with hearing, causes stress, hampers concentration and work efficiency, or causes accidents. Noise levels are measured in decibel-A (dbA) sound pressure units that vary with different human activities (Figure 22-10).

Sound pressure becomes damaging at about 85 dbA and painful at around 120 dbA. At 180 dbA, sound can kill. Prolonged exposure to sound levels above 85 dbA can cause permanent hearing damage. Just one-and-a-half minutes of exposure to 110 decibels or more can cause such damage. About one of every eight children and teens in the United States has some permanent hearing loss, mostly from listening to music at loud levels.

Cities Affect Local Climates and Cause Light Pollution. On average, cities tend to be warmer, rainier, foggier, and cloudier than suburbs and nearby rural areas. In cities, the enormous amount of heat generated by cars, factories, furnaces, lights, air conditioners, and heat-absorbing dark roofs and streets creates an *urban heat island* that is surrounded by cooler suburban and rural areas. As cities grow and merge (Figure 22-6), their heat islands merge, which can reduce the natural dilution and cleansing of polluted air.

In areas with hot climates, the urban heat island effect puts heat stress on humans and many other organisms. It can also greatly increase dependence on air conditioning for cooling, and it can increase the formation of photochemical smog (see Figures 18-11 and 18-12, p. 475) by speeding up the chemical reactions involved in its formation. This in turn increases energy consumption, greenhouse gas emissions, and other forms of air pollution in a vicious circle, or positive feedback loop.

The artificial light created by cities (Figures 22-2, top and 22-4) is a form of *light pollution* that affects some plant and animal species. For example, some endangered sea turtles lay their eggs on beaches at night and require darkness to do so. In addition, each year large numbers of migrating birds, lured off course by the lights of high-rise buildings, fatally collide with these structures. Light pollution also makes it difficult for astronomers and urban dwellers to study and enjoy the night sky.

THINKING ABOUT
Disadvantages of Urbanization

Which two of the disadvantages discussed here for living in urban areas do you think are the most serious? Explain.

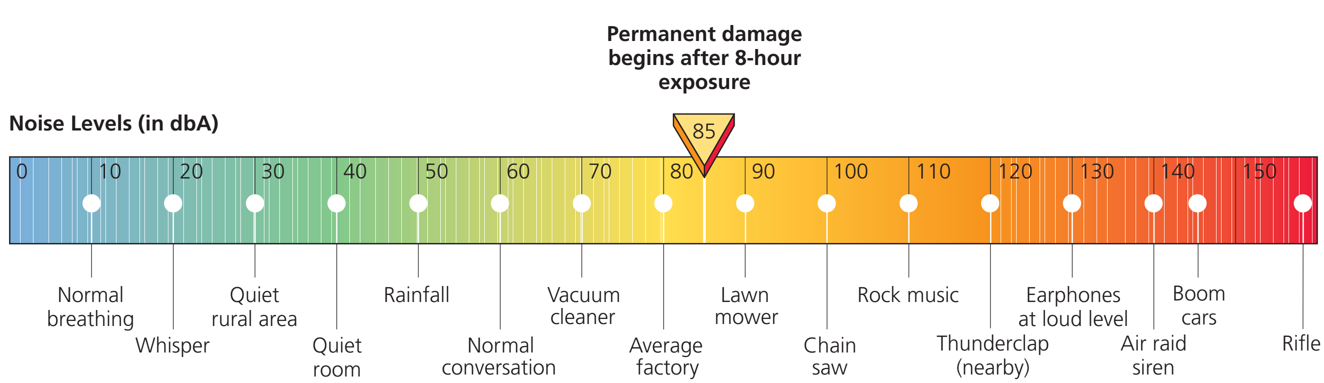


Figure 22-10 This chart lists *noise levels* of some common sounds (in decibel-A [dbA] sound pressure units). You are being exposed to a sound level high enough to cause permanent hearing damage if a noise requires you to raise your voice to be heard, if a noise causes your ears to ring, or if a noise makes nearby speech seem muffled. Prolonged exposure to lower noise levels and occasional loud sounds may not damage your hearing, but such exposure can greatly increase internal stress. **Question:** How many times per day are your ears subjected to noise levels of 85 dbA or more?

Life Is a Desperate Struggle for the Urban Poor in Less-Developed Countries

Poverty is a way of life for many urban dwellers in less-developed countries. At least 1 billion people live under crowded and unsanitary conditions in cities in these countries (Figure 22-11), and according to a 2006 UN study, that number could reach 1.4 billion by 2020. In sub-Saharan Africa, more than seven of every ten urban residents live in such conditions, according to the UN.

Some of these people live in *slums*—areas dominated by dilapidated tenements and rooming houses where numerous people might live in a single room (see Figure 6-19, p. 141). Asia's largest slum, Dharavi, in Mumbai (Bombay), India, is home to 600,000 people and has one public toilet for every 800 residents.

Other poor people live in *squatter settlements* and s*hantytowns* on the outskirts of cities. They build shacks from corrugated metal, plastic sheets, scrap wood, cardboard, and other scavenged building materials, or they live in rusted shipping containers and junked cars. Some shantytowns are illegal subdivisions where landowners rent land to the poor without city approval. Others are illegal *squatter settlements* where people take over unoccupied land without the owners' permission, simply because it is their only option for survival.

Poor people living in shantytowns and squatter settlements or on the streets (Figure 6-21, p. 143) usually lack clean water supplies, sewers, electricity, and roads, and are exposed to severe air and water pollution as well as hazardous wastes from nearby factories. Many of these settlements are in locations especially prone to landslides, flooding, or earthquakes. Some city governments regularly bulldoze squatter shacks and send police to drive illegal settlers out. The people usually move back in within a few days or weeks, or build another shantytown elsewhere.

Governments can address these problems. For example, they can slow the migration from rural to urban areas by improving education, health care, and family planning in the countryside, and by encouraging investment in small towns. Governments can also designate land for squatter settlements and supply them with clean water and sanitation, as Curitiba, Brazil, has done (**Core Case Study**). Guaranteeing regular bus service enables workers living in such settlements to travel to and from their workplaces.

CORE CASE STUDY

In Brazil and Peru, governments legally recognize existing slums (*favelas*) and grant legal titles to the land. They base this on evidence that poor people usually improve their living conditions once they know they have a permanent place to live. They can then become productive working citizens who contribute to tax revenues that, in turn, pay for the government programs that assist the poor. In some cases, impoverished people with titles to land have developed their own schools, day care centers, and other such structures for social improvement. Unfortunately, in many of the poorest countries, extensive government corruption diverts some of the limited funds available to help the poor into the hands of those who need it least.

United Nations

Figure 22-11 *Global outlook:* Extreme poverty forces hundreds of millions of people to live in slums and shantytowns, such as this one in Rio de Janeiro, Brazil, with no access to adequate water supplies, sewage disposal, and other vital services.

HOW WOULD YOU VOTE?

Should squatters living in or near cities in less-developed countries be given title to the land they live on? Cast your vote online at **www.cengage.com/login**.

CASE STUDY

Mexico City

Mexico City—the world's second most populous city—is an urban area in crisis. Its 20.5 million residents represent a number roughly equal to the entire population of Australia or the U.S. state of New York. Each year, at least 400,000 new residents arrive.

Mexico City suffers from severe air pollution, close to 50% unemployment, deafening noise, overcrowding, traffic congestion, inadequate public transportation, and a soaring crime rate. More than one-third of its residents live in slums called *barrios* or in squatter settlements that lack running water and electricity.

At least 3 million people in the barrios have no sewage facilities. As a result, huge amounts of human waste are deposited in gutters, vacant lots, and open ditches every day, attracting armies of rats and swarms of flies. When the winds pick up dried excrement, a *fecal snow* blankets parts of the city. This bacteria-laden fallout leads to widespread salmonella and hepatitis infections, especially among children.

Mexico City has one of the world's worst air pollution problems (Figure 22-12) because of a combination of factors: too many cars, polluting factories, a warm, sunny climate and thus more smog, and topographical bad luck. The city sits in a high-elevation, bowl-shaped valley surrounded on three sides by mountains—conditions that trap air pollutants at ground level. Breathing its air is said to be roughly equivalent to smoking three packs of cigarettes per day, and respiratory diseases are rampant. (See *The Habitable Planet,* Video 11 at **www.learner.org/resources/series209.html** to learn how scientists are measuring air pollution levels in Mexico City.)

The city's air and water pollution cause an estimated 100,000 premature deaths per year. Writer Carlos Fuentes has nicknamed it "Makesicko City."

Large-scale water withdrawals from the city's aquifer have caused parts of the city to subside by 9 meters (30 feet) during the last century. Some areas are now subsiding as much as 30 centimeters (1 foot) a year. Mexico City's growing population increasingly relies on water pumped in from as far away as 150 kilometers (93 miles). Large amounts of energy are used to pump this water overland and then uphill 1,000 meters (3,300 feet) to the city.

Progress has been made in solving some of Mexico City's problems. The percentage of days each year in which air pollution standards are violated has fallen from 50% to 20%. The city government has banned cars in its central zone and requires air pollution controls on all cars made after 1991. It has also phased out use of leaded gasoline and called for old buses, taxis, and delivery trucks to be replaced with vehicles that produce fewer emissions. The city also bought land for use as green space and planted more than 25 million trees to help absorb pollutants. In 2009, the city formed a Waste Commission. It is working to build state-of-the-art waste processing centers that, within a few years, will process as much as 85% of the city's solid waste through recycling and composting, as well as by burning some of it for energy.

GOOD NEWS

THINKING ABOUT
Mexico City and Curitiba

CORE CASE STUDY

What are two sustainability strategies used in Curitiba, Brazil, (**Core Case Study**) that might be helpful in Mexico City?

Mark Edwards/Peter Arnold, Inc.

Figure 22-12 Photochemical smog in Mexico City, Mexico, is caused by cars and factories that generate pollutants and by the city's location within a bowl-shaped valley that traps emissions, causing them to accumulate to dangerous levels.

22-3 How Does Transportation Affect Urban Environmental Impacts?

▶ **CONCEPT 22-3 In some countries, many people live in widely dispersed urban areas and depend mostly on motor vehicles for their transportation, which greatly expands their ecological footprints.**

Cities Can Grow Outward or Upward

If a city cannot spread outward, it must grow vertically—upward and downward (below ground)—so that it occupies a small land area with a high population density. Most people living in *compact cities* such as Hong Kong, China, and Tokyo, Japan, get around by walking, biking, or using mass transit such as rail or buses. Some high-rise apartment buildings in these Asian cities contain everything from grocery stores to fitness centers so their residents do not need to travel for food, entertainment, and other services.

In other parts of the world, a combination of plentiful land, relatively cheap gasoline, and networks of highways have produced *dispersed cities* whose residents depend on motor vehicles for most travel (**Concept 22-3**). Such car-centered cities are found in the United States, Canada, Australia, and other countries where ample land often is available for these cities to expand outward. The resulting urban sprawl (Figure 22-7) can have a number of undesirable effects (Figure 22-8).

The United States is a prime example of a car-centered nation. With 4.6% of the world's people, the United States has almost one-third of the world's passenger cars and commercial vehicles. In its dispersed urban areas, passenger vehicles are used for 98% of all transportation, and three of every four residents drive alone to work every day. Largely because of urban sprawl, all Americans combined drive about the same distance each year as the total distance driven by all other drivers in the world, and in the process use about 43% of the world's gasoline.

Motor Vehicles Have Advantages and Disadvantages

Motor vehicles provide mobility and offer a convenient and comfortable way to get from one place to another. For many people, they are also symbols of power, sex appeal, social status, and success. Much of the world's economy is also built on producing motor vehicles and supplying fuel, roads, services, and repairs for them.

Despite their important benefits, motor vehicles have many harmful effects on people and on the environment. Globally, automobile accidents kill approximately 1.2 million people a year—an average of 3,300 deaths per day—and injure another 15 million people. They also kill about 50 million wild animals and family pets every year.

In the United States, motor vehicle accidents kill more than 40,000 people per year and injure another 5 million, at least 300,000 of them severely. *Car accidents have killed more Americans than have all the wars in the country's history.*

Motor vehicles are the world's largest source of outdoor air pollution, which causes 30,000–60,000 premature deaths per year in the United States, according to the Environmental Protection Agency. They are also the fastest-growing source of climate-changing CO_2 emissions. In addition, they account for two-thirds of the oil used (mostly in the form of gasoline) in the United States and one-third of the world's oil consumption.

Motor vehicles have helped create urban sprawl and the car commuter culture. At least a third of the world's urban land and half of that in the United States is devoted to roads, parking lots, gasoline stations, and other automobile-related uses. This prompted urban expert Lewis Mumford to suggest that the U.S. national flower should be the concrete cloverleaf (Figure 22-13).

Another problem is congestion. If current trends continue, U.S. motorists will spend an average of 2 years of their lives in traffic jams, as streets and freeways often resemble parking lots. According to a 2008 report by the American Society of Civil Engineers, about 45% of all major urban U.S. highways are regularly congested. Traffic congestion in some cities in less-developed countries is much worse. Building more roads may not be the answer. Many analysts agree with economist Robert Samuelson that "the number of cars expands to fill available concrete."

Reducing Automobile Use Is Not Easy, but It Can Be Done

Some environmental scientists and economists suggest that we can reduce the harmful effects of automobile use by making drivers pay directly for most of the environmental and health costs caused by their automobile use—a *user-pays* approach, based on honest environmental accounting.

One way to phase in such *full-cost pricing* would be to charge a tax or fee on gasoline to cover the estimated

Figure 22-13 Concrete cloverleafs like this tangled network of thruways in the U.S. city of Los Angeles, California, are found in most of the world's increasingly car-dependent cities.

harmful costs of driving. According to a study by the International Center for Technology Assessment, such a tax would amount to about $3.18 per liter ($12 per gallon) of gasoline in the United States (see Chapter 16, p. 402). Gradually phasing in such a tax, as has been done in many European nations, would spur the use of more energy-efficient motor vehicles and mass transit, decrease dependence on imported oil, and thus increase economic and national security. It would also reduce pollution and environmental degradation and help to slow projected climate change.

RESEARCH FRONTIER

Determining the full costs of using gasoline and how to include such costs in its market price; see **www.cengage.com/login**.

Proponents of this approach urge governments to do two major things. *First*, fund programs to educate people about the hidden costs they are paying for gasoline. *Second*, use gasoline tax revenues to help finance mass transit systems, bike lanes, and sidewalks as alternatives to cars, and reduce taxes on income, wages, and wealth to offset the increased taxes on gasoline. Such a *tax shift* would help to make higher gasoline taxes more politically and economically acceptable.

Europe, Japan, Singapore, and China have all developed rapid mass transit systems within and between urban areas, as well as networks of sidewalks and bike lanes in many urban and suburban areas. Analysts warn that countries such as the United States that lag behind in developing such systems will face great difficulties in dealing with the projected decline in oil production and with rapidly rising oil and gasoline prices. The end result could be a sharp decline for suburban housing and shopping centers as they become environmentally and economically unsustainable. As noted earlier in this chapter, there is some evidence that this is beginning to happen already in some U.S. suburban areas.

Taxing gasoline heavily would be difficult in the United States, for three reasons. *First*, it faces strong opposition from two groups. One group is made up of those people who feel they are already overtaxed, many of whom are largely unaware of the huge hidden costs they are paying for gasoline. The other group is made up of the powerful transportation-related industries such as carmakers, oil and tire companies, road builders, and many real estate developers.

Second, the dispersed nature of most U.S. urban areas makes people dependent on cars. *Third*, fast, efficient, reliable, and affordable mass transit options, bike lanes, and sidewalks are not widely available in the United States. These factors make it politically difficult to raise gasoline taxes. But U.S. taxpayers might accept sharp increases in gasoline taxes if a tax shift were employed, as mentioned above.

Another way to reduce automobile use and urban congestion is to raise parking fees and charge tolls on roads, tunnels, and bridges leading into cities—especially during peak traffic times. Densely populated Singapore is rarely congested because it auctions the rights to buy a car, and its cars carry electronic sensors that automatically charge the drivers a fee every time they enter the city. Several European cities have also imposed stiff fees for motor vehicles entering their central cities.

Examples include London, England, Stockholm, Sweden, and Milan, Italy.

Paris, France, which has some of Europe's worst traffic congestion, has upgraded its mass transit system and created express lanes for buses and bicycles on main thoroughfares, while reducing the lanes available for cars. The city also established a program that provides almost 21,000 bikes for rent at 1,450 rental stations throughout the city at a cost of just over $1 a day. Sadly, within two years 80% of the bikes had been stolen or vandalized and had to be replaced at great cost. Portland, Oregon, also had to abandon its bike-sharing program because of theft and vandalism. However, the U.S. city of Boston, Massachusetts, plans to start such a program.

In Germany, Austria, Italy, Switzerland, and the Netherlands, more than 300 cities have *car-sharing* networks (see the Case Study that follows). Members reserve a car in advance or call the network and are directed to the closest car. They are billed monthly for the time they use a car and the distance they travel. In Berlin, Germany, car sharing has cut car ownership by 75%. According to the Worldwatch Institute, car sharing in Europe has reduced the average driver's CO_2 emissions by 40–50%. Car-share companies have sprouted up in the United States in cities such as Madison, Wisconsin, Portland, Oregon, New York, New York, and Los Angeles, California, among others.

CASE STUDY

Zipcars

In 1999, Robin Chase and Antje Danielson, two entrepreneurs living in Cambridge, Massachusetts (USA) recognized a need among city dwellers who were tired of paying high rates for parking, insurance, and other costs of owning a car. In cities with extensive mass transit systems such as New York, New York, and Boston, Massachusetts, a car amounts to a significant expense because of these high costs and because the mass transit option would allow almost anyone to get along without a car much of the time. So why pay the high costs for a car that you may only use occasionally?

To Chase and Danielson, the answer was: don't pay those costs; instead, join a car-sharing network and pay a much lower price for the convenience of having a car when you need it, renting it by the hour. The two women formed Zipcar, a network whose membership has doubled almost every year since 1999. In 2009, its 325,000 members in the United States were sharing 6,500 cars (10–15% of them hybrid cars).

To become a *Zipster*, as the members call themselves, you pay a small application charge and an annual $50 fee. In cities where they are available, members can rent a Zipcar for $6 to $10 per hour, which includes the costs of gas, insurance, and maintenance. They make reservations online and are told where to go to pick up the car. A membership card unlocks the vehicle. When finished with the car, the member returns it to where it was picked it up, and charges for the use of the vehicle are applied to the member's credit card.

Traveling cleaning crews (many of them college students) clean the cars once each week. Members agree to keep the cars clean and not to smoke or allow dogs to damage the cars. The system seems to work, as Zipcars are always booked.

Now, several businesses, including Google, ask their employees to use Zipcars for daily business trips in and around the cities where they work. The company's president estimates that car sharing costs the company about a third of the cost of keeping company cars and reimbursing employees for using their own cars.

THINKING ABOUT
Car Sharing

If you are or someday might be a car owner living in a city where car-sharing is available, would you consider selling your car and joining a car-sharing network? Explain.

Some Cities Promote Alternatives to Cars

Mayors and urban planners in many parts of the world are beginning to rethink the role of the car in urban transportation systems and are providing a mix of other options, as they have in Curitiba, Brazil (**Core Case Study**). Leaders in less-developed countries are recognizing that most of their people could never afford to own automobiles, and they are questioning the development of expensive car-oriented systems that mostly benefit the affluent minority of their citizens.

CORE CASE STUDY

There are several alternatives to motor vehicles, each with its own advantages and disadvantages. One widely used alternative is the *bicycle* (Figure 22-14). Bicycles reduce congestion, promote physical fitness, emit no CO_2 or other air pollutants, cost little to buy and operate, and reduce the need for parking space. Each year, the number of bicycles produced globally is about 2.5 times the number of cars produced. There is also a growing use of electric bicycles.

Bicycling and walking account for about a third of all urban trips in the Netherlands and in Copenhagen, Denmark. By contrast, bicycles account for only about 1% of urban trips in the United States. But one of five Americans say they would bicycle to work if safe bike lanes were available and if their employers provided secure bike storage and showers at work. There is a growing *complete streets movement* in the United States that is devoted to making city streets as useful and safe for bicyclists and pedestrians as they are for cars and trucks.

THINKING ABOUT
Bicycles

Do you, or would you, use a conventional or an electric bicycle to go to and from work or school? Explain.

Trade-Offs

Bicycles

Advantages	Disadvantages
Are quiet and non-polluting	Provide little protection in an accident
Take few resources to make	Provide no protection from bad weather
Burn no fossil fuels	Are impractical for long trips
Require little parking space	Secure bike parking not yet widespread

Figure 22-14 Bicycle use has advantages and disadvantages. The key to increasing bicycle use is the creation of bicycle-friendly systems, including bike lanes. Some cities actually provide bicycles that people can rent at a very low cost. In addition, Japan and the Netherlands strive to integrate the use of bicycles and commuter rail by providing secure bicycle parking at rail stations. **Question:** Which single advantage and which single disadvantage do you think are the most important?

Heavy-rail systems (subways, elevated railways, and metro trains) and *light-rail* systems (streetcars, trolley cars, and tramways) have their advantages and disadvantages (Figure 22-15). At one time, all major U.S. cities had effective light-rail systems, but they were dismantled to promote car and bus use (see Case Study, p. S10, in Supplement 3). However, such systems are being built again in several U.S. cities. An outstanding example is the light-rail system in Minneapolis, Minnesota, which opened in 2005 and surprised planners by drawing 50% more riders than they had expected.

The rail system in Hong Kong, China, is one of the world's most successful, primarily because the city is densely populated and thus half its population can walk to a subway station within 5 minutes. Owning a car is also extremely expensive in this crowded city, which helps to make the rail system attractive to almost everyone.

Buses are the most widely used form of mass transit within urban areas worldwide, mainly because they have more advantages than disadvantages (Figure 22-16). Curitiba, Brazil, has one of the world's best bus rapid transit systems, which carries tens of thousands of passengers a day (**Core Case Study**, Figure 22-1). But the system is now feeling the strain of population pressures, and car use is increasing in Curitiba. Transportation officials there are considering building a light-rail system to help carry the rapidly growing passenger load.

Similar bus rapid transit systems have been developed in Bogotá, Colombia, and are being planned for cities such as Mexico City, Mexico; Jakarta, Indonesia; Seoul, South Korea; Beijing and 20 other cities in China; Ottawa and Toronto in Canada; and the U.S. cities of Los Angeles, California; Minneapolis, Minnesota; and Las Vegas, Nevada.

A *rapid-rail system between urban areas* is another option for reducing the use of cars. In western Europe and Japan, high-speed bullet trains travel between cities at up to 306 kilometers (190 miles) per hour. Such trains began operating in Japan in 1964 and now carry almost a million passengers a day. Since 1964, there has not been a single casualty, and late arrivals average only 6 seconds, explaining why some analysts consider this system to be one of the new wonders of the world.

Trade-Offs

Mass Transit Rail

Advantages	Disadvantages
Uses less energy and produces less air pollution than cars do	Expensive to build and maintain
Use less land than roads and parking lots use	Cost-effective only along a densely populated corridor
Causes fewer injuries and deaths than cars	Commits riders to transportation schedules

Figure 22-15 Mass transit rail systems in urban areas have advantages and disadvantages. **Question:** Which single advantage and which single disadvantage do you think are the most important?

Trade-Offs

Buses

Advantages	Disadvantages
Reduce car use and air pollution	Can lose money because they require affordable fares
Can be rerouted as needed	Can get caught in traffic and add to noise and pollution
Cheaper than heavy-rail system	Commit riders to transportation schedules

Figure 22-16 Bus rapid transit systems (where several buses running in express lanes can be coupled together) and conventional bus systems in urban areas have advantages and disadvantages. **Question:** Which single advantage and which single disadvantage do you think are the most important?

Trade-Offs

Rapid Rail

Advantages	Disadvantages
Much more energy efficient per rider than cars and planes are	Costly to run and maintain
Less air pollution than cars and planes	Causes noise and vibration for nearby residents
Can reduce need for air travel, cars, roads, and parking areas	Adds some risk of collision at car crossings

Figure 22-17 Rapid-rail systems between urban areas have advantages and disadvantages. Western Europe and Japan have high-speed bullet trains that travel between cities at up to 306 kilometers (190 miles) per hour. **Question:** Which single advantage and which single disadvantage do you think are the most important?

Figure 22-17 lists the major advantages and disadvantages of such rapid-rail systems.

In the United States, nearly half of all households have no reasonable access to bus or train service, according to the American Society of Civil Engineers. But a high-speed bullet train network could replace airplanes, buses, and private cars for most medium-distance travel between major American cities (Figure 22-18). Some planners call for placing high-speed train tracks along interstate freeways, as the federal government already owns the roads and adjacent rights-of-way. These established transportation corridors could also be used for a new electric grid system, which could provide a more fuel-efficient means to run the trains.

Six Middle Eastern nations—Saudi Arabia, Bahrain, Kuwait, Oman, Qatar, and the United Arab Emirates—plan to spend more than $100 billion to build a modern railway network that will link them together. China has the world's fastest bullet train, and by 2010, will have completed a vast network of 42 high-speed train routes throughout the country, which is roughly the same size as the United States. One major goal of China's leaders is to make the country more economically competitive by providing fast and energy-efficient transportation among its major cities.

In the United States, planners have been talking about building high-speed trains for decades, but plans have been slow to materialize. As of 2014, there will likely be only one such train running on a line between Tampa and Orlando, Florida. However, in 2010, the U.S. government began planning for 12 other high-speed rail corridors in various locations around the country. Part of the reason for the delay in building rapid-rail systems in the United States is that revenues from gasoline taxes have been used mostly to build highways at the expense of mass transit.

CONNECTIONS

Wind Farms and High-Speed Trains

Ever ride on a *wind train*? Americans could get that opportunity if the visions of some planners become reality. A few railroad companies are exploring the idea of powering cross-country trains with electricity from wind farms, most of which are already located in the right places for such a plan. Wind trains would be highly efficient with little or no emissions of greenhouse gases or other air pollutants.

HOW WOULD YOU VOTE? ✓

Should the United States (or the country where you live) develop rapid-rail systems to connect some of its urban areas, even though this will be quite costly? Cast your vote online at **www.cengage.com/login**.

Figure 22-18 **Solutions:** Some potential routes for high-speed bullet trains in the United States and parts of Canada are shown here. Such a system would allow rapid, comfortable, safe, and affordable travel between major cities in a region. It would greatly reduce dependence on cars, buses, and airplanes for trips between these urban areas and would also decrease greenhouse gas emissions and other forms of air pollution. **Question:** Why do you think such a system has not been developed in the United States? (Data from High Speed Rail Association, U.S. Department of Transportation, Amtrak)

22-4 How Important Is Urban Land-Use Planning?

▶ **CONCEPT 22-4 Urban land-use planning can help to reduce uncontrolled sprawl and slow the resulting degradation of air, water, land, biodiversity, and other natural resources.**

Conventional Land-Use Planning

Most urban and some rural areas use various forms of **land-use planning** to determine the best present and future use of each parcel of land.

Land-use planning has often encouraged future population growth and economic development, regardless of its environmental and social consequences. This typically has led to uncontrolled or poorly controlled urban growth and sprawl.

A major reason for this often-destructive process in the United States and in some other countries is heavy reliance on *property taxes* levied on all buildings and land parcels based on their economic value. In the United States, 90% of the revenue used by local governments to provide public services, such as schools, police and fire protection, and water and sewer systems, comes from property taxes. As a result, local governments often raise money by promoting urban growth, because they usually cannot raise property tax rates enough on existing properties to meet expanding needs.

Once a land-use plan is developed, governments control the uses of various parcels of land by legal and economic methods. The most widely used approach is **zoning**, in which various parcels of land are designated for certain uses such as residential, commercial, or mixed use. However, zoning can be used to control growth and protect areas from certain types of development. For example, cities such as Portland, Oregon (USA), and Curitiba, Brazil, (**Core Case Study**) have used zoning to encourage high-density development along major mass transit corridors and to reduce automobile use and air pollution. CORE CASE STUDY

Despite its usefulness, zoning has several drawbacks. One problem is that some developers can influence or modify zoning decisions in ways that threaten or destroy wetlands, prime cropland, forested areas, and open space. Another problem is that zoning often favors high-priced housing, factories, hotels, and other businesses over protecting environmentally sensitive areas and providing low-cost housing, again because most local governments depend on property taxes for their revenue.

THINKING ABOUT
Property Taxes

What alternatives to depending on property taxes for revenue do local governments have? Which, if any, of these alternatives would you support? Explain.

In addition, overly strict zoning can discourage innovative approaches to solving urban problems. For example, the pattern in the United States and in some other countries has been to prohibit businesses in residential areas, which increases suburban sprawl. Some urban planners want to return to *mixed-use zoning* to help reduce this problem. In the 1970s, Portland, Oregon, managed to cut driving and gasoline consumption by resurrecting the idea of neighborhood grocery stores (see Case Study, p. 604).

Smart Growth Works

Smart growth is one way to encourage more environmentally sustainable development that requires less dependence on cars, controls and directs sprawl, and reduces wasteful resource use (see Case Study, p. 604). It recognizes that urban growth will occur, but at the same time, it uses zoning laws and other tools to channel that growth into areas where it can cause less harm.

Smart growth can discourage sprawl, reduce traffic, protect ecologically sensitive and important lands and waterways, and develop neighborhoods that are more enjoyable places in which to live. Figure 22-19 (p. 604) lists popular smart growth tools that we can use to prevent and control urban growth and sprawl.

Curitiba, Brazil, (**Core Case Study**) has also used a variety of such strategies to control sprawl and reduce dependence on the car. Several studies have shown that most forms of smart growth provide more jobs and spur more economic renewal than does conventional economic growth. (See *The Habitable Planet*, Video 5, at **www.learner.org/resources/series209.html** to learn the use of smart growth for controlling population growth and urban sprawl in Cape Cod, Massachusetts [USA].) CORE CASE STUDY

China has taken the strongest stand of any country against urban sprawl. The government has designated 80% of the country's arable land as *fundamental land*. Building on such land requires approval from local and provincial governments and from the State Council, the central government's chief administrative body. This is somewhat like having to get congressional approval for a new subdivision in the United States. However, China's approach goes to an extreme; developers violating the rules can face the death penalty.

Many European countries have been successful in discouraging urban sprawl in favor of compact cities.

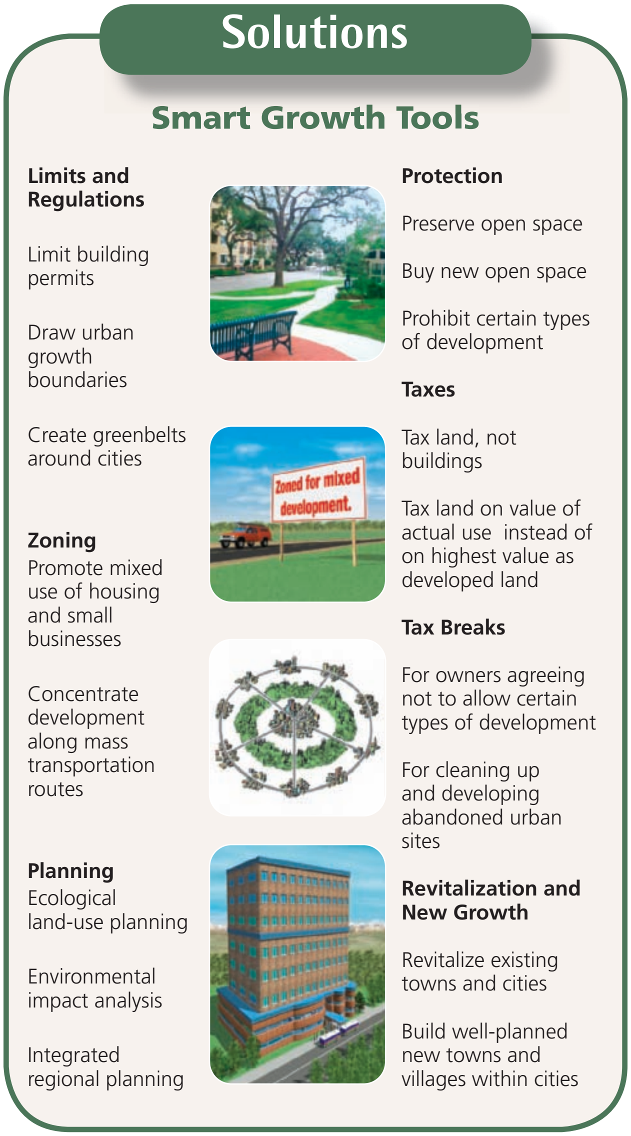


Figure 22-19 We can use these *smart growth* or *new urbanism tools* to prevent and control urban growth and sprawl. **Questions:** Which five of these tools do you think would be the best methods for preventing or controlling urban sprawl? Which, if any, of these tools are used in your community?

They have controlled development at the national level and imposed high gasoline taxes to discourage car use and to encourage people to live closer to workplaces and shops. High taxes on heating fuel encourage people to live in apartments and small houses. These governments have used most of the resulting gasoline and heating fuel tax revenues to develop efficient train and other mass transit systems within and between cities.

■ **CASE STUDY**

Smart Growth in Portland, Oregon

The U.S. city of Portland, Oregon, has used smart growth strategies to control sprawl and reduce dependence on automobiles. Since 1975, Portland's population has grown by about 50%, but its urban area has expanded by only 2%. In addition, abundant green space and natural beauty is just 20 minutes from downtown.

The city has built an efficient light-rail and bus system that carries 45% of all commuters to downtown jobs—a much higher percentage than in most U.S. cities. By reducing traffic, Portland was able to convert a former expressway and huge parking lot into a waterfront park.

Portland encourages clustered, mixed-use neighborhood development, with stores, light industries, professional offices, high-density housing, and access to mass transit, which allows most people to meet their daily needs without a car. In addition to its excellent light-rail and bus lines, Portland has further reduced car use by developing an extensive network of bike lanes and walkways. Employers are encouraged to give their employees bus passes instead of providing parking spaces.

Since 1975, the city's air pollution has decreased by 86%. Portland is frequently cited as one of the most livable cities in the United States and in 2008, environmental researcher and writer Elizabeth Svoboda ranked it as the greenest city in the United States. In order, the next nine greenest U.S. cities were San Francisco, California; Boston, Massachusetts; Oakland, California; Eugene, Oregon; Cambridge, Massachusetts; Berkeley, California; Chicago, Illinois; Austin, Texas; and Minneapolis, Minnesota.

THINKING ABOUT
Portland and Curitiba

CORE CASE STUDY

How is the urban strategy of Portland, Oregon, similar to that of Curitiba, Brazil (**Core Case Study**)? How do their strategies differ?

Preserving and Using Open Space

One way to preserve open space outside a city is to draw an urban growth line around each community and to allow no urban development outside that boundary. This *urban growth boundary* approach is used in the U.S. states of Oregon, Washington, and Tennessee. However, the Seattle region of Washington State found that using a growth boundary to increase housing densities inside the line had the unintended effect of encouraging low-density housing and sprawl in rural and natural areas just beyond the boundary.

Another approach is to surround a large city with a *greenbelt*—an open area reserved for recreation, sustainable forestry, or other nondestructive uses. Satellite towns are often built outside these greenbelts. Ideally, the outlying towns are self-contained, not sprawling, and are linked to the central city by a public transport system that does minimal damage to the greenbelt.

Many cities in western Europe and the Canadian cities of Toronto and Vancouver have used this approach. By establishing a greenbelt outside its urban growth boundary, Seattle, Washington, could have minimized urban sprawl just beyond that line. Greenbelt areas can

age fotostock/SuperStock

Figure 22-20 With almost 344 hectares (850 acres) that include woodlands, lawns, and small lakes and ponds, New York City's Central Park is a dramatic example of a large open space in the center of a major urban area.

provide vital ecological services such as absorption of CO_2 and other air pollutants, which can make urban air more breathable and help to cut a city's contribution to projected climate disruption.

A more traditional way to preserve large blocks of open space is to create municipal parks. Examples of large urban parks in the United States are Central Park in New York City (Figure 22-20); Golden Gate Park in San Francisco, California; and Grant Park in Chicago, Illinois.

In 1883, officials in the U.S. city of Minneapolis, Minnesota, vowed to create "the finest and most beautiful system of public parks and boulevards of any city in America." In the eyes of many, this goal has been achieved. Today, the city has 170 parks strategically located so that most homes in Minneapolis are within six blocks of a green space. Similarly, Jacksonville, Florida (USA), has a high ratio of parkland to total city area.

22-5 How Can Cities Become More Sustainable and Livable?

CONCEPT 22-5 An *ecocity* allows people to choose walking, biking, or mass transit for most transportation needs; to recycle or reuse most of their wastes; to grow much of their food; and to protect biodiversity by preserving surrounding land.

New Urbanism Is Growing

Since World War II, the typical approach to suburban housing development in the United States has been to bulldoze a tract of woods or farmland and build rows of houses on standard-size lots (Figure 22-21, middle, p. 606). Many of these developments and their streets, with names like Oak Lane, Cedar Drive, Pheasant Run, and Fox Valley, are named after the trees and wildlife they displaced.

In recent years, builders have increasingly used a pattern known as *cluster development,* in which high-density housing units are concentrated on one portion of a parcel, and the rest of the land (often 30–50%) is used as commonly shared open space (Figure 22-21, bottom). When this is done properly, residents can enjoy more open and recreational space within aesthetically pleasing surroundings. They might also see lower heating and cooling costs because some walls are shared in multiple-family dwellings. Developers can also cut their costs for site preparation, roads, utilities, and other forms of infrastructure.

Some communities are going further and using the goals of *new urbanism*, which is a modern form of what could be called *old villageism*, to develop entire villages

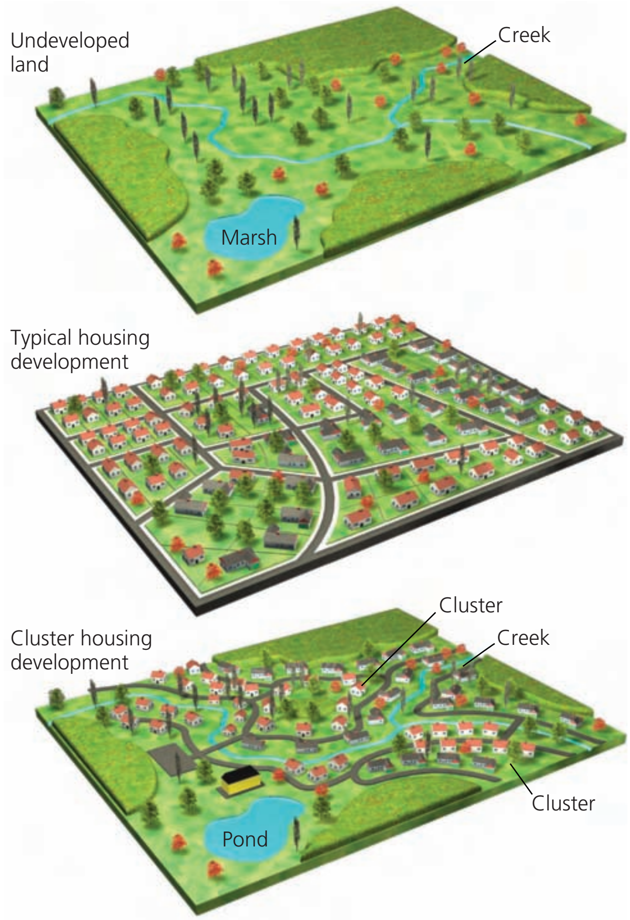


Figure 22-21 These models compare a *conventional housing development* (middle) with a *cluster housing development* (bottom). With a cluster development, houses, town houses, condominiums, and two- to six-story apartments are built on part of the tract. The rest, typically 30–50% of the area, is left as open space for wildlife preserves, parks, and walking and cycling paths.

and promote mixed-use neighborhoods within existing cities. These goals include:

- *walkability*, with most stores and recreational activities within a 10-minute walk of any home.
- *mixed-use and diversity,* which provides a blend of pedestrian-friendly shops, offices, apartments, and homes to encourage people of different ages, classes, cultures, and races to move into the villages.
- *quality urban design,* emphasizing beauty, aesthetics, and architectural diversity.
- *environmental sustainability* based on development with minimal environmental impact.
- *smart transportation,* with well-designed train and bus systems connecting neighborhoods, towns, and cities.

A prominent example of new urbanism is a new suburb of Freiburg, Germany, called Vauban (see the Case Study that follows). Examples of new urban villages in the United States are Mayfaire, in Wilmington, North Carolina; Mizner Place in Boca Raton, Florida; Middleton Hills near Madison, Wisconsin; Yardley, Pennsylvania; Kentlands in Gaithersberg, Maryland; Valencia, California (near Los Angeles); and Stapleton, Colorado (built on an old airport site in Denver).

RESEARCH FRONTIER

Evaluating, improving, and implementing more environmentally sustainable new urbanism; see **www.cengage.com/login**.

THINKING ABOUT
New Urbanism

Is there an example of new urbanism in or near the place where you live? Would you like to live in such a village? Explain.

CASE STUDY
The New Urban Village of Vauban

Since the early 1990s, the city of Freiburg, Germany, has given high priority to controlling urban sprawl. As part of that effort, the city planned a new suburb called Vauban, completed in 2006 and designed to be virtually free of cars.

A small minority of homeowners in Vauban have cars. Street parking, driveways, and garages are generally forbidden in the village. Car owners have two places to park—two large garages on different sides of town—and a parking space costs $40,000.

Vauban is designed so that each of its 5,000 homes is located within easy walking distance of train lines that connect to surrounding communities. Stores, banks, restaurants, and schools are also within walking distance of all homes. The town has numerous bike paths and a car-sharing club. Mass transit allows residents to work or shop in Freiburg, a city of about 200,000 people.

The community has no single-family homes. People live in stylish row houses within four- and five-story buildings that were designed with an emphasis on use of passive solar energy (Figure 16-11, left, p. 409). The shared walls between these homes help them to be highly energy-efficient. In addition, 65% of the energy used for electricity and heating in Vauban comes from solar power or from an efficient central cogeneration plant that runs on wood chips and provides central heating and electric power for Vauban residents. Vauban's planners and designers hope that some of the best features of this urban ecovillage will be widely used in other planned communities around the world.

THINKING ABOUT
Vauban and Curitiba

CORE CASE STUDY

What are two differences between Curitiba, Brazil, and Vauban, Germany, in terms of how each is trying to be more sustainable? Which model do you think would work better for the community in which you live or go to school?

The Ecocity Concept: Cities for People, Not Cars

According to most environmentalists and urban planners, the primary problem with large cities is not urban growth but our failure to make them more sustainable and livable. These same environmentalists and planners call for us to make new and existing urban areas more self-reliant, sustainable, and enjoyable places to live through good ecological design. (See the Guest Essay on this topic by David Orr on the website for this chapter.)

New urbanism is a step in the right direction, but we can go further by creating more environmentally sustainable cities, called *ecocities* or *green cities*, which emphasize the following goals built around the three **principles of sustainability** (See back cover):

- Use solar and other locally available, renewable energy resources, and design buildings to be heated and cooled as much as possible by natural means.
- Build and redesign cities for people, not for cars.
- Use energy and matter resources efficiently.
- Prevent pollution and reduce waste.
- Reuse, recycle, and compost 60–85% of all municipal solid waste.
- Protect and encourage biodiversity by preserving undeveloped land and protecting and restoring natural systems and wetlands in and around cities.
- Promote urban gardens, farmers markets, and community-supported agriculture.
- Use zoning and other tools to keep urban sprawl at environmentally sustainable levels.

An ecocity is a people-oriented city, not a car-oriented city. Its residents are able to walk, bike, or use low-polluting mass transit for most of their travel. Trees and plants adapted to the local climate and soils are planted throughout the city to provide shade, beauty, and wildlife habitats, and to reduce air pollution, noise, and soil erosion. Small organic gardens and a variety of plants adapted to local climate conditions often replace monoculture grass lawns.

An ecocity's buildings, vehicles, and appliances meet high energy-efficiency standards. Some planners suggest that ecocities could evolve to become energy-independent. They see homes and businesses containing their own power plants, with solar panels and wind turbines on many roofs providing power to the buildings. These home power plants could also be used to recharge plug-in hybrid cars (Figure 16-6, right, p. 403) and all-electric vehicles. In addition, food waste and lawn and garden trimmings could be put into digesters to make natural gas for heating and cooking.

In an ecocity, abandoned lots and industrial sites are cleaned up and restored, and put to new uses. For example, in Curitiba, Brazil, (**Core Case Study**) an old gunpowder storage building was converted into a theatre, a foundry into a shopping mall, the old railroad station into a railway museum, and a quarry into an amphitheatre.

In Curitiba and other cities, polluted creeks and rivers have been cleaned up and nearby forests, grasslands, wetlands, and farms have been preserved. Parks are easily available to everyone. Curitiba also employs a municipal shepherd who tends a flock of sheep, which munch the grass in the parks. Thus, instead of spending money and energy on mowing, the city uses its grass as a resource. Meat and wool from the sheep are periodically sold to help the city pay for social programs and the sheep manure is used as organic fertilizer.

In an ecocity, much of the food that people eat comes from nearby organic farms, solar greenhouses, community gardens, and small gardens grown on rooftops, in yards, and in windows boxes. The UN Food and Agriculture Organization (FAO) has estimated that such urban food production supplies food for about one-fifth of the world's 3.4 billion urban residents. The FAO projects that with organized programs and financial incentives, much more of the world's food could be grown in or near cities. Experts project that rising oil prices will increase food shipping costs, which could cause a shift from globalized agriculture to more localized food production in urban areas (Science Focus, p. 608).

Finally, an ecocity provides plenty of educational opportunities for its residents by teaching them about environmental problems and solutions. This includes not only school curricula, but also botanical gardens, humane and sustainable zoos and aquaria, and outdoor learning centers. Curitiba, Brazil (**Core Case Study**), has established Lighthouses of Knowledge—free educational centers located strategically around the city. They include libraries, Internet access, job training, and other resources.

GOOD NEWS

This may sound like a futuristic dream, but ecocities are real, as you saw in this chapter's opening **Core Case Study**. An example of an emerging ecocity is Bogotá, Colombia. Its transformation began in 1998 when Enrique Peñalosa was elected mayor. His major goal was to improve life for the 5.6 million city residents who did not own cars. Within a short time, under his leadership and that of his successor Antanas Mockus, the city built an efficient and widely used bus rapid transit system; established hundreds of kilometers of bicycle lanes and pedestrian-only streets throughout the city; renovated or created 1,200 parks; planted more than 100,000 trees; and encouraged citizens to become involved in improving their local neighborhoods. As a result, between 1998 and 2006, rush-hour traffic decreased by 40%, traffic-related deaths dropped by 20%, and Bogotá's citizens developed a strong sense of civic pride.

Other examples of cities that have attempted to become more environmentally sustainable and livable include Waitakere City, New Zealand; Stockholm and Malmo in Sweden; Helsinki, Finland; Vancouver, British Columbia, in Canada; and in the United States,

SCIENCE FOCUS

Urban Indoor Farming

Scientists are studying various ways to grow more food indoors in urban areas. One method that city dwellers could implement quickly is the use of rooftop greenhouses to provide them with most of their fruits and vegetables. Researchers have found that such greenhouses use as little as 10% of the water and 5% of the area occupied by conventional farms to produce similar yields.

In 2007, Sun Works, a company in New York City (USA) that designs energy-efficient urban greenhouses, built a demonstration greenhouse on a barge floating in the Hudson River. It used solar power and recycled water to grow vegetables and fruits (see Figure 12-36, p. 311) and is now operated by the nonprofit Groundwork Hudson Valley group as an educational center for thousands of annual visitors. In 2008, Sun Works installed a greenhouse on top of a school in the city. It serves as a science teaching area and supplies produce for the school cafeteria. Ted Caplow, executive director of Sun Works, projects that the rooftops of New York City could provide roughly twice the greenhouse area needed to supply the entire city with fruits and vegetables.

A more far-reaching idea is to use hydroponic gardens (see Figure 12-6, p. 282) to provide the water and nutrients to grow fruits and vegetables on glass walls of offices and other buildings. The crops would be grown in small containers in a space between two thick glass panes that make up the wall of a building. Such glass walls would also provide light and passive solar heating during winter. These walls would have automatic shading systems to keep the plants and building interior cool during very hot weather. Vertical conveyor belts would lower the plants for harvesting and replanting on a year-round basis.

Some scientists envision *vertical farms* in 30-story buildings, each occupying a single city block. Each of these farms could provide vegetables, fruits, chickens, eggs, and fish (grown in aquaculture tanks) for 50,000 people. Hydroponic crops would be grown on the upper floors. Chickens (and the eggs they produce) and fish that feed on plant waste would be grown on lower floors.

Nitrogen and other plant nutrients could be extracted from the animal wastes, and perhaps from city sewage treatment plants, and recycled to the plants. Electricity for heating and lighting could be provided by geothermal, solar, or wind energy, energy from composted plant and animal wastes, and fuel cells powered by hydrogen produced with the use of renewable energy. Such a system would mimic nature by applying all three **principles of sustainability**.

Critical Thinking

What are three ecological advantages and three environmental disadvantages of greatly increasing urban farming? Do you believe that the advantages outweigh the disadvantages? Explain.

Portland, Oregon (Case Study, p. 604); Davis, California; Olympia, Washington; and Chattanooga, Tennessee (see Chapter 1, Case Study, p. 25).

The Ecovillage Movement is Growing

Another innovative approach is the growing global *ecovillage movement*, in which small groups of people come together to design and live in more sustainable villages in rural and suburban areas, and in neighborhoods or "eco-hoods" within cities.

Ecovillagers use diverse methods to live more sustainably and to decrease their ecological footprints. Strategies include generating electricity from solar cells, small wind turbines, and small hydropower systems; collecting rainwater; using composting toilets; using solar cookers (see Figure 16-17, p. 412) and rooftop solar collectors to provide hot water; cooperating in the development of organic farming plots; and using passive solar design, energy-efficient houses, and living roofs, as discussed in Chapter 16. In Findhorn, Scotland, residents have reduced their average ecological footprint per person by about 40% by using some of these methods, and other cities claim similar reductions. Another example is Vauban, Germany (see Case Study, p. 606).

One example in the United States is Los Angeles Ecovillage, started in 1993 as a project to show how people in the middle of a sprawling and unsustainable city such as Los Angeles, California, can establish small pockets of sustainability. It consists of two small apartment buildings with about 55 residents and a common courtyard. Working together, its members use solar panels to heat much of their hot water. They compost their organic wastes and use the compost in a large courtyard garden that provides vegetables and fruits, and serves as a community commons area for relaxation and social interaction. The ecovillage is within walking distance of subway and bus stops, and members who live without a car pay a lower rent. The group has also established a bicycle repair shop.

Another example of an ecovillage is the BedZED housing development in inner London, England. It was designed to be energy-efficient, built out of local and recycled materials, and is heated and powered by solar cells and by a cogeneration power plant that runs on biomass to generate heat and electricity. It is located near a train station so that residents can get along without cars. Residents also harvest rainwater and recycle *gray water*, or water that is slightly polluted such as dishwater, for gardening and other uses (see Chapter 13, pp. 337–338), and they grow vegetables in on-site organic gardens. The average ecological footprint per person in this ecovillage is about 33% smaller than that of London as a whole, and some residents have a 70% smaller footprint per person.

By 2008, there were more than 375 ecovillages, over half of them in Europe and North America. Other examples are found near Ithaca, New York, and Asheville, North Carolina, in the United States; Munksård near Copenhagen, Denmark; Porto Alegre in Brazil;

Mbam in Senegal, Africa; Sieben Linden in Germany; and Findhorn in Scotland. Ecovillages and ecocities and various individual projects provide us with a laboratory for improving the ecological design of houses and other buildings (see Case Study that follows), basing such improvements on the three **principles of sustainability**.

CASE STUDY

A Living Building

There are a growing number of experiments in expanding the boundaries of green building and more sustainable architecture. An example of leading-edge sustainable design is the Omega Center for Sustainable Living (OCSL), an award-winning green building at the Omega Institute for Holistic Studies, a nonprofit, educational retreat center in Rhinebeck, New York (USA) (Figure 22-22).

The OCSL is a state-of-the art environmental education center and a water reclamation facility that cleans and recycles the Omega Institute's campus wastewater using zero chemicals and zero net energy. The building includes a classroom, a mechanical room, a greenhouse, and constructed wetlands, where people come to learn about innovative solutions to pressing environmental problems. It was designed to achieve Leadership in Energy and Environmental Design (LEED®) Platinum certification, and to be one of the first certified Living Buildings in the United States.

A Living Building is built around the following design goals:

- Take into account the climate, vegetation, and other characteristics of the surrounding ecoregion and keep the building from interfering with those characteristics.
- Make the building capable of using only renewable resources for its energy needs.
- Include a system for capturing, treating, and recycling all water used in the building.
- Make the building highly energy efficient and design it to be aesthetically pleasing.

The heart of the OCSL is a large greenhouse containing a water filtration system called the Eco Machine™, based on a design pioneered by John Todd (Figure 20-C, p. 553). This living system uses plants, bacteria, algae, snails, and fungi to recycle Omega campus wastewater into clean water used to restore the aquifer under Omega's property. The Eco Machine™ reclaims wastewater from toilets, as well as gray water from showers and baths. All water coming through the Eco Machine™ is purified and returned to the aquifer, creating a closed loop hydrological process.

The building is oriented with a southern exposure in order to maximize passive solar performance. It has a long span of windows on its south side, and incoming heat is stored in the building's large mass of concrete and in the water within the Eco Machine™. In addition, the building has a geothermal system (based

Photo by Gregory Edwards

Figure 22-22 In 2009, the Omega Institute opened the doors to the Omega Center for Sustainable Living (OCSL), a pioneering project in sustainable building design. The OCSL is self-sustaining, in that it recycles its wastewater, is heated and cooled by a geothermal system, and generates electricity using panels of solar cells. The building also adds little or no carbon dioxide to the atmosphere.

on the general design shown in Figure 16-31, p. 425) that cools the building in summer and, with radiant floor heating, supplements the solar gain in winter. The building's electrical needs are served by solar cells. Also, it has a vegetated green roof system combined with a recycled reflective steel roof to help reduce heat loss during winter and heat gain during summer.

RESEARCH FRONTIER

Ecocity and ecobuilding design; see **www.cengage.com/login**.

Here are this chapter's *three big ideas*:

- Urbanization is increasing steadily and the numbers and sizes of urban areas are growing rapidly, especially in less-developed countries.
- Most urban areas are unsustainable with their large and growing ecological footprints and high levels of poverty.
- Urban areas can be made more sustainable and livable just as some cities and villages already are.

REVISITING Curitiba, Brazil, and Sustainability

CORE CASE STUDY

SUSTAINABILITY

In this chapter, we saw that urban areas around the world face numerous challenges largely related to population growth. We know that just in less-developed countries, more than a million people are added to urban areas each week. We have also seen that despite the environmental problems plaguing cities, there are a growing number of inspiring examples of cities and villages around the world that are striving to become more environmentally sustainable. While cities can magnify environmental problems, they can also gather people with the energy and imagination needed to solve some of those problems.

Curitiba, Brazil, (**Core Case Study**) is one city in a less-developed country that has made great strides toward becoming environmentally sustainable. Its 3.2 million people have opportunities to live well and improve their lives, and its ecological footprint is considerably smaller than that of most cities its size. Curitiba's story gives us hope for developing more sustainable cities. The most difficult challenge is to convert cities with little or no hope to cities full of hope, as inspiring and innovative leaders have done for Curitiba and Bogotá, Colombia.

Curitiba and other ecocities and ecovillages apply the **principles of sustainability** in their efforts to become more sustainable urban areas. People in these communities rely more on solar energy for growing food and providing power than do people in more conventional cities. They also reuse and recycle resources much more frequently and systematically, as nature recycles nutrients. In preserving and using green spaces, these cities and villages value and preserve biodiversity and use it to enhance their own health and well-being.

A sustainable world will be powered by the sun; constructed from materials that circulate repeatedly; made mobile by trains, buses, and bicycles; populated at sustainable levels; and centered around just, equitable, and tight-knit communities.

GARY GARDNER

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 587. Describe how Curitiba, Brazil, has attempted to become a more sustainable city (**Core Case Study**). CORE CASE STUDY
2. Distinguish between **urbanization** and **urban growth**. Describe two factors that increase the population of a city.
3. List four global trends in urban growth. Describe four phases of urban growth in the United States.
4. What is **urban sprawl**? List five factors that have promoted urban sprawl in the United States. List five undesirable effects of urban sprawl.
5. What are four advantages of urbanization? What are six disadvantages of urbanization? What is **noise pollution** and how can we reduce it? Explain why most cities and urban areas are not sustainable.

6. Describe some of the problems faced by poor people who live in urban areas. How can governments help to reduce these problems? Describe the urban problems of Mexico City, Mexico.

7. Distinguish between compact and dispersed cities, and give an example of each. What are the major advantages and disadvantages of motor vehicles? List four ways to reduce dependence on motor vehicles. Describe the major advantages and disadvantages of relying more on **(a)** bicycles, **(b)** mass transit rail systems, **(c)** bus rapid transit systems within urban areas, and **(d)** rapid-rail systems between urban areas.

8. What is **land-use planning**? What is **zoning** and what are its limitations? What is **smart growth**? List five tools used to promote smart growth. Describe strategies used by the U.S. city of Portland, Oregon, to help control urban sprawl and reduce dependence on automobiles. What are three ways to preserve open spaces around a city?

9. What are new urbanism's five key goals and why is Vauban, Germany, a good example of it? What is cluster development? List eight goals of ecocity and ecovillage design. Summarize the scientific exploration of urban indoor farming. Describe three strategies used within ecovillages to make their neighborhoods more sustainable. Describe an example of a highly sustainable living building.

10. Explain how people in Curitiba, Brazil, (**Core Case Study**) have applied each of the three **principles of sustainability** to make their city more sustainable. CORE CASE STUDY SUSTAINABILITY

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. Curitiba, Brazil, (**Core Case Study**) has made significant progress in becoming a more environmentally sustainable and desirable place to live. If you live in an urban area, what steps, if any, has your community taken toward becoming more environmentally sustainable? CORE CASE STUDY

2. In Curitiba, Brazil, (**Core Case Study**) recycling rates have fallen in recent years, even though they are still among the highest in the world. Former Mayor Jaime Lerner attributes this decline to failure on the part of the city's leadership to encourage recycling. List five ways in which you think Curitiba, or any city, could encourage residents to recycle. CORE CASE STUDY

3. Do you think that urban sprawl is a problem and something that should be controlled? Develop three arguments to support your answer. Compare your arguments with those of your classmates.

4. Write a brief essay that includes at least three reasons why you **(a)** enjoy living in a large city, **(b)** would like to live in a large city, or **(c)** do not wish to live in a large city. Be specific in your reasoning. Compare your essay with those of your classmates.

5. One issue debated at a UN conference was the question of whether housing is a universal *right* (a position supported by most less-developed countries) or just a *need* (supported by the United States and several other more-developed countries). What is your position on this issue? Defend your choice.

6. If you own a car or hope to own one, what conditions, if any, would encourage you to rely less on your car and to travel to school or work by bicycle, on foot, by mass transit, or by carpool?

7. Do you believe the United States or the country in which you live should develop a comprehensive and integrated mass transit system over the next 20 years, including an efficient rapid-rail network for travel within and between its major cities? How would you pay for such a system?

8. Consider the goals listed on p. 607 as part of the ecocity concept. How close to reaching each of these goals is the city in which you live or the city nearest to where you live? Pick what you think are the five most important of these goals and describe a way in which that city could meet each of those five goals.

9. Congratulations! You are in charge of the world. List the three most important components of your strategy for dealing with urban growth and sustainability in **(a)** more-developed countries and **(b)** less-developed countries.

10. List two questions that you would like to have answered as a result of reading this chapter.

ECOLOGICAL FOOTPRINT ANALYSIS

Under normal driving conditions, an internal combustion engine produces approximately 200 grams (0.2 kilograms, or 0.44 pounds) of CO_2 per kilometer driven. In one large city, there are 7 million cars, and each car is driven an average of 20,000 kilometers (12,400 miles) per year.

1. Calculate the carbon footprint per car, that is, the number of metric tons (and tons) of CO_2 produced by a typical car in one year. Calculate the total carbon footprint for all cars in the city, that is, the number of metric tons (and tons) of CO_2 produced by all the cars in one year. (*Note:* 1 metric ton = 1,000 kilograms = 1.1 tons)
2. If 20% of the people were to use a carpool or to take mass transit in the city instead of driving their cars, how many metric tons (and how many tons) of these CO_2 emissions would be eliminated?
3. By what percentage, and by what average distance driven, would use of cars in the city have to be cut in order to reduce by half the carbon footprint calculated in question 1?

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengagebrain.com/shop/ISBN/0538735341** and choose Chapter 22 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

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Economics, Environment, and Sustainability

23

Muhammad Yunus and Microloans for the Poor

CORE CASE STUDY

Poverty is defined as the inability to meet one's basic economic needs. According to a 2008 study by the World Bank, poverty is the way of life for nearly half of the world's people who have to live on an income equivalent to less than $2.25 per day. Moreover, one of every five people who live in extreme poverty struggles to survive on an income equivalent to less than $1.25 a day. It is very difficult for most middle-class and affluent individuals around the world to even begin to understand the impact of this economic fact of life for one of every two people on the planet.

Poverty has numerous harmful health and environmental effects, and is viewed as one of the four major causes of the environmental problems we face (see Figure 1-17, p. 20). Thus, reducing poverty is an urgent challenge that has numerous economic, health, and environmental benefits.

One way to decrease poverty is to use free market capitalism to help the poor build better lives by working their way out of poverty. Most of the world's poor are eager to work to escape from their desperate circumstances. But they do not have a credit record or other means needed to get a loan in order to buy seeds and fertilizer to grow enough food or start a small business.

In 1983, economist Muhammad Yunus (Figure 23-1) started the Grameen (Village) Bank in Bangladesh, a country with a high poverty rate and a rapidly growing population. Since then, the bank has provided a total of $7.4 billion in *microloans* of $50 to $500 at very low interest rates to 7.6 million impoverished people who do not qualify for loans at traditional banks. About 97% of these loans have been used by women, mostly to plant crops or to start small businesses. A woman might also use such a loan to buy a cow, a bicycle for transportation, or a small irrigation pump.

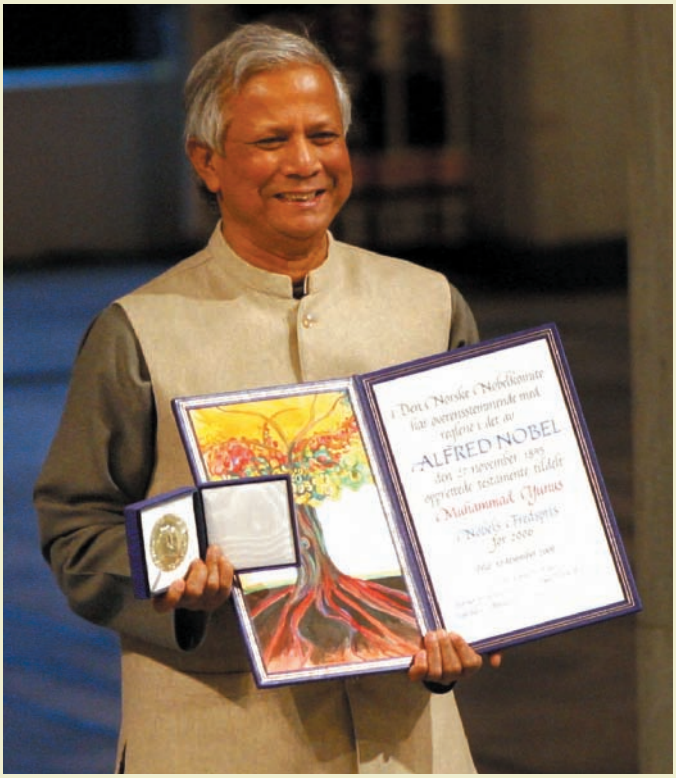
GOOD NEWS

To promote loan repayment, the bank puts borrowers into groups of five. If a group member fails to make a weekly payment, other members must pay it. The average repayment rate on its microloans has been 95% or higher—much greater than the average repayment rate for loans by conventional banks. In addition, the bank has made a consistent profit.

Typically, about half of the bank's microborrowers move above the poverty line and improve their lives within 5 years of receiving their loans. Birth rates are also lower among most of the borrowers.

Muhammad Yunus and his Grameen Bank developed a new business model that combined the power of market capitalism with the desire for a more humane and sustainable world. In 2006, Yunus and his colleagues at the bank jointly won the Nobel Peace Prize for their pioneering use of microcredit. Banks based on the Grameen microcredit model have spread to 58 countries, including the United States. By 2009, this approach had helped at least 133 million people worldwide to work their way out of poverty—85% of them in Asia.

Because the environment and the economy are intimately linked, improving environmental quality also improves the economy and the quality of life for the world's people. Thus, *the sustainability revolution is also an economic revolution*. According to visionary economic and environmental leaders, making a shift to more environmentally sustainable economies is the biggest investment opportunity of this century. Such a shift will promote cleaner energy, cleaner industrial production, and more sustainable agriculture. It will also reduce poverty, create new jobs, and provide profits by spurring investment in efforts to sustain the natural capital that supports all life and all economies.



©AP Photo/John McConnico

Figure 23-1 In 1983, economist Muhammad Yunus established the Grameen Bank, which makes small loans to poor people in Bangladesh at very low interest rates. These loans have helped 7.6 million of the country's people to improve their lives by working their way out of poverty. This has also helped to slow the country's population growth and to empower women.

Key Questions and Concepts

23-1 How are economic systems related to the biosphere?

CONCEPT 23-1 Ecological economists and most sustainability experts regard human economic systems as subsystems of the biosphere.

23-2 How can we put values on natural capital and control pollution and resource use?

CONCEPT 23-2A Economists have developed several ways to estimate the present and future value of a resource or ecological service, and optimum levels of pollution control and resource use.

CONCEPT 23-2B Comparing the likely costs and benefits of an environmental action is useful, but it involves many uncertainties.

23-3 How can we use economic tools to deal with environmental problems?

CONCEPT 23-3 We can use resources more sustainably by including their harmful environmental and health costs in the market prices of goods and services (*full-cost pricing*); by subsidizing environmentally beneficial goods and services; and by taxing pollution and waste instead of wages and profits.

23-4 How can reducing poverty help us to deal with environmental problems?

CONCEPT 23-4 Reducing poverty can help us to reduce population growth, resource use, and environmental degradation.

23-5 How can we make the transition to more environmentally sustainable economies?

CONCEPT 23-5 We can use the three principles of sustainability as well as various economic and environmental strategies to develop more environmentally sustainable economies.

Note: Supplements 2 (p. S3), 8 (p. S30), and 9 (p. S57) can be used with this chapter.

When it is asked how much it will cost to protect the environment, one more question should be asked: How much will it cost our civilization if we do not?

GAYLORD NELSON

23-1 How Are Economic Systems Related to the Biosphere?

▶ **CONCEPT 23-1 Ecological economists and most sustainability experts regard human economic systems as subsystems of the biosphere.**

Economic Systems Are Supported by Three Types of Resources

An **economic system** is a social institution through which goods and services are produced, distributed, and consumed to satisfy people's needs and wants, ideally in the most efficient way possible.

Three types of capital, or resources, are used to produce goods and services (Figure 23-2). **Natural capital** (see Figure 1-4, p. 9) includes resources and services produced by the earth's natural processes, which support all economies and all life. (See the Guest Essay on natural capital by Paul Hawken at CengageNOW™.)

Human capital, or **human resources**, includes people's physical and mental talents that provide labor, organizational and management skills, and innovation.

Manufactured capital, or **manufactured resources**, refers to items such as machinery, equipment, and factories made from natural resources with the help of human resources.

Market Economic Systems Depend on Interactions between Buyers and Sellers

In a market-based economic system, buyers and sellers interact competitively to make economic decisions about how goods and services are produced, distributed, and consumed.

In a truly *free market* economic system, all economic decisions are governed solely by the competitive inter-

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. GOOD NEWS refers to good news about the environmental challenges we face.

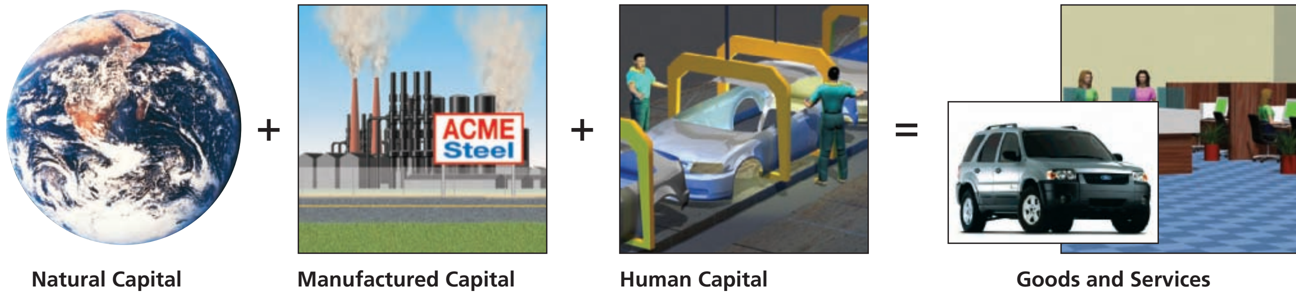


Figure 23-2 In an economic system, we use three types of resources to produce goods and services.

actions of *supply* (the amount of a good or service that is available), *demand* (the amount of a good or service that people want), and *price* (the market cost of a good or service) with little or no government control or interference in these interactions, as shown in Figure 23-3. *Supply* is represented on this graph by the blue line (commonly called a *curve*) showing how much a producer of any good or service is willing to supply (measured on the horizontal *quantity* axis) for different prices (measured on the vertical *price* axis). *Demand* is represented by the red curve showing how much consumers will pay for different quantities of the good or service.

The point at which the curves intersect is called the *market price equilibrium point*, where the supplier's price matches what buyers are willing to pay for some quantity and a sale is made. In Figure 23-3, it is the point at which the supply and demand curves intersect.

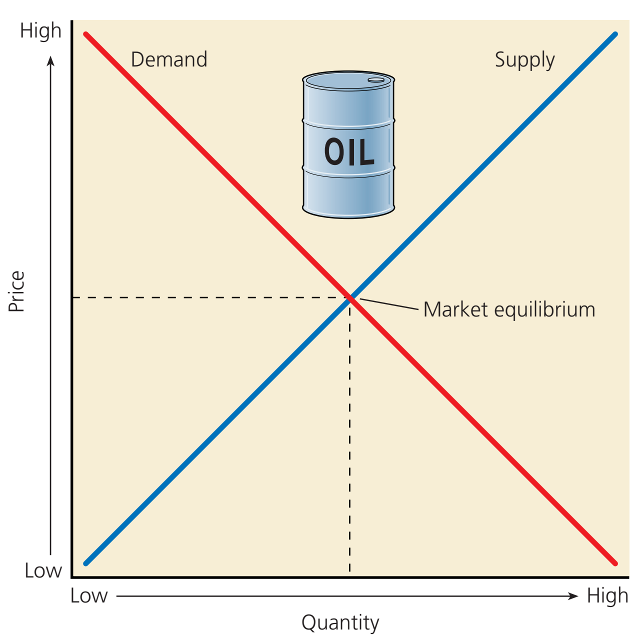


Figure 23-3 This graph shows supply and demand curves and market equilibrium for a good such as oil in a market economic system. If all factors except supply, demand, and price are held fixed, market equilibrium occurs at the point where the supply and demand curves intersect. This represents the price at which sellers are willing to sell and buyers are willing to pay for the good or service provided. **Question:** How would a decrease in the available supply of oil shift the market equilibrium point on this diagram?

Changes in supply and demand can shift one or both curves back and forth, and thus change the equilibrium price. For example, when supply is increased (shifting the blue curve to the right) and demand remains the same, the equilibrium price will go down. Similarly, when demand is increased (shifting the red curve to the right) and supply remains the same, the equilibrium price will increase. Try to imagine how the equilibrium price would change if we moved one or the other of the curves in Figure 23-3 to the left or right to represent changes in supply or demand.

In a *truly* free-market economic system **(1)** no company or small group of companies would control the prices of any goods or services; **(2)** the market prices of goods and services would include all of their direct and indirect costs (full-cost pricing); and **(3)** consumers would be provided with full information about the beneficial and harmful environmental effects of the goods and services available to them.

This rarely happens in today's capitalist market systems. To increase their profits, most businesses try to take business away from their competitors and to exert as much control as possible over the prices of the goods and services they provide. Many companies push for government subsidies (payments to support their businesses), tax breaks, trade barriers, or regulations that will give their products a market advantage over their competitors' products. Worldwide, businesses receive more than $2 trillion in government subsidies and tax breaks each year. This creates an uneven economic playing field that helps to undermine true free-market competition.

Some companies also try to withhold information from consumers about the costs and dangers their products may pose to human health or to the environment, unless the government requires them to provide such information. Thus, buyers often do not get complete information about the harmful environmental impacts of the goods and services they buy.

Economic Growth and Economic Development

Economic growth is an increase in a nation's capacity to provide goods and services to people. It involves making an economy bigger. Accomplishing this increase requires population growth (more producers and consumers), more production and consumption per person, or both.

Economic development is the improvement of human living standards through economic growth. (See Figures 1 and 2, p. S57, in Supplement 9 for graphs of economic growth as measured by the increase in gross world product and gross world product per person.) Economic development focuses on making an economy better by improving human well-being—meeting fundamental human needs for items such as food, shelter, physical and economic security, and good health.

During this century, many analysts call for us to put much greater emphasis on **environmentally sustainable economic development**. Its goal is to use political and economic systems to *encourage* environmentally beneficial and more sustainable forms of economic development, and to *discourage* environmentally harmful and unsustainable forms of economic growth.

Governments Intervene to Help Correct Market Failures

Markets usually work well in guiding the efficient production and distribution of *private goods*. But experience shows that they cannot be relied upon to provide adequate levels of *public services,* such as national security and environmental protection. Economists generally refer to such deficiencies as *market failures*. An important example of a market failure is the inability of markets to prevent the degradation of *open-access resources*, such as clean air and the open ocean. Such resources are not bought and sold in the marketplace, because they are owned by no one and available for use by everyone at little or no charge.

Governments intervene in market systems to provide various public services, such as national security and police and fire protection, and to help correct other market failures. An important application of this is the intervention by governments to protect open-access resources. For example, governments have passed laws to control air and water pollution.

One reason why markets often fail in the area of environmental protection is that they usually do not assign monetary value to the benefits provided by the earth's natural capital or to the harmful effects of various human activities on the environment and on human health. For example, the benefits of leaving an old-growth forest undisturbed (ecological services such as water purification and recreational benefits) usually are not weighed against the monetary value of cutting the timber in the forest.

Scientists and ecological and environmental economists have attempted to place monetary values on various natural resources and ecological services (see Chapter 10, Science Focus, p. 221). For example, ecological economist Robert Costanza and other researchers estimate the value of pollination to be $1.2 trillion per year and the value of natural erosion control to be $5.8 trillion per year. But such values are rarely considered in market transactions. For example, old-growth forests have been clear-cut for their timber, while their nontimber natural capital value (such as ecological services, see Figure 10-A, p. 221) is much higher than the value of their timber and is thus lost. Governments can use economic tools such as regulations, taxes, subsidies, and tax breaks to include the value of natural capital in the market prices of goods and services.

THINKING ABOUT

The Government's Role in an Economy

In a pure free-market economy, the government plays no role, and some economists see this as the best possible economic system. Explain why you agree or disagree with their position.

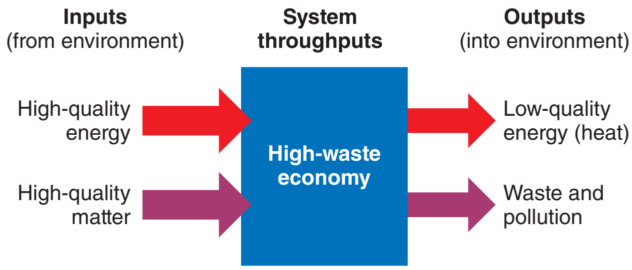
Economists Disagree over the Importance of Natural Capital and Whether Economic Growth Is Sustainable

For more than 200 years, there has been a debate over whether there are limits to economic growth. Now the debate is shifting to questions about what kinds of economic growth and development we should encourage.

Neoclassical economists, such as the late Alfred Marshall (1842–1924) and the late Milton Friedman (1912–2006), viewed natural resources as important but not indispensable because of our ability to find substitutes. For example, if we run out of oil, we should be able to find a substitute such as ethanol, natural gas, or electricity to power motor vehicles. They also contend that continuing economic growth is necessary for providing businesses with profits and workers with jobs.

Neoclassical economists view the earth's natural capital as a subset or part of a human economic system, and they assume that the potential for economic growth is essentially unlimited. Most of today's advanced industrialized countries have **high-throughput economies**, which attempt to boost economic growth by increasing the flow of matter and energy resources extracted from the environment through their economic systems to produce goods and services (Figure 23-4). These resources flow through economies and end up in planetary *sinks* (air, water, soil, and organisms), where some pollutants and wastes can accumulate to harmful levels.

Ecological economists such as Herman Daly (see his Guest Essay at CengageNOW) and Robert Costanza disagree with this model. They point out that there are no substitutes for many vital natural resources, such as air, water, fertile soil, biodiversity, and nature's free ecological services such as climate control, air and water purification, pest control, and nutrient recycling. In contrast



CENGAGENOW™ **Active Figure 23-4** The *high-throughput economies* of most of the world's more-developed countries rely on continually increasing the flow of energy and matter resources to increase economic growth. This practice produces valuable goods and services, but it also converts high-quality matter and energy resources into waste, pollution, and low-quality heat, and in the process, can deplete or degrade various forms of natural capital that support all life and economies. *See an animation based on this figure at* CengageNOW. **Question:** What are three things you regularly do that add to this throughput of matter and energy?

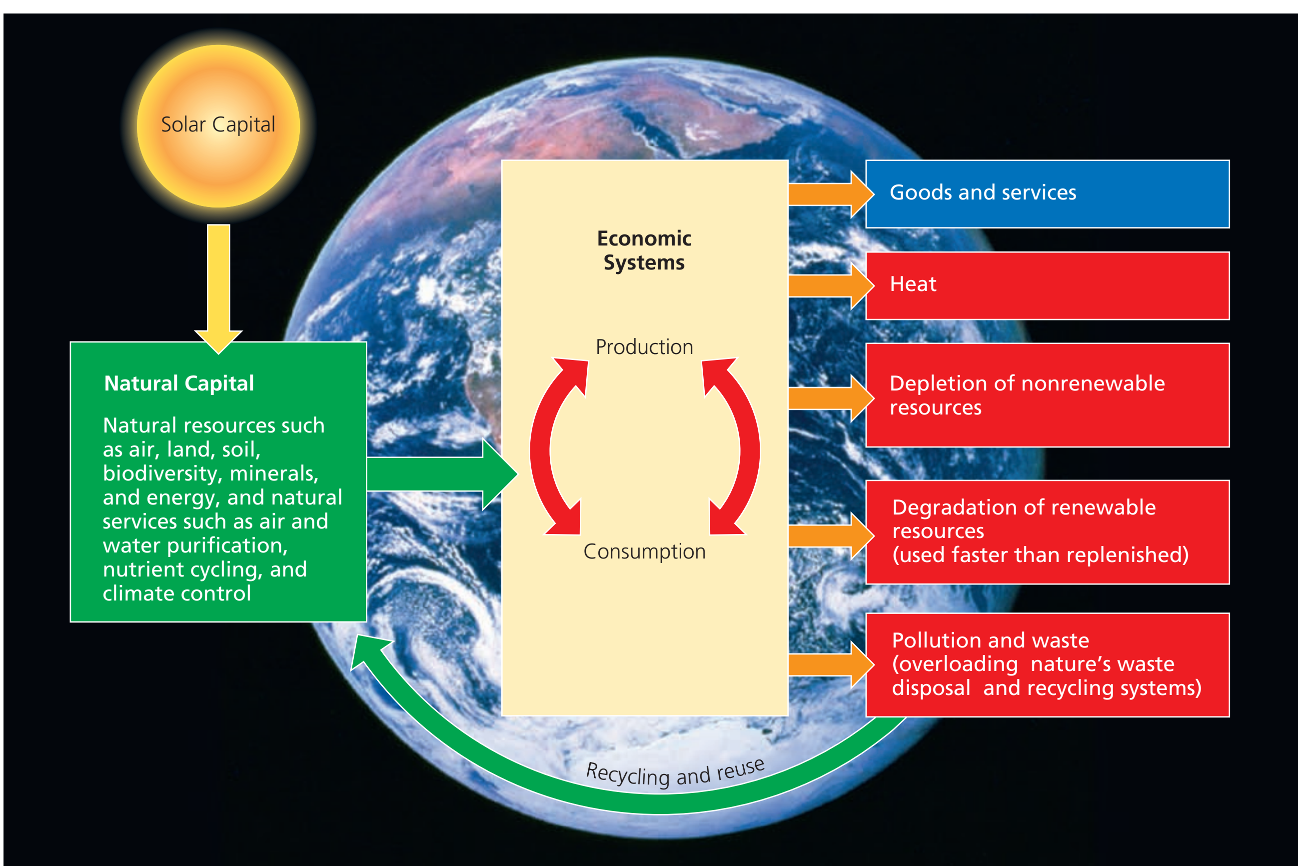
to neoclassical economists, they view human economic systems as subsystems of the biosphere that depend heavily on the earth's irreplaceable natural resources (**Concept 23-1**) (Figure 23-5).

Ecological economists also believe that conventional economic growth eventually will become unsustainable because it can deplete or degrade various irreplaceable forms of natural capital (see Figure 1-4, p. 9), on which all human economic systems depend, and exceed the capacity of the environment to handle the pollutants and wastes we produce.

Ecological economists warn that many people are getting rich in the short term by depleting and degrading the natural capital that sustains all life and economies in the long run. In other words, we are living beyond our ecological means (see Figure 1-13, p. 16) by thinking that we can somehow violate the laws of physics and biology, which ultimately determine what we can and cannot do with the matter and energy resources that we use. Once natural resources are depleted or severely degraded, there is no way to create new resources. As Glenn Pickett, senior vice president of Conservation International points out, "Mother Nature doesn't do bailouts."

In general, the models of ecological economists are built on three major assumptions:

1. Resources are limited and we should not waste them, and there are no substitutes for most types of natural capital. In 2008, Achim Steiner, head of the UN Environment Programme (UNEP), said, "I believe the 21st century will be dominated by the concept of natural capital, just as the 20th century was dominated by financial capital."



CENGAGENOW™ **Active Figure 23-5** *Ecological economists* see all human economies as subsystems of the biosphere that depend on natural resources and services provided by the sun and earth. *See an animation based on this figure at* CengageNOW. **Question:** Do you agree or disagree with this model? Explain.

2. We should encourage environmentally beneficial and sustainable forms of economic development, and discourage environmentally harmful and unsustainable forms of economic growth.
3. The harmful environmental and health effects of producing economic goods and services should be included in their market prices (*full-cost pricing*), so that consumers will have more accurate information about the harmful environmental and health effects of the goods and services they buy.

Taking the middle ground in this debate are *environmental economists*. They generally agree with the model proposed by ecological economists in Figure 23-5, and they argue that some forms of economic growth are not sustainable and should be discouraged. However, unlike ecological economists, they would accomplish this by fine-tuning existing economic systems and tools, instead of redesigning some of them to be more sustainable (Figure 23-5).

THINKING ABOUT
Economic Growth

Do you think that the economy of the country where you live is sustainable or unsustainable? Explain.

CENGAGENOW™ Learn more about how ecological economists view market-based systems, and contrast their views with those of conventional economists at CengageNOW.

What Is the Purpose of a Business?

Strictly speaking, the primary goal of a business is to make a profit for its owners and investors. This is in keeping with business management expert Peter Drucker (1909–2005) who said that "The purpose of business is to create and keep a customer." For a business, sustainability is about staying in business regardless of whether or not doing so promotes environmental sustainability.

Others have expanded the goal of business. Gary Hirshberg, president and CEO of Stonyfield Farm, the world's largest producer of organic yogurt, says that the purpose of business should be "to make a quality product and earn a profit without harming the environment."

So why do we persist in degrading the earth's life-support system? In the rest of this chapter we look at some components of our economic systems that lead to degradation of natural capital, and we examine some possible strategies that can help us to promote environmental and economic sustainability.

23-2 How Can We Put Values on Natural Capital and Control Pollution and Resource Use?

▶ **CONCEPT 23-2A Economists have developed several ways to estimate the present and future value of a resource or ecological service, and optimum levels of pollution control and resource use.**

▶ **CONCEPT 23-2B Comparing the likely costs and benefits of an environmental action is useful, but it involves many uncertainties.**

Protecting Natural Capital

Environmental and ecological economists have developed various tools for estimating the values of the earth's natural capital (see Figure 1-4, p. 9). One approach involves estimating the monetary worth of the earth's natural ecological services and the biological income they provide (see Chapter 10, Science Focus, p. 221). For example, using this approach a team of ecologists and economists estimated that the ecological services provided by the earth's forests (see Figure 10-4, left, p. 221) are worth at least $4.7 trillion a year. This is hundreds of times greater than the estimated value of their economic services (Figure 10-4, right, p. 221).

In 2009, a team of ecological researchers and environmental ministers began making what is called the TEEB study of *The Economics of Ecosystems and Biodiversity*. The three goals of this study are to **(1)** integrate economic and ecological knowledge in order to estimate the economic and ecological values of ecosystem services; **(2)** to evaluate the costs and benefits of actions that could be taken to prevent the decline of these services; and **(3)** to develop toolkits to help local, regional, and international policy makers promote more sustainable development that conserves ecosystems and biodiversity.

The basic problem with these goals is that the estimated economic values of the ecological services provided by forests, oceans, and other ecosystems are not included in the market prices of timber, fish, and other goods that we get from them. Ecological economists point out that until this underpricing is corrected, we will continue our unsustainable use of forests, oceans, the atmosphere, and many of nature's other irreplaceable forms of natural capital.

However, according to neoclassical economists, a product or service has no economic value until it is sold in the marketplace, and thus because they are not sold in the marketplace, ecological services have no economic value. Ecological economists view this as a misleading circular argument designed to exclude serious evaluation of ecological services in the marketplace.

Ecological and environmental economists have developed ways to estimate *nonuse values* of natural resources and ecological services that are not represented in market transactions (**Concept 23-2A**). One such value is an *existence value*—a monetary value placed on a resource such as an old-growth forest or endangered species just because it exists, even though we may never see it or use it. Another is *aesthetic value*—a monetary value placed on a forest, species, or a part of nature because of its beauty. A third type, called a *bequest* or *option value*, is based on the willingness of people to pay to protect some forms of natural capital for use by future generations.

RESEARCH FRONTIER

Developing better ways to estimate the economic values of the earth's natural capital; see **www.cengage.com/login**.

Estimating the Future Value of a Resource Is Controversial

To determine the value of a resource, economists, businesses, and investors use a tool known as the **discount rate**, which is an estimate of a resource's future economic value compared to its present value (**Concept 23-2A**). It is based on the idea that today's value of a resource may be higher than its value in the future. Thus, its future value should be discounted. The size of the discount rate (usually given as a percentage) is a key factor affecting how a resource such as a forest or fishery is used or managed.

At a zero discount rate, for example, the timber from a stand of redwood trees worth $1 million today will still be worth $1 million 50 years from now. However, the U.S. Office of Management and Budget, the World Bank, and most businesses typically use a 10% annual discount rate to evaluate how resources should be used. At this rate, the timber in the stand of redwood trees will be worth only $10,000 in 50 years. Using this discount rate, it makes sense from an economic standpoint for the owner of this resource to cut these trees down as quickly as possible and invest the money in something else.

However, this economic analysis does not take into account the immense economic value of the ecological services provided by forests. They include the absorption of precipitation and gradual release of water within ecosystems, flood reduction, water and air purification, prevention of soil erosion, removal and storage of atmospheric carbon, and provision of a diversity of habitats for various forms of life (see Figure 10-4, left, p. 220).

The one-sided and incomplete economic evaluation currently in use loads the dice against sustaining these important ecological services. If these economic values were included, it would make more sense now and in the future to preserve the redwoods for the ecological services they provide and to find substitutes for redwood products. However, while these ecological services are vital for the earth as a whole and for future generations, they do not provide the current owner of the redwoods with any monetary return.

The value of discount rates is controversial. Proponents cite several reasons for using high (5–10%) discount rates. One is that inflation may reduce the value of their future earnings on a resource. Another is that innovation or changes in consumer preferences could make a product or resource obsolete. For example, the plastic composites made to look like redwood may reduce the future use and market value of this timber. In addition, owners of resources such as forests argue that without a high discount rate, they can make more money by investing their capital in some other venture.

Critics point out that high discount rates encourage rapid exploitation of resources for immediate payoffs, thus making long-term sustainable use of most renewable natural resources virtually impossible. These critics believe that a 0% or even a negative discount rate should be used to protect unique, scarce, and irreplaceable resources such as old-growth forests. They also point out that moderate discount rates of 1–3% would make it profitable to use nonrenewable and renewable resources more slowly and in more sustainable ways. In addition, suppose that an acceptable substitute for a resource such as redwood or oil does not become available. Then these resources and the ecological services they provide could become priceless. This is another major disagreement between neoclassical economists and ecological and environmental economists.

However, in some cases, economic return is not always the determining factor in how resources are used or managed. For example, farmers and owners of forests, wetlands, and other resources often include their *ethical concerns* in determining how they use and manage such resources. Their respect for the land and nature, or what they believe to be their responsibility to future generations, can override their desire for short-term profit at the expense of long-term resource and environmental sustainability.

THINKING ABOUT
Discount Rates

If you owned a forested area, would you want the discount rate for resources such as trees from the forest to be high, moderate, or zero? Explain.

We Can Estimate Optimum Levels of Pollution Control and Resource Use

An important concept in environmental economics is that of *optimum levels* for pollution control and resource use (**Concept 23-2A**). In the early days of a new coal mining operation, for example, the cost of extracting coal is typically low enough to make it easy for developers to recover their investments by selling their product. However, after most of the more readily accessible coal has been removed from a mine, taking what is left can become too costly. In this case, the cost of removal goes up with each additional unit of coal taken—what economists call its *marginal cos*t. Figure 23-6 shows this in terms of supply, demand, and equilibrium. The point at which removing more coal is not worth the cost is where the demand curve crosses the supply curve.

You might think that the best solution for pollution is total cleanup. In fact, there are optimum levels for various kinds of pollution for two reasons. *First,* the cost of pollution control goes up for each additional unit of a pollutant removed from the environment. The main reason for this is that it takes increasing amounts of energy to remove increasingly lower concentrations of a pollutant from the air, water, or soil. *Second*, natural processes such as dilution and chemical cycling can reduce the levels of some pollutants. This helps to make cleanup of a certain amount of pollution affordable, but at some point the cost of additional pollution control is greater than the harmful costs of the pollution to society. That point is the equilibrium point, or the *optimum level* for pollution cleanup.

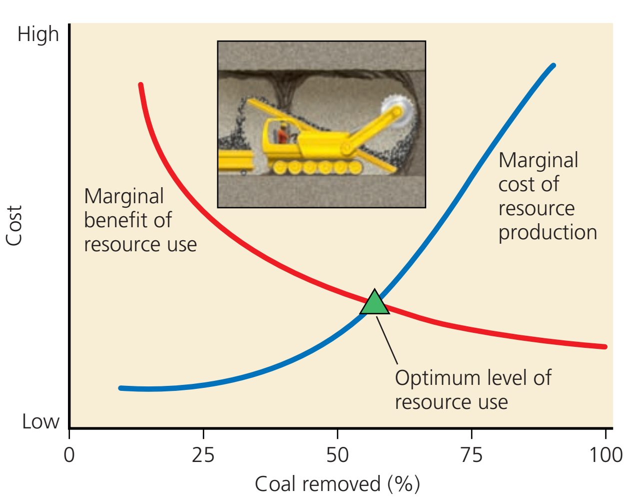


Figure 23-6 *Optimum resource use:* The cost of extracting coal (blue line) from a particular mine rises with each additional unit removed. Mining a certain amount of coal is profitable, but at some point the marginal cost of further removal exceeds the monetary benefits (red line) unless some factor such as scarcity raises the value of the coal remaining in the mine. Where the two curves meet at current prices is theoretically the *optimum level of resource use*. **Question:** How would the location of the optimum level of resource use shift if the price of coal doubled?

Cost–Benefit Analysis Is a Useful but Crude Tool

Another widely used tool for making economic decisions about how to control pollution and manage resources is **cost-benefit analysis**. This is done by comparing estimated costs and benefits for actions such as implementing a pollution control regulation, building a dam on a river, or preserving an area of forest. It involves trying to estimate the optimum level of pollution cleanup or resource use (Figure 23-6).

Making a cost-benefit analysis involves determining who or what might be affected by a particular regulation or project, projecting potential outcomes, evaluating alternative actions, and establishing who benefits and who is harmed. Then an attempt is made to assign monetary costs and benefits to each of the factors and components involved.

Direct costs involving land, labor, materials, and pollution-control technologies are often fairly easy to estimate. But estimates of indirect costs of clean air and water that are not traded in the marketplace are difficult to make and are controversial. We can put estimated price tags on human life, good health, clean air and water, and natural capital such as an endangered species, a forest, and a wetland. However, the monetary values assigned to these vary widely depending on individual assumptions, value judgments, and the discount factors used.

Because of these drawbacks, a cost-benefit analysis can lead to wide ranges of benefits and costs with a lot of room for error, and this is a source of controversy. For example, one cost-benefit analysis sponsored by a U.S. industry estimated that compliance with a standard to protect American workers from vinyl chloride would cost $65–90 billion. In the end, meeting the standard cost the industry less than $1 billion. A study by the Washington, DC–based Economic Policy Institute found that the estimated costs projected by industries for complying with proposed environmental regulations in the United States are almost always more (and often much more) than the actual costs of implementing the regulations. In such cases, inflated cost-benefit analyses are used as an economic and political ploy by industries to prevent, weaken, or delay compliance with pollution standards.

If conducted fairly and accurately, cost-benefit analysis is a useful tool for helping to make economic decisions, but it always includes uncertainties (**Concept 23-2B**). To minimize possible abuses and errors, environmental economists advocate using the following guidelines for a cost-benefit analysis:

- Clearly state all assumptions used.
- Include estimates of the ecological services provided by the resources involved.
- Estimate short- and long-term benefits and costs for all affected population groups.
- Compare the costs and benefits of alternative courses of action.

23-3 How Can We Use Economic Tools to Deal with Environmental Problems?

CONCEPT 23-3 We can use resources more sustainably by including their harmful environmental and health costs in the market prices of goods and services (*full-cost pricing*); by subsidizing environmentally beneficial goods and services; and by taxing pollution and waste instead of wages and profits.

Most Things Cost a Lot More Than We Might Think

The *market price*, or *direct price*, that we pay for something does not include most of the *indirect*, or *external*, *costs* of harm to the environment and human health associated with its production and use. For this reason, such costs are also called *hidden costs*. For example, if we buy a car, the direct price we pay includes the *direct*, or *internal*, *costs* of raw materials, labor, and shipping, and a markup for dealer profit. In using the car, we pay additional direct costs for gasoline, maintenance, repair, and insurance.

However, we do not pay the harmful external costs, some of which affect other people now and in the future. For example, to extract and process raw materials to make a car, manufacturers use nonrenewable energy and mineral resources, produce solid and hazardous wastes, disturb land, pollute the air and water, and release greenhouse gases into the atmosphere. These hidden external costs can have short- and long-term harmful effects on other people, on future generations, and on the earth's life-support systems.

Because these harmful external costs are not included in the market price of a car, most people do not connect them with car ownership. Still, the car buyer and other people in a society pay these hidden costs sooner or later, in the forms of poorer health, higher expenses for health care and insurance, higher taxes for pollution control, traffic congestion, and environmental degradation and destruction of ecosystems to build highways and parking lots. Similarly, when a farmer practices high-input industrialized farming, or a power plant pollutes the water in a river, those costs are also not added to your food prices or your electric bill.

Many economists and environmental experts believe that these harmful external costs should be included in the market prices of goods and service in what is called *full-cost pricing* (**Concept 23-3A**). They cite this failure to include the harmful environmental costs in the market prices of goods and services as one of the major causes of the environmental problems we face (see Figure 1-17, p. 20). In his 2006 analysis of the economics of climate change, for example, Nicholas Stern, former chief economist of the World Bank, described the failure to include the estimated harmful costs of projected climate change during this century in the prices of fossil fuels as "a market failure on the greatest scale the world has ever seen."

CONNECTIONS

Environmental Costs, Consumer Demands, and Environmental Problems

Excluding the harmful environmental costs from the market prices of goods and services hides them from consumers. Many consumers therefore do not learn about their negative effects and are less likely to demand more environmentally beneficial goods and services. Thus, hiding these costs promotes pollution, resource waste, and environmental degradation.

THINKING ABOUT

Hidden Costs

Were you aware of the external costs involved in producing, buying, and owning a car (or any other item)? Do you believe that such hidden costs should be included in the prices of goods and services? Explain.

Environmental Economic Indicators Could Help Us Reduce Our Environmental Impact

Economic growth is usually measured by the percentage change in a country's **gross domestic product** (**GDP**): the annual market value of all goods and services produced by all firms and organizations, foreign and domestic, operating within a country. Changes in a country's economic growth per person are measured by **per capita GDP**: the GDP divided by a country's total population at midyear.

GDP and per capita GDP indicators provide a standardized and useful method for measuring and comparing the economic outputs of nations. The GDP is deliberately designed to measure such outputs without distinguishing between goods and services that are environmentally or socially beneficial and those that are harmful.

Environmental and ecological economists and environmental scientists call for the development and widespread use of new indicators—called *environmental indicators*—to help monitor environmental quality and human well-being. One such indicator is the **genuine progress indicator (GPI)**—the

GOOD NEWS

GDP plus the estimated value of beneficial transactions that meet basic needs, but in which no money changes hands, minus the estimated harmful environmental, health, and social costs of all transactions. The per capita GPI would be the GPI for a country divided by that country's population at mid-year. Redefining Progress, a nonprofit organization that develops economic and policy tools to help promote environmental sustainability, introduced the GPI in 1995. (This group also developed the concept of ecological footprints, Figure 1-13, p. 16.)

Examples of beneficial transactions included in the GPI include unpaid volunteer work, health care and child care provided by family members, and housework. Harmful costs that are subtracted to arrive at the GPI include costs of pollution, resource depletion and degradation, and crime. The GPI is calculated as follows:

Genuine progress indicator = GDP + benefits not included in market transactions − harmful environmental and social costs

Figure 23-7 compares the per capita GDP and GPI for the United States between 1950 and 2004 (the latest data available). While the per capita GDP rose sharply over this period, the per capita GPI stayed nearly flat and even declined slightly and fluctuated.

Bhutan, a South Asian nation in the Himalaya Mountains, is located between China and India. Since 1972, its government has been using the concept of *gross national happiness (GNH)* as a measure of its efforts toward sustainable economic development. Its GNH is based on an evaluation of the country's conservation of its natural environment, preservation of cultural values, fairness in access to its wealth (equity), and good governance.

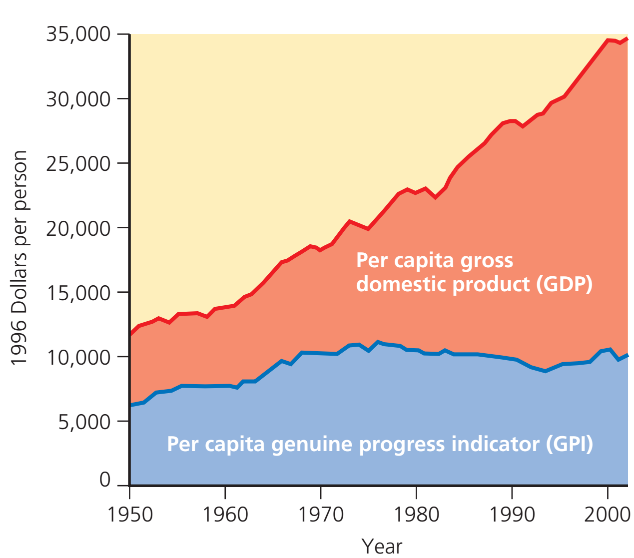


Figure 23-7 *Monitoring environmental progress:* This graph compares the per capita gross domestic product (GDP) and the per capita genuine progress indicator (GPI) in the United States between 1950 and 2004. **Questions:** Would you favor making widespread use of this or similar green economic indicators? Why hasn't this been done? (Data from Redefining Progress, 2006)

The genuine progress indicator, gross national happiness indicator, and other environmental indicators under development are far from perfect, which is true of the GDP as well. But without such environmental indicators, we will not know much about what is happening to people, the environment, and the planet's natural capital, nor will we have a way to evaluate which policies are likely to work best in improving environmental quality and life satisfaction.

Business entrepreneur and environmental writer Paul Hawken (see his Guest Essay on Natural Capital at CengageNOW) has this to say about relying on GNP to guide our economy and well-being: "At present we are stealing the future, selling it to the present, and calling it gross domestic product. We can just as easily have an economy that is based on healing the future instead of stealing it."

RESEARCH FRONTIER

Developing and refining environmental and social quality of life indicators; see **www.cengage.com/login**.

Include the Harmful Environmental Costs of Goods and Services in Their Prices

Most environmental and ecological economists argue for a more *environmentally honest market system*. It would include the estimated harmful environmental and health costs of goods and services in their market prices to reflect as closely as possible their *full costs*—internal costs of production and marketing plus external costs to human health and the environment. This is also a key goal of a truly free-market economic system.

According to environmental and ecological economists, full-cost pricing would reduce resource waste, pollution, and environmental degradation and improve human health by encouraging producers to invent more resource-efficient and less-polluting methods of production. It would also allow consumers to make more informed decisions about the goods and services they buy. Jobs and profits would be lost in environmentally harmful businesses as consumers more often chose green products and services, but jobs and profits would be created in environmentally beneficial businesses. Such shifts in job markets, profits, and types of businesses are a normal part of market-based capitalism. This is why we no longer burn whale oil in lamps to give us light and why we may soon phase out use of very inefficient incandescent lightbulbs.

If a shift to full-cost pricing were phased in over two decades, many environmentally harmful businesses would have time to transform themselves into environmentally beneficial businesses, which would have a better chance of making enough profit to be sustainable. Consumers would also have time to adjust their buying habits to favor more environmentally beneficial products and services.

Full-cost pricing seems to make a lot of sense, but why is it not used more widely? *First,* many producers of harmful and wasteful products would have to charge more for them, and some would go out of business. Naturally, they oppose such pricing. *Second,* it is difficult to estimate many environmental and health costs. But ecological and environmental economists argue that making the best possible estimates is far better than continuing with the current misleading and eventually unsustainable system, which excludes such costs. *Third,* many environmentally harmful businesses have used their political and economic power to obtain environmentally harmful government subsidies and tax breaks that help them make profits. They also fight hard to keep such subsidies, which help them avoid true free-market competition, while often opposing similar subsidies for more sustainable businesses that would compete with them.

HOW WOULD YOU VOTE?

Should full-cost pricing be used to set market prices for goods and services? Cast your vote online at **www.cengage.com/login**.

Governments can use several strategies to encourage or force producers to work toward full-cost pricing. Let us take a closer look at each of these strategies.

Label Environmentally Beneficial Goods and Services

Product eco-labeling and *certification* can encourage companies to develop green products and services and can help consumers select more environmentally beneficial products and services. Eco-labeling programs have been developed in Europe, Japan, Canada, and the United States. The U.S. *Green Seal* labeling program has certified more than 300 products.

Eco-labels are also being used to identify fish caught by sustainable methods (certified by the Marine Stewardship Council) and to certify timber produced and harvested by sustainable methods (see Chapter 10, Science Focus, p. 230).

Eco-labels could include a simple table of numbers, on a scale of 0 to 100 or 0 to 10, that measures factors such as environmental damage, climate impact, carbon footprint, energy, water, and pesticide use, and air and water pollution. Such eco-labeling would inform consumers about the environmental impacts of what they buy and help them to vote with their wallets.

Providing such easily understandable summaries of the sustainability of goods and services could help expose and reduce **greenwashing**: a deceptive practice that some businesses use to spin environmentally harmful products and services as green, clean, or environmentally beneficial (see **http://money.howstuffworks.com/greenwashing1.htm** and **http://govpro.com/green/content/gov_imp_68662/index.html**). For example, in 2008, the U.S. coal industry spent about $45 million on a successful public relations campaign to imbed the words "clean coal" in the minds of Americans, even though certain harmful aspects of mining and using coal will always make it by far the dirtiest fossil fuel (see p. 385).

Some businesses also try to improve the environmental image of their products by working to lower or oppose various government pollution standards. Others work to water down the standards for various products such as certified organic meats, fish, and produce, or sustainably harvested timber, to create their own less stringent eco-label organizations. EnviroMedia Marketing and the University of Oregon have developed a "greenwashing index" with ratings from "authentic" to "bogus" to help consumers evaluate greenwashing advertisements (see **http://www.greenwashingindex.com**).

Reward Environmentally Sustainable Businesses

One way to encourage a shift to full-cost pricing and promote sustainability is to *phase out* environmentally harmful (*perverse*) subsidies and tax breaks for environmentally destructive activities such as burning fossil fuels, clear-cutting forests, overfishing, and overpumping aquifers. According to environmental scientist Norman Myers, such perverse subsidies and tax breaks cost the world's governments (taxpayers) at least $2 trillion a year—an average $3.8 million a minute! (See Myer's Guest Essay on perverse subsidies at CengageNOW.)

These perverse subsidies and tax breaks distort the economic playing field and create a huge economic incentive for unsustainable resource waste, depletion, and environmental degradation. According to a study by the Earth Council, "There is something unbelievable about the world spending hundreds of billions of dollars annually to subsidize its own destruction."

On paper, phasing out such subsidies may seem like a great idea. In reality, the economically and politically powerful interests receiving them spend a lot of time and money *lobbying*, or trying to influence governments to continue and even increase their subsidies. For example, the fossil fuel and nuclear power industries in the United States are mature and highly profitable industries. Yet, according to Doug Koplow, founder of Earth Track, in 2006, U.S. government subsidies for these industries totaled $56 billion ($39 billion for the oil and natural gas industries, $8 billion for coal, and $9 billion for nuclear power). Such industries also lobby against subsidies and tax breaks for their more environmentally beneficial competitors.

Some countries have begun reducing perverse subsidies. Japan, France, and Belgium have phased out all coal subsidies and Germany plans to do so by 2018. China has cut coal subsidies by about 73% and has imposed a tax on high-sulfur coals.

At the same time, governments could phase in environmentally beneficial subsidies and tax breaks for pollution prevention, ecocity development, sustainable forestry and agriculture, sustainable water use, energy conservation, and renewable energy use, as well as measures to slow projected climate change (**Concept 23-3**). Making such subsidy shifts would encourage the transition from environmentally harmful to more environmentally beneficial businesses.

THINKING ABOUT
Subsidies

Do you favor phasing out environmentally harmful government subsidies and tax breaks and phasing in environmentally beneficial ones? Explain. What are three things you could you do to help bring this about? How might such subsidy shifting affect your lifestyle?

Tax Pollution and Wastes Instead of Wages and Profits

Another way to discourage pollution and resource waste is to tax them. This would involve using *green taxes*, or *ecotaxes*, to help include many of the harmful environmental and health costs of production and consumption in market prices (**Concept 23-3**). Taxes could be levied on a per-unit basis on the amount of pollution and hazardous waste produced by a farm, business, or industry, and on the use of fossil fuels, nitrogen fertilizer, timber, minerals, water, and other resources. Figure 23-8 lists some of the advantages and disadvantages of using green taxes.

HOW WOULD YOU VOTE?

Do the advantages of green taxes outweigh their disadvantages? Cast your vote online at **www.cengage.com/login**.

To many analysts, the tax system in most countries is backward. It *discourages* what we want more of—jobs, income, and profit-driven innovation—and *encourages* what we want less of—pollution, resource waste, and environmental degradation. A more environmentally sustainable economic and political system would *lower* taxes on labor, income, and wealth, and *raise* taxes on environmentally harmful activities that produce pollution, wastes, and environmental degradation. Some 2,500 economists, including eight Nobel Prize winners in economics, have endorsed this *tax shifting* concept.

Proponents point out three requirements for successful implementation of green taxes. *First,* green taxes

Trade-Offs

Environmental Taxes and Fees

Advantages	Disadvantages
Help bring about full-cost pricing	Low-income groups are penalized unless safety nets are provided
Encourage businesses to develop environmentally beneficial technologies and goods to save money	Hard to determine optimal level for taxes and fees
Easily administered by existing tax agencies	Governments may use money as general revenue instead of improving environmental quality and reducing taxes on income, payroll, and profits

Figure 23-8 Using green taxes to help reduce pollution and resource waste has advantages and disadvantages. **Questions:** Which single advantage and which single disadvantage do you think are the most important? Why?

would have to be phased in over 10–20 years to allow businesses to plan for the future. *Second,* income, payroll, or other taxes would have to be reduced by the same amount as the green tax so that there would be no net increase in taxes. *Third,* the poor and lower-middle class would need a safety net to reduce the regressive nature of any new taxes on essentials such as fuel and food.

In Europe and the United States, polls indicate that once such tax shifting is explained to voters, 70% of them support the idea. Germany's green tax on fossil fuels, introduced in 1999, has reduced pollution and greenhouse gas emissions, helped to create up to 250,000 new jobs, lowered taxes on wages, and greatly increased use of renewable energy resources.

To help reduce carbon dioxide emissions, since 1997 Costa Rica has imposed a 3.5% tax on the market values of any fossil fuels that are burned in the country. The tax revenues go into a national forest fund to pay indigenous communities to help protect the forests around them and reverse deforestation, and to help them work their way out of poverty. The country has also taxed water use to reduce water waste and pollution, and the tax revenues are used to pay villagers living upstream to reduce their inputs of water pollutants.

The U.S. Congress has not enacted green taxes, mostly because politically powerful industries, including the automobile, fossil fuel, mining, and chemical industries, claim that such taxes will reduce their competitiveness and harm the economy by raising the prices of their goods and services. In addition, most voters have been conditioned to oppose any new taxes and have not been educated about the economic and environmental benefits of tax shifting.

HOW WOULD YOU VOTE?

Do you favor shifting taxes from wages and profits to pollution and waste? Cast your vote online at **www.cengage.com/login**.

Environmental Laws and Regulations Can Discourage or Encourage Innovation

Environmental regulation is a form of government intervention in the marketplace that is widely used to help control or prevent pollution and to reduce resource waste and environmental degradation. It involves enacting and enforcing laws that set pollution standards, regulate harmful activities such as the release of toxic chemicals into the environment, and protect certain irreplaceable or slowly replenished resources such as public forests from unsustainable use.

So far, most environmental regulation in the United States and many other more-developed countries has involved passing laws that are enforced through a *command and control* approach. Critics say that this strategy can unnecessarily increase costs and discourage innovation, because many of these regulations concentrate on enforcing cleanup instead of prevention. Some regulations also set compliance deadlines that are too short to allow companies to find innovative solutions to pollution and excessive resource use. They may also require the use of specific technologies where less costly but equally effective alternatives might be available.

A different approach favored by many economists as well as environmental and business leaders, is to use *incentive-based environmental regulations*. Rather than requiring all companies to follow the same fixed procedures or use the same technologies, this approach uses the economic forces of the marketplace to encourage businesses to be innovative in reducing pollution and resource waste. The experience of several European nations shows that *innovation-friendly environmental regulation* sets goals, frees industries to meet them in any way that works, and allows enough time for innovation. This can motivate companies to develop green products and industrial processes that create jobs. It can also increase company profits and make the companies more competitive in national and international markets.

For years, many companies generally fought against environmental regulation. But in recent years, a growing number of companies have realized the economic and competitive advantages of making environmental improvements. They now recognize that the value of their shareholders' investments depend in part on having a good environmental record. They also see that improvements to energy efficiency and resource conservation can save money and boost profits. In other words, environmental stewardship can be good for business. They also realize that if they do not produce a waste or pollutant, they can reduce government-mandated paperwork and avoid lawsuits by parties that might have suffered damage, had the pollutant been produced.

Use the Marketplace to Reduce Pollution and Resource Waste

In one incentive-based regulation system, the government decides on acceptable levels of total pollution or resource use, sets limits, or *caps*, to maintain these levels, and gives or sells companies a certain number of *tradable pollution* or *resource-use permits* governed by the caps.

With this *cap-and-trade* approach, a permit holder not using its entire allocation can save credits for future expansion, use them in other parts of its operation, or sell them to other companies. The United States has used this *cap-and-trade* approach to reduce the emissions of sulfur dioxide (see Chapter 18, pp. 486–487) and other air pollutants. Tradable rights can also be established among countries to help preserve biodiversity and to reduce emissions of greenhouse gases and other regional and global pollutants.

Figure 23-9 lists the advantages and disadvantages of using tradable pollution and resource-use permits. The effectiveness of such programs depends on how high or low the initial cap is set, and on the rate at which the cap is reduced to encourage further innovation.

Trade-Offs

Tradable Environmental Permits

Advantages	Disadvantages
Flexible	Big polluters and resource wasters can buy their way out
Easy to administer	May not reduce pollution at dirtiest plants
Encourage pollution prevention and waste reduction	Caps can be too high and not regularly reduced to promote progress
Permit prices determined by market transactions	Self-monitoring of emissions can allow cheating

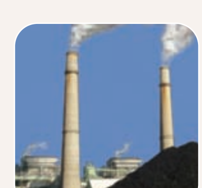


Figure 23-9 Using tradable pollution and resource-use permits to reduce pollution and resource waste has advantages and disadvantages. **Questions:** Which two advantages and which two disadvantages do you think are the most important? Why?

HOW WOULD YOU VOTE?

Do the advantages of using tradable permits to reduce pollution and resource waste outweigh the disadvantages? Cast your vote online at **www.cengage.com/login**.

Reduce Pollution and Resource Waste by Selling Services Instead of Things

In the mid-1980s, German chemist Michael Braungart and Swiss industry analyst Walter Stahel independently proposed a new economic model that would provide profits while greatly reducing resource use and waste for a number of goods. Their idea for more sustainable economies focuses on shifting from the current *material-flow economy* (Figure 23-4) to a *service-flow economy.* Instead of buying many goods outright, customers lease or rent the *services* that such goods provide. In a service-flow economy, a manufacturer makes more money if its product uses the minimum amount of materials, lasts as long as possible, is energy efficient, produces as little pollution (including greenhouse gases) and wastes as possible in its production and use, and is easy to maintain, repair, remanufacture, reuse, or recycle.

Such an economic shift is under way in some businesses. Since 1992, Xerox has been leasing most of its copy machines as part of its mission to provide *document services* instead of selling photocopiers. When a customer's service contract expires, Xerox takes the machine back for reuse or remanufacture. It has a goal of sending no material to landfills or incinerators. To save money, Xerox designs machines to have few parts,

INDIVIDUALS MATTER

GOOD NEWS

Ray Anderson

Ray Anderson (Figure 23-A) is the founder of Interface, a company based in Atlanta, Georgia (USA). The company is the world's largest commercial manufacturer of carpet tiles, with 26 factories in six countries, customers in 110 countries, and more than $1 billion in annual sales.

Anderson changed the way he viewed the world—and his business—after reading Paul Hawken's book *The Ecology of Commerce*. In 1994, he announced plans to develop the nation's first totally sustainable green corporation. Since then, he has implemented hundreds of projects with goals of producing zero waste, greatly reducing energy use, reducing fossil fuel use, relying on solar energy, and copying nature. Three of his goals are to have the company put back more into nature than it takes; to do good, not just to do no harm; and to influence other business leaders to adopt similar goals by providing a successful example. He agrees with Paul Hawken that business, as the world's most powerful institution, has an ethical obligation to help lead the world toward being more sustainable by using more sustainable business practices and product designs.

Observing that there is no material waste in nature, Anderson began the transition of his business with a focus on sharply cutting waste in his company. Within 16 years of setting this and other environmental goals, Interface had decreased water usage by 74%, cut its net greenhouse gas emissions by 94%, reduced solid waste by 63%, reduced fossil fuel use by 60%, and lowered energy use by 44%. The company also gets 27% of its total energy and 88% of its electricity from renewable resources. These efforts have saved the company more than $433 million.

Interface

Figure 23-A Ray Anderson is one of the world's most respected and effective leaders in making businesses more sustainable.

Anderson also sent his carpet design team into the forest and told them to learn how nature would design floor covering. What the team discovered is nature's biodiversity sustainability principle. They observed that there were no regular repeating patterns on the forest floor. Instead of order there was diversity and chaos. They came back and created a line of carpet tiles, no two of which had the same design. Within 18 months after it was introduced, this new product line was the company's top-selling design. Buyers like it because it seems to bring nature indoors. Similar product lines based on the diversity principle now make up 52% of the company's sales.

In implementing nature's biodiversity principle of sustainability, the company has also applied nature's chemical cycling, or no-waste, sustainability principle. The tiles are made from recycled fibers, and because the random design tiles do not have to look alike and can be taken out of a box and laid down randomly, there is no need for large orders of one style, some of which are usually wasted. Also, the carpet tile factory runs partly on solar energy, thus applying another of nature's sustainability principles. In addition, the company invented a new carpet recycling process that does not emit carbon dioxide to the atmosphere.

To help achieve its goal of zero waste, Interface plans to stop selling carpet and to lease it. The company will install, clean, and inspect the carpet on a monthly basis, repair or replace worn carpet tiles overnight, and recycle worn-out tiles into new carpeting.

Anderson is one of a growing number of business leaders committed to finding more economically and ecologically sustainable, yet profitable, ways to do business. Sales have increased to $1 billion, making Interface the world's largest seller of carpet tiles, and profits have tripled. Anderson has also created a new consulting group as part of Interface to help other businesses start on the path toward being more sustainable. He believes that businesses can and should practice environmental stewardship and social responsibility in order to benefit their profit margins, as well as people and the planet. He argues that businesses should use head and heart to guide their journey toward environmental sustainability.

be energy efficient, and emit as little noise, heat, ozone, and chemical waste as possible. Canon in Japan and Fiat in Italy are taking similar measures.

In Europe, Carrier has begun shifting from selling heating and air conditioning equipment to providing a service to customers that gives them the indoor temperatures they want. It makes higher profits by leasing and installing energy-efficient heating and air conditioning equipment that lasts as long as possible and is easily rebuilt or recycled. Carrier also makes money helping clients to save energy by adding insulation, eliminating heat losses, and boosting energy efficiency in offices and homes. Ray Anderson, CEO of a large carpet tile company, plans to lease rather than sell carpet to his customers (Individuals Matter, at left).

THINKING ABOUT
Selling Services

Do you favor a shift in some cases from selling goods to selling the services that the goods provide? List three services that you would be willing to lease.

23-4 How Can Reducing Poverty Help Us to Deal with Environmental Problems?

▶ **CONCEPT 23-4 Reducing poverty can help us to reduce population growth, resource use, and environmental degradation.**

The Gap between the Rich and the Poor Is Getting Wider

According to the World Bank and the United Nations, 1.4 billion people—a number greater than the entire population of China and 4.5 times the size of the U.S. population—struggle to survive on an income equivalent to less than $1.25 a day (Figure 23-10).

Poverty has numerous harmful health and environmental effects. Reducing poverty benefits individuals, economies, and the environment, while empowering women and helping to slow population growth (**Core Case Study** and **Concept 23-4**).

CORE CASE STUDY

Most neoclassical economists believe that a growing economy can help the poor by creating more jobs and providing greater tax revenues, which can be

Ron Giling/Peter Arnold, Inc.

Figure 23-10 This mother and her child live in poverty on the edges of Mumbai (formerly Bombay), India, a thriving urban center.

used to help the poor to help themselves. This economic process is often referred to as the *trickle-down effect*. However, since 1960, most of the benefits of global economic growth, as measured by income, have been *flooding up* to the rich, rather than trickling down to workers at the bottom of the economic ladder.

Since 1980, this *wealth gap* between the rich and the poor has grown. In 2005, the United Nations calculated that the world's 500 richest people earned more than the world's 416 million poorest people. South African President Thabo Mbeki told delegates at the 2003 Johannesburg World Summit on Sustainable Development, "A global human society based on poverty for many and prosperity for a few, characterized by islands of wealth, surrounded by a sea of poverty, is unsustainable."

We Can Reduce Poverty

GOOD NEWS

Some nations have climbed out of abject poverty within a short period of time. For example, South Korea and Singapore made the journey from being poor, less-developed nations to becoming world-class industrial powers in only two decades. They did this by focusing on education, hard work, and discipline, all of which attracted investment capital. China and India are on a similar path. For example, between 1990 and 2007, the estimated number of people living in extreme poverty in China dropped from 685 million to 213 million.

Analysts point out that reducing poverty will require the governments of most of the less-developed countries to make policy changes. This will have to include emphasizing education to develop a trained workforce that can participate in an increasingly globalized economy.

To assist in this process, governments, businesses, international lending agencies, and wealthy individuals in more-developed countries could also undertake these measures:

- Mount a massive global effort to combat malnutrition and the infectious diseases that kill millions of people prematurely (see Figure 17-16, p. 458, and Figure 17-17, p. 459).
- Provide universal primary school education for the world's nearly 800 million illiterate adults (a number that is 2.5 times the size of the U.S. population). According to Nobel Prize–winning economist Amartya Sen, "Illiteracy and innumeracy are a greater threat to humanity than terrorism." Illiteracy can also foster terrorism and strife within countries by creating large numbers of unemployed individuals who have little hope of improving their lives or those of their children.
- Provide assistance to stabilize population growth in less-developed countries as soon as possible, mostly by investing in family planning, reducing poverty, and elevating the social and economic status of women.
- Focus on sharply reducing the total and per capita ecological footprints of their own countries as well as those of rapidly growing less-developed countries such as China and India (see Figure 1-13, p. 16).
- Make large investments in small-scale infrastructure such as solar-cell power facilities in villages (see Figure 16-19, p. 413), as well as sustainable agriculture projects that would enable less-developed nations to work towards more energy-efficient and sustainable economies.
- Encourage lending agencies to make small loans to poor people who want to increase their income (**Core Case Study**).

CORE CASE STUDY

In 2007, the World Bank reported that all regions of the less-developed world, with the notable exception of sub-Saharan Africa, were on track to cut in half their numbers of people living in poverty by 2015.

GOOD NEWS

Revisiting Microlending

Microlending gives hope to the poor. Studies show that small loans can motivate recipients and help them to improve their lives much more than outright gifts of money can.

For example, within 5 years of getting a loan, about half of the Grameen Bank's microborrowers (**Core Case Study**) move above the poverty line and improve their lives. Between 1975 and 2005, the Grameen Bank's innovative approach helped to reduce the poverty rate in Bangladesh from 74% to 40%, mostly because of the hard work of the people receiving the microloans. In addition, birth rates are lower among most of the borrowers, a majority of whom are women, and as a result, they gain more freedom and control over their lives.

CORE CASE STUDY

With a microloan, an individual in India could buy a bicycle that he or she could use to gather and sell paper and other materials for recycling. Families in rural areas could use a microloan to buy a solar cell panel so they could have electricity for use in their homes or in small businesses (Figure 23-11). Villagers could join together and borrow money to install a community water pump or to set up a village solar-cell electrical system.

Microlending is spreading around the world. The downside is that loan sharks have gotten into the game, taking advantage of some poor people in Mexico and Nigeria by making small loans with interest rates and fees of up to 70%. But in 2004, two Stanford University graduates, Matt Flannery and Premal Shah, set up a nonprofit Internet site, **kiva.org**, where individuals from around the world who need small loans can connect with investors and entrepreneurs who have money to loan. Prospective borrowers post photos of themselves along with their stories and a business plan showing how they would use a small loan.

National Renewable Energy Laboratory

Figure 23-11 A microloan helped these women in a rural village in India to buy a small solar-cell panel (installed on the roof behind them) that provides electricity to help them make a living, thus applying the solar energy sustainability principle.

Achieve the World's Millennium Development Goals

In 2000, the world's nations set goals—called Millennium Development Goals—for sharply reducing hunger and poverty, improving health care, achieving universal primary education, empowering women, and moving toward environmental sustainability by 2015. More-developed countries pledged to donate 0.7% of their annual national income to less-developed countries to help them in achieving these goals. But by 2009, only five countries—Denmark, Luxembourg, Sweden, Norway, and the Netherlands—had donated what they had promised.

In fact, the average amount donated in most years has been 0.25% of national income. The United States—the world's richest country—gives only 0.16% of its national income to help poor countries and Japan, another wealthy country, gives only 0.18%, compared with the 0.9% given by Sweden. For any country, deciding whether or not to commit 0.7% of annual national income toward the Millennium Development Goals is an ethical issue that requires individuals and nations to evaluate their priorities (Figure 23-12).

THINKING ABOUT
The Millennium Development Goals

Do you think the country where you live should devote 0.7% of its annual national income toward achieving the Millennium Development goals? Explain.

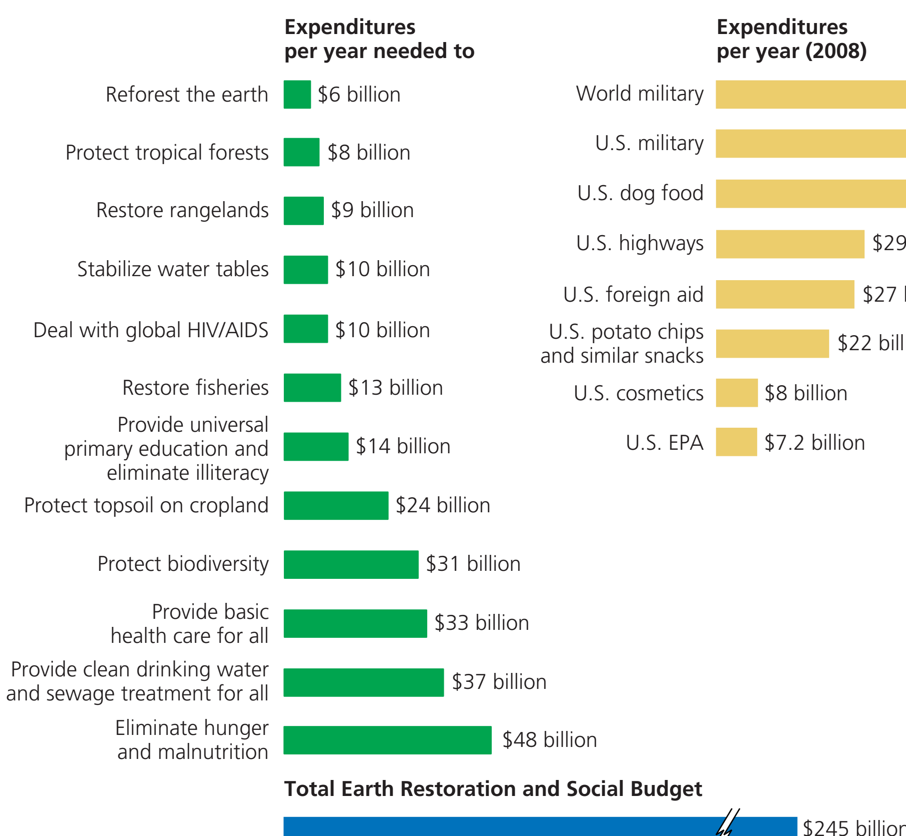


Figure 23-12 What should our priorities be? **Question:** Which item on the right side of the figure would you do without or reduce to pay for solving some of the problems listed on the left side of the figure? (Data from United Nations, World Health Organization, U.S. Department of Commerce, U.S. Office of Management and Budget, World Bank, Earth Policy Institute, and Stockholm International Peace Research Institute)

23-5 How Can We Make the Transition to More Environmentally Sustainable Economies?

▶ **CONCEPT 23-5 We can use the three principles of sustainability as well as various economic and environmental strategies to develop more environmentally sustainable economies.**

We Are Living Unsustainably

What might happen if growing populations continue to use and waste more energy and matter resources at an increasing rate in today's high-throughput economies (Figure 23-4)? The law of conservation of matter (see Chapter 2, p. 43) and the two laws of thermodynamics (see Chapter 2, p. 47) tell us that eventually, this resource consumption and waste will exceed the capacity of the environment to sufficiently renew those resources, to dilute and degrade waste matter, and to absorb waste heat. Indeed, according to some estimates our ecological footprints are already using the renewable resources of 1.4 planet Earths and probably will be using that of two planet Earths by 2050 (see Figure 1-13, p. 16).

In other words, we are living unsustainably and depleting the earth's natural capital. No one knows how long we can continue on this path, but environmental alarm bells are going off.

A temporary solution to this problem is to convert our linear throughput economy into a circular **matter recycling and reuse economy**. Such an economy mimics nature by recycling and reusing most matter outputs instead of dumping them into the environment. This involves applying the chemical recycling **principle of sustainability**.

Although changing to a matter recycling and reuse economy would buy some time, it would not allow ever more people to use ever more resources indefinitely, even if all matter resources were somehow perfectly recycled and reused. The two laws of thermodynamics tell us that recycling and reusing material resources always requires using high-quality energy (which cannot be recycled) and adds waste heat and various pollutants to the environment.

Use Lessons from Nature to Shift to More Sustainable Economies

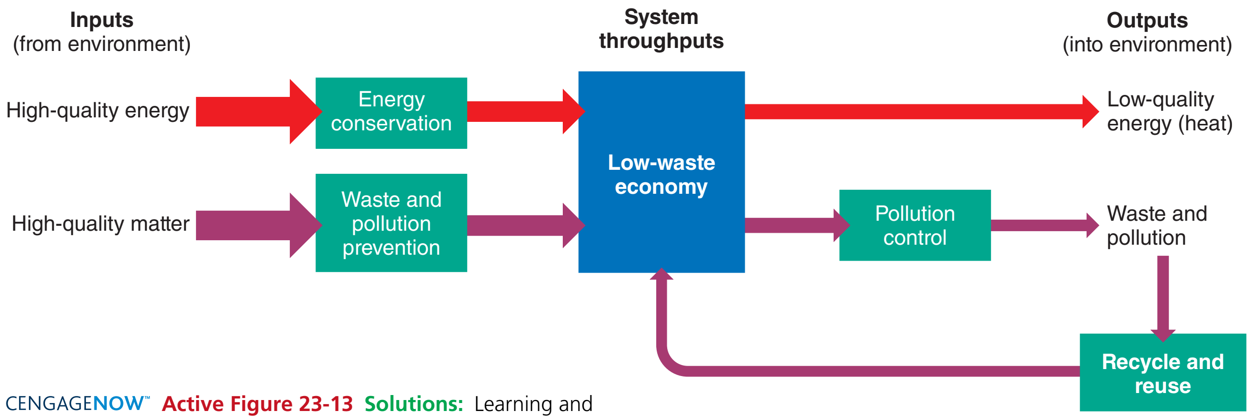
In this chapter, we have seen a sharp contrast between the beliefs of neoclassical economists and those of ecological economists. In 2001, environmental scientist Donella Meadows contrasted these two views as follows:

- The first commandment of economics is: Grow. Grow forever. The first commandment of the Earth is: Enough. Just so much and no more.
- Economics says: Compete. The Earth says: Compete, yes, but keep your competition in bounds. Don't annihilate. Take only what you need. Leave your competitor enough to live. Wherever possible, don't compete, cooperate.
- Economics says: Use it up fast. Don't bother with repair; the sooner something wears out, the sooner you'll buy another. This makes the gross national product go round. Throw things out when you get tired of them. Get the oil out of the ground and burn it now. The earth says: What's the hurry? When something wears out, don't discard it, turn it into food for something else.
- Economics discounts the future. Take your profits from a resource such as a forest now. The earth says: Nonsense. Give to the future. Never take more in your generation than you give back to the next.
- The economic rule is: Do whatever makes sense in monetary terms. The Earth says: Money measures nothing more than the relative power of some humans over other humans, and that power is puny compared with the power of the climate, the oceans, the uncounted multitudes of one-celled organisms that created the atmosphere, that recycle the waste, and that have lasted for 3 billion years. The fact that the economy, which has lasted about 200 years, puts zero values on these things means that the economy knows nothing about value—or lasting.

As environmental expert Lester R. Brown observes, "It is decision time. Like earlier civilizations that got into environmental trouble, we can decide to stay with business as usual and watch our modern economy decline and eventually collapse, or we can consciously move onto a new path, one that will sustain economic progress."

The three scientific laws governing matter and energy changes and the three **principles of sustainability** (see back cover) suggest that the best long-term solution to our environmental and resource problems is to shift from a high-throughput (high-waste) economy based on ever-increasing matter and energy flow (Figure 23-4) to a more sustainable **low-throughput (low-waste) economy**, as summarized in Figure 23-13. In other words, we can live more sustainably by controlling human population growth, greatly reducing poverty, using and wasting

GOOD NEWS



CENGAGENOW™ **Active Figure 23-13** **Solutions:** Learning and applying lessons from nature can help us design and manage more sustainable economies. A *low-throughput economy*, based on energy flow and matter recycling, works with nature to reduce excessive throughput and the unnecessary waste of matter and energy resources (green boxes). This is done by **(1)** reusing and recycling most nonrenewable matter resources; **(2)** using renewable resources no faster than they are replenished; **(3)** reducing resource waste by using matter and energy resources more efficiently; **(4)** reducing unnecessary and environmentally harmful forms of consumption; **(5)** emphasizing pollution prevention and waste reduction; and **(6)** controlling population growth to stabilize the number of matter and energy consumers. *See an animation based on this figure at* CengageNOW. **Question:** What are three ways in which your school could decrease its unsustainable economic and environmental practices, and three ways that it could promote more sustainable economic and environmental practices?

less matter and energy resources, and reusing, recycling, or composting most matter resources. In making such an economic shift we need to distinguish between actions that *decrease unsustainability* and those that *increase sustainability*, as shown in Figure 23-14. While we need to take both types of action, only the second type provides sustainability.

CENGAGENOW™ Compare how energy is used in high- and low-throughput economies at CengageNow.

Make Money and Create Jobs by Shifting to an Eco-Economy

Figure 23-14 summarizes suggestions by Paul Hawken, Lester R. Brown, and other environmental and business leaders for using the economic tools discussed in this chapter to make the transition to more environmentally sustainable economies over the next several decades. Such strategies would also apply the three **principles of sustainability** (see back cover). Hawken has a simple golden rule for such an economy: *"Leave the world better than you found it, take no more than you need, try not to harm life or the environment, and make amends if you do."* Figure 23-15 (p. 632) shows some of the components of societies that have more sustainable economic systems.

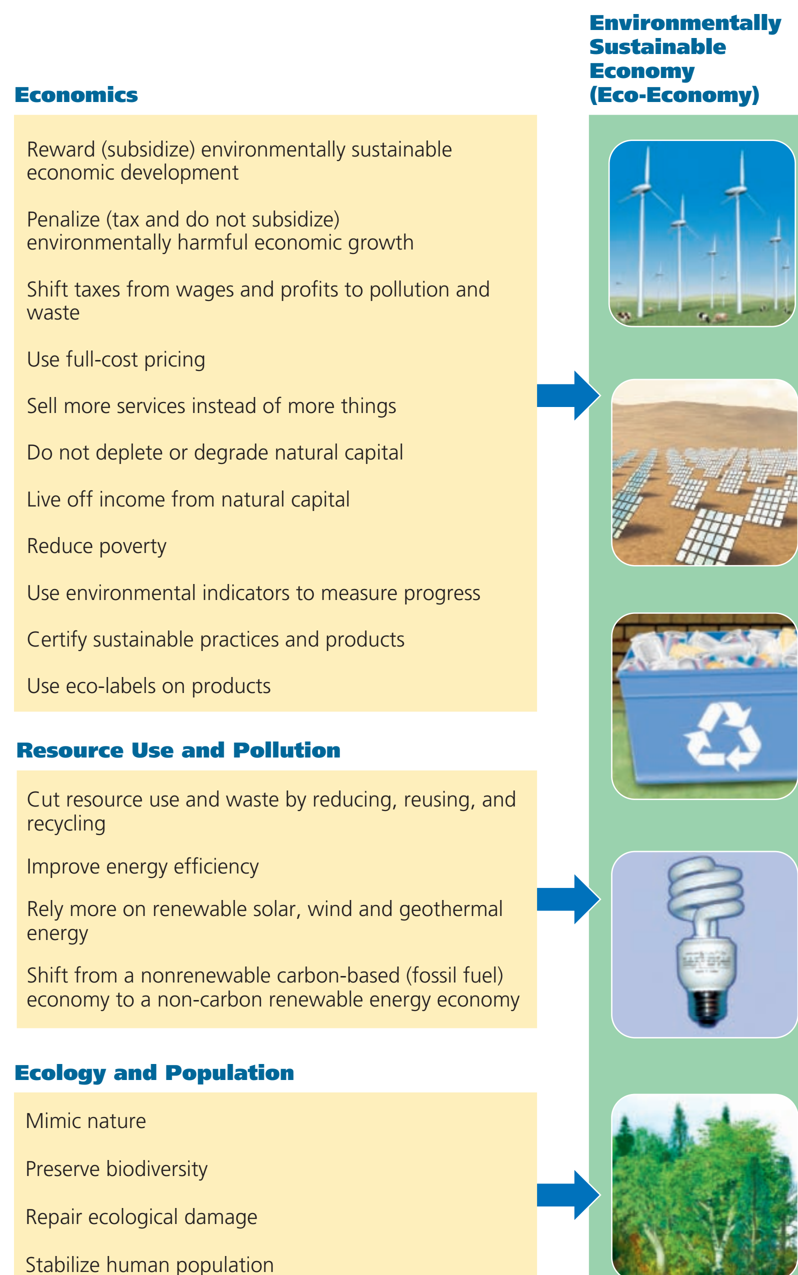


Figure 23-14 **Solutions:** We can use certain principles for shifting to more environmentally sustainable economies, or *eco-economies*, during this century. **Question:** Which five of these solutions do you think are the most important?

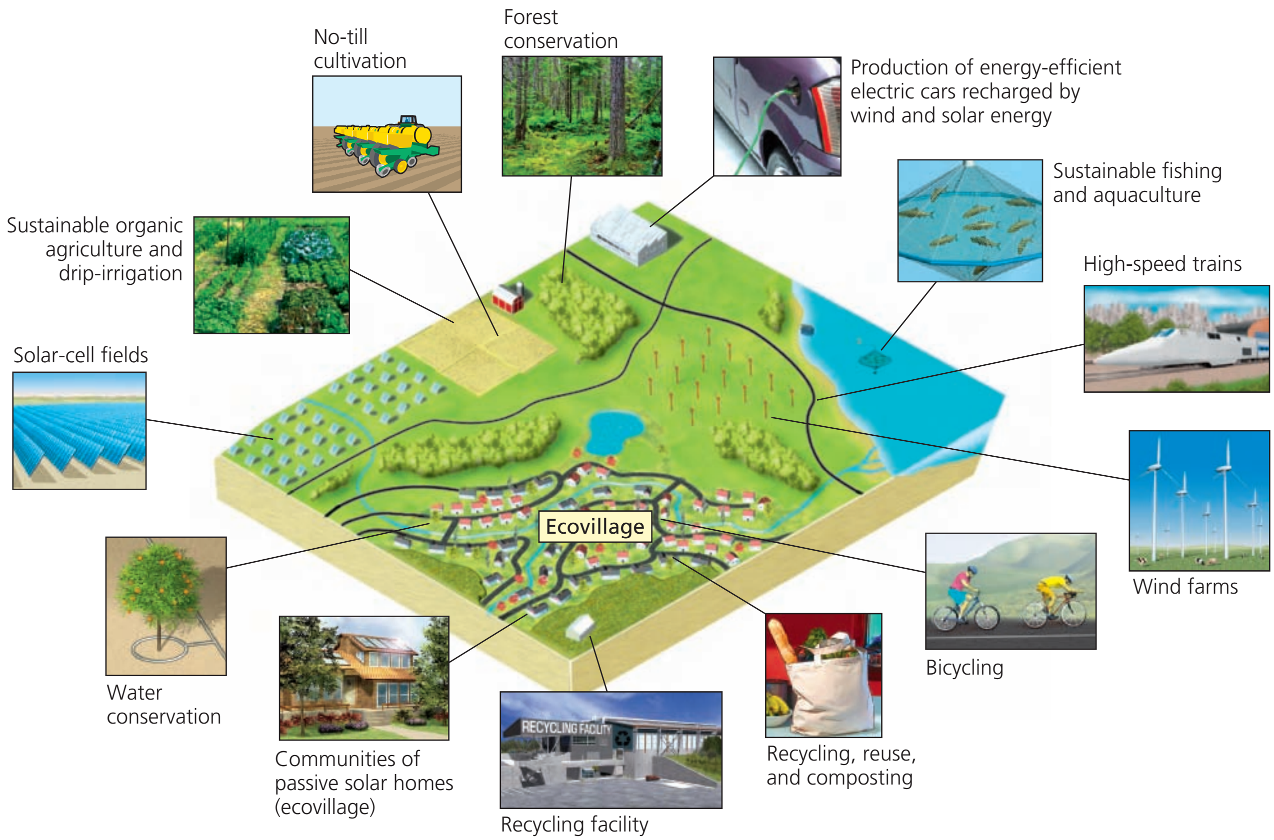


Figure 23-15 **Solutions:** These are some of the components of more environmentally sustainable economic development favored by ecological and environmental economists. The goal is to get economic systems to put more emphasis on conserving and sustaining the air, water, soil, biodiversity, and other natural resources that in turn sustain all life and all economies. Such a shift toward more efficient resource use, cleaner energy, cleaner production, ecocities, and natural capital preservation can stimulate economies, create jobs, and be profitable. **Question:** What are three new types of jobs that could be generated by such an economy?

In making the shift to eco-economies, some industries and businesses will disappear or remake themselves, and new ones will appear—a normal process in a dynamic and creative capitalist economy. *Ecological succession* occurs when changes in environmental conditions enable certain species to move into an area and replace other species that are no longer favored by the changing environmental conditions (see Figure 5-20, p. 120). By analogy, *economic succession* in a dynamic capitalist economy occurs as new and more innovative businesses replace older ones that can no longer thrive under changing economic conditions.

When environmental conditions change, species and ecosystems that cannot adapt disappear. Nature does not subsidize them or prop them up. This is one of the ways in which a rich and changing diversity of species and habitats have survived for billions of years. In other words, failure is an opportunity for innovation in nature. Some economists and environmental scientists call for us to apply this lesson from nature to our own societies as we struggle to make the transition toward environmental and economic sustainability.

Improving environmental quality and striving for environmental sustainability is now a major growth industry. It is creating profits and large numbers of new *green jobs* (Figure 23-16). Examples of such jobs include those devoted to developing efficient batteries, retrofitting homes and other buildings with insulation and energy-efficient windows, modernizing the electrical grid system, and developing low-carbon renewable energy resources such as solar power (Figure 23-17).

GOOD NEWS

THINKING ABOUT
Green Careers

Are there any green careers listed in Figure 23-17 that interest you?

Making the shift to more sustainable economies will require governments and industries to greatly increase their spending on research and development—especially in environmental, energy-efficiency, and renewable-energy areas—and on scientific and engineering education. Educational institutions around the world can also play a key role in making the transition to more sustainable economies by giving all students a basic environmental education and developing business

Environmentally Sustainable Businesses and Careers




- Aquaculture
- Biodiversity protection
- Biofuels
- Climate change research
- Conservation biology
- Ecotourism management
- Energy-efficient product design
- Environmental chemistry
- Environmental design and architecture
- Environmental economics
- Environmental education
- Environmental engineering
- Environmental entrepreneur
- Environmental health
- Environmental law
- Environmental nanotechnology
- Fuel cell technology
- Geographic information systems (GIS)
- Geothermal geologist
- Hydrogen energy
- Hydrologist
- Marine science
- Pollution prevention
- Recycling and reuse
- Selling services in place of products
- Solar cell technology
- Sustainable agriculture
- Sustainable forestry
- Urban gardening
- Urban planning
- Waste reduction
- Watershed hydrologist
- Water conservation
- Wind energy

Figure 23-16 **Green careers:** Some key environmental businesses and careers are expected to flourish during this century, while environmentally harmful, or *sunset*, businesses are expected to decline. See the website for this book for more information on various environmental careers. **Question:** How could some of these careers help you to apply the three principles of sustainability?

schools that integrate sustainable business planning and management into their curricula. Maybe the next phase of your environmental science education lies in one of these areas.

Here are this chapter's *three big ideas:*

- Making a transition to more sustainable economies will require finding ways to estimate and include the harmful environmental and health costs of producing goods and services in their market prices.
- Making this economic transition will also mean phasing out environmentally harmful subsidies and tax breaks, and replacing them with environmentally beneficial subsidies and tax breaks.
- Other tools to use in this transition are to tax pollution and wastes instead of wages and profits, and to use most of the revenues from these taxes to promote environmental sustainability and to reduce poverty.

National Energy Renewable Laboratory

Figure 23-17 Selling and installing solar-cell systems is a rapidly growing business and a source of many new green jobs in the United States and in many other countries.

REVISITING Muhammad Yunus, Microloans, and Sustainability

The case study that opens this chapter shows how Muhammad Yunus used capitalism to provide small loans for poor individuals to help them work their way out of poverty. This immensely successful and rapidly spreading form of lending also promotes sustainability by improving environmental quality and reducing population growth.

On a larger scale, shifting to eco-economies by applying the three **principles of sustainability** and using the principles listed in Figure 23-14 over the next several decades will result in a new reduce-reuse-recycle economy (Figure 23-15) powered by a diversity of solar and other renewable energy resources. This new economy will also have a diverse transportation system that relies more on rail, buses, and bicycles, and less on cars. Slowing population growth will also help to reduce the consumption of environmentally harmful goods and services.

According to environmental and ecological economists, a key to accomplishing these goals is to create an honest marketplace based on full-cost pricing that tells the ecological truth about how our goods and services are produced and delivered. This will allow consumers to make better-informed choices about what they buy.

Making this shift will require bold leadership by business leaders and elected officials. It will also require bottom-up political pressure from informed and concerned citizens who vote at the polls as well as with their wallets by refusing to buy environmentally harmful goods and services. Forward-looking investors, corporate executives, and political leaders are recognizing that sustainability is good for the environment and good for business.

We have an economy that tells us that it is cheaper to degrade our life support system than to renew, restore, and sustain it. . . .Working for the earth is not a way to get rich, it is a way to be rich.

PAUL HAWKEN

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 614. Describe the nature and importance of microlending in helping people to work their way out of poverty (**Core Case Study**). Explain why the sustainability revolution is also an economic revolution.

2. What is an **economic system**? Distinguish among **natural capital**, **human capital (human resources)**, and **manufactured capital (manufactured resources)**. Describe the interactions between supply, demand, and market prices in a market economic system.

3. Define **economic growth**, **economic development**, and **environmentally sustainable economic development**. Compare how neoclassical economists and ecological and environmental economists view economic systems. What is a **high-throughput economy**? What three assumptions do ecological economists use to build models of economic systems?

4. Describe ways in which economists estimate the economic values of natural goods and services. Why are such values not included in the market prices of goods and services? Define **discount rate** and discuss the controversy over how to assign such rates. Describe how economists can estimate the optimal levels for pollution control and resource use. Define **cost-benefit analysis** and discuss its advantages and limitations.

5. Why do products and services cost more than most people think? Distinguish between direct (internal) and indirect (external) costs of goods and services and give an example of each that is related to a specific product. What is full-cost pricing and what are some benefits of using it to determine the market values of goods and services? Give three reasons why it is not widely used.

6. Define **gross domestic product (GDP)** and **per capita GDP**. What is the **genuine progress indicator (GPI)** and how does it differ from the gross domestic product economic indicator? What are the advantages of providing consumers with eco-labels on the goods and services they buy? What is **greenwashing**? Give an example of it.

7. Describe the benefits of shifting from environmentally harmful (unsustainable) to more environmentally beneficial (sustainable) government subsidies and tax breaks. Give three examples of environmentally harmful and three examples of environmentally beneficial government subsidies and tax breaks. What is the major reason that

environmentally harmful subsidies have not been phased out? Should we tax pollution and wastes instead of wages and profits? Explain. What are the major advantages and disadvantages of using green taxes? What are three requirements for implementing green taxes? Distinguish between command-and-control and incentive-based government regulations, and describe the advantages of the second approach. What is the cap-and-trade approach to implementing environmental regulation, and what are the major advantages and disadvantages of this approach?

8. What are some environmental benefits of selling services instead of goods? Give two examples of this approach. Describe Ray Anderson's attempts to develop a more environmentally sustainable carpet business.

9. How is poverty related to population growth and environmental degradation? List three ways in which governments can help to reduce poverty. What are the advantages of making microloans to the poor? What are millennium development goals and what role should more-developed countries play in helping the world achieve these goals? What is a **matter recycling and reuse economy**? What is a **low-throughput (low-waste) economy**? List six ways to shift to more environmentally sustainable economies. Name five new businesses and careers that would be important in such eco-economies.

10. What are this chapter's *three big ideas*? Describe connections between microloans, more environmentally sustainable economies, and the three **principles of sustainability**.

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. Describe the microloan program developed by Muhammad Yunus (**Core Case Study**) and explain why it is important, giving at least three major reasons.

2. Should we attempt to maximize economic growth by producing and consuming more and more economic goods and services? Explain. What are the alternatives?

3. According to one definition, *sustainable economic development* involves meeting the needs of the present human generation without compromising the ability of future generations to meet their needs. What do you believe are the needs referred to in this definition? Compare this definition with the characteristics of a low-throughput economy described in Figure 23-13.

4. Is environmental regulation bad for the economy? Explain. Describe harmful and beneficial forms of environmental regulation.

5. Suppose that over the next 20 years, the environmental and health costs of goods and services are internalized until their market prices more closely reflect their total costs. What harmful effects and what beneficial effects might such full-cost pricing have on your lifestyle and on the lives of any children, grandchildren, and great grandchildren you might have?

6. Explain why reducing poverty should be a major environmental goal. List three ways in which reducing poverty could benefit you. Why do you think the world has not focused more intense efforts on reducing poverty?

7. Are you for or against shifting to a *service-flow economy* based on buying services instead of things, and on leasing instead of buying various services? Explain. If you are for such a shift, what do you think are the three most important strategies for making it happen? If you are opposed, what are your main objections to the idea?

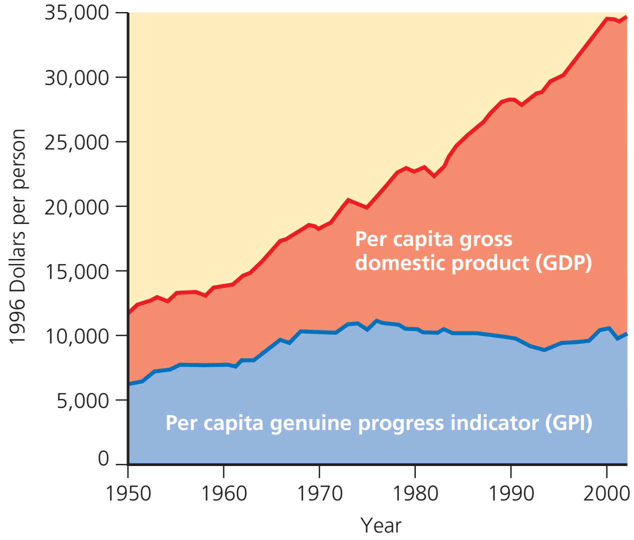
8. Explain why you agree or disagree with each of the major principles for shifting to a more environmentally sustainable economy listed in Figure 23-14. Which three of these principles do you believe are the most important and why?

9. Congratulations! You are in charge of the world. List your five most important strategies for shifting to eco-economies over the next 50 years.

10. List two questions that you would like to have answered as a result of reading this chapter.

DATA ANALYSIS

Figure 1 Comparison of per capita gross domestic product (GDP) and per capita genuine progress indicator (GPI) in the United States.



1. What was the monetary difference between per capita GDP and per capita GPI in **(a)** 1950 and **(b)** 2004?
2. **(a)** By what percentage did the per capita GDP increase between 1950 and 1975, and between 1975 and 2004? **(b)** By what percentage did the per capita GPI increase between 1950 and 1975, and decrease between 1975 and 2004?
3. What conclusion can you draw from the answers to questions 1 and 2?

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengagebrain.com/shop/ISBN/0538735341** and choose Chapter 23 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

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Politics, Environment, and Sustainability

24

Denis Hayes—A Practical Environmental Visionary

CORE CASE STUDY

As a college student, Denis Hayes (Figure 24-1) took some time to explore the world on foot. He had studied ecology and political science in college, and one day he grabbed his backpack, filled it with books, and started traveling to see "what was actually going on" in the countries he had studied.

One night while hitch-hiking in Africa, he rested on a hillside and started to put together what he had learned and what he had seen. He thought about how the principles of ecology apply to everything from amoeba to orangutans. Sometime shortly after that, Hayes decided to spend his life figuring out how human societies could benefit from organizing themselves around ecological principles. He has said: "Pretty much from birth, I had an awareness of that awesome natural beauty being torn apart by industrial processes."

Denis Hayes is currently president and CEO of The Bullitt Foundation of Seattle, Washington (USA). The foundation seeks to deal with key environmental problems in the U.S. Pacific Northwest by focusing on urban ecological issues and on restoring and protecting ecosystem services in the surrounding environment. It also seeks to harness the entrepreneurial power of business to create competitive industries that are based on ecological principles and sustainable technologies. Hayes's goal is to use the resources of the foundation to help make the U.S. Pacific Northwest a global model for more sustainable development.

Courtesy of Denis Hayes/The Bullitt Foundation

Figure 24-1 Denis Hayes has focused his energy on helping people to pay more attention to ecological principles in deciding what policies they support and in taking political action to support sustainability. He has received numerous awards, including the Jefferson Medal for Outstanding Public Service and the highest awards given by the Sierra Club, the Humane Society of the United States, and the Global Environmental Facility of the World Bank. In 2008, the Audubon Society listed him as one of the 100 Environmental Heroes of the Twentieth Century.

At age 25, Hayes was enrolled in the Kennedy School of Government at Harvard University in Cambridge, Massachusetts (USA), at the same time that Senator Gaylord Nelson of the state of Wisconsin was organizing environmental teach-ins on college campuses. Hayes approached Nelson about organizing such an event at Harvard, and later the senator asked Hayes to organize an event for the whole country.

What started out as a plan for a number of teach-ins became Earth Day—April 22, 1970—thought of by many analysts as the beginnning of the modern environmental movement. That day involved teach-ins and much more—thousands of public demonstrations focused on pollution, toxic waste, nuclear power, coal mining, lead contamination, and other urgent environmental issues. More than 20 million people took part. Later, Hayes worked on building the Earth Day Network, which now includes more than 180 nations. As a result, each year, Earth Day is now celebrated globally.

Hayes has held an incredible variety of important environmental positions. Since the first Earth Day, he has worked as an environmental lobbyist, a member of an interdisciplinary research organization, a researcher for the Worldwatch Institute, the head of the U.S. Solar Energy Research Institute, a professor of energy and resource studies at the University of California at Santa Cruz, and director of the Illinois State Energy Office. He helped to found Green Seal, one of the most respected eco-labeling programs, and has won many national and international awards (Figure 24-1).

In terms of lessons learned, Hayes has this to say about one of the most important ones: "Democracy works when people are paying attention to the facts. . . . Earth Day, once we got people to focus their attention on the issues, produced a tidal wave of public support for smart, cost-effective legislation that dramatically improved the environment." Denis Hayes is a person who has made, and is still making, a difference.

In this chapter, we look at how politics can have harmful and beneficial effects on the environment. We examine how politics and environmental science interact. And we consider how any and all of us can make a difference by becoming involved in these processes.

Key Questions and Concepts

24-1 What is the role of government in making the transition to more sustainable societies?

CONCEPT 24-1 Through its policies, a government can help to protect environmental and public interests, and to encourage more environmentally sustainable economic development.

24-2 How is environmental policy made?

CONCEPT 24-2A Policy making involves enacting laws, funding programs, writing rules, and enforcing those rules with government oversight—a complex process that is affected at each stage by political processes.

CONCEPT 24-2B Individuals can work together to become part of political processes that influence how environmental policies are made and whether or not they succeed. (*Individuals matter.*)

24-3 What is the role of environmental law in dealing with environmental problems?

CONCEPT 24-3 We can use environmental laws and regulations to help control pollution, set safety standards, encourage resource conservation, and protect species and ecosystems.

24-4 What are the major roles of environmental groups?

CONCEPT 24-4 Grassroots groups are growing and combining their efforts with those of large environmental organizations in a global sustainability movement.

24-5 How can we improve global environmental security?

CONCEPT 24-5 Environmental security is necessary for economic security and is at least as important as national security.

24-6 How can we implement more sustainable and just environmental policies?

CONCEPT 24-6 Making the transition to more sustainable societies will require that nations and groups within nations cooperate and make the political commitment to achieve this transition.

Note: Supplements 2 (p. S3), 3 (p. S6), and 8 (p. S30) can be used with this chapter.

You see things, and you say "Why?"
But I dream things that never were; and I say "Why not?"
GEORGE BERNARD SHAW

24-1 What Is the Role of Government in Making the Transition to More Sustainable Societies?

▶ **CONCEPT 24-1 Through its policies, a government can help to protect environmental and public interests, and to encourage more environmentally sustainable economic development.**

Government Can Serve Environmental and Other Public Interests

Business and industry thrive on change and innovations that lead to new technologies, products, and opportunities for profits. This process, often referred to as *free enterprise*, can lead to higher living standards for many people, but it can also create harmful impacts on other people and on the environment.

Government on the other hand, especially democratic government working in the interest of the public, can act as a brake on business enterprises that might result in harm to people or to the environment. Achieving the right balance between free enterprise and government regulation is not easy. Too much government intervention can strangle enterprise and innovation. Too little can lead to environmental degradation and social injustices, and even to a weakening of the government by business interests and global trade policies. **Explore More:** See a Case Study at **www.cengage.com/login** to learn about global trade and the environment.

Analysts point out that in today's global economy, some multinational corporations, which often have budgets larger than the budgets of many countries, have greatly increased their economic and political power

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. GOOD NEWS refers to good news about the environmental challenges we face.

over national, state, and local governments, and ordinary citizens. However, businesses can also serve environmental and public interests. Green businesses create products and services that help to sustain or improve environmental quality while improving people's lives. They make up one of the world's fastest growing business sectors and are an increasing source of new jobs.

Many argue that government is the best mechanism for dealing with some of the broader economic and political issues we face, some of which we have discussed in this book. These include:

- *Full-cost pricing* (see Chapter 23, pp. 622–623): governments can provide subsidies and levy taxes that have the effect of adding harmful environmental and health costs to the market prices of some goods and services.
- *Market failures* (see Chapter 23, p. 616): governments can use taxes and subsidies to level the playing field wherever the marketplace is not operating freely due to unfair advantages held by some players.
- *The tragedy of the commons:* government is the only power that can preserve common or open-access renewable resources (see Chapter 1, p. 15) such as clean air and groundwater, and the ozone layer in the stratosphere. This is also the case in a cap-and-trade market approach to solving a problem such as air pollution (see Chapter 18, pp. 486–487), because government oversight is necessary to administer such a program.

The roles played by a government are determined by its **policies**—the set of laws and regulations it enacts and enforces, and the programs it funds (**Concept 24-1**). **Politics** is the process by which individuals and groups try to influence or control the policies and actions of governments at local, state, national, and international levels. One important application of this process is the development of **environmental policy—**environmental laws and regulations that are designed, implemented, and enforced, and environmental programs that are funded by one or more government agencies.

According to social scientists, the development of public policy in democracies often goes through a *policy life cycle* consisting of four stages illustrated in Figure 24-2. This figure also shows the general positions of some major environmental problems in the policy life cycle in the United States and most other more-developed countries.

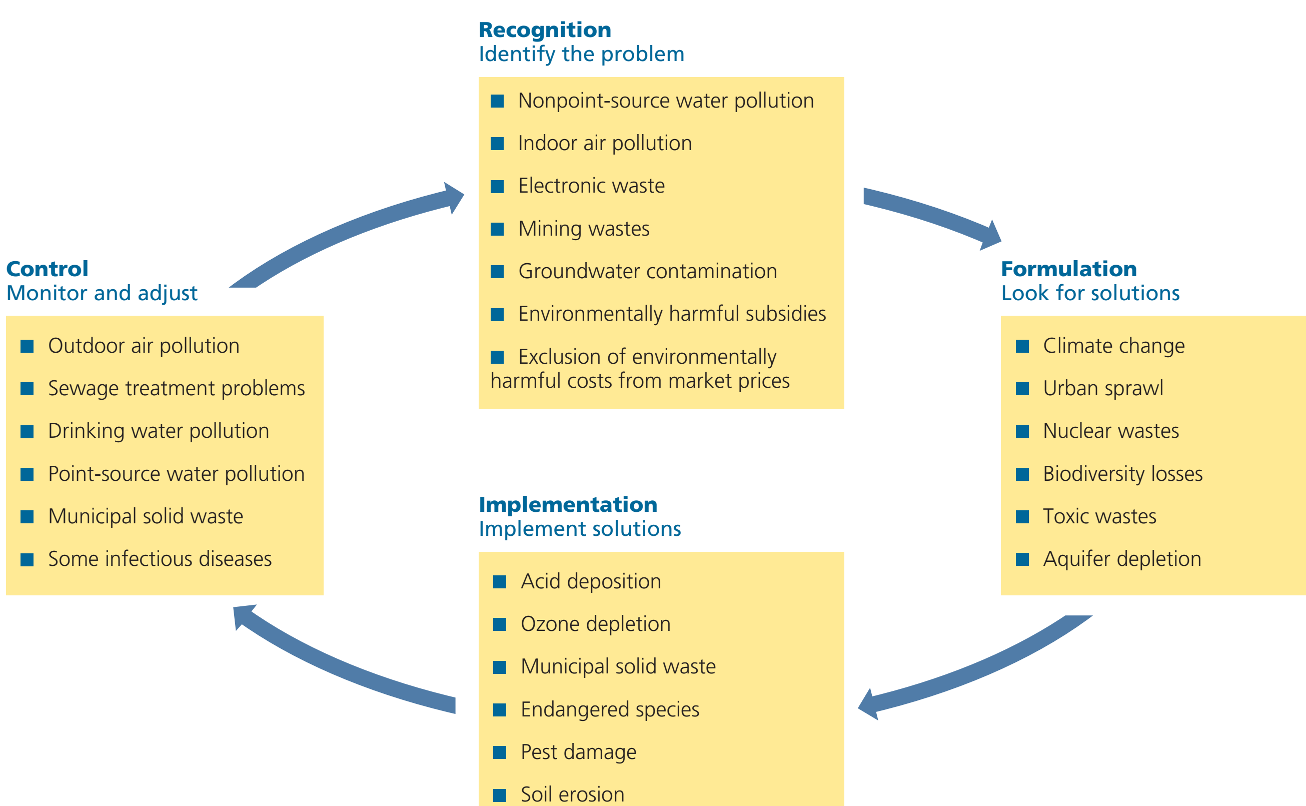


Figure 24-2 This diagram illustrates *the policy life cycle*, including the positions of some major environmental problems within the cycle in the United States and most of the world's other more-developed countries. (The positions of some problems vary by country. This is a snapshot of a typical set of problems.) The four stages are *recognition* (identify a problem); *formulation* (identify specific causes of the problem and develop a solution such as a law or program to help deal with it); *implementation* (put the solution into effect); and *control* (monitor progress and make adaptations as needed). Note that many of the problems listed have not made it through all four phases.

The policy process is usually cyclical, because in the fourth stage, control, a policy is evaluated according to feedback from the market or environment. Seldom is everyone happy with a policy, and usually, adjustments have to be made or a policy might even have to be abandoned, and the process starts again. Ideally, policies are revised and fine-tuned until they succeed in serving all or most of the affected parties in a reasonably balanced way. The most difficult problem is getting a policy to the control phase.

Democracy Does Not Always Allow for Quick Solutions

Democracy is government by the people through elected officials and representatives. In a *constitutional democracy*, a constitution (a document recording the rights of citizens and the laws by which a government functions) provides the basis of government authority and, in most cases, limits government power by mandating free elections and guaranteeing the right of free speech.

Political institutions in most constitutional democracies are designed to allow gradual change that ensures economic and political stability. In the United States, for example, rapid and destabilizing change is curbed by a system of checks and balances that distributes power among three branches of government—*legislative, executive,* and *judicial*—and among federal, state, and local governments.

In passing laws, developing budgets, and formulating regulations, elected and appointed government officials must deal with pressure from many competing *special-interest groups.* Each of these groups advocates passing laws, providing subsidies or tax breaks, or establishing regulations favorable to its cause, while attempting to weaken or repeal laws, subsidies, tax breaks, and regulations unfavorable to its position. Some special-interest groups such as corporations are *profit-making organizations.* Others are *nongovernmental organizations (NGOs)*, most of which are nonprofit, such as labor unions and environmental organizations.

The design for stability and gradual change in democracies is highly desirable. But several features of democratic governments hinder their ability to deal with environmental problems. For example, problems such as climate change and biodiversity loss are complex and difficult to understand. Such problems also have long-lasting effects, are interrelated, and require integrated, long-term solutions that emphasize prevention. But because local, state, and national elections are held as often as every 2 years, most politicians spend much of their time seeking reelection and tend to focus on short-term, isolated issues rather than on long-term, complex, and time-consuming problems.

One of our greatest challenges is to place more emphasis on long-term thinking and policies and to educate political leaders and the public about the need for long-range thinking and actions. Another problem is that many political leaders, with hundreds of issues to deal with, have too little understanding of how the earth's natural systems work and how those systems support all life, economies, and societies. Again, there is an urgent need to educate politicians and voters about these vital matters.

Certain Principles Can Guide Us in Making Environmental Policy

Analysts suggest that when evaluating existing or proposed environmental policies, legislators and individuals should be guided by seven principles designed to minimize environmental harm:

- *The humility principle:* Our understanding of nature and how our actions affect nature is quite limited.
- *The reversibility principle:* Try not to make a decision that cannot be reversed later if the decision turns out to be wrong. For example, two essentially irreversible actions affecting the environment are the production of indestructible hazardous and toxic waste in coal-burning power plants (see Chapter 15, Case Study, p. 384), which we must try to store safely and essentially forever; and production of deadly radioactive wastes through the nuclear power fuel cycle, which must be stored safely for 10,000–240,000 years (see Chapter 15, p. 391). A possible third such irreversible action in the making is the capturing and storing of carbon dioxide underground or under the ocean to help slow projected climate change, which commits us to trying to ensure that these deposits will never leak out (see Chapter 19, Science Focus, p. 515).
- *The net energy principle:* Do not encourage the widespread use of energy alternatives or technologies with low net-energy yields (see Chapter 15, Science Focus, pp. 372–373), which cannot compete in the open marketplace without government subsidies. Examples of energy alternatives with fairly low or negative net energy yields include nuclear power (considering the whole fuel cycle), tar sands, and shale oil, as discussed in Chapter 15, and hydrogen and ethanol made from corn, as discussed in Chapter 16.
- *The precautionary principle:* When substantial evidence indicates that an activity threatens human health or the environment, take precautionary measures to prevent or reduce such harm, even if some of the cause-and-effect relationships are not well established, scientifically.
- *The prevention principle:* Whenever possible, make decisions that help to prevent a problem from occurring or becoming worse.

- *The polluter-pays principle:* Develop regulations and use economic tools such as green taxes to ensure that polluters bear the costs of dealing with the pollutants and wastes they produce. This is an important way to include some of the harmful environmental and health effects of goods and services in their market prices (*full-cost pricing*).
- *The environmental justice principle:* Establish environmental policy so that no group of people bears an unfair share of the burden created by pollution, environmental degradation, or the execution of environmental laws. (See the Guest Essay on this subject by Robert D. Bullard at CengageNOW.)

Implementing such principles is not easy and will require that policy makers throughout the world, especially in more-developed countries, become more environmentally literate, based on the latest scientific information about environmental problems and possible solutions to them.

THINKING ABOUT
Environmental Political Principles

Which three of the seven principles listed here do you think are the most important? Why? Which ones do you think influence legislators in your city, state, or country?

24-2 How Is Environmental Policy Made?

▶ **CONCEPT 24-2A Policy making involves enacting laws, funding programs, writing rules, and enforcing those rules with government oversight—a complex process that is affected at each stage by political processes.**

▶ **CONCEPT 24-2B Individuals can work together to become part of political processes that influence how environmental policies are made and whether or not they succeed. (*Individuals matter.*)**

How Democratic Government Works: The U.S. Model

The U.S. federal government consists of three separate but interconnected branches: legislative, executive, and judicial. The *legislative branch,* called the Congress, consists of the House of Representatives and the Senate, which jointly have two main duties. One is to approve and oversee government policy by passing laws that establish a government agency or instruct an existing agency to take on new tasks or programs. The other is to oversee the functioning and funding of agencies in the executive branch concerned with carrying out government policies.

The *executive branch* consists of the president and a staff who oversee the agencies authorized by Congress to carry out government policies. The president proposes annual budgets, legislation, and appointees for executive positions, which must be approved by Congress. The president also tries to persuade Congress and the public to support executive policy proposals. Citizens use the ballot box to elect the president and vice-president in the executive branch and members of Congress in the legislative branch.

The *judicial branch* consists of the Supreme Court and lower federal courts. These courts, along with state and local courts, enforce and interpret different laws passed by legislative bodies in terms of their adherence to the rights and responsibilities of government and citizens as established by the U.S. Constitution. Decisions made by the various courts make up a body of law known as *case law.* Previous court rulings are used as legal guidelines, or *precedents*, to help make new legal decisions and rulings. Judges at the federal level are appointed by the president with the advice and consent of the Senate, and judges at state and local levels of government are variously appointed by executives or elected by voters.

The major function of the federal government in the United States (and in other democratic countries) is to develop and implement policies for dealing with various issues. Policy is typically composed of *laws* passed by the legislative branch, *regulations* instituted by the agencies of the executive branch to put laws and programs into effect, and *funding* approved by Congress and the president to finance the executive agencies' programs and to implement and enforce the laws and regulations (**Concept 24-2A**).

Converting a bill introduced in the U.S. Congress into a law is a complex process. An important factor in this process is **lobbying**, in which individuals or groups contact legislators in person, or hire lobbyists (representatives) to do so, in order to persuade legislators to vote or act in their favor. The opportunity to lobby elected representatives is an important right for everyone in a democracy. However, some critics of the American system believe lobbyists of large corporations and other organizations have grown too powerful and that their influence overshadows the input that legislators get from ordinary citizens.

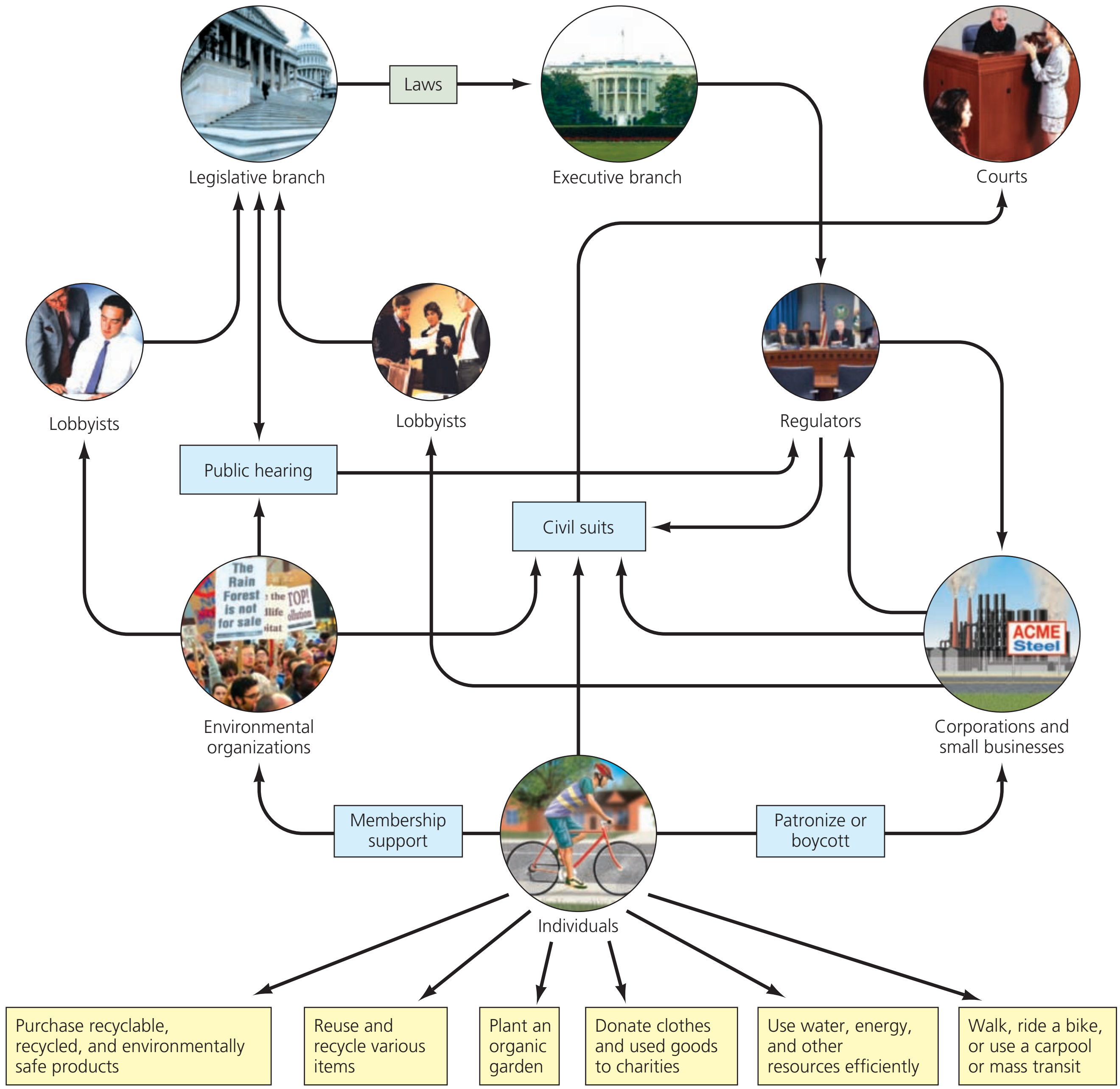


Figure 24-3 This is a greatly simplified overview of how individuals, corporations, and environmental organizations interact with each other and with the legislative, executive, and judicial branches of the U.S. government. The bottom of this diagram also shows some ways in which individuals can bring about environmental change through their own lifestyles. (See the website for this book for details on contacting elected representatives.)

Data from the U.S. Senate Office of Public Records showed that in 2009, more than 13,700 registered corporate lobbyists spent $3.49 billion on efforts to influence the 538 members of the U.S. Congress—an average of $6.5 million per member. Corporations are the source of billions of dollars used to finance election campaigns. In 2010, the U.S. Supreme Court ruled that corporations can spend as much money as they want on ads for or against specific candidates running for election. Figure 24-3 presents a simplified overview of how individuals and lobbyists interact with the three branches of government in the United States.

Most environmental bills are evaluated by as many as ten committees in the U.S. House of Representatives and the Senate. Effective proposals often are weakened by this fragmentation and by lobbying from groups opposing these laws. Nonetheless, since the 1970s, a number of important environmental laws have been passed in the United States, as discussed throughout this text. Figure 24-4 lists some of the major environmental laws passed in the United States since 1969. **Explore More:** Go to a **www.cengage.com/login** to see a series of timelines that describe some of the key events in U.S. environmental history.

1969	National Environmental Policy Act (NEPA)
1970	Clean Air Act
1971	
1972	Clean Water Act; Coastal Zone Management Act; Federal Insecticide, Fungicide, and Rodenticide Act; Marine Mammal Protection Act
1973	Endangered Species Act
1974	Safe Drinking Water Act
1975	
1976	Resource Conservation and Recovery Act (RCRA); Toxic Substances Control Act; National Forest Management Act
1977	Soil and Water Conservation Act; Clean Water Act; Clean Air Act Amendments
1978	National Energy Act
1979	
1980	Superfund law; National Energy Act Amendments; Coastal Zone Management Act Amendments
1981	
1982	Endangered Species Act Amendments
1983	
1984	Hazardous and Solid Waste Amendments to RCRA; Safe Drinking Water Act Amendments
1985	Endangered Species Act Amendments
1986	Superfund Amendments and Reauthorization
1987	Clean Water Act Amendments
1988	Federal Insecticide, Fungicide, and Rodenticide Act Amendments; Endangered Species Act Amendments
1989	
1990	Clean Air Act Amendments; Reauthorization of Superfund; Waste Reduction Act
1991	
1992	Energy Policy Act
1993	
1994	
1995	Endangered Species Act Amendments
1996	Safe Drinking Water Act Amendments

Figure 24-4 These are some of the major environmental laws and their amended versions enacted in the United States since 1969. No major new environmental laws have been passed since the 1970s.

Developing Environmental Policy Is a Controversial Process

In the United States, passing a law is not enough to make policy (**Concept 24-2A**). The next step involves trying to get Congress to appropriate enough funds to implement and enforce each law. Indeed, developing and adopting a budget to finance government agencies, the programs for which they are responsible, and the enforcement of laws and regulations within those programs is the most important and controversial activity of the executive and legislative branches.

Once Congress has passed a law and funded a program, the appropriate government department or agency must draw up regulations for implementing it. A group affected by the program and its regulations may take the agency to court for failing to implement and enforce the regulations effectively or for enforcing them too rigidly.

Businesses facing environmental regulations often put political pressure on regulatory agencies and executives to appoint people from the regulated industries or groups to high positions within the agencies. In other words, the regulated try to take over the regulatory agencies and become the regulators—described by some as "putting foxes in charge of the henhouse."

In addition, people in regulatory agencies work closely with officials in the industries they are regulating, often developing friendships with them. Some industries and other regulated groups offer high-paying jobs to regulatory agency employees in an attempt to influence their regulatory decisions.

Environmental science should play a major role in the formulation of environmental policy, according to many analysts. However, politics usually plays a bigger role, and the scientific and political processes are quite different (Science Focus, p. 644).

CASE STUDY

Managing Public Lands in the United States—Politics in Action

No nation has set aside as much of its land for public use, resource extraction, enjoyment, and wildlife habitat as has the United States. The federal government manages roughly 35% of the country's land, which belongs to every American. About three-fourths of this federal public land is in Alaska and another fifth is in the western states (Figure 24-5, p. 645).

Some federal public lands are used for many different purposes. For example, the *National Forest System* consists of 155 national forests and 22 national grasslands. These lands, managed by the U.S. Forest Service (USFS), are used for logging, mining, livestock grazing, farming, oil and gas extraction, recreation, and conservation of watershed, soil, and wildlife resources.

The Bureau of Land Management (BLM) manages large areas of land—40% of all land managed by the federal government and 13% of the total U.S. land surface—mostly in the western states and Alaska. These lands are used primarily for mining, oil and gas extraction, logging, and livestock grazing.

The U.S. Fish and Wildlife Service (USFWS) manages 549 *national wildlife refuges* (Figure 9-21, p. 211). Most refuges protect habitats and breeding areas for

SCIENCE FOCUS

Science and Politics—Principles and Procedures

The rules of inquiry and debate in science and politics are quite different. Science is based on a set of principles designed to make scientific investigations completely open to critical review and testing. Four such principles are:

1. *Any scientific claim must be based on hard evidence and subject to peer review.* This helps to prevent scientists from lying about procedures or falsifying evidence.
2. *Scientists can never establish absolute proof about anything.* Instead, they seek to establish a high degree of certainty about the results of their research.
3. *Scientists vigorously debate the validity of scientific research.* Such debates focus on the scientific evidence and results, not on personalities involved.
4. *Science advances through the open sharing and peer review of research methods, results, and conclusions.* There are two exceptions to this: first, some scientists who own or work for companies need to protect their research until legal patents can be obtained. Second, government scientists whose work involves national security often keep their research secret.

In politics, on the other hand, there are no such established and respected principles. In order to win elections and gain influence, politicians use unwritten rules that change frequently. While many politicians would like to base their decisions and actions on facts, others suggest that what matters more than facts is how the public perceives what they do and say. This makes the political process far less open to review and criticism than any scientific process is.

Without such openness, the political process has often come to involve tactics that most scientists would reject. For example, some politicians pick and choose facts to support a claim that is not supported by the whole of a body of evidence. They then repeat such a claim over and over until it becomes part of the news media cycle. If this misuse of evidence is not exposed, as it usually is in science, these unsupported claims can become accepted as truth.

Another political tactic that often goes unchallenged is to change a debate about facts to a discussion focused on personal attacks. Such a tactic is meant to make one's opponents look weak and it helps a politician to avoid serious discussion of issues. In scientific debate, such a shift away from a fact-based discussion is not tolerated by most participants.

Unfortunately, in the process, due to the lack of openness and peer review, these tactics have helped some groups to gain political or economic advantages. Representatives of industries whose profits might be reduced by government regulation of their harmful environmental activities have used tactics of secrecy, disinformation, and character assassination to discredit reliable scientific research and the scientists conducting it (see Individuals Matter, p. 522). People have learned how to spread disinformation quickly in this media age of almost instant global news coverage, text messaging, and Internet blogs and videos. These tactics have been effective and have set back the use of valid scientific research (see Science Focus, p. 511).

While the Internet allows almost anyone to quickly spread disinformation, it also allows almost anyone to check the validity of much information and to detect and publicize lies and distortions. Learning how to detect and evaluate disinformation is one of the most important purposes of education. In this book, we work hard to show that most environmental problems have many sides and that any proposed solution has advantages and disadvantages. The question we each need to ask and think about is whether the advantages of any course of action outweigh its disadvantages and vice versa. This is no easy task, and it requires an open mind and critical thinking.

Critical Thinking

Give two examples of widely accepted results of scientific research that have been politicized to the point where they are largely doubted or ignored by the public.

waterfowl and big game to provide a harvestable supply of these species for hunters. Permitted activities in most refuges include hunting, trapping, fishing, oil and gas development, mining, logging, grazing, some military activities, and farming.

The uses of some other public lands are more restricted. The *National Park System*, managed by the National Park Service (NPS), includes 58 major parks (Figure 7-16, p. 163, Figure 10-22, p. 237, and Figure 24-6) and 331 national recreation areas, monuments, memorials, battlefields, historic sites, trails, seashores, and lakeshores. Only camping, hiking, sport fishing, and boating can take place in the national parks, whereas sport hunting, mining, and oil and gas drilling are allowed in national recreation areas.

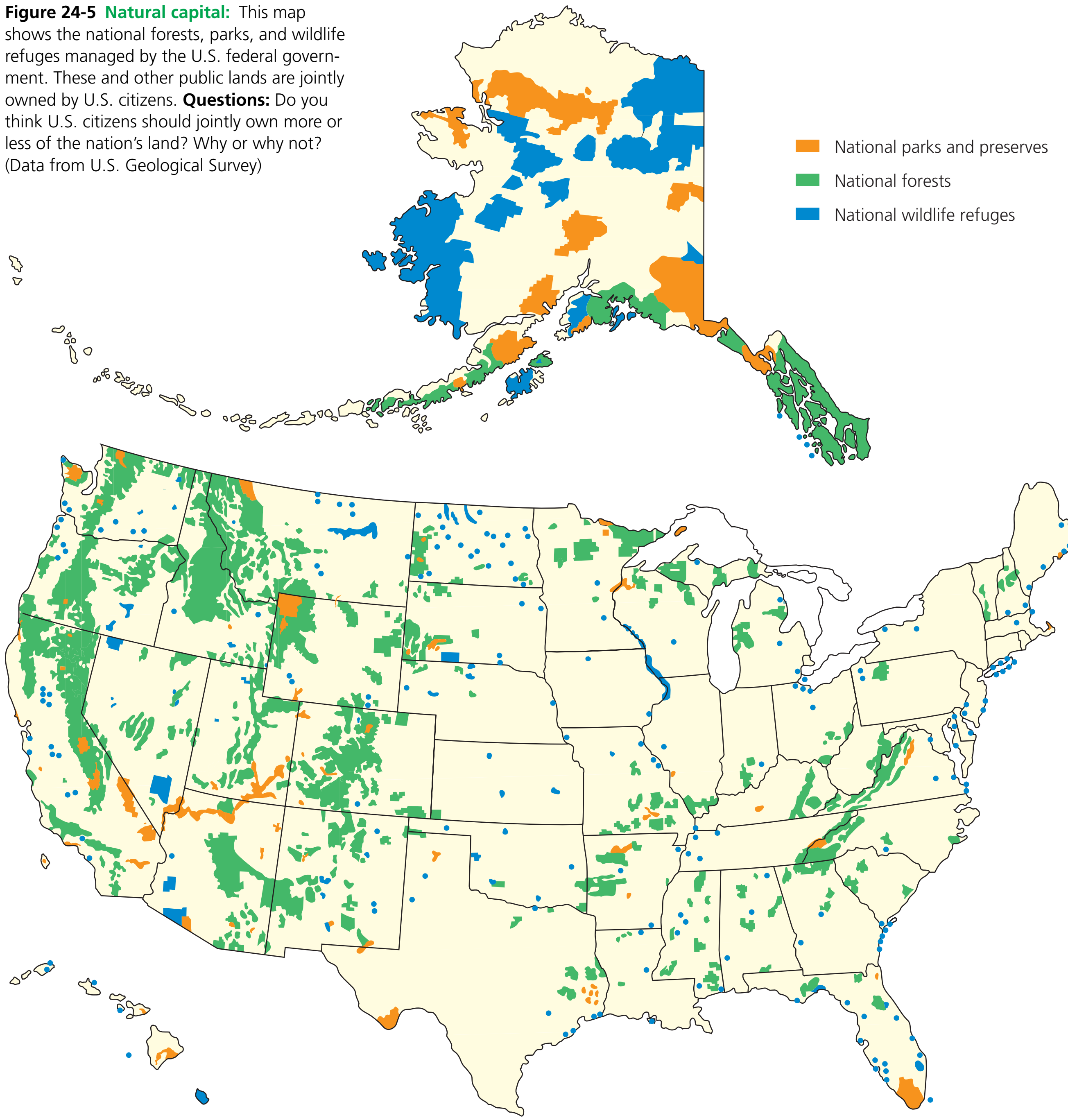
The most restricted public lands are 702 roadless areas that make up the *National Wilderness Preservation System*. These areas lie within the other public lands and are managed by the agencies in charge of those lands. Most of these areas are open only for recreational activities such as hiking, sport fishing, camping, and nonmotorized boating.

Many federal public lands contain valuable oil, natural gas, coal, geothermal, timber, and mineral resources (see Figure 18, p. S49, in Supplement 8). The appropriate use and management of the resources on these lands has been debated since the 1800s.

Most conservation biologists and environmental economists and many free-market economists believe that four principles should govern the use of public lands:

1. They should be used primarily for protecting biodiversity, wildlife habitats, and ecosystems.
2. No one should receive government subsidies or tax breaks for using or extracting resources on public lands.
3. The American people deserve fair compensation for the use of their property.

Figure 24-5 **Natural capital:** This map shows the national forests, parks, and wildlife refuges managed by the U.S. federal government. These and other public lands are jointly owned by U.S. citizens. **Questions:** Do you think U.S. citizens should jointly own more or less of the nation's land? Why or why not? (Data from U.S. Geological Survey)



4. All users or extractors of resources on public lands should be fully responsible for any environmental damage they cause.

There is strong and effective opposition to these ideas. Developers, numerous neoclassical economists, and many citizens tend to view public lands in terms of their usefulness in providing mineral, timber, and other resources. They have succeeded in blocking implementation of the four principles listed above. For example, analyses of budgets and appropriations reveal that in recent years, the government has given an average of $1 billion a year—more than $2.7 million a day—in subsidies and tax breaks to privately owned interests that use public lands for mining, fossil fuel extraction, logging, and grazing.

Some developers and resource extractors have sought to go farther. Here are five of the proposals that such interests have made to get the U.S. Congress to open up more federal lands for development:

1. Sell public lands or their resources to corporations or individuals, usually at proposed prices that are less than market value, or turn over their management to state and local governments.

2. Slash federal funding for administration of regulations over public lands.

Figure 24-6 Yosemite National Park in northern California (USA)—a vast, gorgeous valley in the High Sierra Mountains—is a symbol of the National Park System. The park system manages pristine areas such as this for their natural value and for use by future generations.

3. Cut old-growth forests in the national forests for timber and for making biofuels, and replace them with tree plantations to be harvested for the same purposes.
4. Open national parks, national wildlife refuges, and wilderness areas to oil drilling, mining, off-road vehicles, and commercial development.
5. Eliminate or take regulatory control away from the National Park Service and launch a 20-year construction program in the parks to build new concessions and theme parks that will be run by private firms.

Between 2002 and 2009, the U.S. Congress and the executive branch expanded the extraction of mineral, timber, and fossil fuel resources on U.S. public lands. They also weakened environmental laws and regulations protecting such lands. **Explore More:** See a Science Focus at **www.cengage.com/login** examining the controversy over logging in U.S. National Forests.

HOW WOULD YOU VOTE?

Should much more U.S. public land (or government-owned land in the country where you live) be opened up to the extraction of timber, mineral, and energy resources? Cast your vote online at **www.cengage.com/login**.

Individuals Can Influence Environmental Policy

A major theme of this book is that *individuals matter*. History shows that significant change usually comes from the *bottom up* when individuals join with each other to bring about change. Without previous bottom-up (grassroots) political action by millions of individual citizens and organized citizen groups (Figure 24-7), the air that many people breathe today and the water they drink would be much more polluted, and much more of the earth's biodiversity would have disappeared.

With the growth of the Internet and digital technology, individuals have become more empowered. For example, in a highly unusual chain of events in 2007, Chinese citizens using mobile phone text messaging organized to oppose construction of a chemical plant that would threaten the safety of 1.5 million people in a port city. By building opposition from the ground up—circulating nearly a million phone messages—they persuaded the Chinese government to freeze the construction project and to consider less hazardous alternatives.

Figure 24-8 lists ways in which you can influence and change government policies in constitutional democracies. Many people recycle, buy eco-friendly products, and do other important things to help the environment. But when people work together, starting at the local level, just as Denis Hayes did in organizing Earth Day 1970 (**Core Case Study**), they can influence environmental policy. Hayes's story and other similar examples of individuals making a difference have demonstrated the validity of the observation by Aldo Leopold, American conservationist and writer, that "All ethics rest upon a single premise: that the individual is a member of a community of interdependent parts." **Explore More:** See a Case Study at **www.cengage.com/login** to learn about how one woman organized a successful grassroots effort to save a river from a state of severe pollution.

CORE CASE STUDY

At a fundamental level, all politics is local. What we do to improve environmental quality in our own neighborhoods, schools, and work places has national and global

Figure 24-7 *Global outlook:* Children in Turin, Italy, wear gas masks as part of an organized protest against high levels of air pollution. **Question:** What environmental issue, if any, would lead you to participate in such a demonstration? Explain.

What Can You Do?

Influencing Environmental Policy

- Become informed on issues
- Make your views known at public hearings
- Make your views known to elected representatives, and understand their positions on environmental issues
- Contribute money and time to candidates who support your views
- Vote
- Run for office (especially at local level)
- Form or join nongovernment organizations (NGOs) seeking change
- Support reform of election campaign financing that reduces undue influence by corporations and wealthy individuals

Figure 24-8 **Individuals matter:** These are some ways in which you can influence environmental policy (**Concept 24-2B**). **Questions:** Which three of these actions do you think are the most important? Which ones, if any, do you take?

implications, much like the ripples spreading outward from a pebble dropped in a pond. This is the meaning of the slogan, "Think globally; act locally."

Environmental Leaders Can Make a Big Difference

Not only can we participate, but each of us can also provide environmental leadership in several different ways. First, we can *lead by example*, using our own lifestyles and values to show others that change is possible and can be beneficial. For example, we can use fewer disposable products, eat foods that have been more sustainably produced (see Figure 12-34, p. 310), and walk, bike, or take mass transit to work or school.

Second, we can *work within existing economic and political systems to bring about environmental improvement* by campaigning and voting for informed and eco-friendly candidates and by communicating with elected officials. We can also send a message to companies that we feel are harming the environment through their products or policies by *voting with our wallets*—not buying their products or services—and letting them know why. Another way to work within the system is to choose one of the many rapidly growing green careers highlighted throughout this book and described in Figure 23-16 (p. 633) and on the book's companion website.

Third, we can *run for some sort of local office*. Look in the mirror. Maybe you are one who can make a difference as an officeholder.

Fourth, we can *propose and work for better solutions to environmental problems*. Leadership is much more than just taking a stand for or against something. It also involves coming up with solutions to problems and persuading people to work together to achieve them. If we care enough, each of us can make a difference, as Denis Hayes (**Core Case Study**), Wangari Maathai (see Chapter 10, Core Case Study, p. 217), and Muhammad Yunus (see Chapter 23, Core Case Study, p. 613), have done.

CORE CASE STUDY

Here are two pieces of hopeful news. *First*, research by social scientists indicates that social change requires active support by only 5–10% of the population, which often is enough to lead to a political tipping point. *Second*, experience has shown that reaching such a critical mass can bring about social change much faster than most people think.

GOOD NEWS

THINKING ABOUT
Environmental Leadership

CORE CASE STUDY

What types of environmental leadership does Denis Hayes (**Core Case Study**) practice? What type of environmental leadership interests you?

24-3 What Is the Role of Environmental Law in Dealing with Environmental Problems?

CONCEPT 24-3 We can use environmental laws and regulations to help control pollution, set safety standards, encourage resource conservation, and protect species and ecosystems.

Environmental Law Forms the Basis for Environmental Policy

Environmental law is a body of laws and treaties that broadly define what is acceptable environmental behavior for individuals, groups, businesses, and nations. This body of laws and treaties has evolved through legislative and judicial processes at various levels of government that have usually included attempts to balance competing private, social, and commercial interests. This section of the chapter deals primarily with the U.S. legal system as a model that reveals the advantages and disadvantages of using a legal and regulatory approach to dealing with environmental problems.

One way in which environmental law has evolved is through court cases involving lawsuits, most of which are **civil suits** brought to settle disputes or damages between one party and another. For example, a homeowner may bring a nuisance suit against a nearby factory because of the noise it generates. In such a suit, the **plaintiff**, the party bringing the charge (in this case, the homeowner), seeks to collect damages from the **defendant**, the party being charged (in this case, the factory), for injuries to health or for economic loss.

The plaintiff may also seek an *injunction,* by which the the court hearing the case would order the defendant to stop whatever action is causing the nuisance. Short of closing the factory, often the court tries to find a reasonable or balanced solution to the problem. For example, it may order the factory to reduce noise to certain levels or to eliminate it at night.

A *class action suit* is a civil suit filed by a group, often a public interest, consumer, or environmental group, on behalf of a larger number of citizens, all of whom claim to have experienced similar damages from a product or an action, but who need not be listed and represented individually.

Another concept used in environmental law cases is *negligence*, in which a party causes damage by deliberately acting in an unlawful or unreasonable manner. For example, a company may be found negligent if it fails to handle hazardous waste in a way that it knows is required by a *statutory law* (a law, or *statute*, passed by a legislature). A court may also find a company negligent if it fails to do something a reasonable person would do, such as testing waste for certain harmful chemicals before dumping it into a sewer, landfill, or river (Figure 24-9). Generally, negligence is hard to prove.

Environmental Lawsuits Are Difficult to Win

Several factors limit the effectiveness of environmental lawsuits. *First*, plaintiffs bringing the suit must establish that they have the legal right, or *legal standing*, to do so in a particular court. To have such a right, plaintiffs must show that they have suffered health or financial losses from some alleged environmental harm. *Second*, bringing any lawsuit costs too much for most individuals.

Third, public interest law firms cannot recover their attorneys' fees unless Congress has specifically authorized that they be compensated within the laws that they seek to have enforced. By contrast, corporations can reduce their taxes by deducting their legal expenses—in effect getting a government (taxpayer) subsidy to pay for part of their legal fees. In other words, the legal playing field is uneven and puts individuals and groups that are filing environmental lawsuits at a disadvantage.

Fourth, to stop a nuisance or to collect damages from a nuisance or an act of negligence, plaintiffs must establish that they have been harmed in some significant way and that the defendant caused the harm. Doing this can be difficult and costly. Suppose a company (the defendant) is alleged to have caused cancer in certain individuals (the plaintiffs) by polluting a river. If hundreds of other industries and cities dump waste into that river, establishing that one specific company is the culprit is very difficult and requires expensive investigation, scientific research, and expert testimony.

Fifth, most states have *statues of limitations*, laws that limit how long a plaintiff can take to sue after a particular event occurs. These statutes often make it essentially impossible for victims of cancer, which may take 10–20 years to develop, to file or win a negligence suit.

William Campbell/Peter Arnold, Inc.

Figure 24-9 This stream contains acid runoff from a closed coal mine in the U.S. state of West Virginia. Often, it is difficult or impossible to hold polluters responsible in a court of law.

Sixth, courts can take years to reach a decision. During that time a defendant may continue the allegedly damaging action unless the court issues a temporary injunction against it until the case is decided.

Yet another problem is that corporations and developers sometimes file *strategic lawsuits against public participation (SLAPPs)* targeting citizens who publicly criticize a business for some activity, such as polluting or filling in a wetland. Judges throw out about 90% of the SLAPPs that go to court. But individuals and groups hit with SLAPPs must hire lawyers, and typically spend 1–3 years defending themselves. Most SLAPPs are not meant to be won, but are intended to intimidate individuals and activist groups.

Despite the difficulties of winning environmental lawsuits, some committed and persistent individuals have successfully used the judicial system to fight large corporations that have degraded the environment (Individuals Matter, below).

Analysts have suggested three major reforms to help level the legal playing field for citizens suffering environmental damage. *First,* pressure Congress to pass a law allowing juries and judges to award citizens their attorney fees, to be paid by the defendants, in successful lawsuits.

Second, establish rules and procedures for identifying frivolous SLAPP suits so that cases without factual or legal merit can be dismissed quickly.

Third, raise the fines for violators of environmental laws and punish more violators with jail sentences. Polls indicate that 80% or more of Americans consider damaging the environment to be a serious crime.

Given the influence of corporate wealth and lobbying power, it is unlikely that these reforms will be implemented without strong bottom-up (grassroots) political pressure from concerned citizens. **Explore More:** See **www.cengage.com/login** to learn about the use of alternatives to lawsuits, called *arbitration* and *mediation*.

Major Types of Environmental Laws in the United States

Concerned citizens have persuaded Congress to enact a number of important federal environmental and resource protection laws (Figure 24-4). One type of such legislation *sets standards for pollution levels* (as in the Clean Air Acts, Chapter 18, p. 485). A second type *screens new substances for safety and sets standards* (as in

INDIVIDUALS MATTER

Diane Wilson

In 1989, Diane Wilson (Figure 24-A) was a fourth-generation shrimp boat captain and a working-class mother of five when she had to stop shrimping in Lavaca Bay near Seadrift, Texas, along the U.S. Gulf Coast, because the shrimp catch had declined significantly.

One day, another shrimper brought her a newspaper clipping saying that impoverished Calhoun County, where Seadrift is located, was one of the most polluted counties in the United States. The article went on to say that Lavaca Bay contained a large, underwater Superfund site polluted with toxic mercury.

Despite living in Seadrift all of her life, Wilson had never heard anything about this pollution—so poisonous that it could threaten the health of many of the town's residents as well as the shrimp and fish harvests on which her business depended. She was outraged and set up a public meeting to discuss pollution of the bay caused by chemical plants in the area. Local officials and business leaders were furious about Wilson's complaints because the chemical plants were the county's largest employer. Her character was called into question, neighbors shunned her, thugs threatened her, and she even received death threats.


Photo courtesy of Kate McConnico

Figure 24-A Diane Wilson, shrimp boat captain and author of *An Unreasonable Woman*, made a difference in her community.

Wilson and environmental lawyer Jim Blackburn filed a lawsuit charging Formosa Plastics, a multinational Taiwanese chemical company, with dumping toxic chemicals into the bay. With only a high school education, Wilson learned how to file legal briefs and analyze mountains of scientific and highly technical EPA documents.

After years of legal proceedings, protests, and bad publicity for their corporations, Formosa Plastics and Dow Chemical (which was also being sued for dumping chemicals into the bay) agreed to stop polluting the bay. Wilson is now an activist for environmental and social justice. She has practiced nonviolent protest and civil disobedience in the tradition of Henry David Thoreau, Mahatma Gandhi, and Martin Luther King, and she has gone on hunger strikes to protest releases of toxic chemicals by companies in her community. As a result, she has been arrested and jailed 13 times.

Wilson wrote a book about her struggle entitled *An Unreasonable Woman: A True Story of Shrimpers, Politicos, Polluters, and the Fight for Seadrift, Texas* (Chelsea Green, 2005). She has received numerous environmental awards and acclaim as an important new writer with an inspiring message. Wilson, who likes to call herself "nobody particular," urges everyone to help change the world by being committed to a cause and standing up for what they believe.

the Safe Drinking Water Act, Chapter 20, p. 543). A third type of legislation *encourages resource conservation* (the Resource Conservation and Recovery Act, Chapter 21, p. 578). A fourth type *sets aside or protects certain species, resources, and ecosystems* (the Endangered Species Act, Chapter 9, pp. 209–211, and the Wilderness Act, Chapter 10, p. 242) (**Concept 24-3**).

A fifth type of legislation *requires evaluation of the environmental impact of an activity proposed by a federal agency,* as in the National Environmental Policy Act, or NEPA, passed in 1970. Under NEPA, an *environmental impact statement* (*EIS*) must be developed for every major federal project likely to have an effect on environmental quality. The EIS must describe why the proposed project is needed, identify its beneficial and harmful environmental impacts, suggest methods to lessen harmful impacts, and present an evaluation of alternatives to the project. The EIS documents must be published and are open to public comment.

NEPA does not prohibit environmentally harmful government projects. But more than one-third of the country's land is under federal management, and NEPA requires the managing agencies to take environmental consequences into account in making decisions. It also exposes proposed projects and their possible harmful effects to public scrutiny. Opponents have targeted NEPA as a law to weaken or repeal.

THINKING ABOUT
Environmental Impact Statements

Are you in favor of requiring government agencies to develop environmental impact statements such as those required by NEPA? Explain.

U.S. Environmental Laws and Regulations Have Been under Attack

Environmental laws in the United States have been highly effective, especially in controlling pollution. However, since 1980 a well-organized and well-funded movement has mounted a strong campaign to weaken or repeal existing environmental laws and regulations (Figure 24-4), and to change the ways in which public lands (Figure 24-5) are used.

Three major groups are strongly opposed to various environmental laws and regulations: some corporate leaders and other powerful people who see them as threats to their profits, wealth, and power; citizens who see them as threats to their private property rights and jobs; and state and local government officials who resent having to implement federal laws and regulations with little or no federal funding (unfunded mandates), or who disagree with certain federal regulations.

One problem working against strong regulations is that the focus of environmental issues has shifted from easy-to-see dirty smokestacks and filthy rivers to more complex, controversial, long-term, and often invisible environmental problems such as climate change, biodiversity loss, and groundwater pollution. Explaining such complex issues to the public and mobilizing support for often controversial, long-range solutions to such problems is difficult. (See pp. 511–512 and the Guest Essay on environmental reporting by Andrew C. Revkin at CengageNOW.)

Another problem is that some environmentalists have primarily brought bad news about the state of the environment to the general public. History shows that bearers of bad news are not well received, and opponents of the environmental movement have used this to undermine environmental concerns. History also shows that people are moved to bring about change mostly by an inspiring and hopeful vision of what the world could be like (see Chapter 1, Core Case Study, p. 5). So far, environmental groups have not worked together to develop a broad, compelling, and positive vision.

Since 2000, efforts to weaken environmental laws and regulations have escalated. Nevertheless, independent polls show that more than 80% of the U.S. public strongly support environmental laws and regulations and do not want them weakened. However, polls also show that less than 10% of the U.S. public (and in hard economic times only about 2–3%) consider the environment to be one of the nation's most pressing problems. As a result, environmental concerns often do not get transferred to the ballot box or the pocketbook.

Preventing further weakening of U.S. environmental laws and regulations will require action on several fronts: repairing some of the damages already done; improving existing laws and regulations; stepping up science-based environmental education; and the continuation of organized, grassroots political pressure from concerned citizens—the type of pressure that led to passage of important environmental laws in the first place.

An important political component to the transition to a more environmentally sustainable society is for U.S. citizens (and citizens in other democratic countries) to elect ecologically literate and concerned leaders. Citizens must also insist that leaders work across party lines to end the current political deadlock on most environmental and other key issues that has characterized the U.S. Congress since 1980.

Beginning in the late 1960s, elected officials in the United States were under intense political pressure from citizens to address environmental degradation. This pressure was partly generated and then promoted by people like Denis Hayes and others who were active on Earth Day 1970 (**Core Case Study**). Such political action led the world into the first phase of an environmental revolution. As a result, members of both political parties in the Congress worked together with the executive branch to pass and implement major environmental laws (Figure 24-4), mostly during the 1970s, which became known as the *environmental decade*. **Explore More:** See timetables detailing environmental developments over several decades including the 1970s at **www.cengage.com/login**.

24-4 What Are the Major Roles of Environmental Groups?

▶ **CONCEPT 24-4 Grassroots groups are growing and combining their efforts with those of large environmental organizations in a global sustainability movement.**

Citizen Environmental Groups Play Important Roles

The spearheads of the global conservation, environmental, and environmental justice movements are the tens of thousands of nonprofit nongovernmental organizations (NGOs) working at the international, national, state, and local levels. The growing influence of these organizations is one of the most important changes influencing environmental decisions and policies (**Concept 24-4**).

NGOs range from grassroots groups with just a few members to organizations like the World Wildlife Fund (WWF), a 5-million-member global conservation organization, which operates in 100 countries. Other international groups with large memberships include Greenpeace, The Nature Conservancy, Conservation International, and the Grameen Bank (see Chapter 23, Case Study, p. 613).

Using e-mail, text messages, and the Internet, some environmental NGOs have organized themselves into an array of influential international networks. Examples include the Pesticide Action, Climate Action, International Rivers, and Women's Environment and Development Networks. They collaborate across national borders and monitor the environmental activities of governments, corporations, and international agencies such as the World Bank and the World Trade Organization (WTO). They also help expose corruption and violations of national and international environmental agreements, such as the Convention on International Trade in Endangered Species (CITES), which prohibits international trade of endangered species (see Chapter 9, p. 209).

In recent years, *global public policy networks* have formed in response to rapidly changing conditions in a globalizing world. These innovative groups focus on a particular environmental problem by bringing together governments, the private sector, international organizations, and NGOs. Since the 1990s, more than 50 such networks have emerged. Examples include the *International Forum on Forests*, which develops proposals for sustainable forest management; the *Global Water Partnership*, which works toward integrated water resources management; the *Renewable Energy Policy Network*, which develops policies to spur development of renewable energy; and the *Earth Day Network* (**Core Case Study**). CORE CASE STUDY

In the United States, more than 8 million citizens belong to more than 30,000 NGOs that deal with environmental issues. They range from small grassroots groups to large heavily funded *mainline* groups, the latter usually staffed by expert lawyers, scientists, economists, lobbyists, and fund-raisers. The largest of these groups are the World Wildlife Fund, the Sierra Club, the National Wildlife Federation, the Audubon Society, Greenpeace, Friends of the Earth, and the Natural Resources Defense Council (see the Case Study, p. 652).

THINKING ABOUT
Environmental Organizations

Do you belong to an environmental organization? Why or why not?

The largest groups have become powerful and important forces within the U.S. political system. They have helped to persuade Congress to pass and strengthen environmental laws (Figure 24-4), and they fight attempts to weaken or repeal these laws. GOOD NEWS

Some industries and environmental groups are working together to find solutions to environmental problems. For example, the Environmental Defense Fund worked with McDonald's to redesign its packaging system to eliminate its plastic hamburger containers. Greenpeace worked with a German manufacturer to build a refrigerator that does not use the potent greenhouse gases called HFCs as coolants; now there are more than 300 million of these Greenfreeze refridgerators in homes around the world. In addition, the Rainforest Alliance has worked with Chiquita Banana to certify the health, labor, and environmental practices on its farms.

Some environmental groups have shifted resources from demonstrating and litigating to publicizing research on innovative solutions to environmental problems. For example, to promote the use of chlorine-free paper, Greenpeace Germany printed a magazine using such paper and encouraged readers to demand that magazine publishers switch to chlorine-free paper. Shortly thereafter, several major magazines made that shift.

Some critics such as the U.S. environmental leader James Gustave Speth have criticized the big environmental groups for having the wrong priorities. Speth has stated that these groups need to broaden their efforts from working on selected issues to trying to bring about a new politics. He believes that politics as practiced today "will never deliver environmental sustainability." Therefore, he argues, environmental groups need to vigorously promote regulation of lobbying and other political reforms to make democratic governments more responsive to the needs of citizens and the environment and less dominated by large corporations and other powerful, wealthy interests.

Some environmental groups and networks are already beginning to broaden the focus of their efforts. A good example of an extremely active group is the Natural Resources Defence Council.

■ **CASE STUDY**

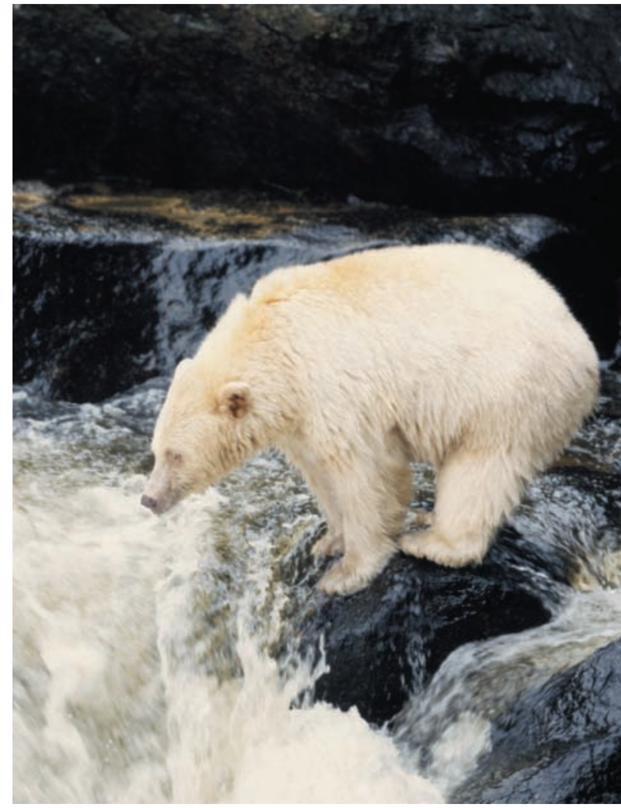
The Natural Resources Defense Council

One of the stated purposes of the Natural Resources Defense Council (NRDC) is "to establish sustainability and good stewardship of the Earth as central ethical imperatives of human society. . . . We work to foster the fundamental right of all people to have a voice in decisions that affect their environment. . . . Ultimately, NRDC strives to help create a new way of life for humankind, one that can be sustained indefinitely without fouling or depleting the resources that support all life on Earth."

To those ends, NRDC goes to court to stop environmentally harmful practices. It also informs and organizes millions of environmental activists, through its website (**www.nrdc.org**), magazines, and newsletters, to take actions to protect the environment—globally, regionally, and locally. For example, its BioGems network, accessible through the website, regularly informs subscribers about environmental threats all over the world, and helps people to take action by donating money, signing petitions, and writing letters to corporate and government officials and newspaper editors.

In 2005, with NRDC's help, U.S. citizens organized massive opposition to a proposed government policy that would have allowed sewer operators to routinely dump virtually untreated sewage into the nation's lakes, rivers, and streams. Because of well-informed, very vocal opposition to this proposal, the U.S. House of Representatives voted overwhelmingly to block the Environmental Protection Agency from finalizing this so-called "blending" proposal.

In another case, in 2001, NRDC helped forge an agreement among Canadian timber companies, environmentalists, native peoples, and the provincial government of British Columbia (Canada) to protect a vast area of the Great Bear Rainforest from destructive logging. This followed years of pressure from NRDC activists on logging companies, their U.S. corporate customers, and provincial officials to protect the habitats of eagles, grizzly bears, wild salmon, and the rare spirit bear, a subspecies of the American black bear with a creamy white fur coat (Figure 24-10).



All Canada Photos/SuperStock

Figure 24-10 The Natural Resources Defense Council (NRDC) has worked to protect the habitat of the rare spirit bear in Canada's British Columbia province. This bear is waiting to catch a salmon. They also eat berries and green plants. During the very cold winters, they hibernate in dry cavities of giant old trees in their coastal rainforest habitats, which are threatened by logging.

THINKING ABOUT
The Work of Environmental Organizations

Do you think it's important for you, regardless of where you live, to help organizations like NRDC to protect forests, bears, and salmon in British Columbia, Canada? Explain.

Grassroots Environmental Groups Bring about Change from the Bottom Up

The base of the environmental movement in the United States and throughout the world consists of thousands of grassroots citizens' groups organized to improve environmental quality, often at the local level. According to political analyst Konrad von Moltke, "There isn't a government in the world that would have done anything for the environment if it weren't for the citizen groups." Taken together, a loosely connected worldwide network of grassroots NGOs working for bottom-up political, social, economic, and environmental change can be viewed as an emerging citizen-based *global sustainability movement* (**Concept 24-4**). GOOD NEWS

Some analysts believe this movement got its start on Earth Day in 1970 (**Core Case Study**). Since CORE CASE STUDY then, many grassroots groups have worked with individuals and communities to oppose harmful projects such as landfills, waste incinerators, and nuclear waste dumps, as well as to fight against the clear-cutting of forests and pollution from factories and power plants. They have also taken action against environmental injustice. (See the Guest Essay on this topic by Robert D. Bullard at CengageNOW.)

Grassroots groups have organized *conservation land trusts* wherein property owners agree to protect their land from development or other harmful environmental activities, often in return for tax breaks on the land's value. These groups have also spurred other similar efforts to save wetlands, forests, farmland, and ranchland from development, while helping to restore clearcut forests and wetlands and rivers that have been degraded by pollution.

The Internet and text-messaging have become important tools for grassroots groups. With these tools, they can expand their membership, raise funds, and quickly plan and execute actions such as demonstrations and rallies. The Internet also helps these groups to be more efficient and to become interconnected within networks, as described above, which can make them even more effective.

Most grassroots environmental groups use the nonviolent and nondestructive tactics of protest marches, tree sitting (see Individuals Matter, below), and other devices for generating publicity to help educate and encourage the public to oppose various environmentally harmful activities. Such tactics often work because they produce bad publicity for practices and businesses that threaten or degrade the environment. For example, after 2 years of pressure and protests, Home Depot agreed to sell only wood products made from certified sustainably grown timber. Within a few months, Lowes and eight other major building supply chains in the United States developed similar policies.

Much more controversial are militant environmental groups that use violent means, such as breaking into labs to free animals used to test drugs and destroying property such as bulldozers and SUVs. Most environmentalists strongly oppose such tactics.

HOW WOULD YOU VOTE?

Do you support the use of nonviolent and nondestructive civil disobedience tactics by environmental groups and individuals? Cast your vote online at **www.cengage.com/login**.

INDIVIDUALS MATTER

GOOD NEWS

Butterfly in a Redwood Tree

Julia Butterfly Hill (Figure 24-B) spent two years of her life on a small platform near the top of a giant redwood tree in California to protest the clear-cutting of an old-growth forest of these ancient trees, some of them more than 1,000 years old. She and other protesters were illegally occupying these trees in the late 1990s as a form of *nonviolent civil disobedience*, similar to that used decades ago by Mahatma Gandhi in his efforts to end the British occupation of India, and by Martin Luther King in the U.S. civil rights movement.

Hill had never participated in an environmental protest or act of civil disobedience. She went to the site to express her belief that it was wrong for the property owner to cut down these ancient giants for short-term economic gain. She planned to stay for only a few days.

But after seeing the destruction and climbing one of these magnificent trees, she ended up staying in the tree for 2 years to publicize what was happening and to help save the surrounding trees. She became a symbol of the protest and, during her stay, used a cell phone to communicate with members of the mass media throughout the world to help develop public support for saving the trees.

AP Photo/Times Standard, Shaun Walker

Figure 24-B Julia Butterfly Hill stood up for her belief in the importance of biodiversity as represented by old-growth forests.

Can you imagine spending 2 years of your life in a tree on a platform not much bigger than a king-sized bed, hovering 55 meters (180 feet) above the ground, while enduring high winds, intense rainstorms, snow, and ice? All around her was noise from trucks, chainsaws, and helicopters.

Although Hill lost her courageous battle to save the surrounding forest, she persuaded Pacific Lumber MAXXAM to save her tree (which she named Luna) and a 60-meter (200-foot) buffer zone around it. Not too long after she descended from her perch, someone used a chainsaw to seriously damage the tree. Cables and steel plates are now used to preserve it.

But maybe Hill did not lose, after all. A book she wrote about her stand, and her subsequent travels to campuses all over the world, have inspired a number of young people to stand up for protecting biodiversity and for other environmental causes.

Julia Butterfly Hill led others by following in the tradition of Gandhi, who said, "My life is my message." Would you spend a day or a week of your life protesting something that you believed to be wrong?

Students and Educational Institutions Can Play Important Environmental Roles

Since the mid-1980s, there has been a boom in environmental awareness on college campuses and in public and private schools around the world. Most student environmental groups work with members of their school's faculty and administration to bring about environmental improvements in their schools and local communities.

GOOD NEWS

Many of these groups make *environmental audits* of their campuses or schools. They gather data on practices affecting the environment and use them to propose changes that will make their campuses or schools more environmentally sustainable while usually saving money in the process. Such audits have focused on implementing or improving recyling programs, convincing university food services to buy more food from local organic farms, shifting from fossil fuels to renewable energy, retrofitting buildings to make them more energy efficient, and implementing concepts of environmental sustainability throughout the curriculum.

In 2008, the National Wildlife Federation published a useful guide for students wishing to perform such audits. See **http://www.nwf.org/campusecology/BusinessCase/index.cfm**.

■ CASE STUDY

The Greening of American Campuses

In 2008, *Sierra Magazine* rated Oberlin College in Ohio as the nation's greenest college. Its students helped to design a more sustainable environmental studies building powered by solar panels, which produce 30% more electricity than the building uses. A living machine (see Chapter 20, Science Focus, p. 553) in the building's lobby purifies all of its wastewater, and half of the school's electricity comes from green sources. The school has a car-sharing program, and student activity fees subsidize public transportation.

At Northland College in Wisconsin, students helped to design a "green" residence hall that features a wind turbine, panels of solar cells, furniture made of recycled materials, and waterless (composting) toilets (Figure 24-11). Northland students voted to impose a *green fee* of $40 per semester on themselves to help finance the college's sustainability programs.

New York University gets all of the electricity it uses from wind power. Vermont's Middlebury College recently converted a historic 18th-century structure to a 21st century environmental center that has received the U.S. Green Building Council's highest certification. In 2009, Middlebury College also opened a biomass gasification plant that has reduced its carbon footprint by 40% and significantly lowered its fuel bills. Evergreen State College in Olympia, Washington, gets all of its electricity from renewable energy resources; uses no herbicides on its landscaping; has an organic farm that produces food for its dining rooms; and has several LEED-certified buildings that have solar panels and living roofs.

Universities and colleges have a special responsibility to promote environmental literacy and encourage environmental stewardship and sustainability. Heads of educational institutions are also recognizing that increasingly, many students will base their decisions on where to go to school partly on what the schools are doing to be more environmentally sustainable.

Fueled by student pressure, many colleges and universities are making progress in integrating sustainability into their institutional cultures. In 2008, Arizona State University opened the country's first School of Sustainability, which employs more than 60 faculty members from more than 40 disciplines. Most U.S. business schools now require students to take at least


Courtesy of Northland College

Figure 24-11 The Environmental Living and Learning Center is an eco-friendly residence hall and meeting space at Northland College in Ashland, Wisconsin. The building, which houses more than 150 students, features a wind turbine and three large solar panels for generating some of the electricity used by the residents. Other green features include passive solar heating, furniture and carpet made from recycled plastic, recycled Mylar window shades that reduce heat loss in winter and prevent excessive solar gain in summer, and a composting toilet system in some of the bathrooms. Northland students had a major role in designing the building, and the space is used by a variety of organizations for meetings and educational programs.

one course with an emphasis on sustainability, ethics, and corporate and social responsibility. At the Georgia Institute of Technology, one goal is for every student to take at least one of the more than 100 available courses having a sustainability emphasis.

THINKING ABOUT
Environmental Groups

What environmental groups exist at your school? Do you belong to such a group? Why or why not?

24-5 How Can We Improve Global Environmental Security?

▶ **CONCEPT 24-5 Environmental security is necessary for economic security and is at least as important as national security.**

Why Is Global Environmental Security Important?

Countries are legitimately concerned with *national security* and *economic security.* However, ecologists and many economists point out that all economies are supported by the earth's natural capital (see Figure 1-4, p. 9, and Figure 23-5, p. 617). Thus, environmental security, economic security, and national security are interrelated (**Concept 24-5**).

According to environmental expert Norman Myers,

> *If a nation's environmental foundations are degraded or depleted, its economy may well decline, its social fabric deteriorate, and its political structure become destabilized as growing numbers of people seek to sustain themselves from declining resource stocks. Thus, national security is no longer about fighting forces and weaponry alone. It relates increasingly to watersheds, croplands, forests, genetic resources, climate, and other factors that, taken together, are as crucial to a nation's security as are military factors.* (See Myers' Guest Essay on this subject at CengageNOW.)

Research by Thomas Homer-Dixon, director of Canada's Trudeau Center for Peace and Conflict Studies, has revealed a strong correlation between growing scarcities of resources, such as cropland, water, and forests, and the spread of civil unrest and violence that can lead to failing states (see Figure 17, p. S64, in Supplement 9). These countries have dysfunctional governments that can no longer provide security and basic services such as education and health care. They generally suffer from a breakdown of law and order, with gangs often ruling the streets, and deterioration of roads, electrical power, water supplies, and other vital forms of infrastructure. Such states often end up in civil wars as groups compete for power, and these wars can spread to nearby countries. Many failing states also become training grounds for terrorists (Afghanistan and Iraq), weapons traders (Nigeria and Somalia), and drug producers (Afghanistan and Myanmar). Together, they also generate millions of refugees displaced from their homes and land, while often fleeing for their lives.

Norman Myers and other analysts call for all countries to make environmental security a major focus of diplomacy and government policy at all levels. This could be implemented by a council of advisers made up of highly qualified experts in environmental, economic, and national security who integrate all three security concerns into their major policy decisions. This would include taking into consideration the enormous harmful environmental impacts of wars. **Explore More:** See a *Science Focus* at **www.cengage.com/login** to learn about the environmental impacts of war.

HOW WOULD YOU VOTE? ✓

Is environmental security just as important as economic and national security? Cast your vote online at **www.cengage .com/login**.

We Can Develop Stronger International Environmental Policies

A number of international environmental organizations help shape and set global environmental policy. Perhaps the most influential is the United Nations, which houses a large family of organizations including the UN Environment Programme (UNEP), the World Health Organization (WHO), the UN Development Programme (UNDP), and the Food and Agriculture Organization (FAO).

Other organizations that make or influence environmental decisions are the World Bank, the Global Environment Facility (GEF), and the World Conservation Union (also known as the IUCN). Despite their often limited funding, these and other organizations have played important roles in:

GOOD NEWS

- expanding understanding of environmental issues,
- gathering and evaluating environmental data,

- developing and monitoring international environmental treaties,
- providing grants and loans for sustainable economic development and reducing poverty, and
- helping more than 100 nations to develop environmental laws and institutions.

In 2008, environmental leader Gus Speth argued that global environmental problems are getting worse and that international efforts to solve them are inadequate. Speth and other environmental leaders propose the creation of a World Environmental Organization (WEO), on the order of the World Health Organization (WHO) and the World Trade Organization (WTO), to help deal with global environmental challenges.

In fact, a WEO would be largely at odds with the WTO. For example, the WTO can challenge and reverse any member nation's legal efforts to reduce greenhouse gas emissions if such efforts are judged to undermine world trade. Similarly, it can challenge and abolish any member nation's subsidy given to an energy efficiency or renewable energy industry if the subsidy is deemed to be damaging to trade. Member nations can move their dirty industries to countries with low standards, thereby continuing to pollute and to grow their ecological footprints, and the WTO does not allow this to be a factor in trade negotiations. A WEO would have to challenge and reverse such policies in order to bring about real international progress toward more sustainability.

Since the 1972 UN Conference on the Human Environment in Stockholm, Sweden, progress has been made in addressing environmental issues at the global level. The conference also created the United Nations Environment Programme (UNEP) to help develop the global environmental agenda. But the UNEP is a small and underfunded agency.

In 1992, governments of more than 178 nations and hundreds of NGOs met at the UN Conference on Environment and Development (UNCED) in Rio de Janeiro, Brazil. The major policy outcome of this conference was Agenda 21, a global agenda for sustainable development in the 21st century, which was adopted by 178 governments, but not including the United States. This ambitious agenda established goals for addressing the world's social, economic, and environmental problems. The conference also established the Commission on Sustainable Development to follow up on the Agenda 21 goals and monitor and report on the agreements at the local, regional, national, and international levels. In 1997, an Earth Summit was held to review the somewhat limited progress made toward implementing the Agenda 21 goals.

Figure 24-12 lists some of the good and bad news about international efforts to deal with global environmental problems such as poverty, climate change, biodiversity loss, and ocean pollution.

The primary focus of the international community on environmental problems has been the development of various international environmental laws and nonbinding policy declarations called *conventions.* And there are more than 500 international environmental treaties and agreements—known as *multilateral environmental agreements* (MEAs).

Trade-Offs

Global Efforts to Solve Environmental Problems

Good News	Bad News
Over 500 international environmental treaties and agreements	Most international environmental treaties lack criteria for evaluating their effectiveness
UN Environment Programme negotiates and monitors environmental treaties	1992 Rio Earth Summit led to nonbinding agreements, inadequate funding, and little improvement in major problems by 2010
1992 Rio Earth Summit adopted principles for handling global environmental problems	2002 Johannesburg Earth Summit failed to deal with climate change, biodiversity loss, and poverty
2002 Johannesburg Earth Summit tried to implement 1992 Rio summit policies and goals	2009 Copenhagen conference failed to deal with projected climate change

Figure 24-12 There is good and bad news about international efforts to deal with global environmental problems. **Question:** Which single piece of good news and which single piece of bad news do you think are the most important?

To date, the Montreal and Copenhagen Protocols for protecting the ozone layer (see Chapter 19, p. 524) are the most successful examples of how the global community can work together to deal with a serious global environmental challenge. Figure 24-13 lists some major problems with MEAs and solutions to these problems.

Corporations Can Play a Key Role in Promoting Environmental Sustainability

In our increasingly globalized economy, it has become clear that governments and corporations must work together to achieve goals for increased environmental sustainability. Governments can set environmental standards and goals through legislation and regulations, and corporations generally have highly efficient ways of accomplishing such goals. Making a transition to more sustainable societies and economies will require huge

Figure 24-13 *Global outlook:* These are some major problems with global environmental treaties and agreements, as well as some solutions to these problems. **Question:** Which problem and which solution do you think are the most important?

amounts of investment capital and significant research and development. Most of this money is will likely have to come from profitable corporations, especially considering the current budgetary pressures faced by most governments. Thus, corporations must play a vital role in achieving a more sustainable future.

The good news is that an increasing number of corporate chief executive officers (CEOs) and investors are aware that there is considerable money to be made from developing and selling green products and services during this century. This switch to new product lines is guided by the concept of *eco-efficiency*, which is about finding ways to create more economic value with less environmental impact by reducing the amount of energy, water, chemicals and other raw materials used per unit of output. In addition to reducing harmful health and environmental impacts, improving eco-efficiency can save businesses money and help them to meet their financial responsibilities to stockholders and investors.

In the early 1990s, Stephan Schmidheiny, a Swiss billionaire, organized a group of CEOs from 48 of the world's largest corporations. It eventually became the World Business Council for Sustainable Development (WBCSD), which is dedicated to promoting sustainable development built around improving eco-efficiency. Today, this council is a highly influential coalition of more than 170 international companies, involving some 700 global business leaders.

24-6 How Can We Implement More Sustainable and Just Environmental Policies?

▶ **CONCEPT 24-6 Making the transition to more sustainable societies will require that nations and groups within nations cooperate and make the political commitment to achieve this transition.**

We Can Shift to More Environmentally Sustainable Societies

A study of nature reveals that all parts of the biosphere are ecologically interdependent. Similarly, all parts of the human *culturesphere* are economically and politically interdependent. This interdependence requires citizens, business leaders, and elected officials to cooperate in trying to find and implement innovative short- and long-term solutions to local, national, and global environmental, economic, and social problems (**Concept 24-6**).

Several guidelines have been suggested for promoting cooperation instead of confrontation as we struggle to make such a transition. *First,* emphasize *preventing or minimizing* environmental problems instead of letting them build up to crisis levels. *Second,* use well-designed and carefully monitored *marketplace solutions* (see Chapter 23, p. 625) to help prevent or reduce the impact of most environmental problems. *Third,* cooperate and innovate to find *win–win solutions* or *tradeoffs* to environmental problems and injustices. *Fourth,* be *honest and objective*. People on both sides of thorny environmental issues should take a vow not to exaggerate or distort their positions in attempts to play win–lose or winner-take-all games.

Making the transition to a more sustainable world will also require governments and their citizens to rethink their priorities. Figure 23-12, (p. 629) shows that it would take about $245 billion a year for the world to meet basic social and health goals, and to provide environmental security for all. This amounts to about one-eighth of what countries spend each year on environmentally harmful subsidies. Converting that portion of those subsidies to environmentally beneficial subsidies and other forms of aid would go a long way toward solving major social and environmental problems.

Dwight D. Eisenhower, a five-star general in the U.S. army, Supreme Commander of Allied Forces in World War II and, later, president of the United States, offered the following advice in helping us decide on our priorities in solving such problems: "Every gun that is made, every warship launched, every rocket fired, signifies in the final sense a theft from those who hunger and are not fed, those who are cold and are not clothed."

The world has the knowledge, technologies, and financial resources to eradicate poverty and malnutrition, eliminate illiteracy, sharply reduce infectious diseases, stabilize human populations, and protect the earth's natural capital. We can do this by restoring the planet's soils, forests, rivers, and oceans, by relying more on renewable energy, and by sharply reducing our unnecessary waste of matter and energy resources.

Making the shift to more equitable and environmentally sustainable global and national societies is primarily an economic, political, and ethical decision (ethics is discussed in the next chapter). It involves shifting to more sustainable forestry (see Figure 10-16, p. 230), organic agriculture (see Figure 12-34, p. 310), water resource use (see Figure 13-23, p. 339), energy resource use (see Figure 16-37, p. 431), and economies (see Figure 23-14, p. 631), while slowing projected climate change (see Figure 19-16, p. 513) and educating the public and elected officials about the urgent need to make this shift over the next several decades. Some countries such as the Netherlands and New Zealand have begun to make such a transition by developing national *green plans* to make the transition to more sustainable societies. **Explore More:** See a Case Study at **www.cengage.com/login** to learn about the efforts of the Netherlands in developing a national green plan for making that country more sustainable.

Some say that the call for making this shift is idealistic and unrealistic. Others say that it is idealistic, unrealistic, and dangerous to keep assuming that our present course is sustainable, and they warn that we have precious little time to change.

Some thoughtful business and political leaders are realizing that "business as usual" is no longer a viable option (see Chapter 23, Individuals Matter, p. 626). The governments of Sweden and Germany have begun shifting taxes from income to pollution and carbon emissions. In the United States, various states and cities, choosing not to wait for the federal government, have enacted their own laws and programs to improve energy efficiency, use more renewable energy, and reduce pollution and greenhouse gas emissions.

As envisioned by Denis Hayes and other leaders on the first Earth Day in 1970 (**Core Case Study**), making a transition to more sustainable ways of living will improve life for most people today and help us to avoid undermining both the earth's natural capital and the futures of our children, grandchildren, and great grandchildren. It will depend on the choices made and the actions taken by everyone, from business and political leaders to ordinary citizens, as we work together to help sustain human civilization during this century.

CORE CASE STUDY

Here are this chapter's *three big ideas:*

- An important outcome of the political process is environmental policy—the body of laws and regulations that are designed, implemented, and enforced, and environmental programs that are funded by one or more government agencies.
- All politics is local, and individuals can work with each other to become part of political processes that influence environmental policies. (*Individuals matter.*)
- Environmental security is necessary for economic security and is at least as important as national security; making the transition to more sustainable societies will require that nations cooperate just as they do for national security purposes.

REVISITING Denis Hayes and Sustainability

CORE CASE STUDY

SUSTAINABILITY

The work of Denis Hayes and other organizers of Earth Day (**Core Case Study**) serves as a model for how to approach dealing with an environmental problem in the political arena. Hayes and his colleagues mustered public opinion and promoted solutions to environmental problems from the grassroots level to the highest levels of government. By mobilizing a critical number of demonstrators across the nation, he got the attention of the news media and of the general public, which then exerted the necessary pressure on legislators to pass major environmental laws in the 1970s (Figure 24-4) to address the environmental problems the country faced.

Hayes also serves as an outstanding example of someone who is compassionate about a set of issues, who envisions solutions to the problems involved, and who has figured out practical ways to make his vision real. He is a role model for anyone interested in becoming an environmental leader.

Policy making can be guided by the three **principles of sustainability** (see back cover). Because environmental and social problems are interrelated, their solutions also are interrelated. For example, relying on solar energy and other renewable energy sources reduces oil and coal use, but it also reduces emissions of greenhouse gases and other air pollutants, thus helping to slow climate change and protect biodiversity. Likewise, reforestation benefits biodiversity, but also increases aquifer recharge, reduces soil erosion, and helps to slow projected climate change by removing carbon dioxide from the atmosphere.

Once we begin these environmentally positive trends, they will reinforce one another and speed up the transition to more sustainable ways of living for societies of today and tomorrow through a positive feedback loop of beneficial change (Figure 2-18, p. 49). Positive change toward sustainability can occur much more rapidly than we think. Any or all of us can also choose to take part in the change by becoming politically active about the issues of our choice or at least politically aware and informed, so as to make the right choices when we go into the voting booth or take part in other activities that affect our environmental and political futures.

As the wagon driver said when they came to a long hard hill,
"Them that's going on with us get out and push. Them that ain't get out of the way."

THOMAS FULGHUM

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 638. Describe the work of Denis Hayes in helping to organize the first Earth Day (**Core Case Study**). CORE CASE STUDY

2. What key roles can governments play in improving environmental quality? What is a government's **policy**? What is **politics**? What is **environmental policy**? What are the four stages of a policy life cycle in democracies? What is a **democracy**? Describe two features of democratic governments that hinder their ability to deal with environmental problems. Describe seven principles that decision makers can use in making environmental policy.

3. What are the three branches of government in the United States and what major role does each play? What is **lobbying**? Why are some analysts concerned about the growing power of some lobbyists? What are three major environmental laws? Explain why developing environmental policy is a difficult and controversial process. What are three ways in which scientific and political processes differ? Why are these differences important for policymaking? What are four major types of public lands in the United States? Describe the controversy over managing these lands.

4. Describe four ways in which individuals in democracies can help to develop or change environmental policy. What does it mean to say that we should *think globally and act locally*? Give an example of such an action. What are four ways to provide environmental leadership?

5. What is **environmental law**? What is a **civil suit**? What are the **plaintiff** and the **defendant** in a lawsuit? Explain why it is difficult to win an environmental lawsuit. What is a SLAPP? List three general types of U.S. environmental laws. Describe how Diane Wilson used the legal system to help deal with a serious environmental problem in her community. What is an environmental impact statement?

6. Explain how and why U.S. environmental laws have been under attack since 1980. How effective have the attacks been? Describe Julia Butterfly Hill's efforts to save giant redwood trees in California from being cut down.

7. Describe the roles of grassroots and mainstream environmental organizations and give an example of each type of organization. Describe the role and effectiveness of the Natural Resources Defense Council (NRDC) in the United States. Give two examples of successful roles that students have played in improving environmental quality.

8. Explain the importance of environmental security, relative to economic and national security. List two pieces of good news and two pieces of bad news about international efforts to deal with global environmental problems. List three problems with global environmental treaties and agreements. Describe roles that corporations can play in helping to achieve environmental sustainability, and give an example of such an effort.

9. What are four guidelines for shifting to more environmentally sustainable societies?

10. Explain how the work of Denis Hayes and other organizers of Earth Day 1970 serves as a model for changing public opinion and influencing government policy (**Core Case Study**)? How can the three **principles of sustainability** guide wise environmental policymaking? CORE CASE STUDY SUSTAINABILITY

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. If it were 1970, would you participate in a teach-in or other demonstration on Earth Day (**Core Case Study**)? Why or why not? Do you think that a similar global demonstration is called for now, focused on today's environmental challenges? If so, why do you think this has not yet happened as it did in 1970? CORE CASE STUDY

2. Pick an environmental problem that affects the area where you live and decide where in the policy life cycle (Figure 24-2) the problem could best be placed. Apply the cycle to this problem and describe how the problem has progressed (or will likely progress) through each stage. If your problem has not progressed to the control stage, describe how you think the problem would best be dealt with in that stage.

3. Explain why you agree or disagree with each of the seven principles listed on pp. 640–641, which are recommended by some analysts for use in making environmental policy decisions. Which three of these principles do you think are the most important? Why?

4. What are two ways in which the scientific process described in Chapter 2 (see Figure 2-2, p. 33) parallels the policy life cycle (Figure 24-2)? What are two ways in which they differ?

5. Explain why you agree or disagree with **(a)** each of the four principles that biologists and some economists have suggested for using public lands in the United States (pp. 644–645), and with **(b)** each of the five suggestions made by developers and resource extractors for managing and using U.S. public lands (p. 645).

6. Do you think that corporations and government bodies are ever justified in filing SLAPP lawsuits? Give three reasons for your answer. Do you think that potential defendants of SLAPP suits should be protected in any way from such suits? Explain.

7. Government agencies can help to keep an economy growing or to boost certain types of economic development by, for example, building or expanding a major highway through an undeveloped area. Proponents of such development have argued that requiring environmental impact statements for these projects interferes with efforts to help an economy. Do you agree? Is this a problem? Why or why not?

8. List three ways in which you could apply **Concept 24-6** to making your lifestyle more environmentally sustainable.

9. Congratulations! You are in charge of the country where you live. List the five most important components of your environmental policy.

10. List two questions that you would like to have answered as a result of reading this chapter.

DATA ANALYSIS

Choose an environmental issue that you have studied in this course, such as climate change, population growth, or biodiversity loss. Conduct a poll of students, faculty, staff, and local residents by asking them the questions that follow relating to your particular environmental issue. Poll as many people as you can in order to get a large sample. Create categories. For example, note whether each respondent is male or female. By creating such categories, you are placing each person into a *respondent pool*. You can add other questions about age, political leaning, and other factors to refine your pools.

Poll Questions

Question 1 On a scale of 1 to 10, how knowledgeable are you about environmental issue X?

Question 2 On a scale of 1 to 10, how aware are you of ways in which you, as an individual, impact environmental issue X?

Question 3 On a scale of 1 to 10, how important is it for you to learn more about environmental issue X?

Question 4 On a scale of 1 to 10, how sure are you that an individual can have a positive influence on environmental issue X?

Question 5 On a scale of 1 to 10, how sure are you that the government is providing the appropriate level of leadership with regard to environmental issue X?

1. Collect your data and analyze your findings to measure any differences among the respondent pools.

2. List any major conclusions you would draw from the data.

3. Publicize your findings on your school's website or in the local newspaper.

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengagebrain.com/shop/ISBN/0538735341** and choose Chapter 24 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

For students with access to premium online resources, log on to **www.cengage.com/login**.

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Environmental Worldviews, Ethics, and Sustainability

25

Biosphere 2—A Lesson in Humility

CORE CASE STUDY

In 1991, eight scientists (four men and four women) were sealed inside Biosphere 2, a $200 million glass and steel enclosure designed to be a self-sustaining life-support system (Figure 25-1) that would add to our understanding of Biosphere 1: the earth's life-support system.

A sealed system of interconnected domes was built in the desert near Tucson, Arizona (USA). It contained artificial ecosystems including a tropical rain forest, savanna, and desert, as well as lakes, streams, freshwater and saltwater wetlands, and a mini-ocean with a coral reef.

Biosphere 2 was designed to mimic the earth's natural chemical recycling systems. Water evaporated from its ocean and other aquatic systems and then condensed to provide rainfall over the tropical rain forest. The precipitation trickled through soil filters into the marshes and back into the ocean before beginning the cycle again.

The facility was stocked with more than 4,000 species of plants and animals, including small primates, chickens, cats, and insects, selected to help maintain life-support functions. Human and animal excrement and other wastes were treated and recycled to help support plant growth. Sunlight and external natural gas-powered generators provided energy. The Biospherians were to be isolated for 2 years and raise their own food using intensive organic agriculture. They were to breathe air that was purified and recirculated by plants and to drink water cleansed by natural chemical cycling processes.

From the beginning, many unexpected problems cropped up and the life-support system began to unravel. The level of oxygen in the air declined when soil organisms converted it to carbon dioxide. As a result, the Biospherians suffered from headaches, shortness of breath, and the threat of CO_2 and nitrous oxide poisoning. Additional oxygen had to be pumped in from the outside to keep the Biospherians from suffocating.

Tropical birds died after the first freeze. An invading ant species got into the enclosure, proliferated, and killed off most of the system's original insect species. As a result, the facility was overrun with cockroaches, katydids, and ants. In total, 19 of the Biosphere's 25 small animal species went extinct. Before the 2-year period was up, all plant-pollinating insects went extinct, thereby dooming to extinction most of the plant species.

Despite many problems, the facility's waste and wastewater were recycled. With much hard work, the Biospherians were also able to produce 80% of their food supply, despite rampant weed growths, spurred by higher CO_2 levels, that crowded out food crops. However, they suffered from persistent hunger and weight loss.

In the end, an expenditure of $200 million failed to maintain this life-support system for eight people for 2 years. Since 2007, the University of Arizona has been leasing the Biosphere 2 facility for biological research and to provide environmental education for school teachers.

Ecologists Joel E. Cohen and David Tilman, who evaluated the project, concluded, "No one yet knows how to engineer systems that provide humans with life-supporting services that natural ecosystems provide for free." Biosphere 2 is an example of how we can view the earth's life-support system in different ways, based on our worldviews and ethical frameworks, which is the topic of this chapter.

PRNewsFoto/Huron Valley Travel

Figure 25-1 Biosphere 2, constructed near Tucson, Arizona, was designed to be a self-sustaining life-support system for eight people sealed into the facility in 1991. The experiment failed mostly because of a breakdown in its nutrient cycling systems.

Key Questions and Concepts

25-1 What are some major environmental worldviews?

CONCEPT 25-1 Major environmental worldviews differ on which is more important—human needs and wants, or the overall health of ecosystems and the biosphere.

25-2 What is the role of education in living more sustainably?

CONCEPT 25-2 The first step to living more sustainably is to become environmentally literate, primarily by learning from nature.

25-3 How can we live more sustainably?

CONCEPT 25-3 We can live more sustainably by becoming environmentally literate, learning from nature, living more simply and lightly on the earth, and becoming active environmental citizens.

Note: Supplements 3 (p. S6) and 9 (p. S57) can be used with this chapter.

The main ingredients of an environmental ethic are caring about the planet and all of its inhabitants, allowing unselfishness to control the immediate self-interest that harms others, and living each day so as to leave the lightest possible footprints on the planet.

ROBERT CAHN

25-1 What Are Some Major Environmental Worldviews?

▶ **CONCEPT 25-1 Major environmental worldviews differ on which is more important—human needs and wants, or the overall health of ecosystems and the biosphere.**

There Are a Variety of Environmental Worldviews

People disagree on how serious different environmental problems are and what we should do about them. These conflicts arise mostly out of differing **environmental worldviews**—how people think the world works and what they believe their role in the world should be. Part of an environmental worldview is determined by a person's **environmental ethics**—what one believes about what is right and what is wrong in our behavior toward the environment. **Explore More:** See a Case Study at **www.cengage.com/login** to learn more about the environmental aspects of various philosophies and religions.

Worldviews are built from our answers to fundamental questions: Who am I? Why am I here? What should I do with my life? These views provide key principles or values that give us a sense of meaning and purpose, while helping us to sort out and evaluate the continual flood of information and misinformation that bombards us. People with widely differing environmental worldviews can take the same data, be logically consistent in their analysis of those data, and arrive at quite different conclusions, because they start with different assumptions and values. Figure 25-2 summarizes the four major beliefs of each of three major environmental worldviews.

Some environmental worldviews are human-centered (anthropocentric), focusing primarily on the needs and wants of people; others are *life-* or *earth-centered* (biocentric), focusing on individual species, the entire biosphere, or some level in between, as shown in Figure 25-3. As you move from the center of Figure 25-3 to the outside rings, the worldviews become less human-centered and more life- or earth-centered.

Most People Have Human-Centered Environmental Worldviews

It is not surprising that most environmental worldviews are human centered. One such worldview held by many people is the **planetary management worldview**. Figure 25-2 (left) summarizes the major beliefs of this worldview.

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. GOOD NEWS refers to good news about the environmental challenges we face.

Figure 25-2 This is a comparison of three major environmental worldviews (**Concept 25-1**). **Questions:** Which of these descriptions most closely fits your worldview? Which of them most closely fits the worldviews of your parents?

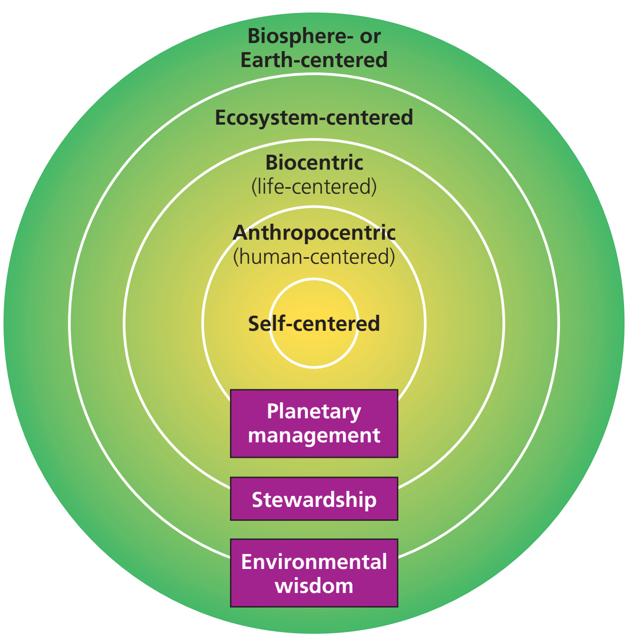


Figure 25-3 Environmental worldviews lie on a scale running from more self- and human-centered (center) to life-, biosphere- or earth-centered (outer rings). Also, as we move out from the center, from human-centered to more earth-centered worldviews, we tend to value other life forms more for their right to exist than for the products and services they can provide for us.

According to this view, humans are the planet's most important and dominant species, and we can and should manage the earth mostly for our own benefit. The values of other species and parts of nature are based primarily on how useful they are to us. According to this view of nature, human well-being depends on the degree of control that we have over natural processes. As the world's most important and intelligent species, we can also redesign the planet and its life-support systems to support us and our ever-growing economies. This was the basic reasoning behind the Biosphere 2 project (**Core Case Study**).

CORE CASE STUDY

Here are three variations of the planetary management environmental worldview:

- The *no-problem school:* We can solve any environmental, population, or resource problem with more economic growth and development, better management, and better technology.
- The *free-market school:* The best way to manage the planet for human benefit is through a free-market global economy with minimal government interference and regulation. All public property resources should be converted to private property resources, and the global marketplace, governed only by free-market competition, should decide essentially everything.
- The *spaceship-earth school:* The earth is like a spaceship: a complex machine that we can understand, dominate, change, and manage, in order to provide a good life for everyone without overloading natural systems. This view developed after people saw photographs taken from outer space showing the earth as a finite planet, or an island in space (see Figure 1-18, p. 21).

Another human-centered environmental worldview is the **stewardship worldview**. It assumes that we have an ethical responsibility to be caring and responsible managers, or stewards, of the earth. Figure 25-2 (center) summarizes the major beliefs of this worldview.

According to the stewardship view, as we use the earth's natural capital, we are borrowing from the earth and from future generations. We have an ethical responsibility to pay this debt by leaving the earth in at least as good a condition as what we now enjoy. Stewardship is what parents do to help provide a better future for their children and grandchildren. When thinking about our responsibility toward future generations, some analysts suggest we consider the wisdom expressed in a law of the 18th-century Iroquois Six Nations Confederacy of Native Americans: *In our every deliberation, we must consider the impact of our decisions on the next seven generations.*

Can We Manage the Earth?

Some people believe any human-centered worldview will eventually fail because it wrongly assumes we now have or can gain enough knowledge to become effective managers or stewards of the earth. As biologist and environmental philospher René Dubos (1901–1982) observed, "The belief that we can manage the earth and improve on nature is probably the ultimate expression of human conceit, but it has deep roots in the past and is almost universal." According to environmental leader Gus Speth, "This view of the world—that nature belongs to us rather than we to nature—is powerful and pervasive—and it has led to much mischief."

According to some critics of human-centered worldviews, the unregulated global free-market approach will not work because it is based on increased degradation and depletion of the earth's natural capital. Also, critics say, it focuses on short-term economic benefits with little regard for the long-term harmful environmental, health, and social consequences that are a result of this worldview.

The image of the earth as an island or spaceship has played an important role in raising global environmental awareness. But critics argue that thinking of the earth as a spaceship that we can manage is an oversimplified, arrogant, and misleading way to view an incredibly complex and ever-changing planet.

Critics of human-centered worldviews point out that we do not even know how many plant and animal species live on the earth, much less what their roles are and how they interact with one another and their nonliving environment. We still have much to learn about what goes on in a handful of soil, a patch of forest (Figure 25-4), the bottom of the ocean, and most other parts of the planet. As biologist David Ehrenfeld puts it, "In no important instance have we been able to demonstrate comprehensive successful management of the world, nor do we understand it well enough to manage it even in theory." This belief is supported by the failure of the Biosphere 2 project (**Core Case Study**). CORE CASE STUDY


Jim Lopes/Shutterstock

Figure 25-4 We have very limited understanding of how these giant sequoia trees in Sequoia National Park (USA), the soil underneath them, and the plants and animals in the surrounding forest ecosystem survive, interact, and change in response to different environmental conditions. Despite this ecological ignorance, we continue to clear-cut large areas of forestland throughout the world. **Questions:** How does this lack of knowledge relate to the planetary management worldview? Does this mean that we should never clear a forest? Explain.

Some People Have Life-Centered and Earth-Centered Environmental Worldviews

Critics of human-centered environmental worldviews argue that they should be expanded to recognize that all forms of life have value as participating members of the biosphere, regardless of their potential or actual use to humans. Many of the world's religions call for such basic respect for all life forms. **Explore More:** See a Case Study at **www.cengage.com/login** to learn more about the environmental aspects of various philosophies and religions.

However, people disagree about how far we should extend our ethical concerns for various forms of life (Figure 25-5). Most people with a life-centered worldview believe we have an ethical responsibility to avoid causing the premature extinction of species through

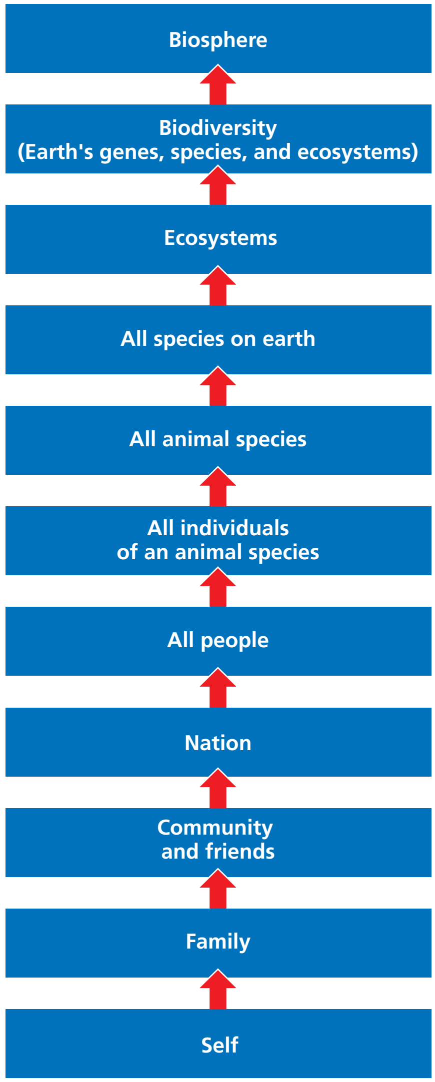


Figure 25-5 Levels of ethical concern: People disagree about how far we should extend our ethical concerns on this scale. **Question:** How far up this scale would you extend your own ethical concerns?

our activities, for two reasons. First, each species is a unique storehouse of genetic information that should be respected and protected simply because it exists. Second, each species has potential economic benefit for human use.

Some people think we should go beyond focusing mostly on species. They believe we have an ethical responsibility to take a wider view and work to prevent degradation of the earth's ecosystems, biodiversity, and the biosphere. This *earth-centered* environmental worldview is devoted to helping to sustain the earth's biodiversity and the functioning of its life-support systems for all forms of life, now and in the future.

People with earth-centered worldviews believe that humans are not in charge of the world and that human economies and other systems are subsystems of the earth's life-support systems (see Figure 23-5, p. 617). Their view is that the natural system that we are all part of is holistic, that is, interconnected and interdependent. They understand that the earth's natural capital (see Figure 1-4, p. 9) keeps us and other species alive and supports our economies. They also understand that preventing the depletion and degradation of this natural capital as a key way to promote environmental sustainability (Figure 25-6). They argue that preserving the earth's natural capital requires that we mimic nature by applying the three **principles of sustainabiliy** (see back cover) to human economies and lifestyles.

Earth-centered worldviews hold that because humans and all forms of life are interconnected parts of the earth's life-support system, it is in our own self-interest not to act in ways that impair the overall system. From this viewpoint, an earth-centered worldview is also more practical than human-centered worldviews.

One earth-centered worldview is called the **environmental wisdom worldview**. Figure 25-2 (right) summarizes its major beliefs. According to this view, we are within and part of—not apart from—the community of life and the ecological processes that sustain all life. This view holds that the sustainability of our species, civilizations, and economies depends on the sustainability of the biosphere, of which we are just one part. Thus, promoting global sustainabilty helps each of us to safeguard our own individual health and safety, as well as our future as a species. In other words, all efforts to promote sustainability are local and personal. In many respects, the environmental wisdom worldview is the opposite of the planetary management worldview (Figure 25-2, left).

The environmental wisdom worldview suggests that the earth does not need us to manage it in order for it

Courtesy of Earth Flag Co.

Figure 25-6 The earth flag is a symbol of commitment to promoting environmental sustainability by working with the earth at the individual, local, national, and international levels. Chief Seattle (1786–1866), leader of the Suquamish and Duwamish Native American tribes in what is now the U.S. state of Washington, summarized this ethical belief: "The earth does not belong to us. We belong to the earth." **Question:** Do you agree or disagree with Chief Seattle's view? Explain.

to survive, whereas we need the earth for our survival. From this perspective, *talk about saving the earth makes no sense, because the earth does not need saving*. Life on earth has sustained itself for billions of years and will continue with or without the very recent arrival of the species that named itself "the doubly-wise species" (*Homo sapiens sapiens*). What we do need to save is the existence of our own species and cultures—which have been around for less than an eyeblink of the 3.5-billion-year history of life on the earth—as well as the existence of other species that may become extinct because of our activities. (See the Guest Essay on this topic by sustainability expert Lester W. Milbrath at CengageNOW.) **Explore More:** See a Case Study at **www.cengage.com/login**

on the deep ecology worldview, which is related to the environmental wisdom worldview.

THINKING ABOUT
Environmental Worldviews and Biosphere 2

CORE CASE STUDY

What environmental worldview is the most compatible with the failure of Biosphere 2 (**Core Case Study**)?

HOW WOULD YOU VOTE?

Which one of the following comes closest to your environmental worldview: planetary management, stewardship, or environmental wisdom? Cast your vote online at **www.cengage.com/login**.

25-2 What Is the Role of Education in Living More Sustainably?

CONCEPT 25-2 **The first step to living more sustainably is to become environmentally literate, primarily by learning from nature.**

How We Can Become More Environmentally Literate?

There is widespread evidence and agreement that we are a species in the process of degrading our own life-support system at an increasing rate and that during this century, this behavior will very likely threaten human civiilization and the existence of up to half of the world's species. Part of the problem stems from our ignorance about how the earth works, what we are doing to its life-sustaining systems, and how we can change our behavior toward the earth. Correcting this begins by understanding three important ideas that form the foundation of environmental literacy:

1. *Natural capital matters* because it supports the earth's life and our economies.
2. *Our ecological footprints are immense and are expanding rapidly*; in fact, they already exceed the earth's estimated ecological capacity (see Figure 1-13, p. 16).
3. *Ecological and climate-change tipping points* (see Figure 19-15, p. 511) *are irreversible and should never be crossed*. Once we cross such a point, neither money nor technology can save us from the resulting consequences, which could last for thousands of years.

According to the environmental wisdom worldview, learning how to work with the earth, instead of thinking of ourselves as being in charge of it and thus working against it, is the key to environmental sustainability and thus to the sustainability of the human species. It involves being motivated by hope and valuing cooperation and moderation, instead of being driven by fear and manipulated by misinformation and believing that having more and more stuff is the key to happiness.

Acquiring environmental literacy involves being able to answer certain key questions and having a basic understanding of certain key topics, as summarized in Figure 25-7.

Science writer Janine M. Benyus and various scientists have been pioneering a new science called *biomimicry*. They urge scientists, engineers, business executives, and entrepreneurs to study the earth's living systems to find out what works and what lasts and how we might copy such earth wisdom. For example, gecko lizards have pads on their feet that allow them to cling to rocks, glass, and other surfaces. Researchers are using this information to develop a new type of adhesive tape. Ray Anderson (see Chapter 23, Individuals Matter, p. 626) created a best-selling carpet tile that mimicks the diverse nature of the floor of a tropical rain forest.

As authors, we also studied how nature works and how life has sustained itself, and we arrived at three **principles of sustainability**, which we have used throughout this book to help you understand environmental problems and evaluate possible solutions to such problems.

SUSTAINABILITY

Can We Learn from the Earth?

Formal environmental education is important, but is it enough? Many analysts say no. They call for us to appreciate not just the economic value of nature, but

Questions to answer

- How does life on earth sustain itself?
- How am I connected to the earth and other living things?
- Where do the things I consume come from and where do they go after I use them?
- What is environmental wisdom?
- What is my environmental worldview?
- What is my environmental responsibility as a human being?

Components

- Basic concepts: sustainability, natural capital, exponential growth, carrying capacity
- Three principles of sustainablility
- Environmental history
- The two laws of thermodynamics and the law of conservation of matter
- Basic principles of ecology: food webs, nutrient cycling, biodiversity, ecological succession
- Population dynamics
- Sustainable agriculture and forestry
- Soil conservation
- Sustainable water use
- Nonrenewable mineral resources
- Nonrenewable and renewable energy resources
- Climate disruption and ozone depletion
- Pollution prevention and waste reduction
- Environmentally sustainable economic and political systems
- Environmental worldviews and ethics

Figure 25-7 Achieving environmental literacy involves being able to answer certain questions and having an understanding of certain key topics (**Concept 25-2**). **Question:** After taking this course, do you feel that you can answer the questions asked here and have a basic understanding of each of the key topics listed in this figure?

also its ecological, aesthetic, and spiritual values. To these analysts, the problem is not just a lack of environmental literacy but also, for many people, a lack of intimate contact with nature and little understanding of how nature works and sustains us.

We face a dangerous paradox. At a time when humans have more technology and power than ever before to degrade and disrupt nature, most people know little about nature, and have little direct contact with it. Technology has led many people to see themselves as being apart from nature instead of being part of it all. Critics of this view warn that it distorts our understanding of what it means to be human and blunts our ethical ability to act responsibly toward the earth. A growing chorus of analysts and ethicists urge us to reconnect with and learn directly from nature as an important way for us to help sustain the earth's precious biodiversity and our own species and cultures.

Some ethicists suggest we kindle a sense of awe, wonder, mystery, excitement, and humility by standing under the stars, sitting in a forest (Figure 25-4), experiencing a mountain lake (Figure 25-8, top), or taking in the majesty and power of the sea (Figure 25-8, bottom). We might pick up a handful of soil and try to sense the teeming microscopic life within it that helps to keep us alive. We might look at a tree, mountain, rock, or bee, or listen to the sound of a bird and try to sense how each of them is connected to us and we to them, through the earth's life-sustaining processes.

Pichugin Dmitry/Shutterstock

Epic Stock/Shutterstock

Figure 25-8 An important way to learn about and to appreciate nature, as well as to develop a sense of humility, is to experience its beauty, power, and complexity first-hand. This involves understanding that we are part of—and not apart from or in charge of—nature.

Such direct experiences with nature reveal parts of the complex web of life that cannot be bought, recreated through technology (**Core Case Study**) CORE CASE STUDY or in a chemistry lab, or reproduced through genetic engineering. Understanding and directly experiencing the precious gifts we receive at no charge from nature can help to foster within us the ethical commitment that we need in order to live more sustainably on this earth.

CONNECTIONS

Disconnecting from Technology and Reconnecting with Nature

Many of us who venture into the natural world want to carry our GPS units, cell phones, I-pods, and other technological marvels that keep us in touch with the world we have temporarily left behind. But this stuff can divert much of our attention from the natural world that surrounds us during such ventures. If our goal is to reconnect with and experience the natural world, it helps to disconnect from these devices.

Earth-focused philosophers say that to be rooted, each of us needs to find a *sense of place*—a stream, a mountain, a yard, a neighborhood lot—any piece of the earth with which we feel as one in a place we know, experience emotionally, and love. According to biologist Stephen Jay Gould (1941–2002), "We will not fight to save what we do not love." When we become part of a place, it becomes a part of us. Then we are driven to defend it from harm and to help heal its wounds.

In other words, find out what you really care about and live a life that shows it. As Mahatma Gandhi (1869–1948), one of India's most revered spiritual and political leaders, observed, "We must become the change we want to see in the world." If we think and act in this way, we might discover and tap into GOOD NEWS what conservationist Aldo Leopold (Individuals Matter, below) called "the green fire that burns in our hearts." We might then develop a passion for using this energy as a force for respecting and working with the earth and with one another.

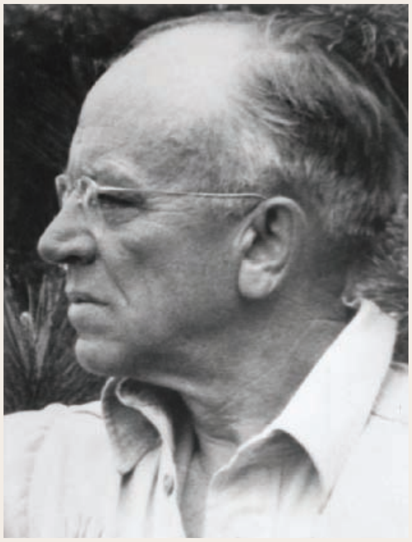
INDIVIDUALS MATTER

Aldo Leopold's Environmental Ethics

According to the renowned American forester, ecologist, and writer Aldo Leopold (Figure 25-A), the role of the human species should be to protect nature, not to conquer it.

In 1933, Leopold became a professor at the University of Wisconsin and in 1935, he helped to found the U.S. Wilderness Society. Through his writings and teachings, he became one of the foremost leaders of the *conservation* and *environmental movements* during the 20th century. His energy and foresight helped to lay the critical groundwork for the field of environmental ethics.

Leopold's weekends of planting trees, hiking, and observing nature firsthand on his Wisconsin farm provided much of the material for *A Sand County Almanac*. Since then, more than 2 million copies of this environmental classic have been sold.



Robert McCabe/Courtesy of the University of Wisconsin—Madison Archives

Figure 25-A **Individuals matter:** *Aldo Leopold* (1887–1948) was a forester, writer, and conservationist. His book, *A Sand County Almanac* (published after his death), is considered an environmental classic that helped to inspire the modern environmental and conservation movements.

The following quotations from his writings reflect Leopold's *land ethic*, and they form the basis for many of the beliefs and principles of the modern stewardship and environmental wisdom worldviews:

- *All ethics so far evolved rest upon a single premise: that the individual is a member of a community of interdependent parts.*
- *To keep every cog and wheel is the first precaution of intelligent tinkering.*
- *That land is a community is the basic concept of ecology, but that land is to be loved and respected is an extension of ethics.*
- *The land ethic changes the role of* Homo sapiens *from conqueror of the land-community to plain member and citizen of it.*
- *We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect.*
- *A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise.*

Critical Thinking

Which of the quotations above do you agree with? Which, if any, of these ethical principles do you put into practice in your own life?

25-3 How Can We Live More Sustainably?

▶ **CONCEPT 25-3 We can live more sustainably by becoming environmentally literate, learning from nature, living more simply and lightly on the earth, and becoming active environmental citizens.**

Can We Live More Simply and Lightly on the Earth?

Sustainability is not only about sustaining resources for our use. It is about working to help sustain the entire web of life, because all past, present, and future forms of life are connected. Here are six ethical guidelines for achieving more sustainable and compassionate societies by converting environmental concerns, literacy, and wisdom into environmentally responsible actions.

1. Use the three **principles of sustainability** (see back cover) to mimic the ways in which nature sustains itself.
2. Do not deplete or degrade the earth's natural capital.
3. Do not waste matter and energy resources.
4. Protect biodiversity.
5. Repair ecological damage that we have caused.
6. Leave the earth in as good a condition as we found it or better.

In the world's affluent societies, businesses use mass advertising to create ever-increasing material wants that lead to high levels of consumption, which in turn support high-throughput economies (see Figure 23-4, p. 617) that create waste and pollution and degrade our life-support system. Some argue that we can avoid this degradation as our technologies become better and more efficient. However, in 2010, the Worldwatch Society noted that during the past three decades, there has been a 30% improvement in resource efficiency, but global resource use has expanded by 50%. According to environmental leader Gus Speth, our cultures based on ever-increasing consumption are setting us up for a "great collision" between the human race with its seemingly infinite demands and the limits to available resources on our finite planet.

Analysts urge people who have a habit of consuming excessively to *learn how to live more simply and sustainably*. Seeking happiness through the pursuit of material things is considered folly by almost every major religion and philosophy.

Yet mass-market advertising persistently and effectivly encourages people to buy more and more things to fill a growing list of wants and imagined needs, presumably as a way to achieve happiness. As American humorist and writer Mark Twain (1835–1910) observed: "Civilization is the limitless multiplication of unnecessary necessities." American comedian George Carlin (1937–2008) put it another way: "A house is just a pile of stuff with a cover on it. It's a place to keep your stuff while you go out and get more stuff."

According to recent research by psychologists, deep down, what a growing number of people really want is more community, not more stuff. They want greater and more fulfilling interactions with family, friends, neighbors, and nature, and a greater opportunity to express their creativity and to have more fun.

Some affluent people in more-developed countries are adopting a lifestyle of *voluntary simplicity*, in which they seek to learn how to live with much less than they are accustomed to having. These people have found that a life based mostly on what one owns is not fulfilling for them. Thus they are living with fewer material possessions and using products and services that have a smaller environmental impact (**Concept 25-3**). Instead of working longer to pay for bigger vehicles and houses, they are spending more time with their loved ones, friends, and neighbors. This voluntary simplicity applies Mahatma Gandhi's *principle of "enoughness"*:

> *The earth provides enough to satisfy every person's need but not every person's greed. When we take more than we need, we are simply taking from each other, borrowing from the future, or destroying the environment and other species.*

Most of the world's major religions have similar teachings: "You cannot be the slave both of God and money." (Christianity: Matthew 6:24); "Eat and drink, but waste not by excess." (Islam: Qur'an 7.31); "One should abstain from acquisitiveness." (Hinduism: Acarangasutra 2.114–19); "He who knows he has enough is rich." (Taoism: Tao Te Ching, Chapter 33); "Give me neither poverty nor riches." (Judaism: Proverbs 30.8); "Whosoever in this world overcomes his selfish cravings, his sorrows fall away from him." (Buddhism: Dhammapada, 336)

How Much Is Enough?

Living more lightly starts with asking this question: How much is enough? Similarly, one can also ask: What do I really need? These are not easy questions to answer. Obviously, each of us has a basic need for enough food, clean air, clean water, shelter, and clothing to keep us alive and in good health. But beyond that, each of us must decide how much of anything is enough.

People in affluent societies are conditioned to want more and more material possessions. Thus, as a result of a lifetime exposure to commercial advertising, they often think of such wants as needs. For example, in increasingly affluent societies certain goods that were once considered luxuries—television sets, cell phones, personal computers, and i-pods—now are considered necessities by a rapidly growing number of people.

THINKING ABOUT
Your Basic Needs

Make a list of your basic needs. Is your list of needs compatible with your environmental worldview?

Some analysts have suggested that the need felt by some people to acquire more and more goods should be treated as an addiction in some cases. There may be a growing need for counselors and support groups on the order of Alcoholics Anonymous to help people break this addiction to material possessions, at least when they habitually run up large personal debts to feed their habits. In addition, personal debts incurred for excessive consumption also contribute to national and global ecological debts when we consider the amounts of energy and materials that go into making consumer goods (Figure 14-12, p. 356). Figure 25-9 lists five steps

- Avoid buying something just because a friend has bought it
- Go on an ad diet by not watching or reading advertisements
- Avoid shopping for recreation and buying on impulse
- Stop using credit and buy only with cash to avoid overspending
- Borrow and share things like books, tools, and other consumer goods

Figure 25-9 Here are five ways to withdraw from an addiction to buying more and more stuff.

that people can use to help them withdraw from this addiction.

Throughout this text, you have encountered lists of steps we can take to live more lightly by reducing the *size* and *impact* of our ecological footprints on the earth. It would be difficult for most of us to do all or even most of these things. So which ones are the most important? The human activities that have the greatest harmful impacts on the environment are *food production*, *transportation*, *home energy use*, and *overall resource use*. Based on this fact, Figure 25-10 lists the *sustainability eight*—8 key ways in which some people are choosing to live more simply.

Food

Reduce meat consumption

Buy or grow organic food and buy locally grown food

Transportation

Reduce car use by walking, biking, carpooling, car-sharing, and using mass transit

Drive an energy-efficient vehicle

Home Energy Use

Insulate your house, plug air leaks, and install energy-efficient windows

Use energy-efficient heating and cooling systems, lights, and appliances

Resource Use

Reduce, reuse, recycle, compost, replant, and share

Use renewable energy resources whenever possible

Figure 25-10 *The sustainability eight* is a list of eight ways in which people can live more lightly on the earth (**Concept 25-3**). **Questions:** Which of these things do you already do? Which, if any, do you hope to do?

THINKING ABOUT
The Sustainability Eight

Which three of the eight steps in Figure 25-10 do you think are the most important? Which three of these things do you already do? Which of them are you thinking about doing? How do your answers to these questions relate to **(a)** the three principles of sustainability, and **(b)** to your environmental worldview?

Living more sustainably is not easy, and we will not make this transition by relying primarily on technological fixes such as recycling, changing to energy-efficient lightbulbs, and driving energy-efficient hybrid cars. These are, of course, important things to do, and they can help us to shrink our ecological footprints and to feel less guilty about our harmful impacts on our life-support system. But these efforts still do not solve the problems of excessive consumption and unnecessary waste of matter and energy resources.

Many of the more effective, far-reaching, and sustainable solutions to these problems will involve changing the way we think about, and act in, the world. It starts with this question: How can I live more sustainably? This involves each of us examining our behavior and perhaps adopting a new environmental worldview. When we change all or part our worldview, we act differently because it no longer makes sense to act the way we did before. When this happens, we might experience a *mindquake*, or mental leap that transforms the way we think and live by opening us up to new possibilities.

The essence of human creativity is to embrace change rather than to fear it. The changes we make that enable us to live more lightly on the earth put us on a path toward true sustainability based on caring for ourselves, for other human beings, and for the earth and its diversity of life forms and processes that sustain us.

Can We Become Better Environmental Citizens?

In the end, the answer to this question comes down to what each of us does to help make the earth a better place to live for current and future generations, for other species, and for the ecosystems that support us. Some suggest that we can move beyond blame, guilt, fear, and apathy by recognizing and avoiding the following two common mental traps that lead to denial, indifference, and inaction:

- *Gloom-and-doom pessimism* (it is hopeless)
- *Blind technological optimism* (science and technofixes will save us)

Avoiding these traps helps us to hold on to, and be inspired by, empowering feelings of realistic hope, rather than to be immobilized by feelings of despair and fear or falsely assured by unrealistic optimism.

THINKING ABOUT
Mental Traps

Have you fallen into either of these traps? If so, are you aware that you have, and how do you think you could free yourself from either of them?

Here is what business entrepreneur and environmental writer Paul Hawken told the 2009 graduating class at the University of Portland in the U.S. state of Oregon:

> When asked if I am pessimistic or optimistic about the future, my answer is always the same: If you look at the science about what is happening on the earth and aren't pessimistic, you don't understand the data. But if you meet the people who are working to restore this earth and the lives of the poor, and you aren't optimistic, you haven't got a pulse . . . This is your century. Take it and run as if your life depends on it.

It is important to recognize that there is no single correct or best solution to each of the environmental problems we face. Indeed, one of nature's three **principles of sustainability** holds that preserving diversity—in this case, being flexible and adaptable in trying a variety of cultural and technological solutions to our problems—is the best way to adapt to the earth's largely unpredictable, ever-changing conditions.

Finally, we should have fun and take time to enjoy life. Laugh every day and enjoy and celebrate nature, beauty, connectedness, friendship, and love. This can empower us to become good earth citizens who practice *good earthkeeping*. As Mahatma Gandhi reminded us, "Power based on love is a thousand times more effective and permanent than power derived from fear."

A Vision for Sustainability

In the first Core Case Study in this book (see Chapter 1, p. 5), we sketched out one possible future for our planet. It is a hopeful and promising vision, and we believe it is attainable, probably within your lifetime. Whether or not it becomes reality is up to us.

The Industrial Revolution was a remarkable global transformation that has taken place over the past 275 years. Now in this century, environmental leaders say it is time for another sort of global transformation—an *environmental* or *sustainability revolution* that could lead to the kind of world we envisioned in the Chapter 1 Core Case Study. Figure 25-11 (p. 672) lists some of the major cultural shifts in emphasis that we will need to make in order to bring about such an environmental revolution.

Current Emphasis	Sustainability Emphasis
Energy and Climate	
Fossil fuels	Direct and indirect solar energy
Energy waste	Energy efficiency
Climate disruption	Climate stabilization
Matter	
High resource use and waste	Less resource use
Consume and throwaway	Reduce, reuse, and recycle
Waste disposal and pollution control	Waste prevention and pollution prevention
Life	
Deplete and degrade natural capital	Protect natural capital
Reduce biodiversity	Protect biodiversity
Population growth	Population stabilization

Figure 25-11 **Solutions:** These are some of the cultural shifts in emphasis that will be necessary to bring about the *environmental* or *sustainability revolution*. **Questions:** Which three of these shifts do you think are most important? Why?

We can use the incredible power of exponential growth to help us bring about a sustainability revolution. Recall that if you could fold a piece of paper in half 50 times (see Chapter 1, p. 20), you would wind up with a stack of paper high enough to reach the sun—some 149 million kilometers (93 million miles) away. We could use the power of exponential growth to promote more sustainable environmental, social, economic, and technological changes at an exhilaring speed (Figure 25-12).

We know what needs to be done and we can change. Experience suggests that in order for a major social change to occur, only 5–10% of the people in the world, or in a country or locality, must be convinced that change must take place and then act to convince a majority of people to bring about such change. We, the authors, believe that we are close to this critical mass, or *political and ethical tipping point*, in terms of our awareness of major environmental issues.

History shows that we can change faster than we might think, once we have the courage to leave behind ideas and practices that no longer work and to nuture new ideas for positive change (Figure 25-12). We can no longer afford to make big mistakes in our treatment of planet Earth, because as biodiversity expert Edward O. Wilson points out, there is only "One Earth. One Experiment." Indeed, as biologist Paul R. Ehrlich observed, "Nature always bats last and owns the stadium."

Some say that making this shift is idealistic and unrealistic. Others say that it is idealistic, unrealistic, and dangerous to keep assuming that our present course is sustainable, and they warn that we have

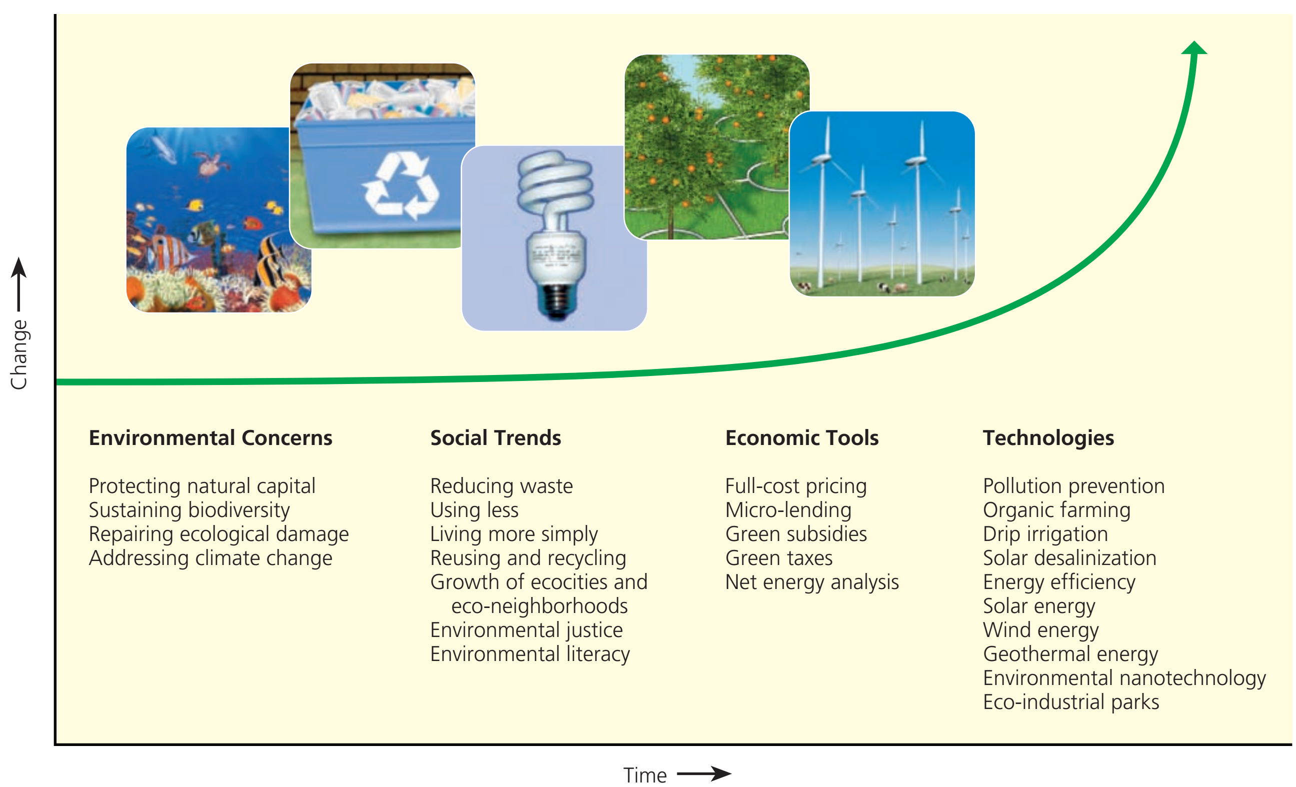


Figure 25-12 Change can occur very rapidly. Using the astonishing power of exponential growth, we could bring about a sustainability revolution in a very short time. Exponential growth starts off slowly, but at some point it increases at a very rapid rate and heads sharply upward. Listed below this curve are some concerns, trends, tools, and technologies that could all be part of a major shift toward a more sustainable world within your lifetime. **Questions:** Which two items in each of these four categories do you believe are the most important to promote? What other items would you add to this list?

precious little time to change. In his 2009 graduation address Paul Hawken observed that "The most unrealistic person in the world is the cynic not the dreamer." As Irish playwright George Bernard Shaw (1856–1950) wrote, "I dream things that never were; and I say, 'Why not?'" If certain individuals had not had the courage to forge ahead with ideas that others called idealistic and unrealistic, very few of the human achievements that we now celebrate would have come to pass.

Here is a one-paragraph summary of this book. We have used three scientific laws that have never been violated—the law of conservation of matter and the two laws of thermodynamics—and three principles of sustainability, derived from our analysis of how nature has sustained itself for billions of years, to help you to understand the environmental problems we face and to evaluate proposed solutions to these problems. The beauty of this is that these three laws and these three principles are very easy to grasp. The challenge is for us, as individuals and as a society, to find and hold on to the personal, ethical, and political will to implement this understanding into our lives, economies, and political systems.

Here are this chapter's *three big ideas:*

- Our environmental worldview plays a key role in how we treat the earth that sustains us and how we treat ourselves.
- We need to become more environmentally literate about how the earth works, how we are affecting its life-support systems that keep us and other species alive, and what we can do to live more sustainably.
- Living more sustainably means learning from nature, living more lightly on the earth, and becoming active environmental citizens who leave small environmental footprints on the earth.

REVISITING Biosphere 2 and Sustainability

CORE CASE STUDY

SUSTAINABILITY

In Biosphere 2 (**Core Case Study**), scientists tried to create a microcosm of the earth that would help us understand how to live more sustainably. What they learned was that nature is so complex that predicting and controlling what will happen in the environment is essentially impossible.

As we explore different paths toward sustainability, we must first understand that our lives and societies depend on *natural capital* and that one of the biggest threats to our ways of life is our active role in *natural capital degradation*. With that understanding, we can begin the search for *solutions* to difficult environmental problems. Competing interests working together to find the solutions must make *trade-offs*, because this is the essence of the political process.

Most of the solutions we end up with will likely be governed by one or more of the three **principles of sustainability**. For the energy to keep our lives and economies going, we will need to depend largely on direct and indirect forms of renewable solar energy. We will need to reuse and recycle as much of our material resources as we can, in keeping with nature's chemical cycling principle, and drasically cut our waste of matter and energy resources. We will benefit by preserving as much as we possibly can of the earth's natural biodiversity. The solutions that work will also likely mimic nature's biodiversity by consisting of a diversity of localized solutions all interconnected in a self-sustaining web.

All of this requires our understanding that *individuals matter*. Virtually all of the environmental progress we have made during the last few decades occurred because individuals banded together to insist that we can do better. The journey begins in our own communities and with our own lifestyles, because in the final analysis, *all sustainability is local and personal*. That is the meaning of the motto, "Think globally; act locally." This is an incredible and exciting time to be alive as we learn how to live more lightly on our planetary home.

When there is no dream, the people perish.

PROVERBS 29:18

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 662. Describe the Biosphere 2 project and the major lessons learned from this project (**Core Case Study**). CORE CASE STUDY
2. What is an **environmental worldview**? What are **environmental ethics**? Distinguish among the following environmental worldviews: **planetary management**, **stewardship**, and **environmental wisdom**. What are three variations of the planetary management worldview? Discuss the controversy over whether we can effectively manage the earth.
3. Discuss the controversy over how far we should extend our ethical concerns for various forms of life (Figure 25-5). Give two reasons why we should not cause the premature extinction of any species. Explain why talking about saving the earth is nonsense.

4. What three ideas make up the foundation of environmental literacy? List six questions that an environmentally literate person should be able to answer.

5. Describe how we can learn from direct experience with the earth. Explain the difficulty that many people have in getting this experience. What is a sense of place and why is it important?

6. Describe Aldo Leopold's principles of environmental ethics. List six ethical guidelines for achieving more sustainable and compassionate societies.

7. Describe the relationship between owning things and being happy. What is *voluntary simplicity*? What is the principle of "enoughness"? How do we distinguish between basic needs and wants?

8. List eight important steps that individuals can take in learning to live more simply and sustainably.

9. Describe two mental traps that can lead to denial, indifference, and inaction concerning the environmental problems we face. List the major shifts involved in achieving more sustainable societies. List two pieces of good news about our ability to make such a cultural shift.

10. How would you summarize the main goal of this textbook? What are this chapter's *three big ideas*? Describe connections between Biosphere 2 (**Core Case Study**), the transition to more environmentally sustainable societies, and the three **principles of sustainability**.

CORE CASE STUDY

SUSTAINABILITY

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. Some analysts argue that the problems with Biosphere 2 (**Core Case Study**) resulted mostly from inadequate design, and that a better team of scientists and engineers could make it work. Explain why you agree or disagree with this view.

CORE CASE STUDY

2. Do you believe that we have an ethical responsibility to leave the earth's natural systems in as good, or better, a condition as they are now? Explain. List three aspects of your lifestyle that hinder implementing this ideal and three aspects that promote this ideal.

3. This chapter summarized several different environmental worldviews. Go through these worldviews and find the beliefs you agree with and then describe your own environmental worldview. Which of your beliefs were added or modified as a result of taking this course? Compare your answers with those of your classmates.

4. Explain why you agree or disagree with the following ideas: **(a)** everyone has the right to have as many children as they want; **(b)** all people have a right to use as many resources as they want; **(c)** individuals should have the right to do whatever they want with land they own, regardless of whether such actions harm the environment, their neighbors, or the local community; **(d)** other species exist to be used by humans; **(e)** all forms of life have a right to exist. Are your answers consistent with the beliefs that make up your environmental worldview, which you described in question 3?

5. The American theologian, Thomas Berry (1914–2009), called the industrial–consumer society, built on the human-centered, planetary management environmental worldview, the "supreme pathology of all history." He said, "We can break the mountains apart; we can drain the rivers and flood the valleys. We can turn the most luxuriant forests into throwaway paper products. We can tear apart the great grass cover of the western plains, and pour toxic chemicals into the soil and pesticides onto the fields, until the soil is dead and blows away in the wind. We can pollute the air with acids, the rivers with sewage, the seas with oil. We can invent computers capable of processing 10 million calculations per second. And why? To increase the volume and speed with which we move natural resources through the consumer economy to the junk pile or the waste heap. If, in these activities, the topography of the planet is damaged, if the environment is made inhospitable for a multitude of living species, then so be it. We are, supposedly, creating a technological wonderworld. But our supposed progress is bringing us to a wasteworld instead of a wonderworld." Explain why you agree or disagree with this assessment. If you disagree, answer at least five of Berry's charges with your own arguments as to why you think he is wrong. If you agree, cite evidence as to why.

6. Some analysts believe that trying to gain environmental wisdom by experiencing the earth and forming an emotional bond with its life forms and processes is unscientific, mystical nonsense based on a romanticized view of nature. They believe that having a better scientific understanding of how the earth works and inventing or improving technologies are the best ways to achieve sustainability. Do you agree or disagree? Explain.

7. Revisit the Core Case study in Chapter 1 (p. 5) entitled "A Vision of a More Sustainable World in 2060." Now that you are near the end of this textbook and course, do you feel that we have a reasonable chance of making the transition described on page 5? Explain. Is your view more or less hopeful than it was when you began this course? Compare your answers with those of your classmates.

8. Do you believe that we have any ethical obligations to maintain a liveable world for future generations of **(a)** humans and **(b)** other species. Explain.

9. If you could use television or YouTube to speak to everyone in the world today about our environmental problems, what are the three most important pieces of environmental wisdom that you would give in your speech? What beliefs from your environmental worldview influenced your selection of these three items? Compare your choices with those of your classmates.

10. List two questions that you would like to have answered as a result of reading this chapter.

ECOLOGICAL FOOTPRINT ANALYSIS

As a class, conduct an ecological footprint analysis of your campus. Work with a partner, or in small groups, to research and investigate a system in your school such as recycling/composting; water use; food service practices; energy use; building management and energy conservation; transportation (both on- and off-campus school-related trips); grounds maintenance; institutional environmental awareness; and environmental education curriculum. Depending on your school and its location, you may be able to add more areas to the investigation. You may decide to study the campus as a whole, or you may decide to break down the campus into smaller research areas, such as dorms, administrative buildings, classroom buildings, grounds, and other areas.

1. After deciding on your group's research area, conduct your analysis. As part of your analysis, develop a list of questions that will help you to determine the ecological impact related to your chosen topic. Each question item in the audit could have a range of responses on a scale of 1 (poor) to 10 (excellent). Or, you may come up with your own measurement system.

2. Analyze your results and share them with the class to determine what can be done to shrink the ecological footprint of your school.

3. Arrange a meeting with school officials to share your action plan with them.

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengagebrain.com/shop/ISBN/0538735341** and choose Chapter 25 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

For students with access to premium online resources, log on to **www.cengage.com/login**.

Find the latest news and research, (including videos and podcasts), at the GLOBAL ENVIRONMENT WATCH. Visit **www.CengageBrain.com** for more information.

Supplements

1 **Measurement Units** S2
Chapters 2, 3

2 **Reading Graphs and Maps** S3
Chapters 1–24

3 **Environmental History of the United States** S6
Chapters 3, 9, 10, 12, 13, 18, 22, 24, 25

4 **Some Basic Chemistry** S11
Chapters 1–4, 12, 14, 17–19, 21

5 **Classifying and Naming Species** S18
Chapters 1, 3–5, 9

6 **Components and Interactions in Major Biomes** S20
Chapters 3, 7, 10, 16, 20

7 **Weather Basics: El Niño, Tornadoes, and Tropical Cyclones** S26
Chapters 7, 18, 19

8 **Maps** S30
Chapters 1, 3, 5–19, 22–24

9 **Environmental Data and Data Analysis** S57
Chapters 3, 6, 7, 14–16, 19, 21–23, 25

SUPPLEMENT 1

Measurement Units (Chapters 2, 3)

LENGTH

Metric
1 kilometer (km) = 1,000 meters (m)
1 meter (m) = 100 centimeters (cm)
1 meter (m) = 1,000 millimeters (mm)
1 centimeter (cm) = 0.01 meter (m)
1 millimeter (mm) = 0.001 meter (m)

English
1 foot (ft) = 12 inches (in)
1 yard (yd) = 3 feet (ft)
1 mile (mi) = 5,280 feet (ft)
1 nautical mile = 1.15 miles

Metric–English
1 kilometer (km) = 0.621 mile (mi)
1 meter (m) = 39.4 inches (in)
1 inch (in) = 2.54 centimeters (cm)
1 foot (ft) = 0.305 meter (m)
1 yard (yd) = 0.914 meter (m)
1 nautical mile = 1.85 kilometers (km)

AREA

Metric
1 square kilometer (km^2) = 1,000,000 square meters (m^2)
1 square meter (m^2) = 1,000,000 square millimeters (mm^2)
1 hectare (ha) = 10,000 square meters (m^2)
1 hectare (ha) = 0.01 square kilometer (km^2)

English
1 square foot (ft^2) = 144 square inches (in^2)
1 square yard (yd^2) = 9 square feet (ft^2)
1 square mile (mi^2) = 27,880,000 square feet (ft^2)
1 acre (ac) = 43,560 square feet (ft^2)

Metric–English
1 hectare (ha) = 2.471 acres (ac)
1 square kilometer (km^2) = 0.386 square mile (mi^2)
1 square meter (m^2) = 1.196 square yards (yd^2)
1 square meter (m^2) = 10.76 square feet (ft^2)
1 square centimeter (cm^2) = 0.155 square inch (in^2)

VOLUME

Metric
1 cubic kilometer (km^3) = 1,000,000,000 cubic meters (m^3)
1 cubic meter (m^3) = 1,000,000 cubic centimeters (cm^3)
1 liter (L) = 1,000 milliliters (mL) = 1,000 cubic centimeters (cm^3)
1 milliliter (mL) = 0.001 liter (L)
1 milliliter (mL) = 1 cubic centimeter (cm^3)

English
1 gallon (gal) = 4 quarts (qt)
1 quart (qt) = 2 pints (pt)

Metric–English
1 liter (L) = 0.265 gallon (gal)
1 liter (L) = 1.06 quarts (qt)
1 liter (L) = 0.0353 cubic foot (ft^3)
1 cubic meter (m^3) = 35.3 cubic feet (ft^3)
1 cubic meter (m^3) = 1.30 cubic yards (yd^3)
1 cubic kilometer (km^3) = 0.24 cubic mile (mi^3)
1 barrel (bbl) = 159 liters (L)
1 barrel (bbl) = 42 U.S. gallons (gal)

MASS

Metric
1 kilogram (kg) = 1,000 grams (g)
1 gram (g) = 1,000 milligrams (mg)
1 gram (g) = 1,000,000 micrograms (μg)
1 milligram (mg) = 0.001 gram (g)
1 microgram (μg) = 0.000001 gram (g)
1 metric ton (mt) = 1,000 kilograms (kg)

English
1 ton (t) = 2,000 pounds (lb)
1 pound (lb) = 16 ounces (oz)

Metric–English
1 metric ton (mt) = 2,200 pounds (lb) = 1.1 tons (t)
1 kilogram (kg) = 2.20 pounds (lb)
1 pound (lb) = 454 grams (g)
1 gram (g) = 0.035 ounce (oz)

ENERGY AND POWER

Metric
1 kilojoule (kJ) = 1,000 joules (J)
1 kilocalorie (kcal) = 1,000 calories (cal)
1 calorie (cal) = 4.184 joules (J)

Metric–English
1 kilojoule (kJ) = 0.949 British thermal unit (Btu)
1 kilojoule (kJ) = 0.000278 kilowatt-hour (kW-h)
1 kilocalorie (kcal) = 3.97 British thermal units (Btu)
1 kilocalorie (kcal) = 0.00116 kilowatt-hour (kW-h)
1 kilowatt-hour (kW-h) = 860 kilocalories (kcal)
1 kilowatt-hour (kW-h) = 3,400 British thermal units (Btu)
1 quad (Q) = 1,050,000,000,000,000 kilojoules (kJ)
1 quad (Q) = 293,000,000,000 kilowatt-hours (kW-h)

Temperature Conversions
Fahrenheit (°F) to Celsius (°C):
°C = (°F − 32.0) ÷ 1.80
Celsius (°C) to Fahrenheit (°F):
°F = (°C × 1.80) + 32.0

Reading Graphs and Maps (Chapters 1–24)

SUPPLEMENT
2

Graphs and Maps Are Important Visual Tools

A **graph** is a tool for conveying information that we can summarize numerically by illustrating that information in a visual format. This information, called *data*, is collected in experiments, surveys, and other information-gathering activities. Graphing can be a powerful tool for summarizing and conveying complex information.

In this textbook and the accompanying web-based Active Graphing exercises, we use three major types of graphs: *line graphs*, *bar graphs*, and *pie graphs*. Here, you will explore each of these types of graphs and learn how to read them. In the web-based Active Graphing exercises, you can try your hand at creating some graphs.

An important visual tool used to summarize data that vary over small or large areas is a **map**. We discuss some aspects of reading maps relating to environmental science at the end of this supplement.

Line Graphs

Line graphs usually represent data that fall in some sort of sequence such as a series of measurements over time or distance. In most such cases, units of time or distance lie on the horizontal *x-axis*. The possible measurements of some quantity or variable such as temperature that changes over time or distance usually lie on the vertical *y-axis*.

In Figure 1, the x-axis shows the years between 1950 and 2010, and the y-axis displays the possible values for the annual amounts of oil consumed worldwide during that time in millions of tons, ranging from 0 to 4,000 million (or 4 billion) tons. Usually, the y-axis appears on the left end of the x-axis, although y-axes can appear on the right end, in the middle, or on both ends of the x-axis.

The curving line on a line graph represents the measurements taken at certain time or distance intervals. In Figure 1, the curve represents changes in oil consumption between 1950 and 2009. To find the oil consumption for any year, find that year on the x-axis (a point called the *abscissa*) and run a vertical line from the axis to the curve. At the point where your line intersects the curve, run a horizontal line to the y-axis. The value at that point on the y-axis, called the *ordinate*, is the amount you are seeking. You can go through the same process in reverse to find a year in which oil consumption was at a certain point.

Questions

1. What was the total amount of oil consumed in the world in 1990?
2. In about what year between 1950 and 2000 did oil consumption first start declining?
3. About how much oil was consumed in 2009? Roughly how many times more oil was consumed in 2009 than in 1970? How many times more oil was consumed in 2009 than in 1950?

Line graphs have several important uses. One of the most common applications is to compare two or more variables. Figure 2 compares two variables: monthly temperature and precipitation (rain and snowfall) during a typical year in a temperate deciduous forest. However, in this case the variables are measured on two different scales, so there are two y-axes. The y-axis on the left end of the graph shows a Centigrade temperature scale, while the y-axis on the right shows the range of precipitation measurements in millimeters. The x-axis displays the first letters of each of the 12 month names.

Questions

1. In what month does most precipitation fall? What is the driest month of the year? What is the hottest month?
2. If the temperature curve were almost flat, running throughout the year at about its highest point of about 30°C, how do you think this forest would change from what it is now (see Figure 7-13, p. 160)? If the annual precipitation suddenly dropped and remained under 25 centimeters all year, what do you think would eventually happen to this forest?

It is also important to consider what aspect of a set of data is being displayed on a graph. The creator of a graph can take two different aspects of one data set and create two very different-looking graphs that would give two different interpretations of the same phenomenon. For example, when talking about any type of

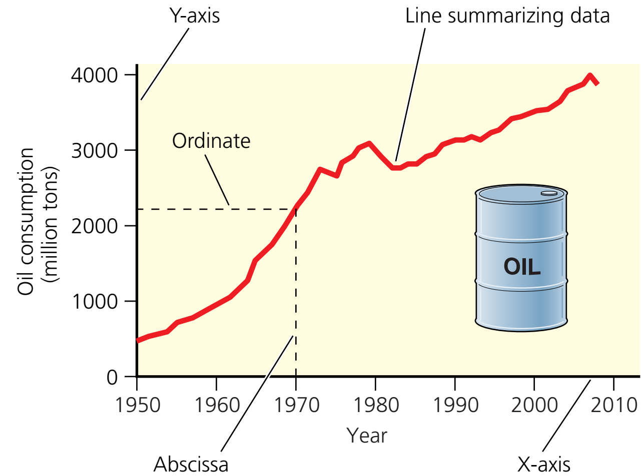


Figure 1 This graph tracks world oil consumption, 1950–2009. (Data from U.S. Energy Information Administration, British Petroleum, International Energy Agency, and United Nations)

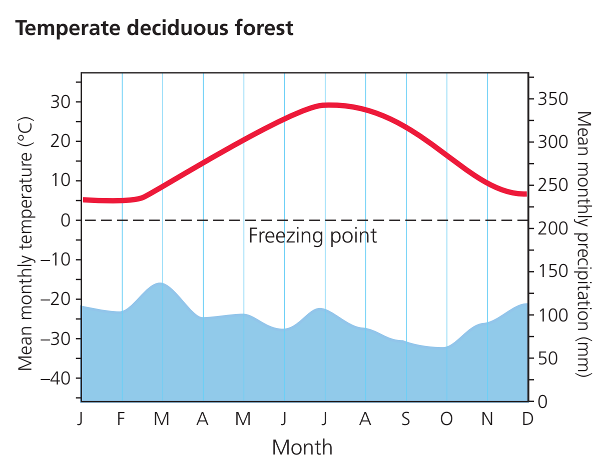


Figure 2 This climate graph shows typical variations in annual temperature (red) and precipitation (blue) in a temperate deciduous forest.

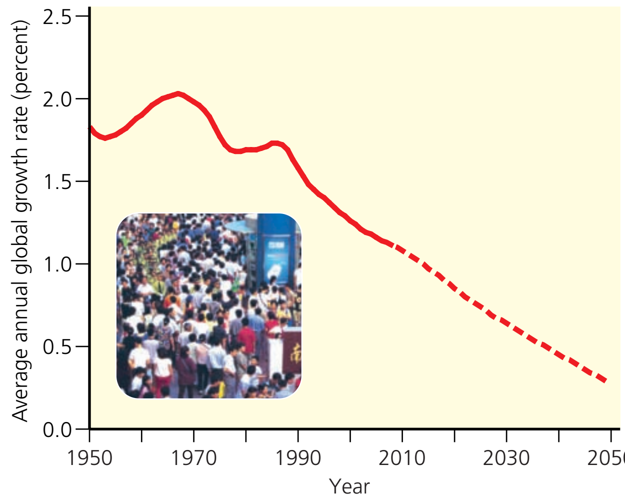


Figure 3 This graph tracks the annual growth rate in world population, 1950–2009 with projections to 2050. (Data from UN Population Division and U.S. Census Bureau)

growth we must be careful to distinguish the question of whether something is growing from the question of how fast it is growing. While a quantity can keep growing continuously, its rate of growth can go up and down.

One of many important examples of growth used in this book is human population growth. For example, the graph in Figure 1-18 (p. 21) gives you the impression that human population growth has, for the most part, been continuous and uninterrupted. However, consider Figure 3, which plots the rate of growth of the human population since 1950. Note that all of the numbers on the y-axis, even the smallest ones, represent growth. The lower end of the scale represents slower growth and the higher end faster growth. Thus, while one graph tracks population growth in terms of numbers of people, the other tracks the rate of growth.

Questions

1. If this graph were presented to you as a picture of human population growth, what would be your first impression?
2. Do you think that reaching a growth rate of 0.5% would relieve those who are concerned about overpopulation? Why or why not?

Bar Graphs

The *bar graph* is used to compare measurements for one or more variables across categories. Unlike the line graph, a bar graph typically does not involve a sequence of measurements over time or distance. The measurements compared on a bar graph usually represent data collected at some point in time or during a well-defined period. For instance, we can compare the *net primary productivity* (*NPP*), a measure of chemical energy produced by plants in an ecosystem, for different ecosystems, as represented in Figure 4.

In most bar graphs, the categories to be compared are laid out on the x-axis, while the range of measurements for the variable under consideration lies along the y-axis. In our example in Figure 4, the categories (ecosystems) are on the y-axis, and the variable range (NPP) lies on the x-axis. In either case, reading the graph is straightforward. Simply run a line perpendicular to the bar you are reading from the top of that bar (or the right or left end, if it lies horizontally) to the variable value axis. In Figure 4, you can see that the NPP for continental shelf, for example, is close to 1,600 kcal/m²/yr.

Questions

1. What are the two terrestrial ecosystems that are closest in NPP value of all pairs of such ecosystems? About how many times greater is the NPP in a tropical rain forest than the NPP in a savannah?
2. What is the most productive of aquatic ecosystems shown here? What is the least productive?

An important application of the bar graph used in this book is the *age structure diagram* (see Figure 6-13, p. 136), which describes a population by showing the numbers of males and females in certain age groups (see Chapter 6, pp. 125–146).

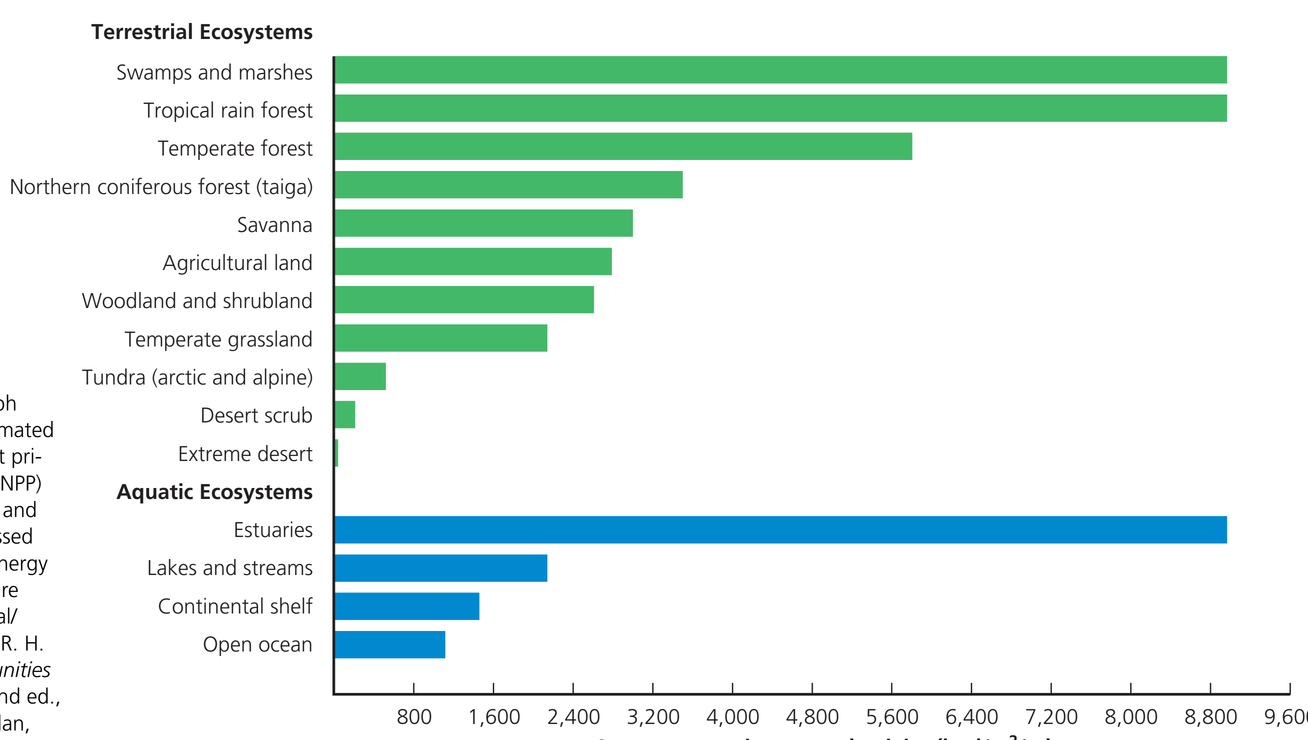


Figure 4 This graph represents the estimated annual average net primary productivity (NPP) in major life zones and ecosystems, expressed as kilocalories of energy produced per square meter per year (kcal/m²/yr). (Data from R. H. Whittaker, *Communities and Ecosystems*, 2nd ed., New York: Macmillan, 1975)

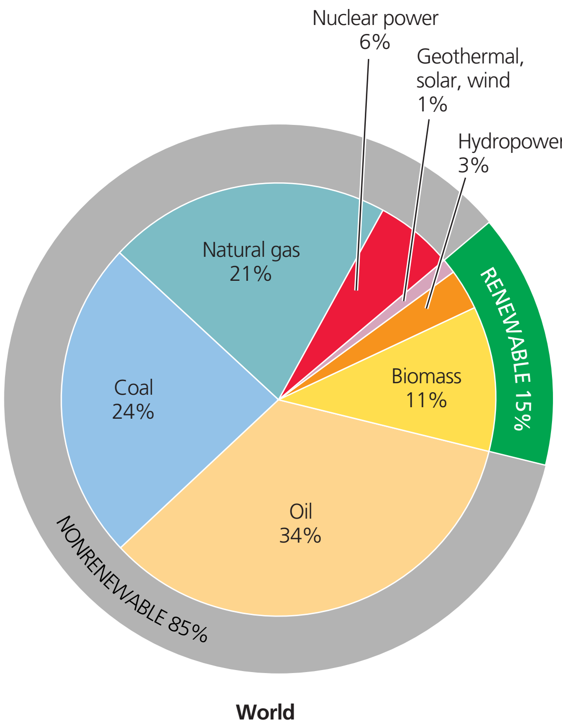


Figure 5 This pie graph represents world energy use by source in 2008.

Pie Graphs

Like bar graphs, *pie graphs* illustrate numerical values for two or more categories. But in addition to that, they can also show each category's proportion of the total of all measurements. The categories are usually ordered on the graph from largest to smallest, for ease of comparison, although this is not always the case. Also, as with bar graphs, pie graphs are generally snapshots of a data set at a point in time or during a defined time period. Unlike line graphs, one pie graph cannot show changes over time.

For example, Figure 5 shows how much each major energy source contributes to the world's total amount of energy used. This graph includes the numerical data used to construct it: the percentages of the total taken up by each part of the pie. But we can use pie graphs without including the numerical data and we can roughly estimate such percentages. The pie graph thereby provides a generalized picture of the composition of a data set.

Figure 15-1 (p. 371) shows this and other data in more detail, and illustrates how we can use pie graphs to compare different groups of categories and different data sets. Also, see the Active Graphing exercise for Chapter 15 on the website for this book.

Questions

1. Do you think that the data showing growth in the use of natural gas, coal, and oil over the years means that the use of other energy categories on this graph has shrunk in that time? Explain.
2. About how many times bigger is oil use than biomass use?

Reading Maps

We can use maps for considerably more than showing where places are relative to one another. For example, in environmental science maps can be very helpful in comparing how people or different areas are affected by environmental problems such as air pollution and acid deposition (a form of air pollution). Figure 6 is a map of the United States showing the relative numbers of premature deaths due to air pollution in the various regions of the country.

Questions

1. Which part of the country generally has the lowest level of premature deaths due to air pollution?
2. Which part of the country has the highest level? What is the level in the area where you live or go to school?

The Active Graphing exercises available for various chapters on this textbook's website will help you to apply this information on graphs. Register and log on to **CengageNOW™** using the access code card in the front of your book. Choose a chapter with an Active Graphing exercise, click on the exercise, and begin learning more about graphing. There is also a data analysis exercise at the end of each chapter in this book. Some of these exercises involve analysis of various types of graphs and maps.

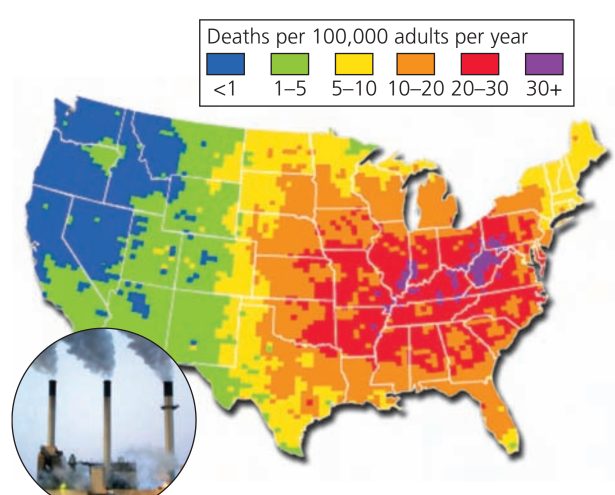


Figure 6 This map shows premature deaths from air pollution in the United States, mostly from very small particles added to the atmosphere by coal-burning power plants. (Data from U.S. Environmental Protection Agency)

SUPPLEMENT

3

Environmental History of the United States (Chapters 3, 9, 10, 12, 13, 18, 22, 24, 25)

The Four Major Eras of U.S. Environmental History

We can divide the environmental history of the United States into four eras. During the *tribal era*, people (now called Native Americans), representing several hundred tribes, distinguished by language and culture, occupied North America for at least 13,000 years before European settlers began arriving in the early 1600s. These hunter–gatherers generally had sustainable, low-impact ways of life because of their relatively limited numbers and modest resource use per person.

Next was the *frontier era* (1607–1890) when European colonists began settling North America. Faced with a continent offering seemingly inexhaustible resources, the early colonists developed a **frontier environmental worldview**. They saw a wilderness to be conquered and managed for human use.

Next came the *early conservation era* (1832–1870), which overlapped the end of the frontier era. During this period, some people became alarmed at the scope of resource depletion and degradation in the United States. They argued that part of the unspoiled wilderness on public lands should be protected as a legacy to future generations. Most of these warnings and ideas were not taken seriously.

This period was followed by an era—lasting from 1870 to the present—featuring an increased role of the federal government and private citizens in resource conservation, public health, and environmental protection. **Explore More:** Go to **www.cengage.com/login** to see timelines of major events that occurred during the environmental history of the United States from 1832 to the present.

The Frontier Era (1607–1890)

During the frontier era, European settlers spread across the land by clearing forests for cropland and settlements. In the process, they displaced the Native Americans who, for the most part, had lived on the land sustainably for thousands of years.

The U.S. government accelerated this settling of the continent and use of its resources by transferring vast areas of public land to private interests. Between 1850 and 1890, more than half of the country's public land was given away or sold cheaply by the government to railroad, timber, and mining companies, land developers, states, schools, universities, and homesteaders to encourage settlement. This era came to an end when the government declared the frontier officially closed in 1890.

Figure 1 Henry David Thoreau (1817–1862) was an American writer and naturalist who kept journals about his excursions into wild areas in parts of the northeastern United States and Canada, and at Walden Pond in Concord, Massachusetts. He sought self-sufficiency, a simple lifestyle, and a harmonious coexistence with nature.

Early Conservationists (1832–1870)

Between 1832 and 1870, some citizens became alarmed at the scope of resource depletion and degradation in the United States. They urged the government to preserve part of the unspoiled wilderness on public lands owned jointly by all people (but managed by the government), and to protect it as a legacy to future generations.

Two of these early conservationists were Henry David Thoreau (1817–1862) and George Perkins Marsh (1801–1882). Thoreau (Figure 1) was alarmed at the loss of numerous wild species from his native eastern Massachusetts. To gain a better understanding of nature, he built a cabin in the woods on Walden Pond near Concord, Massachusetts, lived there alone for 2 years, and wrote *Life in the Woods*, an environmental classic.*

In 1864, George Perkins Marsh, a scientist and member of Congress from Vermont, published *Man and Nature,* which helped legislators and citizens see the need for resource conservation. Marsh questioned the idea that the country's resources were inexhaustible. He also used scientific studies and case studies to show how the rise and fall of past civilizations were linked to the use and misuse of their soils, water supplies, and other resources. Some of his resource conservation principles are still used today.

*I (Miller) can identify with Thoreau. I spent 10 years living in the deep woods studying and thinking about how nature works and writing early editions of the book you are reading. I lived in a remodeled school bus with an attached greenhouse. I used it as a scientific laboratory for evaluating environmental technologies such as passive and active solar energy technologies for heating the bus and any hot water I needed, waste disposal (composting toilets), natural geothermal cooling (earth tubes), ways to save energy and water, and biological control of pests. It was great fun and I learned a lot. In 1990, I came out of the woods to find out more about how to live more sustainably in urban areas, where most people live.

What Happened between 1870 and 1930?

Between 1870 and 1930, a number of actions increased the role of the federal government and private citizens in resource conservation and public health. The *Forest Reserve Act of 1891* was a turning point in establishing the responsibility of the federal government for protecting public lands from resource exploitation.

In 1892, nature preservationist and activist John Muir (Figure 2) founded the Sierra Club. He became the leader of the *preservationist movement,* which called for protecting large areas of wilderness on public lands from human exploitation, except for low-impact recreational activities such as hiking and camping. This idea was not enacted into law until 1964. Muir also proposed and lobbied for creation of a national park system on public lands.

Primarily because of political opposition, effective protection of forests and wildlife on federal lands did not begin until Theodore Roosevelt (Figure 3), an ardent conservationist,

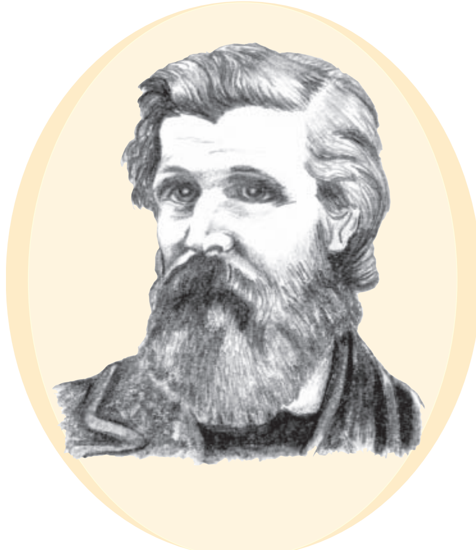


Figure 2 John Muir (1838–1914) was a geologist, explorer, and naturalist. He spent 6 years studying, writing journals, and making sketches in the wilderness of California's Yosemite Valley and then went on to explore wilderness areas in Utah, Nevada, the Northwest, and Alaska. He was largely responsible for establishing Yosemite National Park in 1890. He also founded the Sierra Club and spent 22 years lobbying actively for conservation laws.

Figure 3 Theodore (Teddy) Roosevelt (1858–1919) was a writer, explorer, naturalist, avid birdwatcher, and twenty-sixth president of the United States. He was the first national political figure to bring conservation issues to the attention of the American public. According to many historians, Theodore Roosevelt contributed more than any other U.S. president to natural resource conservation in the United States.

became president. His term of office, 1901–1909, has been called the country's *Golden Age of Conservation*.

While in office he persuaded Congress to give the president power to designate public land as federal wildlife refuges. In 1903, Roosevelt established the first federal refuge at Pelican Island (see Figure 9-21, p. 211) off the east coast of Florida for preservation of the endangered brown pelican, and he added 35 more reserves by 1904. He also more than tripled the size of the national forest reserves.

In 1905, Congress created the U.S. Forest Service to manage and protect the forest reserves. Roosevelt appointed Gifford Pinchot (1865–1946) as its first chief. Pinchot pioneered scientific management of forest resources on public lands. In 1906, Congress passed the *Antiquities Act,* which allows the president to protect areas of scientific or historical interest on federal lands as national monuments. Roosevelt used this act to protect the Grand Canyon and other wilderness areas that would later become national parks.

Congress became upset with Roosevelt in 1907, because by then he had added vast tracts to the forest reserves. Congress passed a law banning further executive withdrawals of public forests. However, on the day before the bill became law, Roosevelt defiantly reserved another large block of land. Most environmental historians view Roosevelt as the country's best environmental president.

Early in the 20th century, the U.S. conservation movement split into two factions over how public lands should be used. The *wise-use,* or *conservationist,* school, led by Roosevelt and Pinchot, believed all public lands should be managed wisely and scientifically to provide needed resources. The *preservationist* school, led by Muir, wanted wilderness areas on public lands to be left untouched. This controversy over use of public lands continues today.

In 1916, Congress passed the *National Park Service Act,* which declared that parks are to be maintained in a manner that leaves them unimpaired for future generations. The act also established the National Park Service (within the Department of the Interior) to manage the park system. Under its first head, Stephen T. Mather (1867–1930), the dominant park policy was to encourage tourist visits by allowing private concessionaires to operate facilities within the parks.

After World War I, the country entered a new era of economic growth and expansion. During the administrations of Presidents Harding, Coolidge, and Hoover, the federal government promoted increased sales of timber, energy, mineral, and other resources found on public lands at low prices to stimulate economic growth.

President Herbert Hoover went even further and proposed that the federal government return all remaining federal lands to the states or sell them to private interests for economic development. But the Great Depression (1929–1941) made owning such lands unattractive to state governments and private investors. The Depression was bad news for the country. But some say that without it we might have little if any of the public lands that today make up about one-third of the total land area of the United States (see Figure 24-5, p. 644).

What Happened between 1930 and 1960?

Along with a second wave of national resource conservation, improvements in public health also began in the early 1930s as President Franklin D. Roosevelt (1882–1945) strove to bring the country out of the Great Depression. He persuaded Congress to enact federal government programs to provide jobs and to help restore the country's degraded environment.

During this period, the government purchased large tracts of land from cash-poor landowners, and established the *Civilian Conservation Corps* (CCC) in 1933. It put 2 million unemployed people to work planting trees and developing and maintaining parks and recreation areas. The CCC also restored silted waterways and built levees and dams for flood control.

The government built and operated many large dams in the Tennessee Valley as well as in the arid western states, including Hoover Dam on the Colorado River (see Figure 13-1, p. 317). The goals were to provide jobs, flood control, cheap irrigation water, and cheap electricity for industry.

In 1935, Congress passed the Soil Conservation Act. It established the *Soil Erosion Service* as part of the Department of Agriculture to correct the enormous erosion problems that had ruined many farms in the Great Plains states during the Depression and created a large area of degraded land known as the *Dust Bowl*. Its name was later changed to the *Soil Conservation Service,* now called the *Natural Resources Conservation Service.* Many environmental historians praise Franklin D. Roosevelt (a Democrat) for his efforts to get the country out of a major economic depression and to help restore environmentally degraded areas.

Federal resource conservation policy changed little during the 1940s and 1950s, mostly because of preoccupation with World War II (1941–1945) and economic recovery after the war.

Between 1930 and 1960, improvements in public health included establishment of public health boards and agencies at the municipal, state, and federal levels; increased public education about health issues; introduction of vaccination programs; and a sharp reduction in the incidence of waterborne infectious diseases, mostly because of improved sanitation and garbage collection.

What Happened during the 1960s?

A number of milestones in American environmental history occurred during the 1960s. In 1962, biologist Rachel Carson (1907–1964) published *Silent Spring,* which documented the pollution of air, water, and wildlife from the use of pesticides such as DDT (see Chapter 12, Individuals Matter, p. 298). This influential book helped to broaden the concept of resource conservation to include preservation of the *quality* of the planet's air, water, soil, and wildlife.

Many environmental historians mark Carson's wake-up call as the beginning of the modern **environmental movement** in the United States. It flourished when a growing number of citizens organized to demand that political leaders enact laws and develop policies to curtail pollution, clean up polluted environments, and protect unspoiled areas from environmental degradation.

In 1964, Congress passed the *Wilderness Act,* inspired by the vision of John Muir more than 80 years earlier. It authorized the government to protect undeveloped tracts of public land as part of the National Wilderness System, unless Congress later decides they are needed for the national good. Land in this system is to be used only for nondestructive forms of recreation such as hiking and camping.

Between 1965 and 1970, the emerging science of *ecology* received widespread media attention. At the same time, the popular writings of biologists such as Paul Ehrlich, Barry Commoner, and Garrett Hardin awakened Americans to the interlocking relationships among population growth, resource use, and pollution.

During that period, a number of events increased public awareness of pollution, such as the realization that pollution and loss of habitat were endangering well-known wildlife species such as the North American bald eagle, grizzly bear, whooping crane, and peregrine falcon.

During the 1968 U.S. Apollo 8 mission to the moon, astronauts photographed the earth for the first time from lunar orbit. This allowed people to see the earth as a tiny blue and white planet in the black void of space, and it led to the development of the *spaceship-earth environmental worldview*. It reminded us that we live on a planetary spaceship that we should not harm because it is the only home we have.

What Happened during the 1970s? The Environmental Decade

During the 1970s, media attention, public concern about environmental problems, scientific research, and action to address environmental concerns grew rapidly. This period is sometimes called the *environmental decade*, or the *first decade of the environment.* Figure 24-4, p. 643 summarizes some of the major U.S. environmental laws passed during this decade and in the 1980s and 1990s.

The first annual *Earth Day* was held on April 20, 1970. This event was proposed by Senator Gaylord Nelson (1916–2005) and organized by Denis Hayes (see Chapter 24, Core Case Study, p. 637). Some 20 million people in more than 2,000 U.S. communities took to the streets to heighten the nation's environmental awareness and to demand improvements in environmental quality.

The *Environmental Protection Agency* (EPA) was established in 1970. In addition, the *Endangered Species Act of 1973* greatly strengthened the role of the federal government in protecting endangered species and their habitats.

In 1978, the *Federal Land Policy and Management Act* gave the *Bureau of Land Management* (BLM) its first real authority to manage the public land under its control, 85% of which is in 12 western states. This law angered a number of western interests whose use of these public lands was restricted for the first time.

In response, a coalition of ranchers, miners, loggers, developers, farmers, some elected officials, and other citizens in the affected states launched a political campaign known as the *sagebrush rebellion*. It had two major goals. *First*, sharply reduce government regulation of the use of public lands. *Second*, remove most public lands in the western United States from federal ownership and management and turn them over to the states. After that, the plan was to persuade state legislatures to sell or lease the resource-rich lands at low prices to ranching, mining, timber, land development, and other private interests. This represented a return to President Herbert Hoover's plan to get rid of all public land, which had been thwarted by the Great Depression. This political movement continues to exist.

In 1977, Congress created the Department of Energy in order to develop a long-range energy strategy to help reduce the country's heavy dependence on imported oil. In 1980, Congress created the *Superfund* as part of the *Comprehensive Environmental Response, Compensation, and Liability Act* (see Chapter 21, p. 578). Its goal was to clean up abandoned hazardous waste sites, including the Love Canal housing development in Niagara Falls, New York, which had to be abandoned when hazardous wastes from the site of a former chemical company began leaking into school grounds, yards, and basements.

During this period the area of land in the National Wilderness System tripled and the area in the National Park System doubled (primarily by adding vast tracts in the state of Alaska).

What Happened during the 1980s? Environmental Backlash

During this decade, farmers, ranchers, and leaders of the oil, coal, automobile, mining, and timber industries strongly opposed many of the environmental laws and regulations developed in the 1960s and 1970s. They organized and funded multiple efforts to defeat environmental laws and regulations—efforts that persist today.

In 1980 the United States led the world in research and development of wind and solar energy technologies. Between 1981 and 1983, however, Congress slashed by 90% government subsidies for renewable energy research and for energy efficiency research, and eliminated tax incentives for the residential solar energy and energy conservation programs enacted in the late 1970s. As a result, the United States lost its lead in developing and selling the wind turbines and solar cells that are rapidly becoming two of the biggest and most profitable businesses of this century. Thus, Americans now buy many of their solar cells from Japan, Germany, and China, and much of the components for wind farms from Denmark, Germany, and China. During the 1980s, Congress, influenced by a growing backlash against many environmental laws enacted in the 1970s, also increased private energy and mineral development and timber cutting on public lands, lowered automobile gas mileage standards, and relaxed federal air and water quality pollution standards.

In 1988, an industry-backed coalition called the *wise-use movement* was formed. Its major goals were to weaken or repeal most of the country's environmental laws and regulations, and destroy the effectiveness of the environmental movement in the United States. Politically powerful coal, oil, mining, automobile, timber, and ranching interests helped back this movement. They argued that environmental laws had gone too far and were hindering economic growth.

What Happened from 1990 to 2010?

Between 1990 and 2010, opposition to environmental laws and regulations gained strength. This occurred because of continuing political and economic support from corporate backers, who not only argued that environmental laws were hindering economic growth, but also helped elect many members of Congress who were generally unsympathetic to environmental concerns. Since 1990, leaders and supporters of the environmental movement have had to spend much of their time and funds fighting these efforts to discredit the movement and weaken or eliminate most environmental laws passed during the 1960s and 1970s.

During the 1990s, many small and mostly local grassroots environmental organizations sprang up to help deal with environmental threats in their local communities. Interest in environmental issues increased on many college and university campuses resulting in the expansion of environmental studies programs at these institutions. In addition, there was growing awareness of critical and complex environmental issues, such as sustainability, population growth, biodiversity protection, and threats from atmospheric warming and projected climate change.

CASE STUDY
The Return of the American Bison

In 1500, before Europeans settled North America, 30–60 million North American bison (Figure 4)—also commonly called buffalo—grazed the plains, prairies, and woodlands of much of the continent. A single herd on the move might take hours to move past one point.

Numerous Native American tribes depended heavily on bison, using virtually every part of the animal for food, clothing, shelter, and a wide variety of tools and weapons. Typically, they killed only the number of animals they needed. However, by 1906 the once-vast range of the bison had shrunk to a tiny area, and the species had been driven nearly to extinction.

How did this happen? First, settlers moving west after the Civil War upset the sustainable balance that had existed between Native Americans and bison. Many tribes on the Great Plains had begun to trade bison skins to settlers for steel knives and firearms; these items were so valuable that the tribes began killing more bison for their hides. However, much worse damage was done when the new settlers undertook a

Jim Parkin/Shutterstock

Figure 4 This herd of American bison (also called buffalo) is grazing in Custer State Park in the Black Hills of the U.S. state of South Dakota. This once-abundant land mammal, the largest in North America, has been brought back from the brink of extinction. These huge animals look docile but they become nervous and unpredictable when threatened by a predator, and this can result in a stampede, a frantic rush of hundreds or thousands of panicked animals. A mature bison can toss a grizzly bear off its back, and it can kick like a mule.

relentless slaughter of the bison. As railroads spread westward in the late 1860s, rail companies hired professional bison hunters—including Buffalo Bill Cody—to supply meat to their construction crews. Passengers also gunned down bison from train windows for sport, leaving the carcasses to rot.

Commercial hunters shot millions of bison for their tongues (considered a delicacy) and hides, leaving most of the meat to rot. "Bone pickers" collected the bleached bones that whitened the prairies and shipped them east to be ground up as fertilizer.

Farmers shot bison because they damaged crops, fences, sod houses, and telegraph poles. Ranchers killed them because they competed with cattle and sheep for grass. The U.S. Army killed at least 12 million bison as part of their campaign to subdue or eliminate the tribes of the Great Plains by killing off their primary source of food. Without the bison, these tribes began to starve and were forced to abandon the fight to preserve their traditional homelands, moving onto small reservations where they received government food rations. This, in turn, allowed for further westward expansion by European immigrants and their descendents engaged in farming, ranching, and the building of railroads.

By 1892, only 85 bison were left from herds that had numbered in the tens of millions. They were given refuge in Yellowstone National Park and protected by an 1893 law prohibiting the killing of wild animals in national parks.

In 1905, sixteen people formed the American Bison Society to protect and rebuild the captive population. Soon thereafter, the federal government established the National Bison Range near Missoula, Montana, and later, the Tallgrass Prairie National Reserve in Oklahoma as part of the U.S. National Park system. Today there are an estimated 500,000 bison, about 97% of them on privately owned ranches and the rest in protected parks and reserves.

The story of the American bison's comeback shows that even a severely endangered species can recover if a few people care enough to help them.

CASE STUDY

Air Pollution in the Past: The Bad Old Days

Modern civilization did not invent air pollution. It probably began when humans discovered fire and used it to burn wood in poorly ventilated caves for warmth and cooking, and inhaled unhealthy smoke and soot.

During the Middle Ages (from about the 5th to the 16th centuries, AD) a haze of wood smoke hung over densely packed urban areas in Europe. The Industrial Revolution (from the 18th to the 19th centuries,) brought even worse air pollution as coal was burned to power factories and heat homes. As a result, there were great increases in respiratory diseases such as asthma and bronchitis, as well as allergies. Many people died from these ailments, especially children and the elderly.

By the 1850s, dense mixtures of coal smoke and fog as "thick as pea soup," sometimes referred to as yellow fog, engulfed London in a sunless gloom during winter months. In 1880, a prolonged coal fog killed an estimated 2,200 people. In 1905, a physician used the word *smog* to describe the deadly mixture of smoke and fog that afflicted London. Another episode in 1911 killed more than 1,100 Londoners.

In December 1952, an even worse yellow fog lasted for 5 days and killed 4,000–12,000 Londoners. Visibility was so low that people walking outside during the day could not see their feet. So many people died that undertakers ran out of coffins.

This tragedy prompted the British Parliament to pass the Clean Air Act of 1956. Before the beneficial effects of the law could be realized, additional air pollution disasters in 1956, 1957, and 1962 killed 2,500 more people. Because of strong air pollution laws, London's air today is much cleaner, and "pea soup" fogs are a thing of the past. Now the major threat is from air pollutants emitted by motor vehicles.

The Industrial Revolution, powered by coal, brought air pollution to the United States. Large industrial cities such as Pittsburgh, Pennsylvania, and St. Louis, Missouri, were known for their smoky air. By the 1940s, the air over some cities was so polluted that people had to turn their automobile headlights on during the day.

The first documented air pollution disaster in the United States occurred on October 29, 1948, in the small industrial town of Donora in Pennsylvania's Monongahela River Valley south of Pittsburgh. Pollutants from the area's coal-burning factories, steel mills, zinc smelters, and sulfuric acid plants became trapped in a dense fog that stagnated over the valley for 5 days. This killer fog resulted from a combination of mountainous terrain surrounding the valley and weather conditions that trapped and concentrated deadly pollutants. About 6,000 of the town's 14,000 inhabitants became sick, and 20 of them died.

In 1963, high concentrations of air pollutants in New York City killed about 300 people and injured thousands. Incidents like these finally resulted in city, state, and federal air pollution control programs in the United States, with the U.S. state of California leading the way. As a result, air quality has dramatically improved throughout the country.

However, many major urban areas in less-developed countries, such as China (see Figure 18-2, p. 465), India (see Figure 15-16, p. 383), and parts of Eastern Europe that depend on burning coal in industries, power plants, and homes, face air pollution levels similar to those in London, England, and in American industrial cities in the 1950s.

> **THINKING ABOUT**
> **Outdoor Air Pollution—Past and Present**
> Explain why you agree or disagree with the statement: "Air pollution in the United States should no longer be a major concern because of the significant progress made in reducing outdoor air pollution since 1970."

CASE STUDY
Trash Production and Recycling in New York City: Past, Present, and Future

You might guess that trash production in New York City has been rising steadily. You would be wrong. In 2002, Columbia University adjunct professor Daniel C. Walsh discovered some surprising facts when analyzing detailed records about what residents of New York City threw away between 1900 and 2000.

He found that the per person output, by weight, of trash dumped by New Yorkers was higher between 1920 and 1940 than it is today—mostly because of the coal ash produced by people burning coal for heat and cooking. The city's highest trash output per person was in 1940, when the rate was more than two times today's output.

During 1962 and 1963, the trash output per New Yorker was at its lowest level for the 20th century, as household coal burning was phased out and paper became the largest component of trash. Between 1964 and 1974, the city's trash output per person rose to slightly above today's levels as returnable, refillable bottles were phased out and the use of throwaway items increased. Since 1975, the weight of trash thrown away per New Yorker has remained about the same because of lighter products and an increase in recycling.

In 1999, New York City passed a mandatory recycling law, but it was not the city's first experience with such recycling. Between 1896 and 1914, the city had a recycling program that required mandatory curbside separation of trash. But this recycling effort faded and died before World War I.

Professor Walsh also found that trash output per person rose in good economic times when people could buy more and fell in bad times as people reduced their spending.

Despite some progress, New York City was one of the first U.S. cities to run out of landfill space for its garbage. Until 2001, most of the city's garbage was buried in its Fresh Kills landfill on Staten Island, the world's largest public landfill. At its peak in 2001, this huge manmade structure, a monument to a throwaway mentality, was taller than the city's Statue of Liberty. However, after filling up in 2001, it was closed. Now it is being transformed into recreational facilities, restored wetlands, and public parkland.

Since 2001, the city has been hauling its massive amounts of garbage to landfill sites in New Jersey, Pennsylvania, and Virginia. Each day, some 600 energy-inefficient and polluting tractor trailer trucks, which if lined up would form a convoy nearly 14 kilometers (9 miles) long, haul trash out of New York City to landfills, some as far as 480 kilometers (300 miles) away.

As oil prices rise and concerns over CO_2 emissions increase, it may become too expensive at some point for New York (and for other cities) to haul garbage long distances to burial sites. Then what?

Instead of focusing mostly on what to do with its garbage (an output approach), environmental scientists urge New York City officials to think more about how to avoid producing so much trash (an input approach). The city could reduce its solid waste output by 60–80% and become a global model of how to shift from a throwaway, urban economy to a reduce-reuse-recycle, urban economy. This transition could be spurred by a *pay-as-you-throw* garbage collection system in which households and businesses pay for the solid wastes they throw away but not for those they recycle or compost.

> **THINKING ABOUT**
> **Analyzing Trash**
> What two lessons can we learn from this analysis of data on New York City's trash?

CASE STUDY
Destroying a Great Mass Transit System in the United States

In 1917, all major U.S. cities had efficient electric trolley or streetcar (light-rail) systems. Many people think of Los Angeles, California, as the original car-dominated city. But in the early 20th century, Los Angeles had the largest electric-rail mass transit system in the United States.

That changed when General Motors, Firestone Tire, Standard Oil of California, Phillips Petroleum, and Mack Truck (which also made buses) formed a holding company called National City Lines. By 1950, the holding company had purchased privately owned streetcar systems in 83 major cities. It then dismantled these systems to increase sales of cars and buses.

The courts found the companies guilty of conspiracy to eliminate the country's light-rail system, but the damage had already been done. The executives responsible were each fined $1, and each company paid a fine of $5,000—less than the profit returned by replacing a single streetcar with a bus.

During this same period, National City Lines worked to convert electric-powered locomotives pulling commuter trains between cities and suburbs to much more expensive, polluting, and less reliable diesel-powered locomotives. The resulting increased costs contributed significantly to the sharp decline of the nation's railroad system.

> **THINKING ABOUT**
> **Light-Rail Systems**
> If National City Lines had not dismantled many light-rail systems, do you think they would still be operating today? Explain.

SUPPLEMENT

4

Some Basic Chemistry (Chapters 1–4, 12, 14, 17–19, 21)

Chemists Use the Periodic Table to Classify Elements on the Basis of Their Chemical Properties

Chemists have developed a way to classify the elements according to their chemical behavior in what is called the *periodic table of elements* (Figure 1). Each horizontal row in the table is called a *period*. Each vertical column lists elements with similar chemical properties and is called a *group*.

The partial periodic table in Figure 1 shows how the elements can be classified as *metals*, *nonmetals*, and *metalloids*. Most of the elements found to the left and at the bottom of the table are *metals*, which usually conduct electricity and heat and are shiny. Examples are sodium (Na), calcium (Ca), aluminum (Al), iron (Fe), lead (Pb), silver (Ag), and mercury (Hg).

Atoms of metals tend to lose one or more of their electrons to form positively charged ions such as Na^+, Ca^{2+}, and Al^{3+}. For example, an atom of the metallic element sodium (Na, atomic number 11) with 11 positively charged protons in its nucleus and 11 negatively charged electrons outside of its nucleus, can lose one of its electrons. It then becomes a sodium ion with a positive charge of 1 (Na^+) because it now has 11 positive charges (protons) but only 10 negative charges (electrons).

Nonmetals, found in the upper right of the table, do not conduct electricity very well. Examples are hydrogen (H), carbon (C), nitrogen (N), oxygen (O), phosphorus (P), sulfur (S), chlorine (Cl), and fluorine (F).

Atoms of some nonmetals such as chlorine, oxygen, and sulfur tend to gain one or more electrons lost by metallic atoms to form negatively charged ions such as O^{2-}, S^{2-}, and Cl^-. For example, an atom of the nonmetallic element chlorine (Cl, atomic number 17) can gain an electron and become a chlorine ion. The ion has a negative charge of 1 (Cl^-) because it has 17 positively charged protons in its nucleus and 18 negatively charged electrons outside of its nucleus. Atoms of nonmetals can also combine with one another to form molecules in which they share one or more pairs of their electrons.

Hydrogen, a nonmetal, is placed by itself above the center of the table because it does not fit very well into any of the groups.

The elements arranged in a diagonal staircase pattern between the metals and nonmetals have a mixture of metallic and nonmetallic properties and are called *metalloids*.

Figure 1 also identifies the elements required as *nutrients* (black squares) for all or some forms of life and elements that are moderately or highly toxic (red squares) to all or most forms of life. Six nonmetallic elements—carbon (C), oxygen (O), hydrogen (H), nitrogen (N), sulfur (S), and phosphorus (P)—make up about 99% of the atoms of all living things.

THINKING ABOUT
The Periodic Table

Use the periodic table to identify by name and symbol two elements that should have chemical properties similar to those of **(a)** Ca, **(b)** potassium, **(c)** S, **(d)** lead.

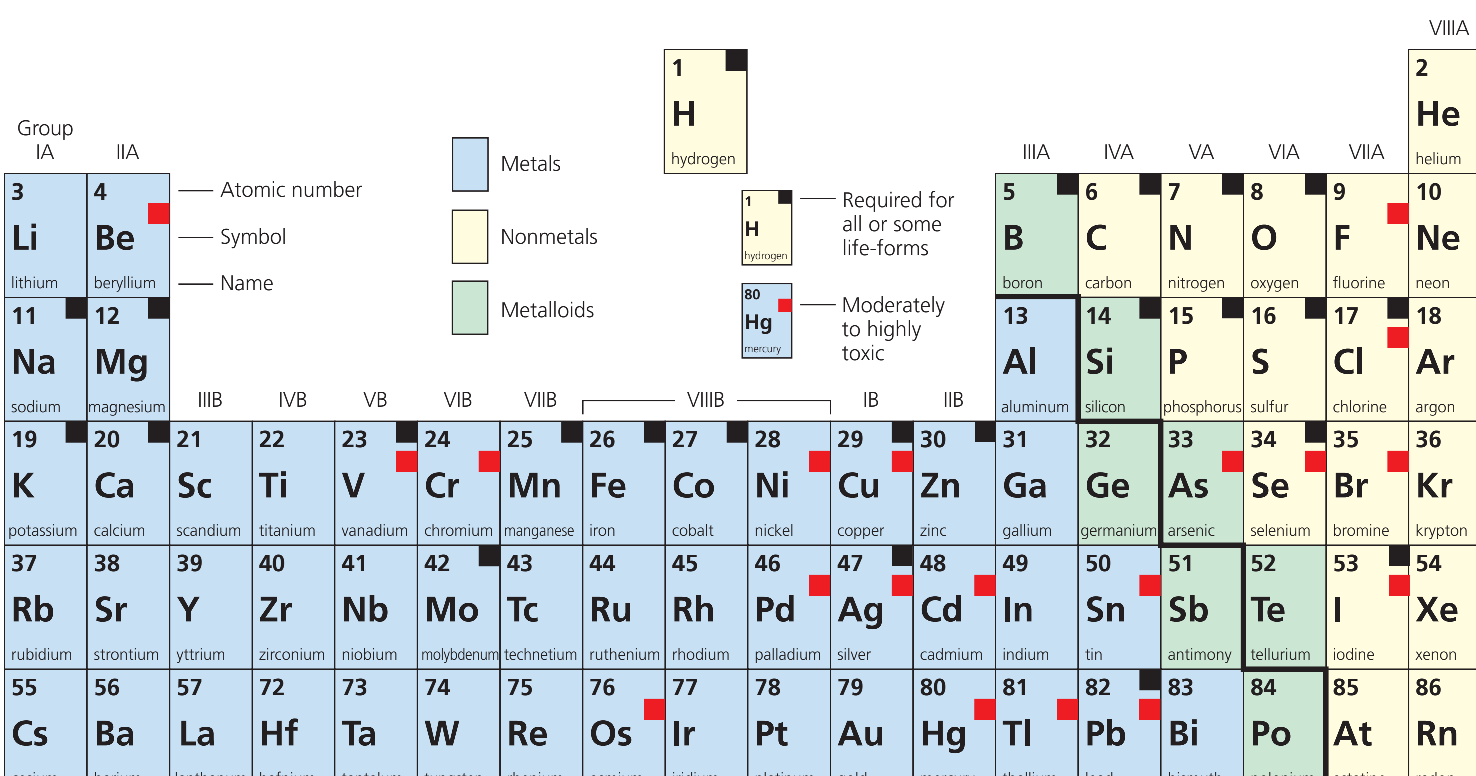
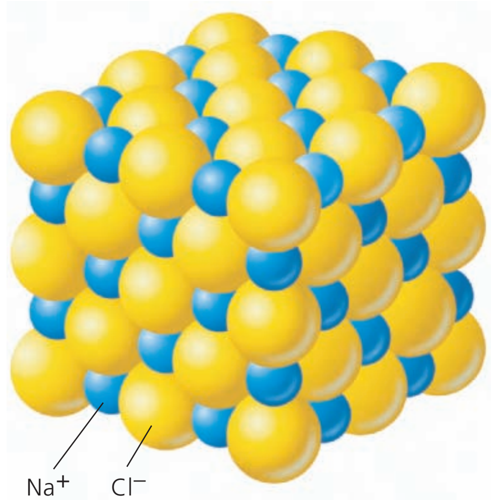


Figure 1 This is an abbreviated periodic table of elements. Elements in the same vertical column, called a *group*, have similar chemical properties. To simplify matters at this introductory level, only 72 of the 118 known elements are shown.

Figure 2 A solid crystal of an ionic compound such as sodium chloride consists of a three-dimensional array of oppositely charged ions held together by *ionic bonds* that result from the strong forces of attraction between opposite electrical charges. They are formed when an electron is transferred from a metallic atom such as sodium (Na) to a nonmetallic element such as chlorine (Cl).



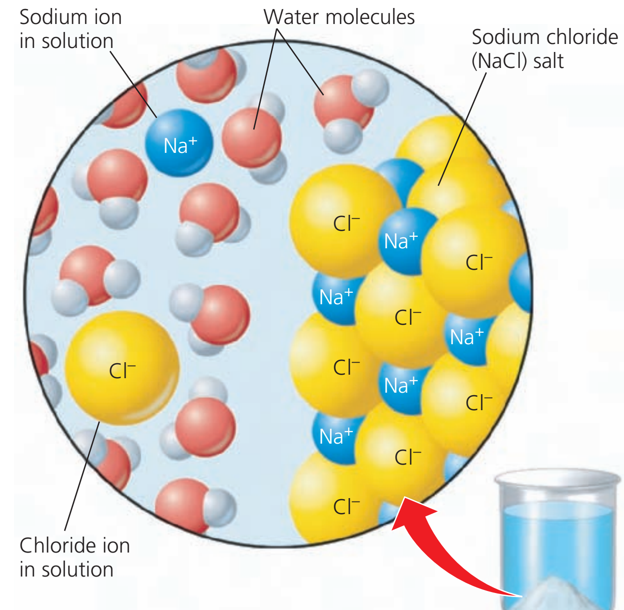


Figure 3 This model illustrates how a salt dissolves in water.

Ionic and Covalent Bonds Hold Compounds Together

Sodium chloride (NaCl) consists of a three-dimensional network of oppositely charged *ions* (Na^+ and Cl^-) held together by the forces of attraction between opposite charges (Figure 2). The strong forces of attraction between such oppositely charged ions are called *ionic bonds*. Because ionic compounds consist of ions formed from atoms of metallic (positive ions) and nonmetallic (negative ions) elements (Figure 1), they can be described as *metal–nonmetal compounds*.

Sodium chloride and many other ionic compounds tend to dissolve in water and break apart into their individual ions (Figure 3).

NaCl	⟶	Na^+	+	Cl^-
sodium chloride (in water)		sodium ion	+	chloride ion

Water, a *covalent compound*, consists of molecules made up of uncharged atoms of hydrogen (H) and oxygen (O). Each water molecule consists of two hydrogen atoms chemically bonded to an oxygen atom, yielding H_2O molecules. The bonds between the atoms in such molecules are called *covalent bonds* and form when the atoms in the molecule share one or more pairs of their electrons. Because they are formed from atoms of nonmetallic elements (Figure 1), covalent compounds can be described as *nonmetal–nonmetal compounds*. Figure 4 shows the chemical formulas and shapes of the molecules that are the building blocks for several common *covalent compounds*.

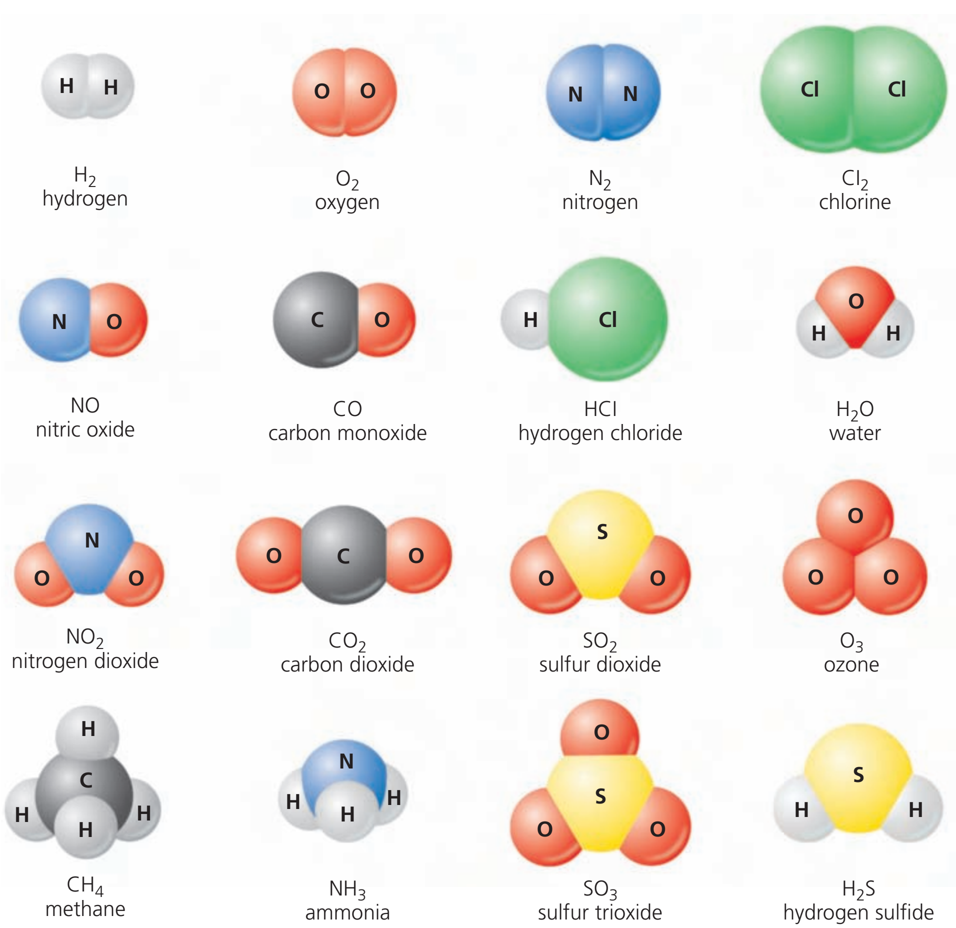


Figure 4 These are the chemical formulas and shapes for some *covalent compounds* formed when atoms of one or more nonmetallic elements combine with one another. The bonds between the atoms in such molecules are called *covalent bonds*.

What Makes Solutions Acidic? Hydrogen Ions and pH

The *concentration*, or number of hydrogen ions (H^+) in a specified volume of a solution (typically a liter), is a measure of its acidity. Pure water (not tap water or rainwater) has an equal number of hydrogen (H^+) and hydroxide (OH^-) ions. It is called a **neutral solution**. An **acidic solution** has more hydrogen ions than hydroxide ions per liter. A **basic solution** has more hydroxide ions than hydrogen ions per liter.

Scientists use **pH** as a measure of the acidity of a solution based on its concentration of hydrogen ions (H^+). By definition, a neutral solution has a pH of 7, an acidic solution has a pH of less than 7, and a basic solution has a pH greater than 7.

Each single unit change in pH represents a tenfold increase or decrease in the concentration of hydrogen ions per liter. For example, an acidic solution with a pH of 3 is ten times more

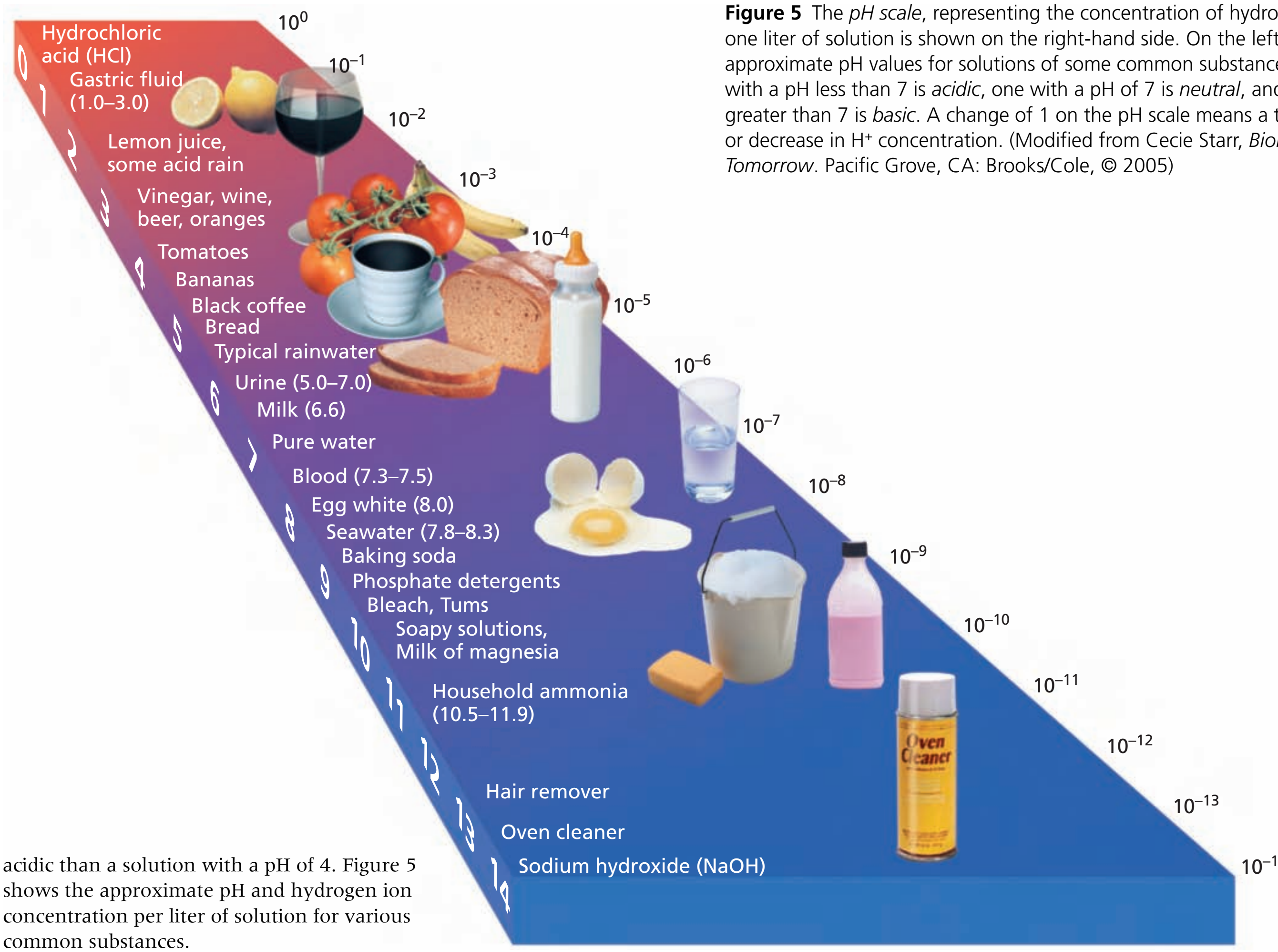


Figure 5 The *pH scale*, representing the concentration of hydrogen ions (H^+) in one liter of solution is shown on the right-hand side. On the left side, are the approximate pH values for solutions of some common substances. A solution with a pH less than 7 is *acidic*, one with a pH of 7 is *neutral*, and one with a pH greater than 7 is *basic*. A change of 1 on the pH scale means a tenfold increase or decrease in H^+ concentration. (Modified from Cecie Starr, *Biology: Today and Tomorrow*. Pacific Grove, CA: Brooks/Cole, © 2005)

acidic than a solution with a pH of 4. Figure 5 shows the approximate pH and hydrogen ion concentration per liter of solution for various common substances.

THINKING ABOUT
pH

A solution has a pH of 2. How many times more acidic is this solution than one with a pH of 6?

The measurement of acidity is important in the study of environmental science, as environmental changes involving acidity can have serious environmental impacts. For example, when coal and oil are burned they give off acidic compounds that can return to the earth as *acid deposition* (see Figure 18-14, p. 477, and Figure 18-15, p. 478), which has become a major environmental problem.

There Are Weak Forces of Attraction between Some Molecules

Ionic and covalent bonds form between the ions or atoms *within* a compound. There are also weaker forces of attraction *between* the molecules of covalent compounds (such as water) resulting from an unequal sharing of electrons by two atoms.

For example, an oxygen atom has a much greater attraction for electrons than does a hydrogen atom. Thus, the electrons shared between the oxygen atom and its two hydrogen atoms in a water molecule are pulled closer to the oxygen atom, but not actually transferred to the oxygen atom. As a result, the oxygen atom in a water molecule has a slightly negative partial charge and its two hydrogen atoms have a slightly positive partial charge (Figure 6).

The slightly positive hydrogen atoms in one water molecule are then attracted to the slightly negative oxygen atoms in another water molecule. These forces of attraction *between* water molecules are called *hydrogen bonds* (Figure 6).

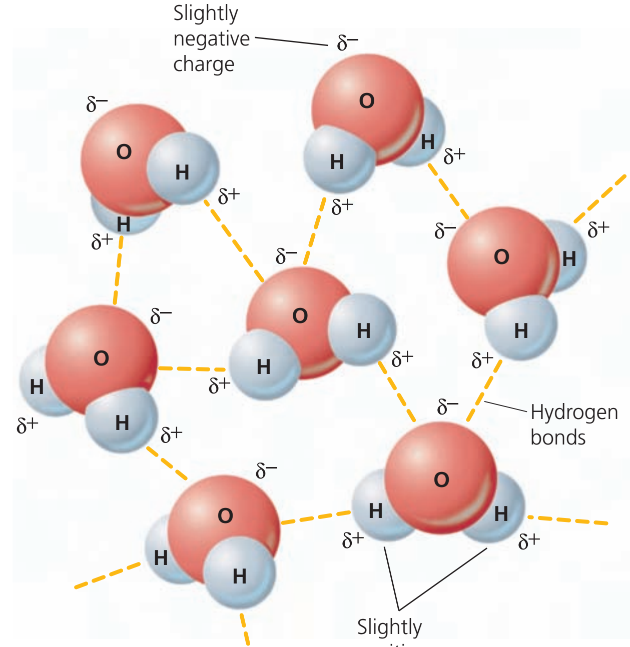


Figure 6 *Hydrogen bond:* The slightly unequal sharing of electrons in the water molecule creates a molecule with a slightly negatively charged end and a slightly positively charged end. Because of this electrical polarity, the hydrogen atoms of one water molecule are attracted to the oxygen atoms in other water molecules. These fairly weak forces of attraction *between* molecules (represented by the dashed lines) are called *hydrogen bonds*.

They account for many of water's unique properties (see Chapter 3, Science Focus, p. 68). Hydrogen bonds also form between other covalent molecules or between portions of such molecules containing hydrogen and nonmetallic atoms with a strong ability to attract electrons.

Four Types of Large Organic Compounds Are the Molecular Building Blocks of Life

Larger and more complex organic compounds, called *polymers*, consist of a number of basic structural or molecular units (*monomers*) linked by chemical bonds, somewhat like rail cars linked in a freight train. Four types of macromolecules—complex carbohydrates, proteins, nucleic acids, and lipids—are molecular building blocks of life.

Complex carbohydrates consist of two or more monomers of *simple sugars* (such as glucose, Figure 7) linked together. One example is the starches that plants use to store energy and also to provide energy for animals that feed on plants. Another is cellulose, the earth's most abundant organic compound, which is found in the cell walls of bark, leaves, stems, and roots.

Proteins are large polymer molecules formed by linking together long chains of monomers called *amino acids* (Figure 8). Living organisms use about 20 different amino acid molecules to build a variety of proteins, which play different roles. Some help to store energy. Some are components of the *immune system* that protects the body against diseases and harmful substances by forming antibodies that make invading agents harmless. Others are *hormones* that are used as chemical messengers in the bloodstreams of animals to turn various bodily functions on or off. In animals, proteins are also components of hair, skin, muscle, and tendons. In addition, some proteins act as *enzymes* that catalyze or speed up certain chemical reactions.

Nucleic acids are large polymer molecules made by linking hundreds to thousands of four types of monomers called *nucleotides*. Two nucleic acids—DNA (**d**eoxyribo**n**ucleic **a**cid) and RNA (**r**ibo**n**ucleic **a**cid)—participate in the building of proteins and carry hereditary information used to pass traits from parent to offspring. Each nucleotide consists of a *phosphate group*, a *sugar molecule* containing five carbon atoms (deoxyribose in DNA molecules and ribose in RNA molecules), and one of four different *nucleotide bases* (represented by A, G, C, and T, the first letter in each of their names, or A, G, C, and U in RNA) (Figure 9). In the cells of living organisms, these nucleotide units combine in different numbers and sequences to form *nucleic acids* such as various types of RNA and DNA (Figure 10).

Hydrogen bonds formed between parts of the four nucleotides in DNA hold two DNA strands together like a spiral staircase, forming a double helix (Figure 10). DNA molecules can unwind and replicate themselves.

The total weight of the DNA needed to reproduce all of the world's people is only about 50 milligrams—the weight of a small match. If the DNA coiled in your body were unwound, it would stretch about 960 million kilometers (600 million miles)—more than six times the distance between the sun and the earth.

The different molecules of DNA that make up the millions of species found on the earth are like a vast and diverse genetic library. Each species is a unique book in that library. The *genome* of a species is made up of the entire sequence of DNA "letters" or base pairs that combine to "spell out" the chromosomes in typical members

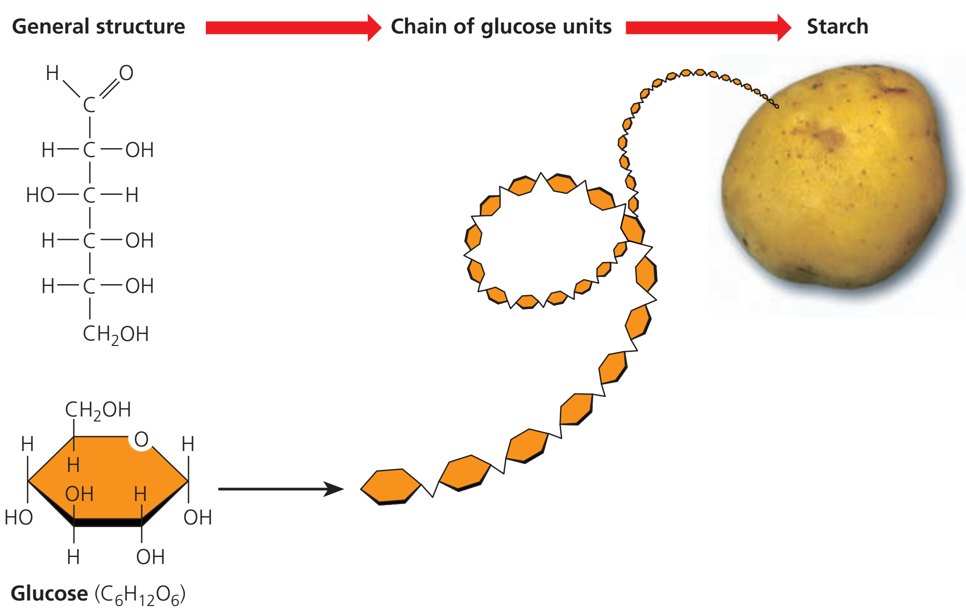


Figure 7 Straight-chain and ring structural formulas of glucose, a simple sugar that can be used to build long chains of complex carbohydrates such as starch and cellulose.

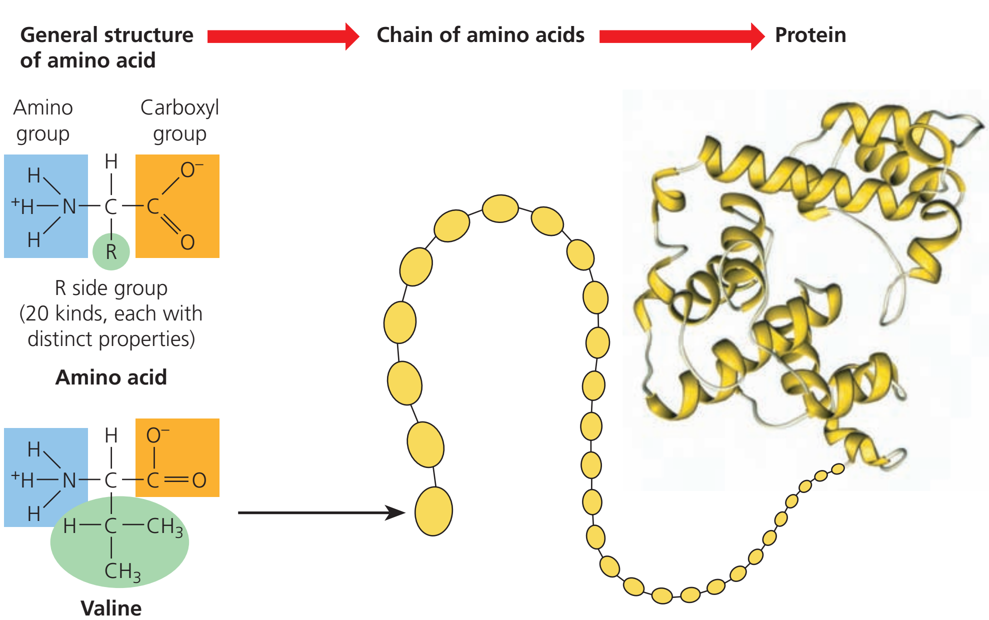


Figure 8 This model illustrates both the general structural formula of amino acids and a specific structural formula of one of the 20 different amino acid molecules that can be linked together in chains to form proteins that fold up into more complex shapes.

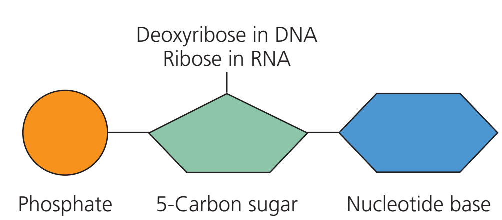


Figure 9 This diagram shows the generalized structures of the nucleotide molecules linked in various numbers and sequences to form large nucleic acid molecules such as various types of DNA (deoxyribonucleic acid) and RNA (ribonucleic acid). In DNA, the five-carbon sugar in each nucleotide is deoxyribose; in RNA it is ribose. The four basic nucleotides used to make various forms of DNA molecules differ in the types of nucleotide bases they contain—guanine (G), cytosine (C), adenine (A), and thymine (T). (Uracil, labeled U, occurs instead of thymine in RNA.)

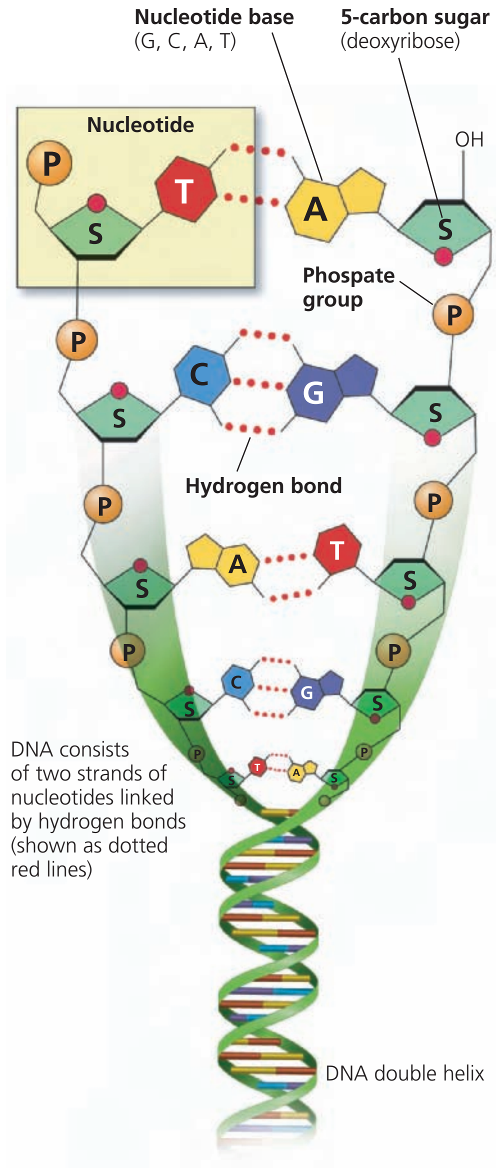


Figure 10 Portion of the double helix of a DNA molecule. The double helix is composed of two spiral (helical) strands of nucleotides. Each nucleotide contains a unit of phosphate (P), deoxyribose (S), and one of four nucleotide bases: guanine (G), cytosine (C), adenine (A), and thymine (T). The two strands are held together by hydrogen bonds formed between various pairs of the nucleotide bases. Guanine (G) bonds with cytosine (C), and adenine (A) with thymine (T).

of each species. In 2002, scientists were able to map out the genome for the human species by analyzing the 3.1 billion base sequences in human DNA.

Lipids, a fourth building block of life, are a chemically diverse group of large organic compounds that do not dissolve in water. Examples are *fats and oils* for storing energy (Figure 11), *waxes* for structure, and *steroids* for producing hormones.

Figure 12 shows the relative sizes of simple and complex molecules, cells, and multicelled organisms.

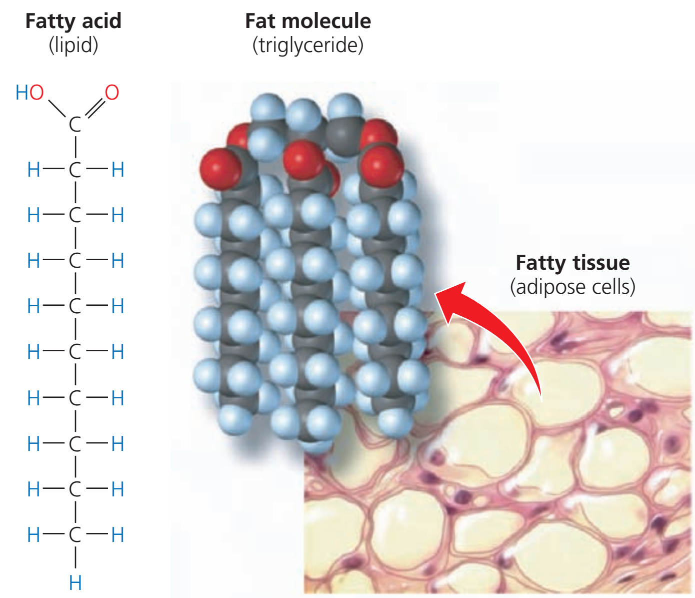


Figure 11 The structural formula of fatty acid that is one form of lipid (left) is shown here. Fatty acids are converted into more complex fat molecules (center) that are stored in adipose cells (right).

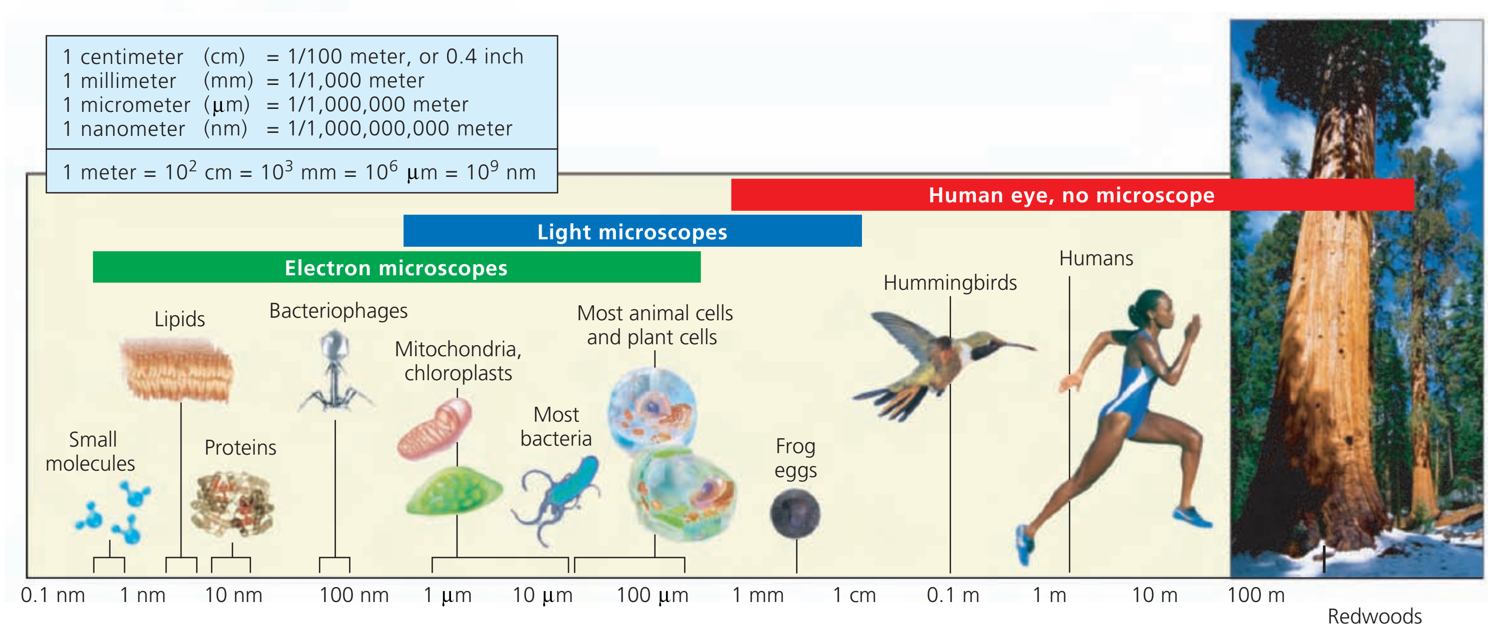


Figure 12 This chart compares the relative size of simple molecules, complex molecules, cells, and multicellular organisms. This scale is exponential, not linear. Each unit of measure is ten times larger than the unit preceding it. (Used by permission from Cecie Starr and Ralph Taggart, *Biology*, 11th ed. Belmont, CA: Thomson Brooks/Cole, © 2006)

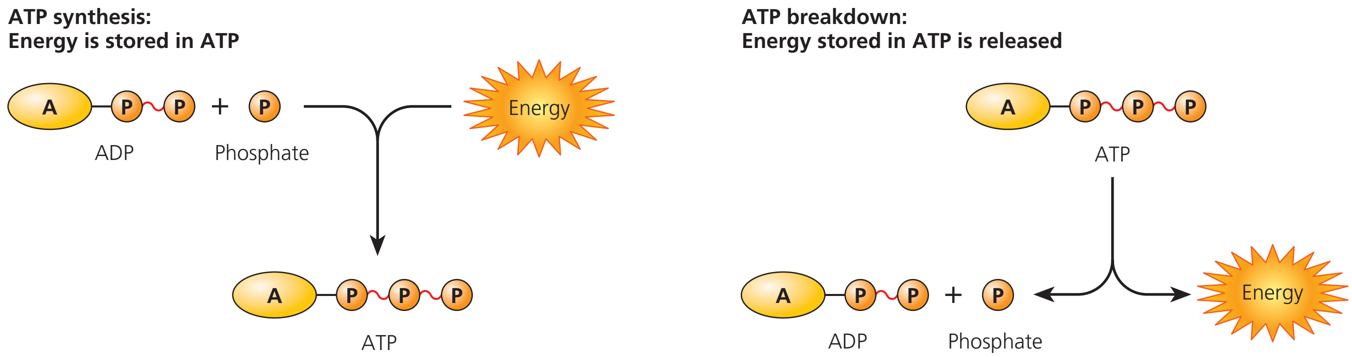


Figure 13 These models represent energy storage and release in cells.

Certain Molecules Store and Release Energy in Cells

Chemical reactions occurring in plant cells during photosynthesis (see Chapter 3, p. 59) release energy that is absorbed by adenosine diphosphate (ADP) molecules and stored as chemical energy in adenosine triphosphate (ATP) molecules (Figure 13, left). When cellular processes require energy, ATP molecules release it to form ADP molecules (Figure 13, right).

Chemists Balance Chemical Equations to Keep Track of Atoms

Chemists use a shorthand system, or equation, to represent chemical reactions. These chemical equations are also used as an accounting system to verify that no atoms are created or destroyed in a chemical reaction as required by the law of conservation of matter (see Chapter 2, p. 43). As a consequence, each side of a chemical equation must have the same number of atoms or ions of each element involved. Ensuring that this condition is met leads to what chemists call a *balanced chemical equation*. The equation for the burning of carbon ($C + O_2 \rightarrow CO_2$) is balanced because one atom of carbon and two atoms of oxygen are on both sides of the equation.

Consider the following chemical reaction: When electricity passes through water (H_2O), the latter can be broken down into hydrogen (H_2) and oxygen (O_2), as represented by the following equation:

H_2O	$\rightarrow$	H_2	+	O_2
2 H atoms 1 O atom		2 H atoms		2 O atoms

This equation is unbalanced because one atom of oxygen is on the left side of the equation but two atoms are on the right side.

We cannot change the subscripts of any of the formulas to balance this equation because that would change the arrangements of the atoms, leading to different substances. Instead, we must use different numbers of the molecules involved to balance the equation. For example, we could use two water molecules:

$2\ H_2O$	$\rightarrow$	H_2	+	O_2
4 H atoms 2 O atoms		2 H atoms		2 O atoms

This equation is still unbalanced. Although the numbers of oxygen atoms on both sides of the equation are now equal, the numbers of hydrogen atoms are not.

We can correct this problem by having the reaction produce two hydrogen molecules:

$2\ H_2O$	$\rightarrow$	$2\ H_2$	+	O_2
4 H atoms 2 O atoms		4 H atoms		2 O atoms

Now the equation is balanced, and the law of conservation of matter has been observed. For every two molecules of water through which we pass electricity, two hydrogen molecules and one oxygen molecule are produced.

THINKING ABOUT
Chemical Equations

Try to balance the chemical equation for the reaction of nitrogen gas (N_2) with hydrogen gas (H_2) to form ammonia gas (NH_3).

Scientists Are Learning How to Build Materials from the Bottom Up

Nanotechnology (see Chapter 14, Science Focus, p. 365) uses atoms and molecules to build materials from the bottom up using atoms of the elements in the periodic table as its raw materials. A *nanometer* (nm) is one-billionth of a meter—equal to the length of about 10 hydrogen atoms lined up side by side. A DNA molecule (Figure 9) is about 2.5 nanometers wide. A human hair has a width of 50,000 to 100,000 nanometers.

For objects smaller than about 100 nanometers, the properties of materials change dramatically. At this *nanoscale* level, materials can exhibit new properties, such as extraordinary strength or increased chemical activity that they do not exhibit at the much larger *macroscale* level with which we are all familiar.

For example, scientists have learned how to make tiny tubes of carbon atoms linked together in hexagons. Experiments have shown that these carbon nanotubes are the strongest material ever made—60 times stronger than high-grade steel. Such nanotubes have been linked together to form a rope so thin that it is invisible, but strong enough to suspend a pickup truck.

At the macroscale, zinc oxide (ZnO) can be rubbed on the skin as a white paste to protect against the sun's harmful UV rays; at the nanoscale it becomes transparent and is being used in invisible coatings to protect the skin and fabrics from UV damage. Because silver (Ag) can kill harmful bacteria, silver nanocrystals are being incorporated into bandages for wounds and other antibacterial and antifungal products such as the imitation hair in some fuzzy animal toys, as well as in pet beds and clothing.

Researchers hope to incorporate nanoparticles of hydroxyapatite, with the same chemical structure as tooth enamel, into toothpaste to put coatings on teeth that prevent the penetration of bacteria. Nanotech coatings now being used on cotton fabrics form an impenetrable barrier that causes liquids to bead and roll off. Such stain-resistant fabrics, used to make clothing, rugs, and furniture upholstery, could eliminate the need to use harmful chemicals for removing stains.

Self-cleaning window glass coated with a layer of nanoscale titanium dioxide (TiO_2) particles is now available. As the particles interact with UV rays from the sun, dirt on the surface of the glass loosens and washes off when it rains. Similar products can be used for self-cleaning sinks and toilet bowls.

Scientists are working on ways to replace the silicon in computer chips with carbon-based nanomaterials that greatly increase the processing power of computers. Biological engineers are working on nanoscale devices that could deliver drugs on the cellular level. Such devices could penetrate cancer cells and deliver nanomolecules that could kill the cancer cells from the inside. Researchers also hope to develop nanoscale crystals that could change color when they detect tiny amounts (measured in parts per trillion) of harmful substances such as chemical and biological warfare agents, and food pathogens. For example, a color change in food packaging could alert a consumer when a food is contaminated or has begun to spoil. The list of possibilities continues to grow.

By 2010, more than 1,000 products containing nanoscale particles were commercially available and thousands more were in the research and development pipeline. Examples are found in cosmetics, sunscreens, fabrics (including odor-eating socks), pesticides, food additives, energy drinks, solar cells (Figure 16-8, right, p. 413) and food packaging (including some hamburger containers and plastic beer bottles).

So far, these products are unregulated and unlabeled. In addition, consumers and government officials don't know what companies are using nanomaterials, what kinds and amounts they are using, and in what products they are using them. This concerns many health and environmental scientists because the tiny size of nanoparticles can allow them to penetrate the body's natural defenses against invasions by foreign and potentially harmful chemicals and pathogens. Nanoparticles of a chemical tend to be much more chemically reactive than macroparticles of the same chemical, largely because the tiny nanoparticles have relatively large surface areas for their small mass. This means that a chemical that is harmless at the macroscale may be hazardous at the nanoscale when they are inhaled, ingested, or absorbed through the skin.

We know little about such effects and risks at a time when the use of untested and unregulated nanoparticles is increasing exponentially. A few toxicological studies are sending up red flags:

- In 2004, Eva Olberdorster, an environmental toxicologist at Southern Methodist University in the U.S. state of Texas, found that fish swimming in water loaded with a type of carbon nanomolecules called buckyballs experienced brain damage within 48 hours.
- In 2005, NASA researchers found that injecting commercially available carbon nanotubes into rats caused significant lung damage.
- A 2005 study by researchers at the U.S. National Institute of Occupational Safety and Health found substantial damage to the hearts and aortas of mice exposed to carbon nanotubes.
- In 2008, a team of researchers, including Andrew Maynard and Ken Donaldson, injected short and long straight nanotubes into mice tissues. They found that the short tubes did not cause lesions but the long tubes did produce lesions that could develop into mesothelioma, a deadly form of lung cancer caused by the inhalation of small needles of asbestos fibers. The study also suggested that curly carbon nanotubes did not have such harmful effects, suggesting that further research could lead to safe carbon nanotube products.

In 2004, the British Royal Society and Royal Academy of Engineering recommended that we avoid the environmental release of nanoparticles and nanotubes as much as possible until more is known about their potential harmful impacts. As a precautionary measure, they recommended that factories and research laboratories treat manufactured nanoparticles and nanotubes as if they were hazardous to their workers and to the general public. Others have called for regulation of the use of nanoparticle materials, labeling products with such materials, and greatly increasing research on the potential harmful health effects of nanoparticles. **GREEN CAREER:** nanotechnology

THINKING ABOUT
Nanotechnology

Do you think that the benefits of nanotechnology outweigh its potentially harmful effects? Explain. What are three things you would do to reduce its potentially harmful effects?

RESEARCH FRONTIER

Learning more about nanotechnology and how to reduce its potentially harmful effects; see **www.cengage.com/login**.

SUPPLEMENT

5

Classifying and Naming Species (Chapters 1, 3–5, 9)

All organisms on the earth today are descendants of single-cell organisms that lived almost 4 billion years ago. As a result of biological evolution through natural selection, life has evolved into six major groups of species, called *kingdoms*: *eubacteria, archaebacteria, protists, fungi, plants,* and *animals* (see Chapter 4, pp. 85–88). This evolutionary view sees the development of life as an ever-branching tree of species diversity, sometimes called the *tree of life* (Figure 1).

On the basis of their cell structure, we can classifiy organisms as either *eukaryotic* or *prokaryotic*. A eukaryotic cell is surrounded by a membrane and has a distinct *nucleus* (a membrane-bounded structure containing genetic material in the form of DNA) and several other internal parts called *organelles* that are also surrounded by membranes. Most organisms consist

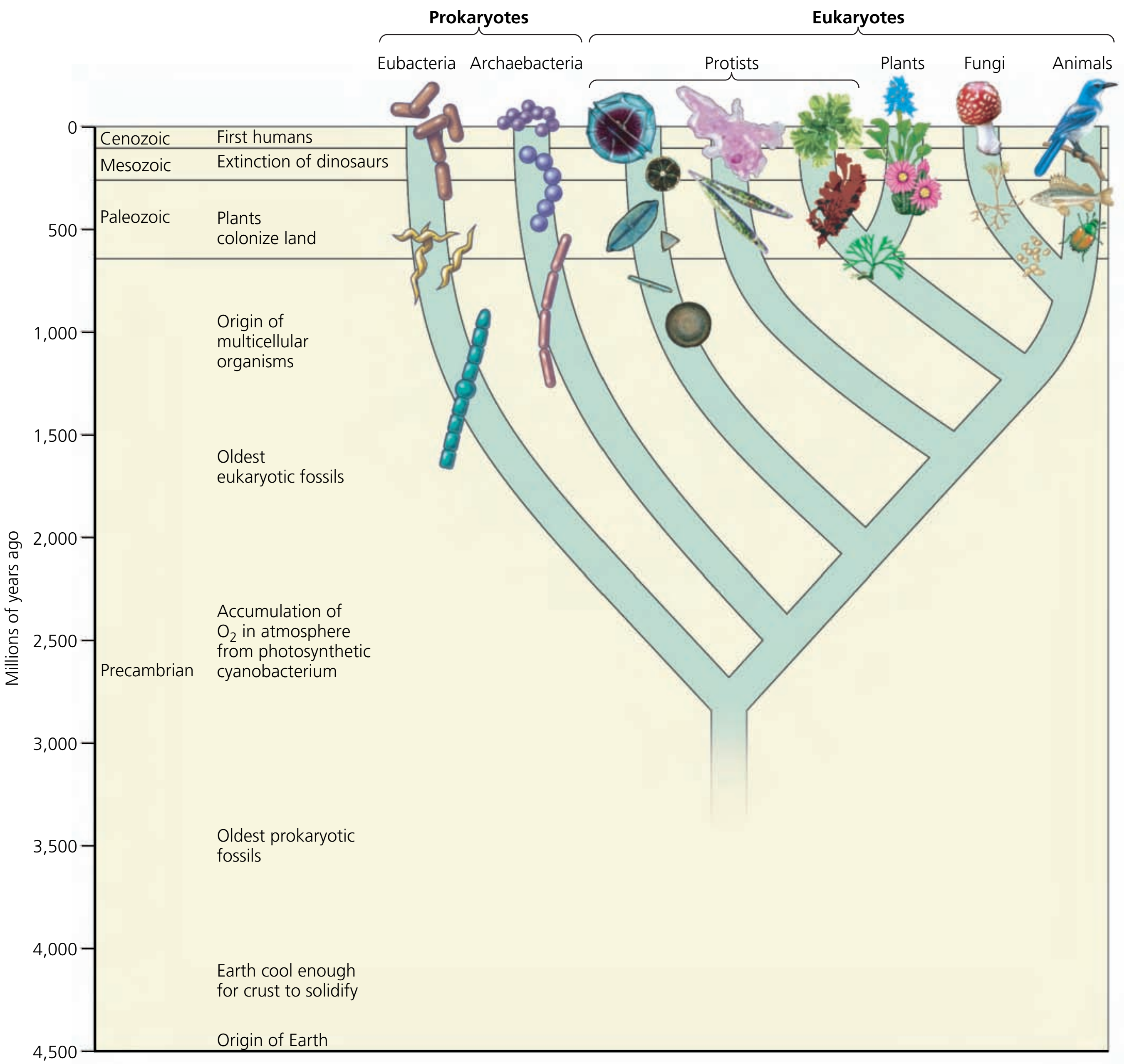


Figure 1 This diagram provides an overview of the evolution of life on the earth into six major kingdoms of species as a result of natural selection.

of eukaryotic cells. A prokaryotic cell is also surrounded by a membrane but it has no distinct nucleus and no other internal parts surrounded by membranes.

Eubacteria are prokaryotes with single cells that lack a nucleus and other internal compartments found in the cells of species from other kingdoms. Examples include various cyanobacteria and bacteria such as *staphylococcus* and *streptococcus*.

Archaebacteria are single-celled bacteria that are closer to eukaryotic cells than to eubacteria, and they are found in extreme environments. Examples include methanogens, which live in oxygen-free sediments of lakes and swamps and in animal guts; halophiles, which live in extremely salty water; and thermophiles, which live in hot springs, hydrothermal vents, and acidic soil.

The remaining four kingdoms—protists, fungi, plants, and animals—are eukarotes with one or more cells that have a nucleus and complex internal compartments. *Protists* are mostly single-celled eukaryotic organisms, such as diatoms, dinoflagellates, amoebas, golden brown and yellow-green algae, and protozoans. Some protists cause human diseases such as malaria (see Chapter 17, pp. 443–444) and sleeping sickness.

Fungi are mostly many-celled, sometimes microscopic, eukaryotic organisms such as mushrooms, molds, mildews, and yeasts. Many fungi are decomposers (see Figure 3-9, left, p. 61). Other fungi kill various plants and animals and cause huge losses of crops and valuable trees.

Plants are mostly many-celled eukaryotic organisms such as red, brown, and green algae and mosses, ferns, and flowering plants (whose flowers produce seeds that perpetuate the species). Some plants such as corn and marigolds are *annuals*, meaning that they complete their life cycles in one growing season. Others are *perennials* such as roses, grapes, elms, and magnolias, which survive from one growing season to another and can live for more than 2 years without being reseeded.

Animals are also many-celled eukaryotic organisms. Most have no backbones and hence are called *invertebrates*. Invertebrates include sponges, jellyfish, worms, arthropods (e.g., shrimp, crabs, insects, and spiders), mollusks (e.g., snails, clams, and octopuses), and echinoderms (e.g., sea urchins and sea stars). *Vertebrates* (animals with backbones and a brain protected by skull bones) include fishes (e.g., sharks and tuna), amphibians (e.g., frogs and salamanders), reptiles (e.g., crocodiles and snakes), birds (e.g., eagles and robins), and mammals (e.g., bats, elephants, whales, and humans).

Within each kingdom, biologists have created subcategories based on anatomical, physiological, and behavioral characteristics. Kingdoms are divided into *phyla*, which are divided into subgroups called *classes*. Classes are subdivided into *orders*, which are further divided into *families*. Families consist of *genera* (singular, *genus*), and each genus contains one or more *species*. (Note that the word *species* is both singular and plural.) Figure 2 shows this detailed taxonomic classification for the current human species.

Most people call a species by its common name, such as robin or grizzly bear. Biologists use scientific names (derived from Latin) consisting of two parts (printed in italics, or underlined) to describe a species. The first word is the capitalized name (or abbreviation) for the genus to which the organism belongs. It is followed by a lowercase name that distinguishes the species from other members of the same genus. For example, the scientific name of the robin is *Turdus migratorius* (Latin for "migratory thrush") and the grizzly bear goes by the scientific name *Ursus horribilis* (Latin for "horrible bear").

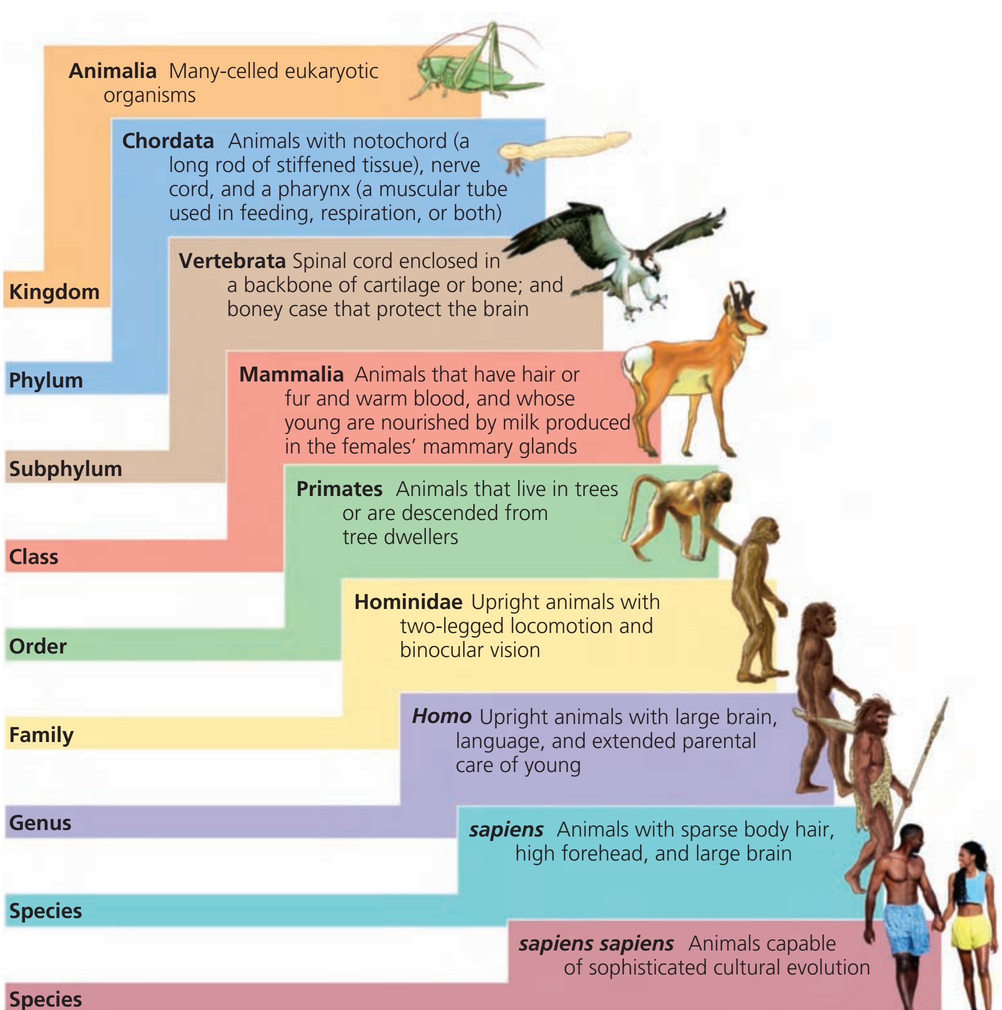


Figure 2 This diagram illustrates the taxonomic classification of the latest human species, *Homo sapiens sapiens*.

SUPPLEMENT

6 Components and Interactions in Major Biomes (Chapters 3, 7, 10, 16, 20)

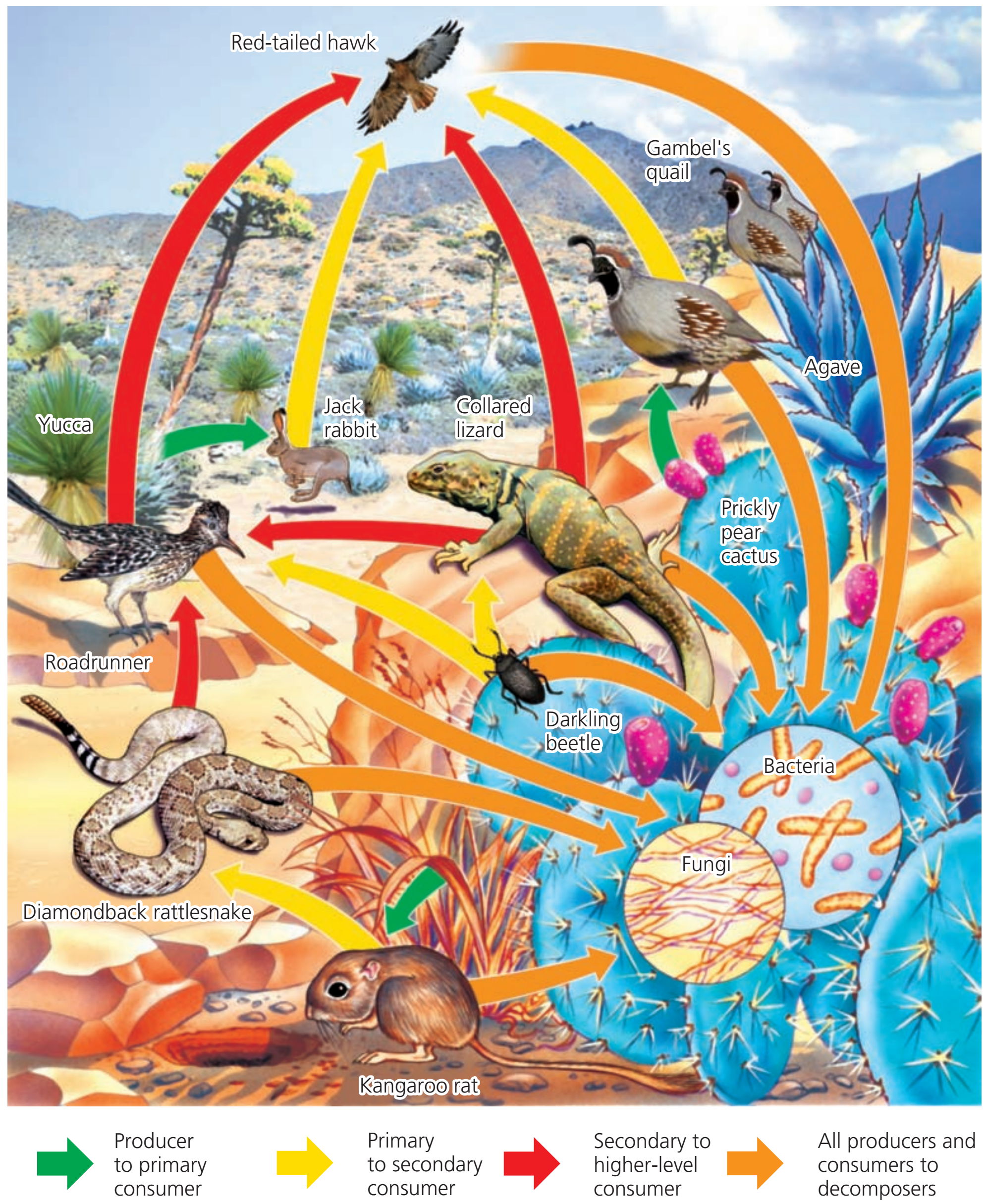
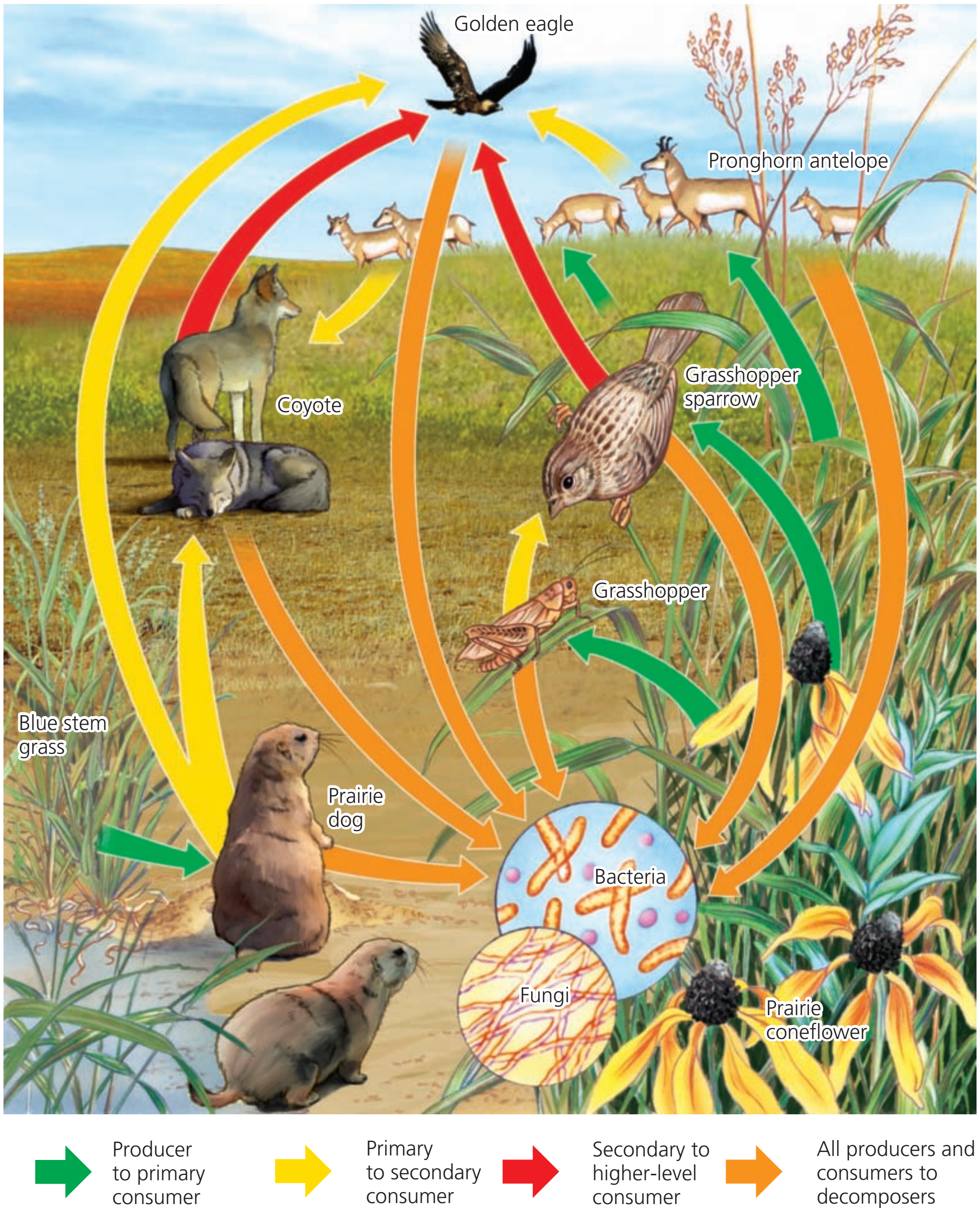


Figure 1 This diagram illustrates some components and interactions in a *temperate desert ecosystem* in North America. When these organisms die, decomposers break down their organic matter into minerals that plants can use. Colored arrows indicate transfers of matter and energy among producers, primary consumers (herbivores), secondary or higher-level consumers (carnivores), and decomposers. Organisms are not drawn to scale. **Question:** Which species might undergo population growth and which species might suffer a population decline if the diamondback rattlesnake were eliminated from this ecosystem?



CENGAGENOW™ **Active Figure 2** Some of the components and interactions in a *temperate tall-grass prairie ecosystem* in North America are represented here. When these organisms die, decomposers break down their organic matter into minerals that plants can use. Colored arrows indicate transfers of matter and energy among producers, primary consumers (herbivores), secondary or higher-level consumers (carnivores), and decomposers. Organisms are not drawn to scale. *See an animation based on this figure at* CengageNOW™. **Question:** Which species might increase and which species might decrease in population size if the threatened prairie dog were eliminated from this ecosystem?

Figure 3 Some of the components and interactions in an *arctic tundra (cold grassland) ecosystem* in North America are shown here. When these organisms die, decomposers break down their organic matter into minerals that plants can use. Colored arrows indicate transfers of matter and energy among producers, primary consumers (herbivores), secondary or higher-level consumers (carnivores), and decomposers. Organisms are not drawn to scale. **Question:** Which species might increase and which species might decrease in population size if the arctic fox were eliminated from this ecosystem?

Figure 4 This diagram illustrates some of the components and interactions in a *temperate deciduous forest ecosystem* in North America. When these organisms die, decomposers break down their organic matter into minerals that plants can use. Colored arrows indicate transfers of matter and energy among producers, primary consumers (herbivores), secondary or higher-level consumers (carnivores), and decomposers. Organisms are not drawn to scale. **Question:** Which species might increase and which species might decrease in population size if the broad-winged hawk were eliminated from this ecosystem?

Figure 5 Some of the components and interactions in an *evergreen coniferous* (*boreal* or *taiga*) *forest ecosystem* in North America are shown here. When these organisms die, decomposers break down their organic matter into minerals that plants can use. Colored arrows indicate transfers of matter and energy among producers, primary consumers (herbivores), secondary or higher-level consumers (carnivores), and decomposers. Organisms are not drawn to scale. **Question:** Which species might increase and which species might decrease in population size if the great horned owl were eliminated from this ecosystem?

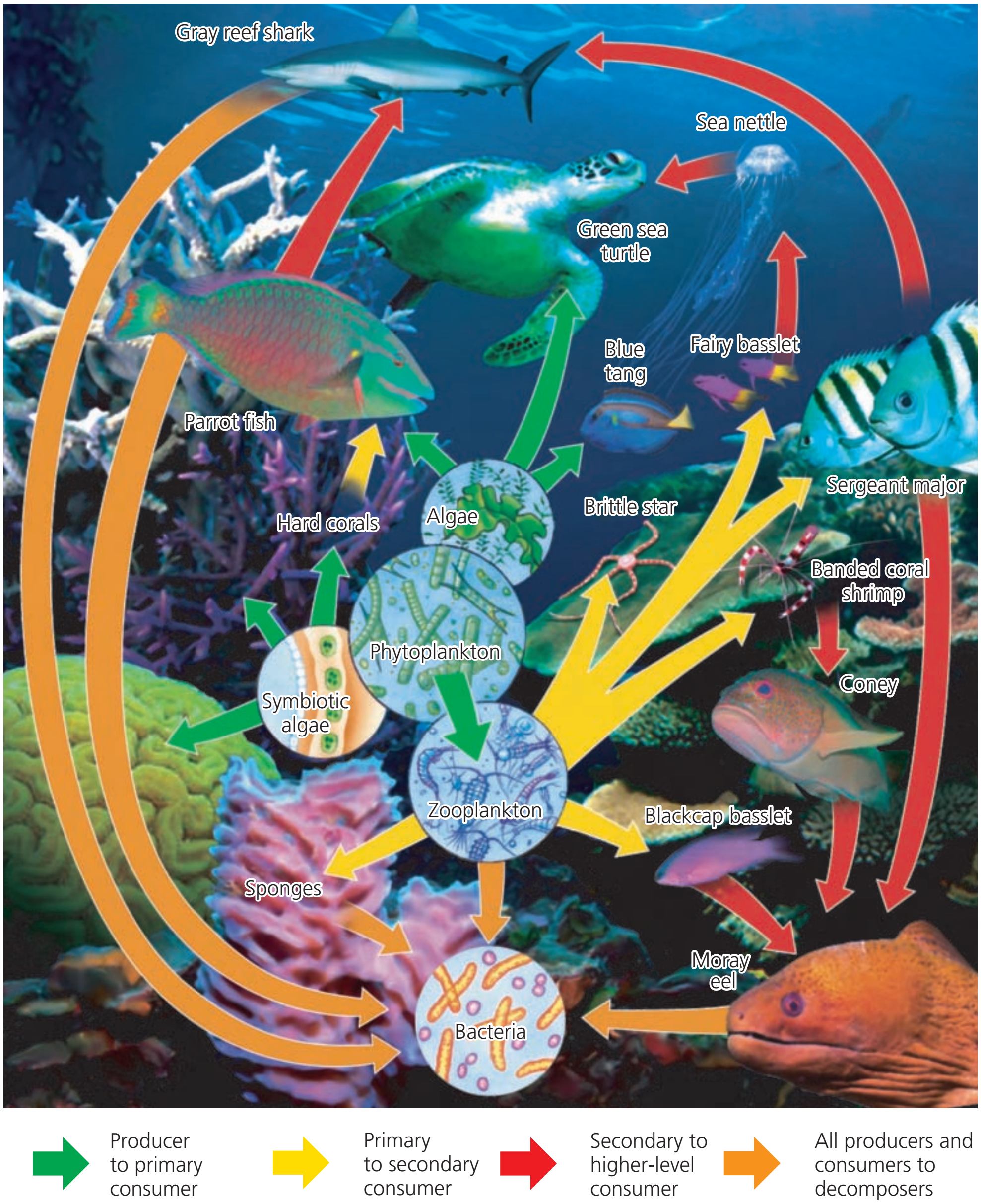


Figure 6 This diagram illustrates some of the components and interactions in a *coral reef ecosystem*. When these organisms die, decomposers break down their organic matter into minerals used by plants. Colored arrows indicate transfers of matter and energy among producers, primary consumers (herbivores), secondary or higher-level consumers (carnivores), and decomposers. Organisms are not drawn to scale. See the photo of a coral reef in Figure 8-1, left, p. 174. **Question:** How would the species in this ecosystem be affected if phytoplankton populations suffered a sharp drop?

SUPPLEMENT

7

Weather Basics: El Niño, Tornadoes, and Tropical Cyclones (Chapters 7, 18, 19)

Weather Is Affected by Moving Masses of Warm and Cold Air

Weather is the set of short-term atmospheric conditions—typically those occurring over hours or days—for a particular area. Examples of atmospheric conditions include temperature, pressure, moisture content, precipitation, sunshine, cloud cover, and wind direction and speed.

Meteorologists use equipment mounted on weather balloons, aircraft, ships, and satellites, as well as radar and stationary sensors, to obtain data on weather variables. They then feed these data into computer models to draw weather maps. Other computer models project the weather for a period of several days by calculating the probabilities that air masses, winds, and other factors will change in certain ways.

Much of the weather we experience results from interactions between the leading edges of moving masses of warm and cold air. Weather changes as one air mass replaces or meets another. The most dramatic changes in weather occur along a **front**, the boundary between two air masses with different temperatures and densities.

A **warm front** is the boundary between an advancing warm air mass and the cooler one it is replacing (Figure 1, left). Because warm air is less dense (weighs less per unit of volume) than cool air, an advancing warm front rises up over a mass of cool air. As the warm front rises, its moisture begins condensing into droplets, forming layers of clouds at different altitudes. Gradually, the clouds thicken, descend to a lower altitude, and often release their moisture as rainfall. A moist warm front can bring days of cloudy skies and drizzle.

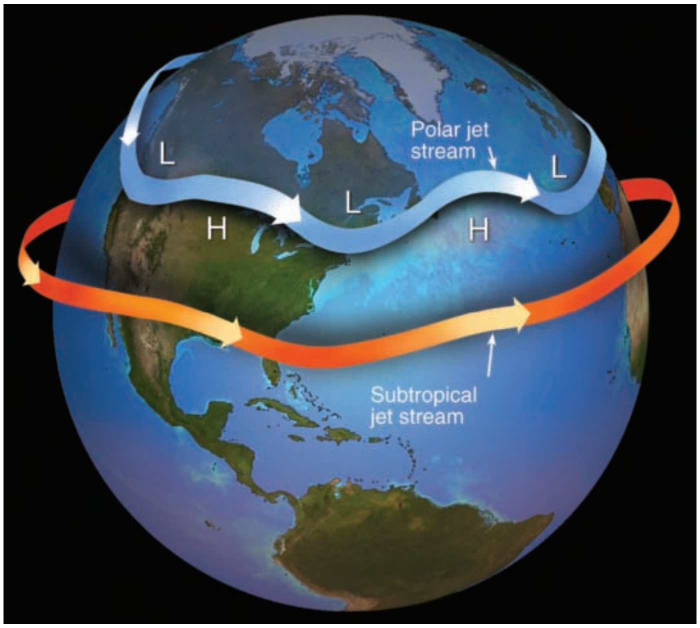


Figure 2 A *jet stream* is a rapidly flowing air current that moves west to east in a wavy pattern. This figure shows a polar jet stream and a subtropical jet stream in winter. In reality, jet streams are discontinuous and their positions vary from day to day. (Used by permission from C. Donald Ahrens, *Meteorology Today*, 8th ed. Belmont, CA: Brooks/Cole, 2006)

A **cold front** (Figure 1, right) is the leading edge of an advancing mass of cold air. Because cold air is denser than warm air, an advancing cold front stays close to the ground and wedges underneath less dense warmer air. An approaching cold front produces rapidly moving, towering clouds called *thunderheads*, with flat, anvil-like tops.

As a cold front passes through, it may cause high surface winds and thunderstorms. After it leaves the area, it usually results in cooler temperatures and a clear sky.

Near the top of the troposphere, hurricane-force winds circle the earth. These powerful winds, called *jet streams*, follow rising and falling paths that have a strong influence on weather patterns (Figure 2).

Weather Is Affected by Changes in Atmospheric Pressure

Changes in atmospheric pressure also affect weather. *Atmospheric pressure* results from molecules of gases (mostly nitrogen and oxygen) in the atmosphere zipping around at very high speeds and hitting and bouncing off everything they encounter.

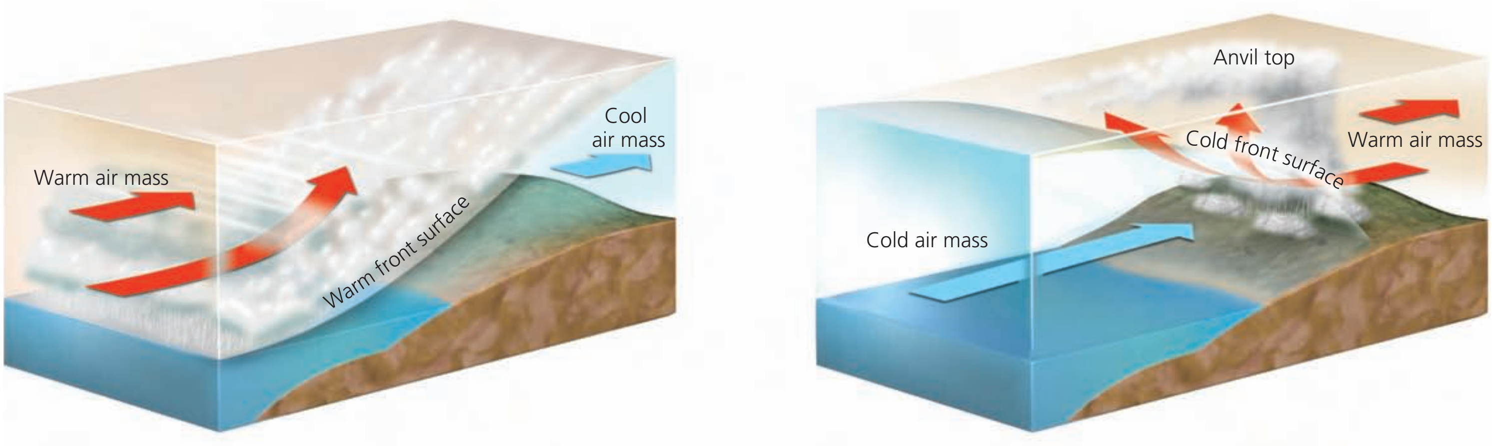


Figure 1 *Weather fronts:* A *warm front* (left) occurs when an advancing mass of warm air meets and rises up over a mass of denser cool air. A *cold front* (bottom) forms when a moving mass of cold air wedges beneath a mass of less dense warm air.

Atmospheric pressure is greater near the earth's surface because the molecules in the atmosphere are squeezed together under the weight of the air above them. An air mass with high pressure, called a **high**, contains cool, dense air that descends slowly toward the earth's surface and becomes warmer. Because of this warming, condensation of moisture usually does not take place and clouds usually do not form. Fair weather with clear skies follows as long as this high-pressure air mass remains over the area.

In contrast, a low-pressure air mass, called a **low**, produces cloudy and sometimes stormy weather. Because of its low pressure and low density, the center of a low rises, and its warm air expands and cools. When the temperature drops below a certain level where condensation takes place, called the *dew point*, moisture in the air condenses and forms clouds.

If the droplets in the clouds coalesce into larger drops or snowflakes heavy enough to fall from the sky, then precipitation occurs. The condensation of water vapor into water drops usually requires that the air contain suspended tiny particles of material such as dust, smoke, sea salts, or volcanic ash. These so-called *condensation nuclei* provide surfaces on which the droplets of water can form and coalesce.

Every Few Years Major Wind Shifts in the Pacific Ocean Affect Global Weather Patterns

An **upwelling**, or upward movement of ocean water, can mix upper levels of seawater with lower levels, bringing cool and nutrient-rich water from the bottom of the ocean to the warmer surface where it supports large populations of phytoplankton, zooplankton, fish, and fish-eating seabirds.

Figure 7-2, p. 149, shows the oceans' major upwelling zones. Upwellings far from shore occur when surface currents move apart and draw water up from deeper layers. Strong upwellings are also found along the steep western coasts of some continents when winds blowing along the coasts push surface water away from the land and draw water up from the ocean bottom (Figure 3).

Every few years, normal shore upwellings in the Pacific Ocean (Figure 4, left) are affected by changes in weather patterns called the *El Niño–Southern Oscillation*, or *ENSO* (Figure 4, right). In an ENSO, often called simply *El Niño*, prevailing winds (Figure 7-3, p. 149) called tropical trade winds blowing east to west weaken or reverse direction. This allows the warmer waters of the

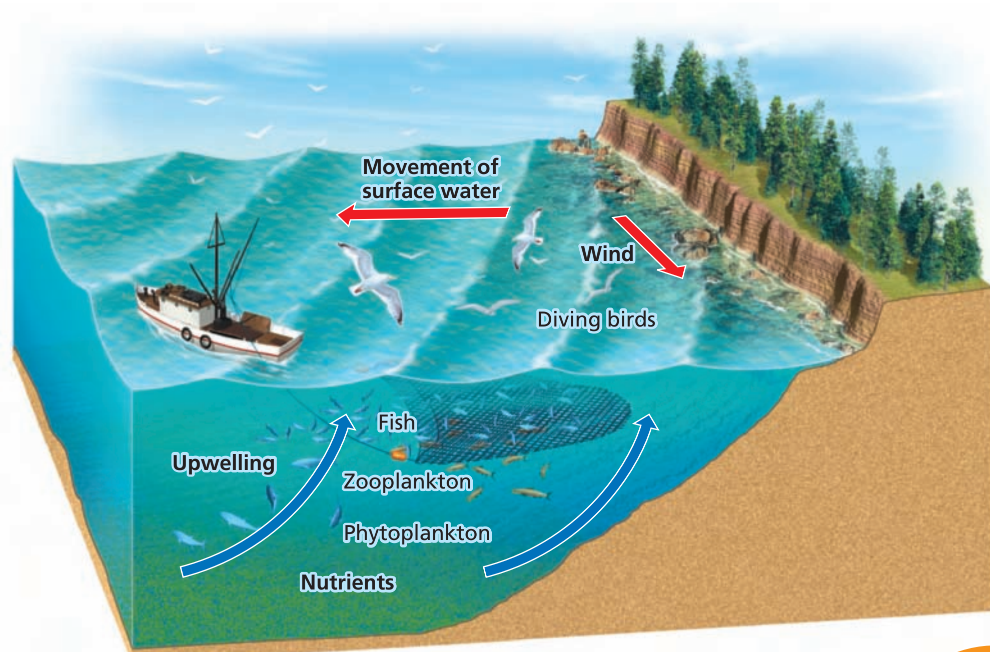


Figure 3 A shore upwelling occurs when deep, cool, nutrient-rich waters are drawn up to replace surface water moved away from a steep coast by wind flowing along the coast toward the equator.

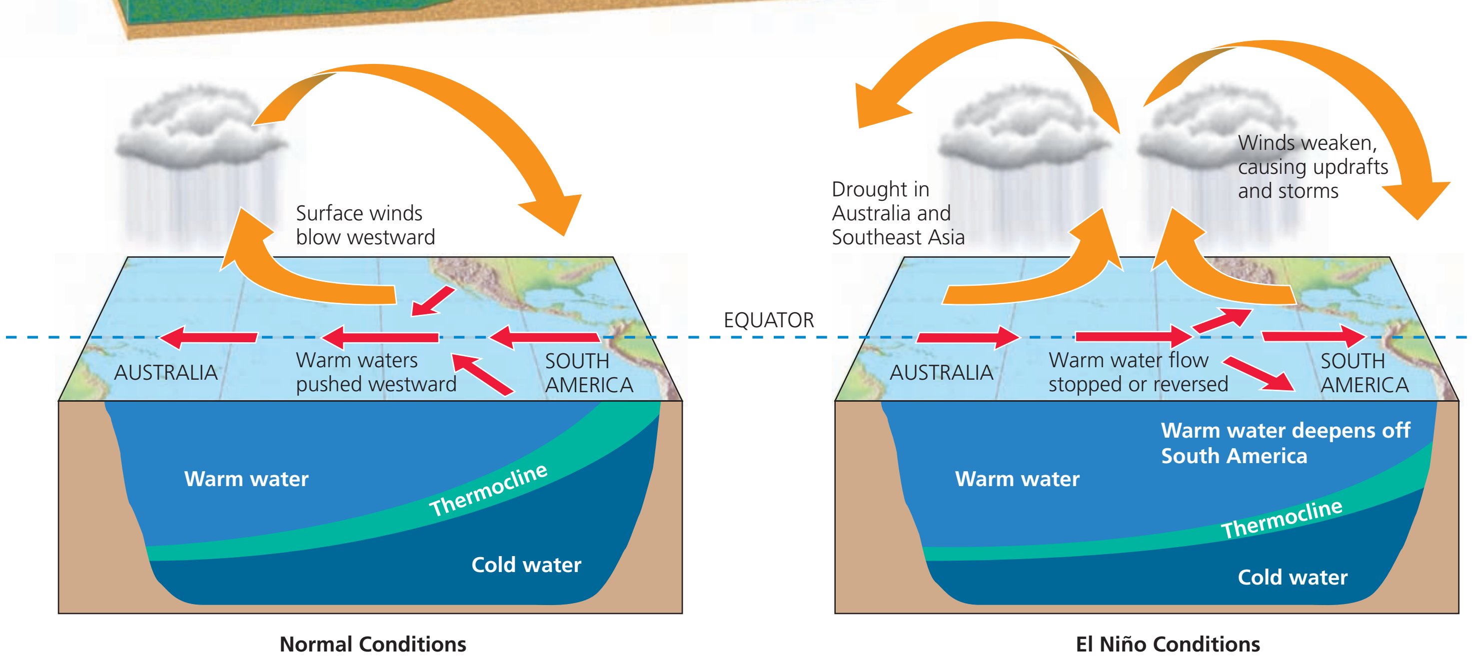


Figure 4 Normal trade winds blowing east to west cause shore upwellings of cold, nutrient-rich bottom water in the tropical Pacific Ocean near the coast of Peru (left). A zone of gradual temperature change called the *thermocline* separates the warm and cold water. Every few years a shift in trade winds known as the *El Niño–Southern Oscillation* (*ENSO*) disrupts this pattern. Trade winds blowing from east to west weaken or reverse direction, which depresses the coastal upwellings and warms the surface waters off South America (right). When an ENSO lasts 12 months or longer, it severely disrupts populations of plankton, fish, and seabirds in upwelling areas and can alter weather conditions over much of the globe (Figure 5).

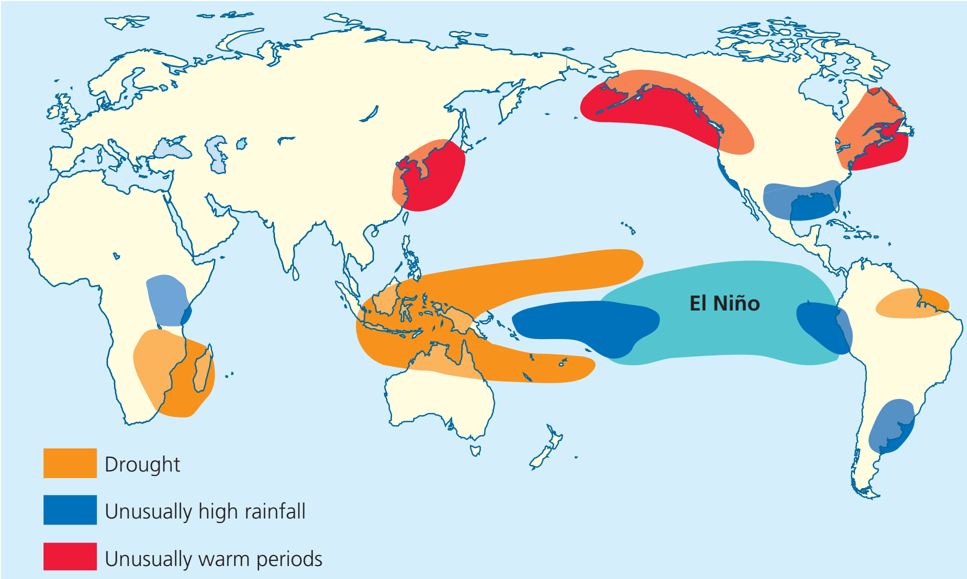


Figure 5 Typical global weather effects of an El Niño–Southern Oscillation. **Question:** How might an ENSO affect the weather where you live or go to school? (Data from United Nations Food and Agriculture Organization)

western Pacific to move toward the coast of South America, which suppresses the normal upwellings of cold, nutrient-rich water (Figure 4, right). The decrease in nutrients reduces primary productivity and causes a sharp decline in the populations of some fish species.

A strong ENSO can alter the weather of at least two-thirds of the globe (Figure 5)—especially in lands along the Pacific and Indian Oceans. Scientists do not know exactly what causes an ENSO, but they do know how to detect its formation and track its progress.

La Niña, the reverse of El Niño, cools some coastal surface waters, and brings back upwellings. Typically, La Niña means more Atlantic Ocean hurricanes, colder winters in Canada and the northeastern United States, and warmer and drier winters in the southeastern and southwestern United States. It also usually leads to wetter winters in the Pacific Northwest, torrential rains in Southeast Asia, lower wheat yields in Argentina, and more wildfires in Florida.

Tornadoes and Tropical Cyclones Are Violent Weather Extremes

Sometimes we experience *weather extremes*. Two examples are violent storms called *tornadoes* (which form over land) and *tropical cyclones* (which form over warm ocean waters and sometimes pass over coastal areas).

Tornadoes, or *twisters*, are swirling, funnel-shaped clouds that form over land. They can destroy houses and cause other serious damage in areas where they touch down on the earth's surface. The United States is the world's most tornado-prone country, followed by Australia.

Tornadoes in the plains of the midwestern United States usually occur when a large, dry, cold-air front moving southward from Canada runs into a large mass of warm humid air moving northward from the Gulf of Mexico. Most tornadoes occur in the spring and summer when fronts of cold air from the north penetrate deeply into the Great Plains and the Midwest.

As the large warm-air mass moves rapidly over the more dense cold-air mass, it rises swiftly and forms strong vertical convection currents that suck air upward, as shown in Figure 6. Scientists hypothesize that the interaction of the cooler air nearer the ground and the rapidly rising warmer air above causes a spinning, vertically rising air mass, or vortex.

Figure 7 shows the areas of greatest risk from tornadoes in the continental United States.

Tropical cyclones are spawned by the formation of low-pressure cells of air over warm tropical seas. Figure 8 shows the formation and structure of a tropical cyclone. *Hurricanes* are tropical cyclones that form in the Atlantic Ocean; those forming in the Pacific Ocean usually are called *typhoons*. Tropical cyclones take a long time to form and gain strength. As a result, meteorologists can track their paths and wind speeds, and warn people in areas likely to be hit by these violent storms.

For a tropical cyclone to form, the temperature of ocean water has to be at least 27ºC (80ºF) to a depth of 46 meters (150 feet). A tropical cyclone forms when areas of low pressure over the warm ocean draw in air from surrounding higher-pressure areas. The earth's rotation makes these winds spiral counterclockwise in the northern hemisphere and clockwise in the southern hemisphere (see Figure 7-3, p. 149). Moist air, warmed by the heat of the ocean, rises in a vortex through the center of the storm until it becomes a tropical cyclone (Figure 8).

The intensities of tropical cyclones are rated in different categories, based on their sustained wind speeds. *Category 1*: 119–153 kilometers per hour (74–95 miles per hour); *Category 2*:

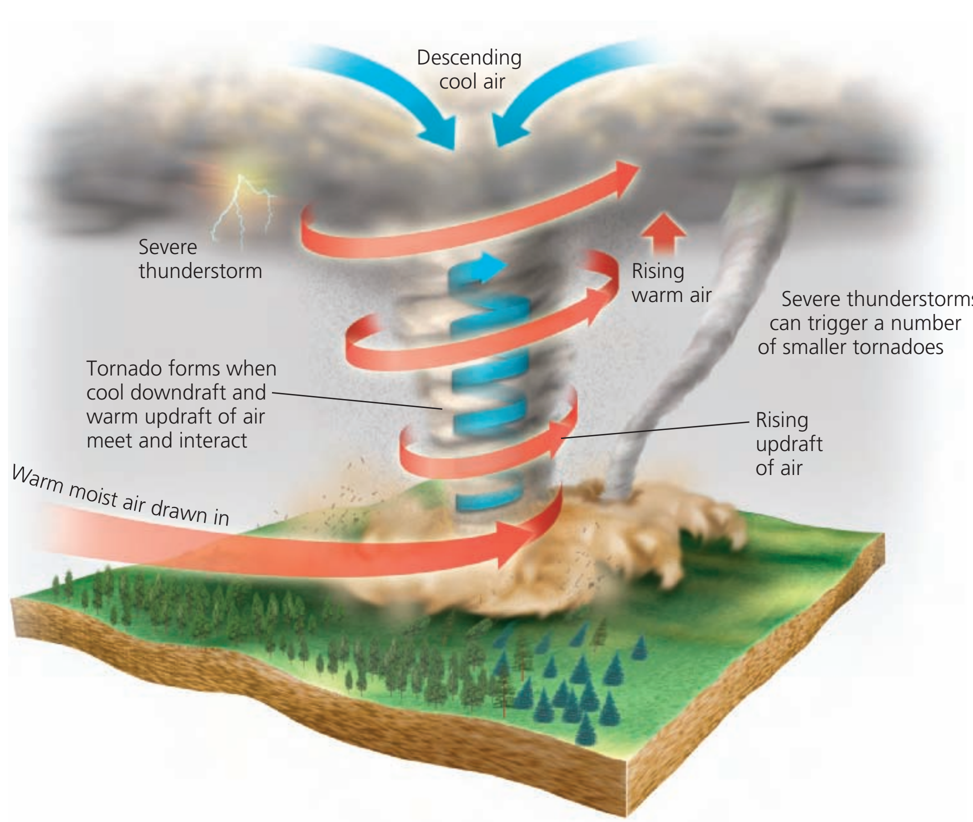


Figure 6 Formation of a *tornado*, or *twister*. Although twisters can form at any time of the year, the most active tornado season in the United States is usually March through August. Meteorologists cannot yet forecast exactly where tornadoes will form at any given time, but research on tornados and advanced computer modeling can help them to identify areas at risk each day for the formation of these deadly storms.

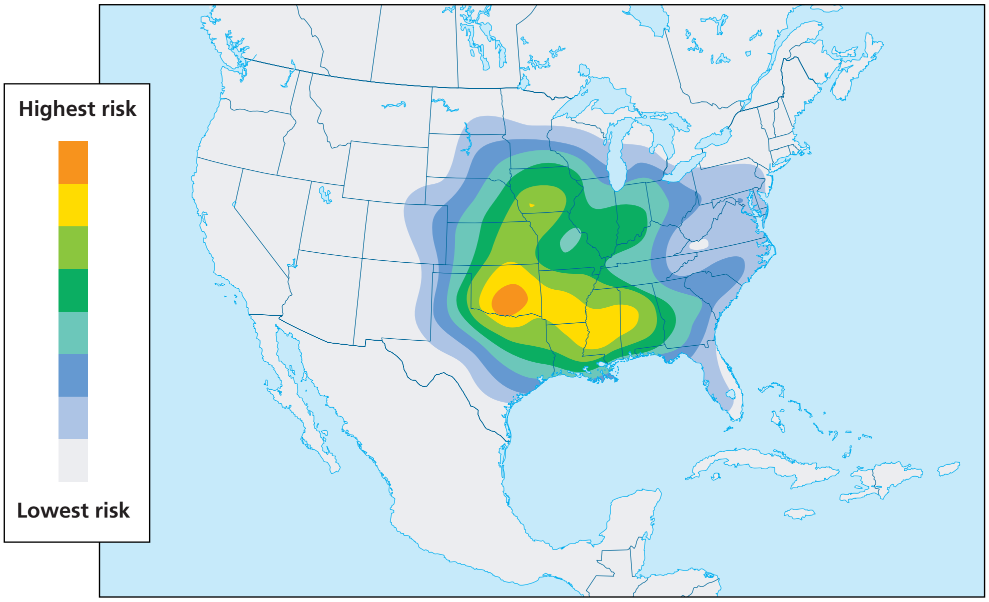


Figure 7 This map shows the relative risk of tornados across the continental United States. (Data from NOAA)

154–177 kilometers per hour (96–110 miles per hour); *Category 3*: 178–209 kilometers per hour (111–130 miles per hour); *Category 4*: 210–249 kilometers per hour (131–155 miles per hour); *Category 5*: greater than 249 kilometers per hour (155 miles per hour). The longer a tropical cyclone stays over warm waters, the stronger it gets. Significant hurricane-force winds can extend 64–161 kilometers (40–100 miles) from the center, or eye, of a tropical cyclone.

Hurricanes and typhoons kill and injure people and damage property and agricultural production. Sometimes, however, the long-term ecological and economic benefits of a tropical cyclone exceed its short-term harmful effects.

For example, in parts of the U.S. state of Texas along the Gulf of Mexico, coastal bays and marshes, because of their unique natural formations and the barrier islands that protect them, normally receive very limited freshwater and saltwater inflows. In August 1999, Hurricane Brett struck this coastal area. According to marine biologists, the storm flushed out excess nutrients from land runoff and swept dead sea-grasses and rotting vegetation from the coastal bays and marshes. It also carved out 12 channels through the barrier islands along the coast, allowing huge quantities of fresh seawater to flood the bays and marshes.

This flushing of the bays and marshes reduced brown tides consisting of explosive growths of algae feeding on excess nutrients. It also increased growth of sea-grasses, which serve as nurseries for shrimp, crabs, and fish, and provide food for millions of ducks wintering in Texas bays. Production of commercially important species of shellfish and fish also increased.

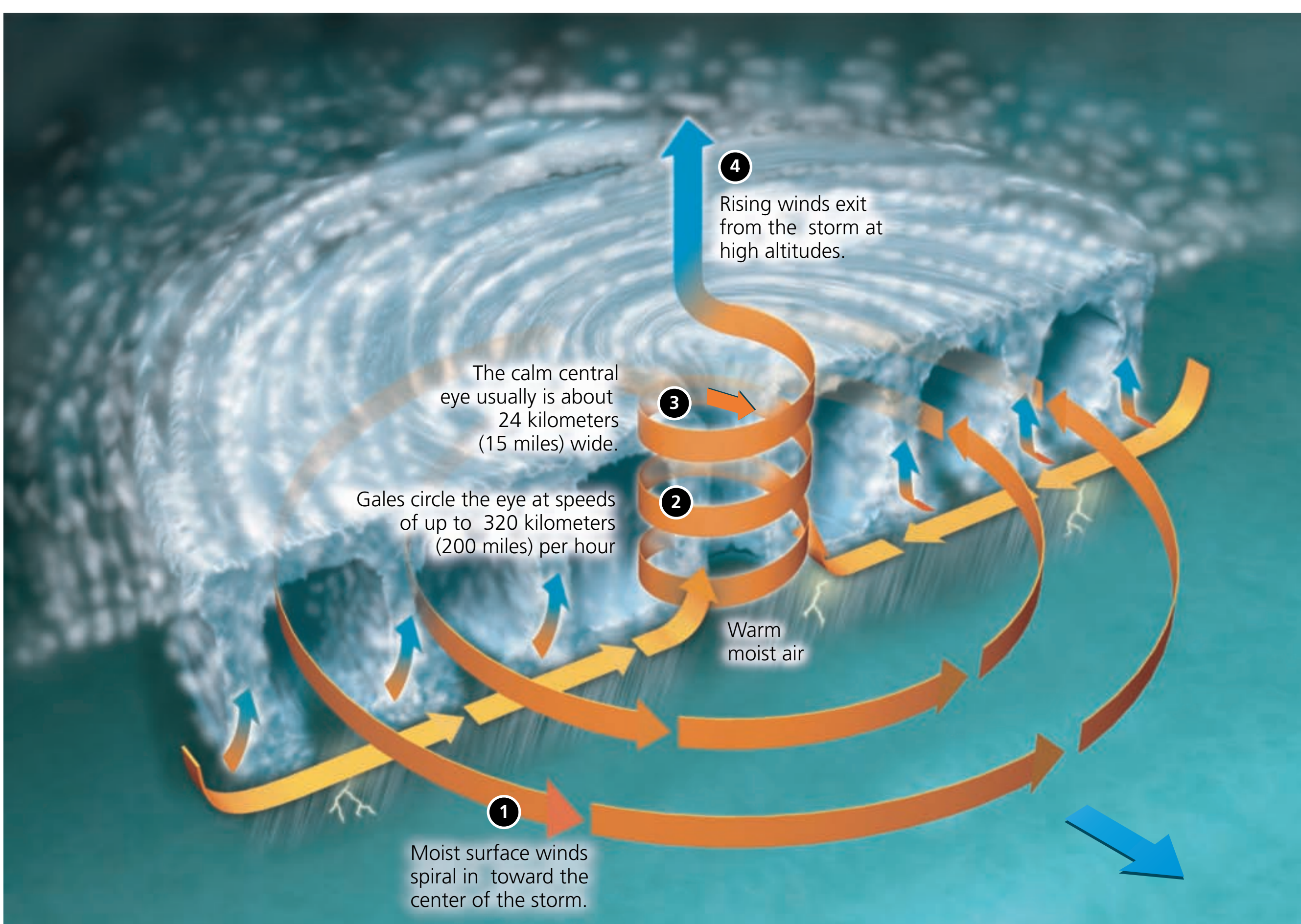


Figure 8 This diagram illustrates the formation of a *tropical cyclone*. Those forming in the Atlantic Ocean are called *hurricanes*; those forming in the Pacific Ocean are called *typhoons*.

SUPPLEMENT

8

Maps (Chapters 1, 3, 5–19, 22–24)

Figure 1 The countries of the world are shown here.

Map Analysis

1. Which is the largest country in **(a)** North America, **(b)** Central America, **(c)** South America, **(d)** Europe, and **(e)** Asia?
2. Which countries surround **(a)** China, **(b)** Mexico, **(c)** Germany, and **(d)** Sudan?


EUROPE
ASIA
AFRICA
AUSTRALIA
ICELAND
NORWAY
SWEDEN
FINLAND
ESTONIA
LATVIA
LITHUANIA
DENMARK
UNITED KINGDOM
IRELAND
NETHERLANDS
BELGIUM
LUXEMBOURG
GERMANY
POLAND
BELARUS
CZECH REP.
SLOVAKIA
AUSTRIA
SWITZERLAND
HUNGARY
MOLDOVA
UKRAINE
FRANCE
SLOVENIA
CROATIA
ROMANIA
BOSNIA-HERZEGOVINA
YUGOSLAVIA
BULGARIA
ITALY
ALBANIA
MACEDONIA
GREECE
PORTUGAL
SPAIN
RUSSIA
KAZAKHSTAN
MONGOLIA
GEORGIA
ARMENIA
AZERBAIJAN
UZBEKISTAN
KYRGYZSTAN
TURKMENISTAN
TAJIKISTAN
TURKEY
NORTH KOREA
SOUTH KOREA
JAPAN
CHINA
CYPRUS
SYRIA
LEBANON
ISRAEL
JORDAN
IRAQ
IRAN
AFGHANISTAN
KUWAIT
SAUDI ARABIA
QATAR
UNITED ARAB EMIRATES
OMAN
YEMEN
PAKISTAN
NEPAL
BHUTAN
BANGLADESH
INDIA
TAIWAN
HONG KONG
MYANMAR
LAOS
THAILAND
VIETNAM
CAMBODIA
PHILIPPINES
SRI LANKA
BRUNEI
MALAYSIA
INDONESIA
PAPUA NEW GUINEA
SOLOMON ISLANDS
VANUATU
FIJI
NEW CALEDONIA
NEW ZEALAND
MOROCCO
TUNISIA
ALGERIA
LIBYA
EGYPT
WESTERN SAHARA
MAURITANIA
MALI
NIGER
CHAD
SUDAN
ERITREA
SENEGAL
BURKINA FASO
GUINEA
GHANA
NIGERIA
ETHIOPIA
SIERRA LEONE
LIBERIA
IVORY COAST
TOGO
BENIN
CAMEROON
CENTRAL AFRICAN REPUBLIC
SOMALIA
EQUATORIAL GUINEA
GABON
CONGO
DEMOCRATIC REPUBLIC OF CONGO
UGANDA
KENYA
RAWANDA
BARUNDI
TANZANIA
ANGOLA
ZAMBIA
MALAWI
MOZAMBIQUE
MADAGASCAR
MAURITIUS
RÉUNION
NAMIBIA
ZIMBABWE
BOTSWANA
SWAZILAND
LESOTHO
SOUTH AFRICA

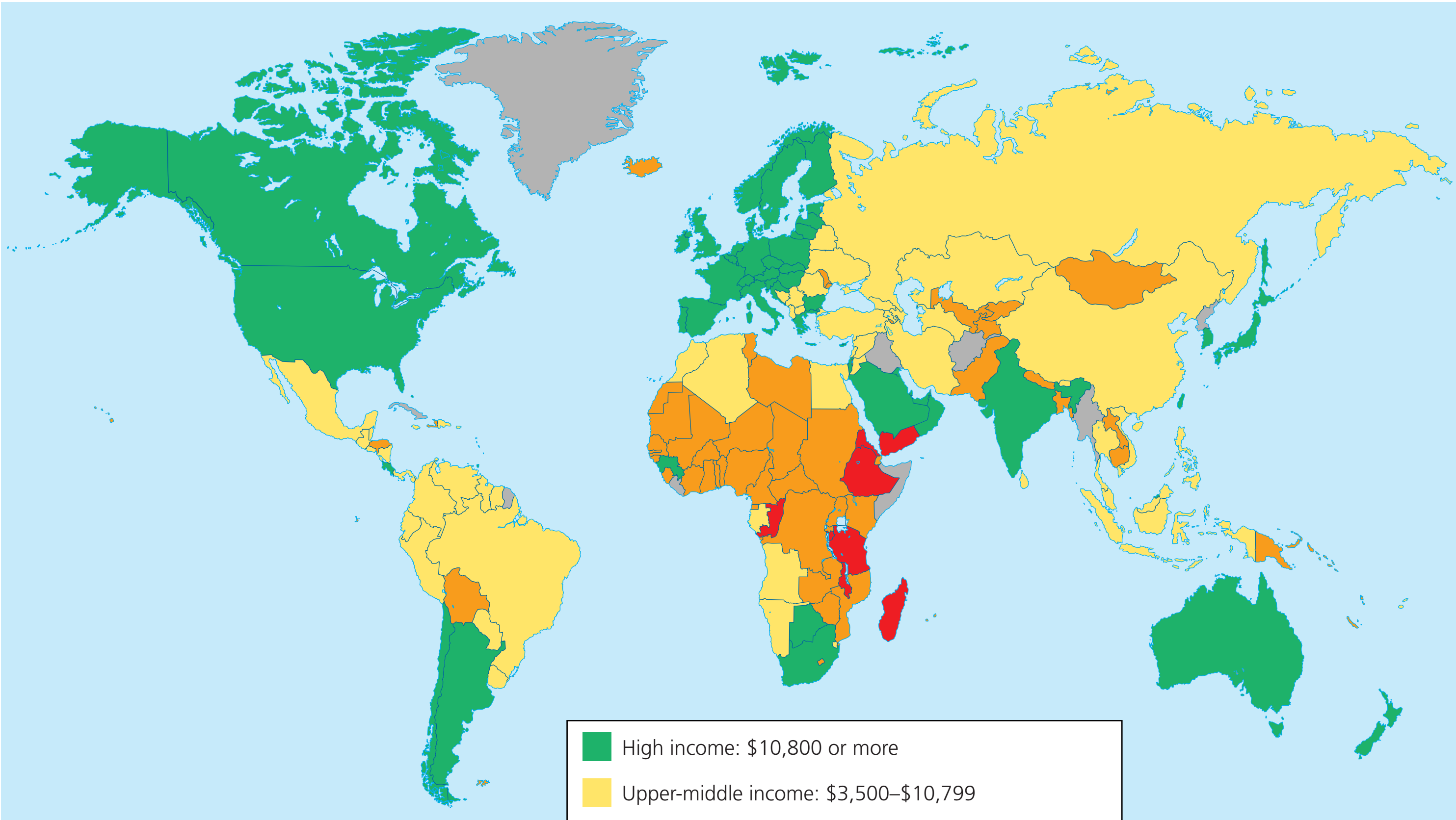


Figure 2 This map shows high-income, upper-middle-income, lower-middle-income, and low-income countries in terms of gross national income (GNI) PPP per capita (U.S. dollars) in 2008. (Data from World Bank and International Monetary Fund)

Data and Map Analysis

1. In how many countries is the per capita average income $899 or less? Look at Figure 1 and find the names of three of these countries.
2. In how many instances does a lower-middle- or low-income country share a border with a high-income country? Look at Figure 1 and find the names of the countries that reflect three examples of this situation.

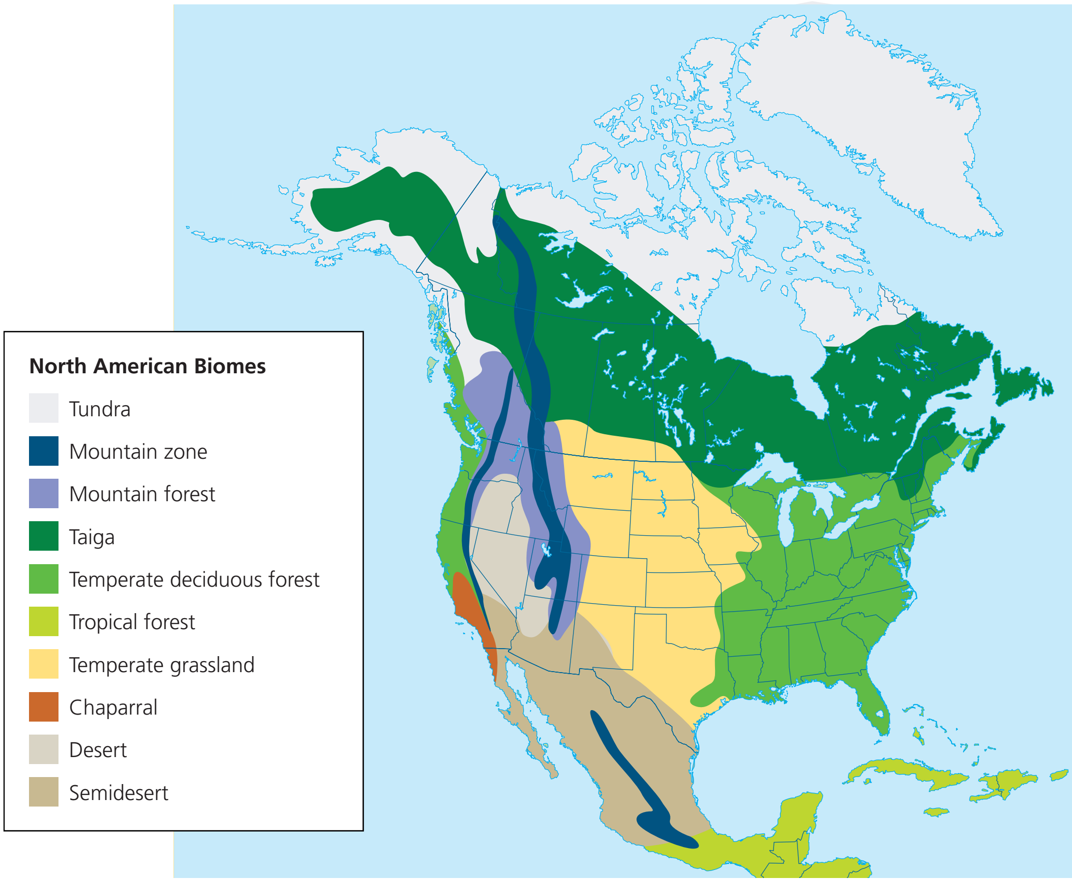


Figure 3 **Natural capital:** This map shows the major biomes found in North America.

Data and Map Analysis

1. Which type of biome occupies the most coastal area?
2. Which biome is the rarest in North America?

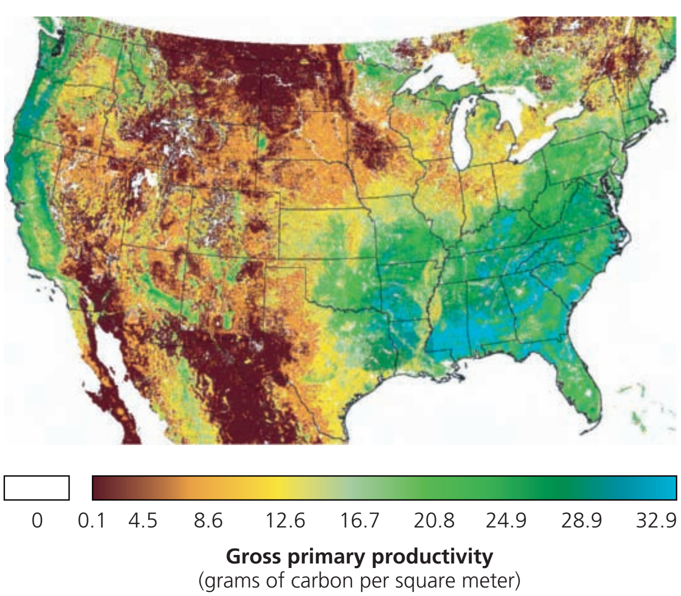


Figure 4 This map illustrates gross primary productivity across the continental United States, based on remote satellite data. The differences roughly correlate with variations in moisture and soil types. (NASA's Earth Observatory)

Data and Map Analysis

1. Comparing the five northwestern-most states with the five southeastern-most states, which of these regions has the greater variety in levels of gross primary productivity? Which of the regions has the highest levels overall?
2. Compare this map with that of Figure 3. Which biome in the United States is associated with the highest level of gross primary productivity?

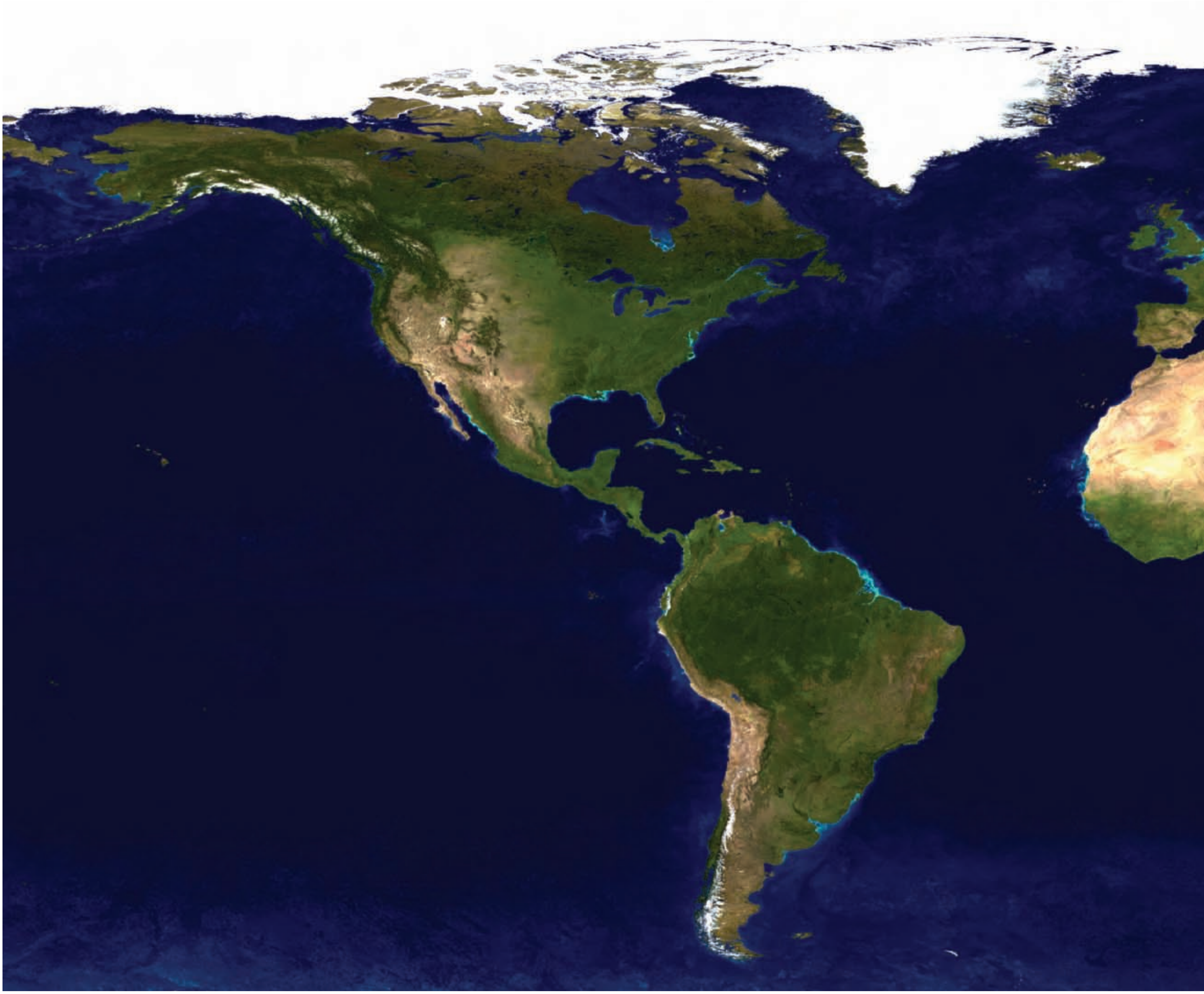
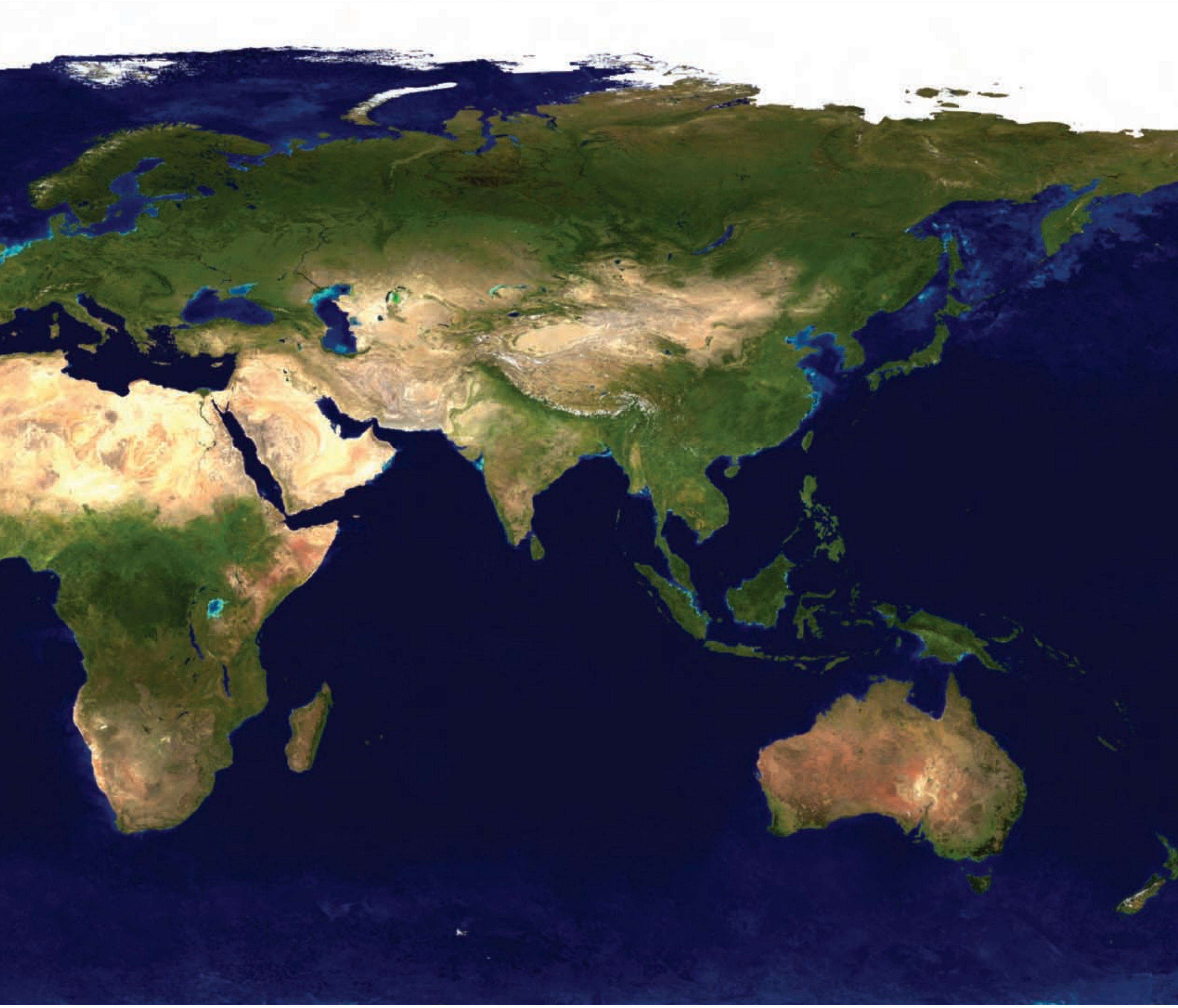


Figure 5 This composite satellite view of the earth shows its major terrestrial and aquatic features.

Data and Map Analysis

1. On which continent does desert make up the largest percentage of total land area? (See Figure 1 of this supplement, p. S30, for continent names.)
2. Which two continents contain large areas of polar ice?



NASA Goddard Space Flight Center Image by Reto Stöckli (land surface, shallow water, clouds). Enhancements by Robert Simmon (ocean color, compositing, 3D globes, animation)

Figure 6 Global map of plant biodiversity. (Used by permission from Kier, et al, "Global Patterns of Plant Diversity and Floristic Knowledge," *Journal of Biogeography* (Wiley-Blackwell), 32, no. 6, (2005): 921–1106)

Data and Map Analysis

1. Which continent holds the largest continuous area of land that hosts more than 5,000 species per eco-region? On which continent is the second largest area of such land? (See Figure 1 of this supplement, p. S30, for continent names.)
2. Of the six categories represented by six different colors on this map, which category seems to occupy the most land area in the world (not counting Antarctica, the large land mass on the bottom of the map, and Greenland)? (See Figure 1 for the names of countries.)

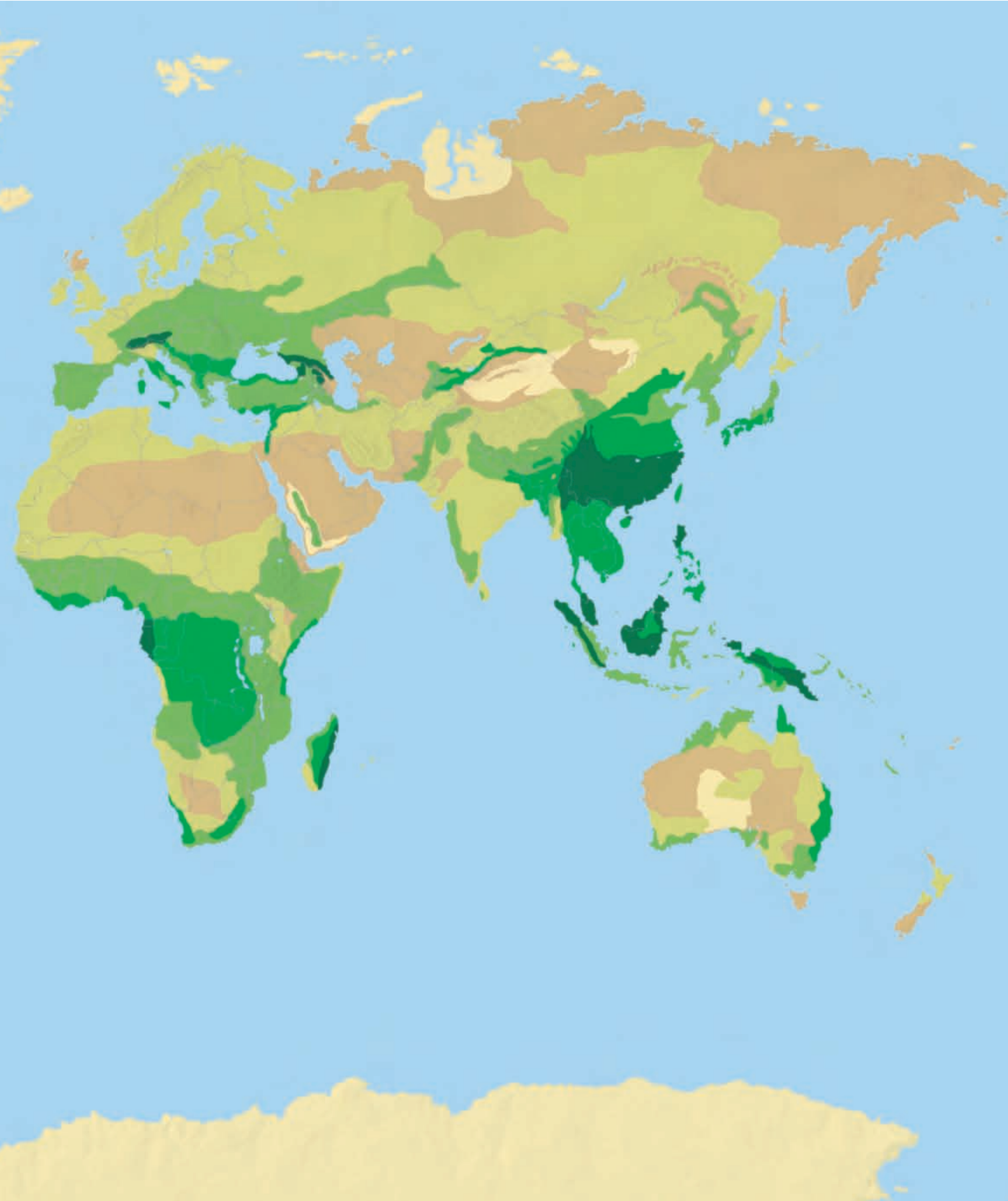
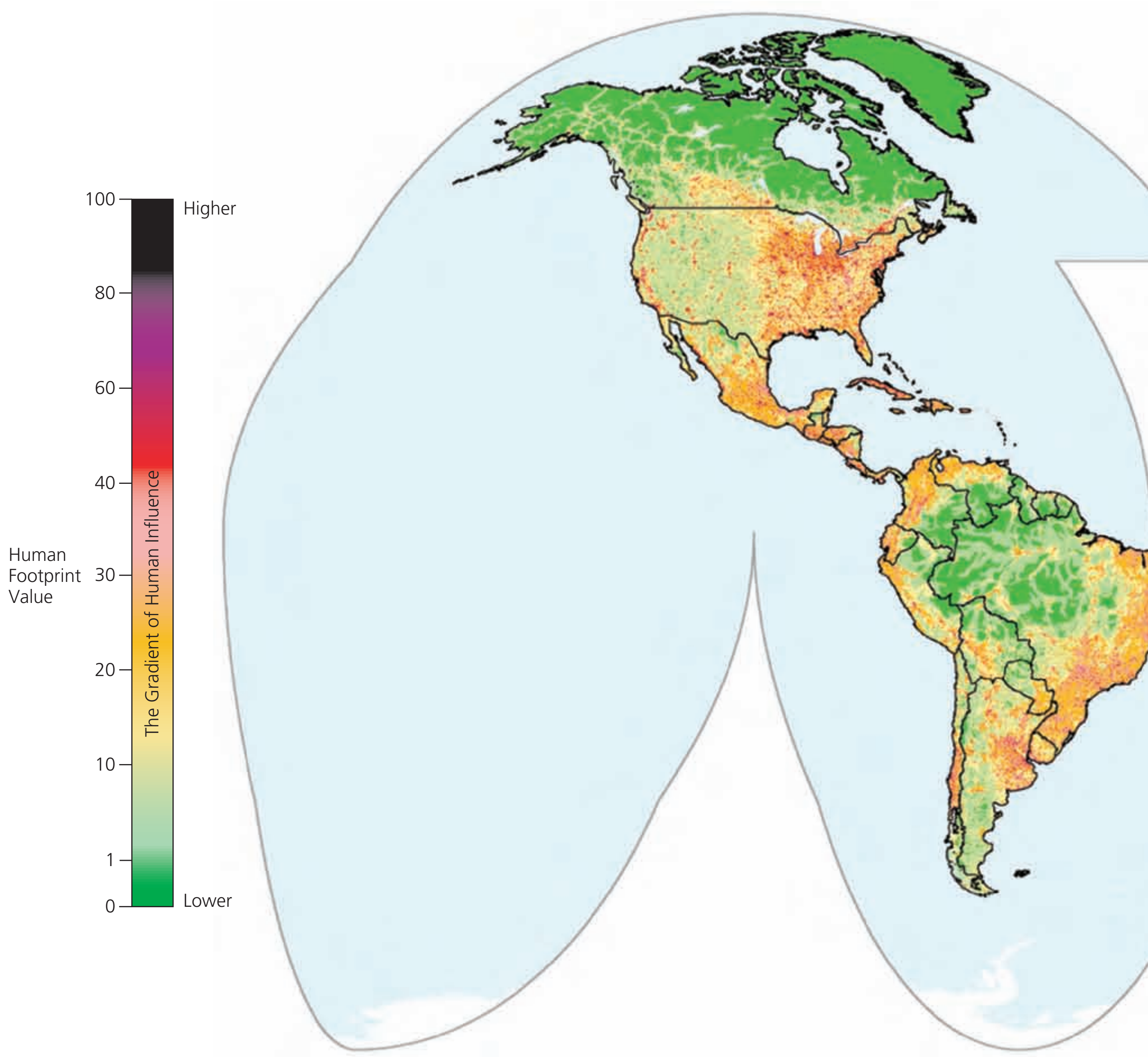
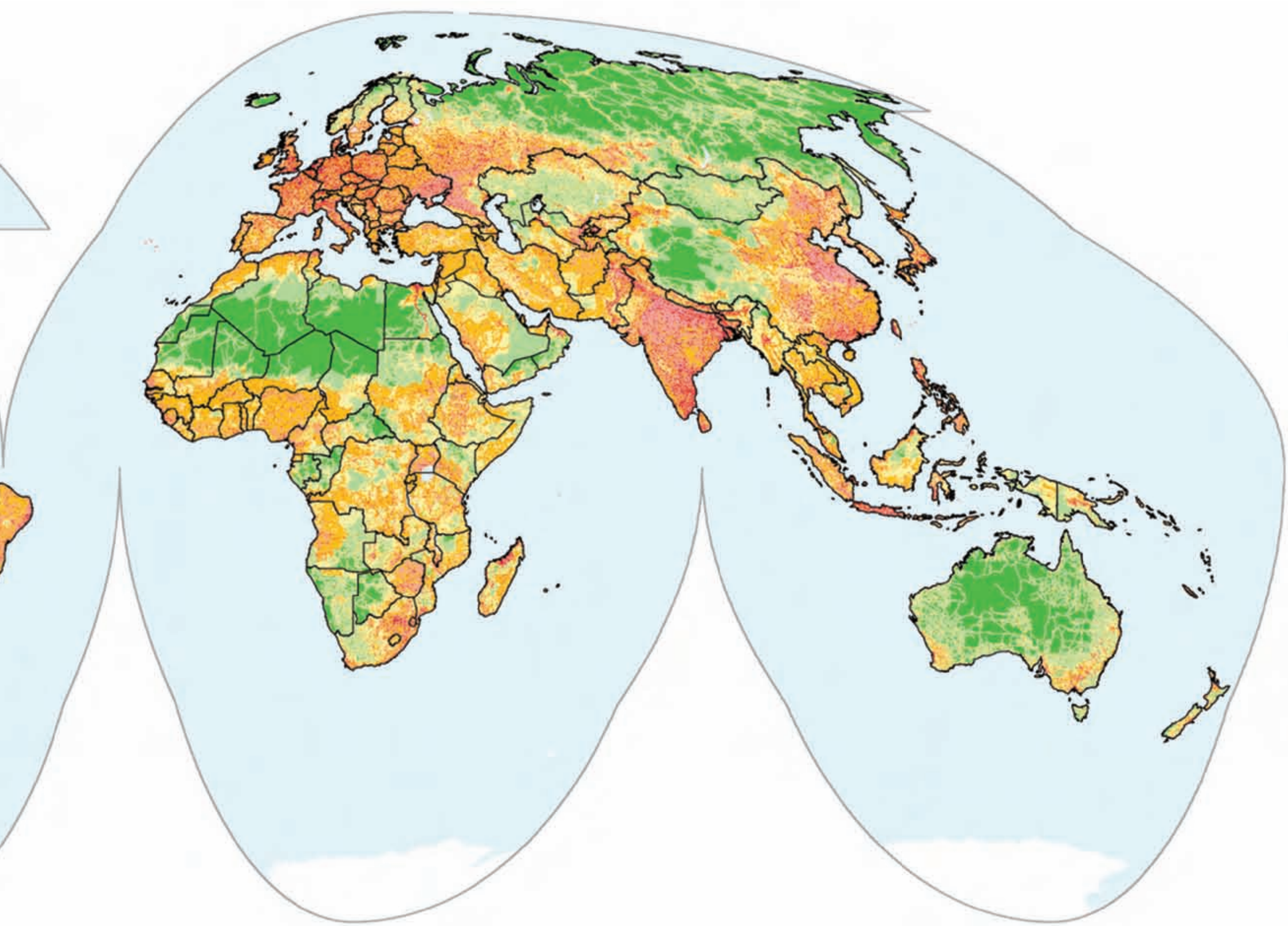


Figure 7 **Natural capital degradation:** This map shows the human footprint on the earth's land surface—in effect the sum of all ecological footprints (see Figure 1-13, p. 16) of the human population. Colors represent the percentage of each area influenced by human activities. Excluding Antarctica and Greenland, human activities have, to some degree, directly affected about 83% of the earth's land surface and 98% of the area where it is possible to grow rice, wheat, or corn. (Data from Wildlife Conservation Society and the Center for International Earth Science Information Network at Columbia University)

Data and Map Analysis

1. What is the human footprint value for the area in which you live? List three other countries in the world that have about the same human footprint value as that of the area where you live. (See Figure 1 of this supplement, p. S30, for country names.)
2. Compare this map with that of Figure 4 and list three countries in which the species number per eco-region is 2,000 or more and the human footprint value is higher than 40 in parts of the country.





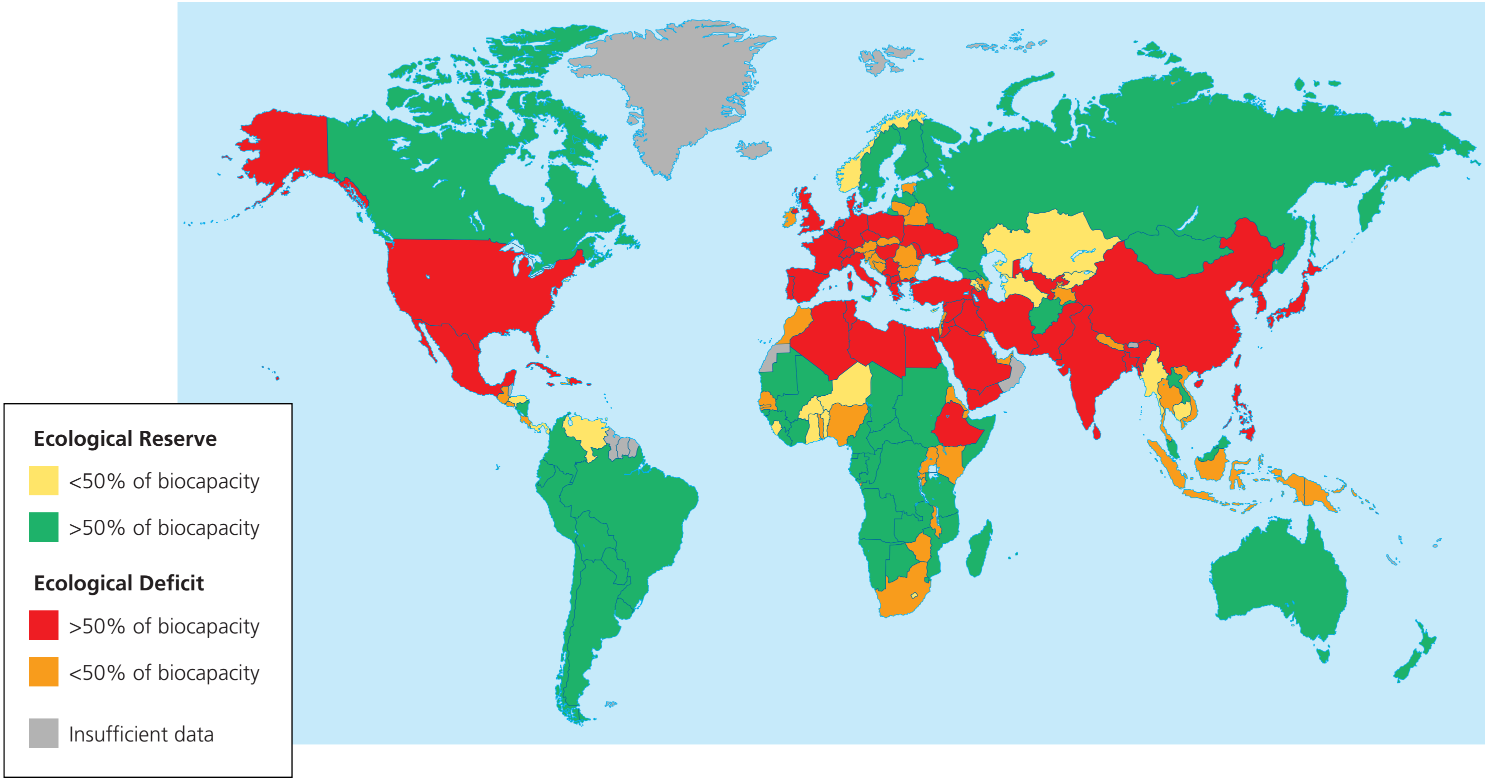


Figure 8 *Ecological Debtors and Creditors:* The ecological footprints of some countries exceed their biocapacity, while other countries still have ecological reserves. (Data from Global Footprint Network)

Data and Map Analysis

1. List five countries, including the three largest, in which the ecological deficit is greater than 50% of biocapacity. (See Figure 1 of this supplement, p. S30, for country names.)
2. On which two continents does land with ecological reserves of more than 50% of biocapacity occupy the largest percentage of total land area? (See Figure 1 of this supplement, p. S30, for continent names.) Look at Figure 7 and, for each of these two continents, list the highest human footprint value that you see on the map.

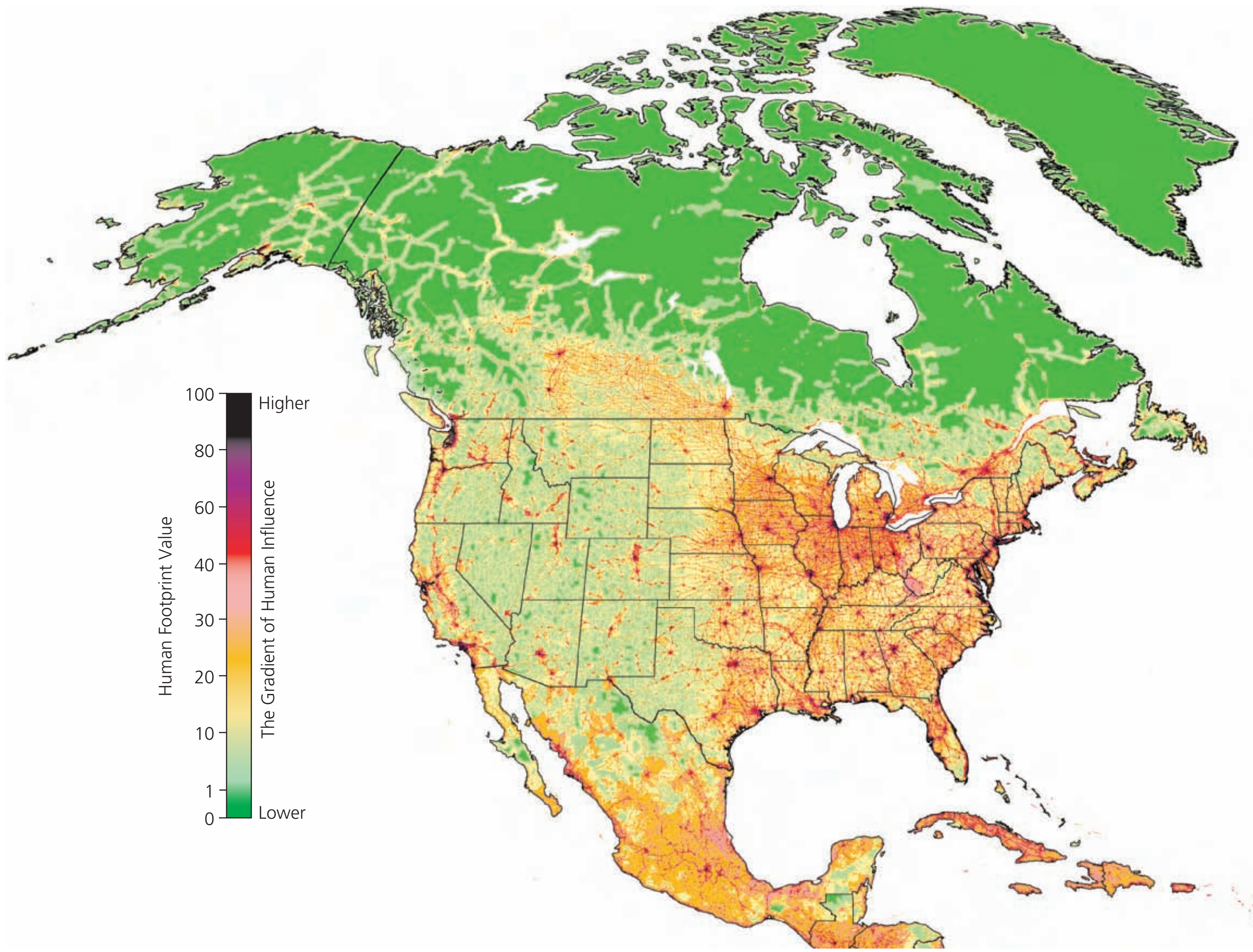


Figure 9 **Natural capital degradation:** This map illustrates the human ecological footprint in North America. Colors represent the percentage of each area influenced by human activities. This is an expanded portion of Figure 7 showing the human footprint on the earth's entire land surface. (Data from Wildlife Conservation Society and the Center for International Earth Science Information Network at Columbia University)

Data and Map Analysis

1. Which corner of the country has the greatest concentration of areas with the highest human footprint values?
2. Comparing this map with that of Figure 5, which biome in North America is located in areas with the highest overall human footprint values?

Figure 10 **Natural capital degradation:** This map shows some of the non-native insect species and disease organisms that have invaded U.S. forests and are causing billions of dollars in damages and tree loss. The light green and orange colors in the map show areas where green or red overlap with yellow. (Data from U.S. Forest Service)

Data and Map Analysis

1. Based on this map, which of these five infestations would you say is the most widespread?
2. Of the two insect infestations, which one is found in the larger number of states?

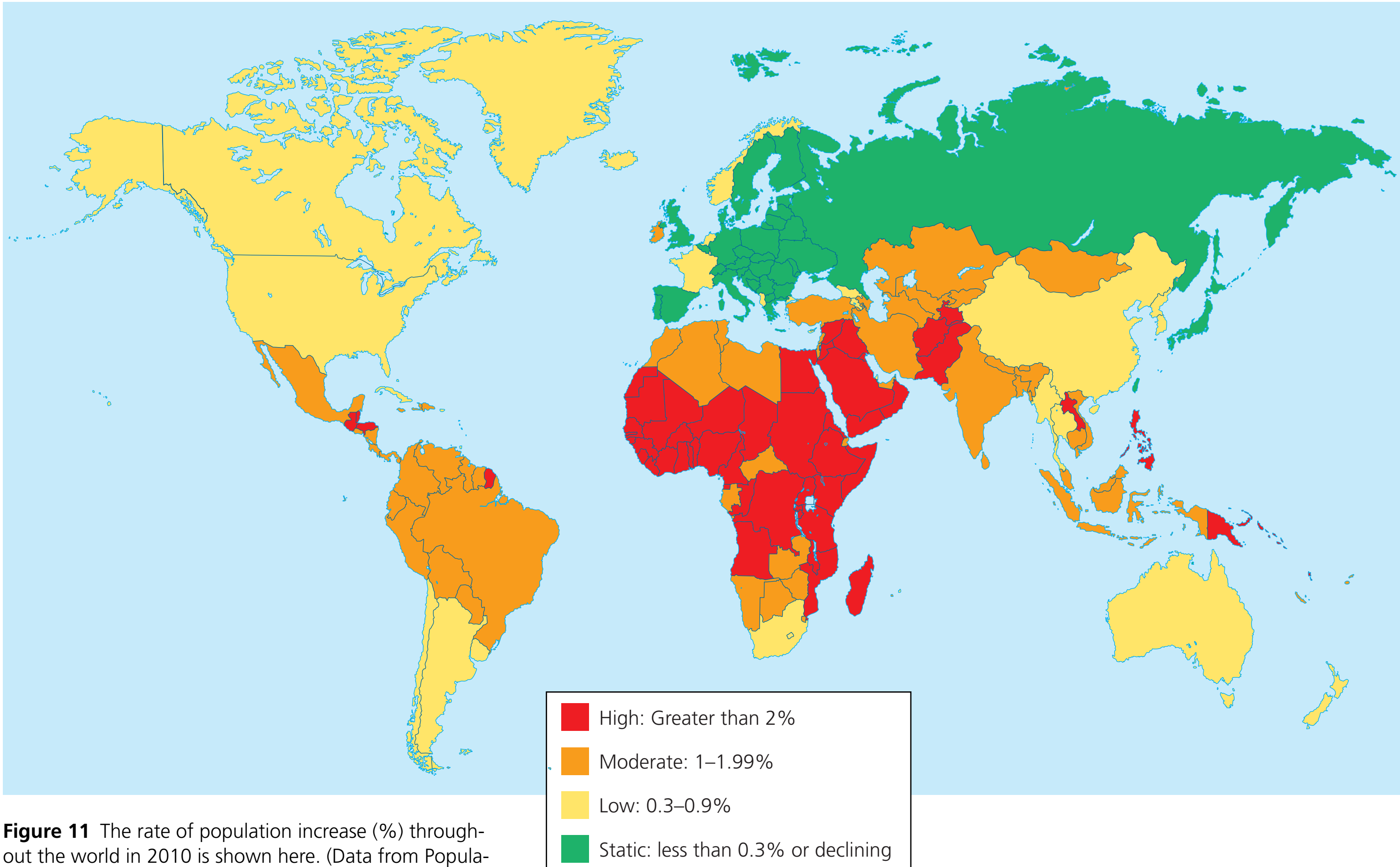


Figure 11 The rate of population increase (%) throughout the world in 2010 is shown here. (Data from Population Reference Bureau and United Nations Population Division)

Data and Map Analysis

1. Which continent has the greatest number of countries with high rates of population increase? Which continent has the greatest number of countries with static rates? (See Figure 1 of this supplement, p. S30, for continent names.)
2. For each category on this map, name the two countries that you think are largest in terms of total area (see Figure 1 for country names).

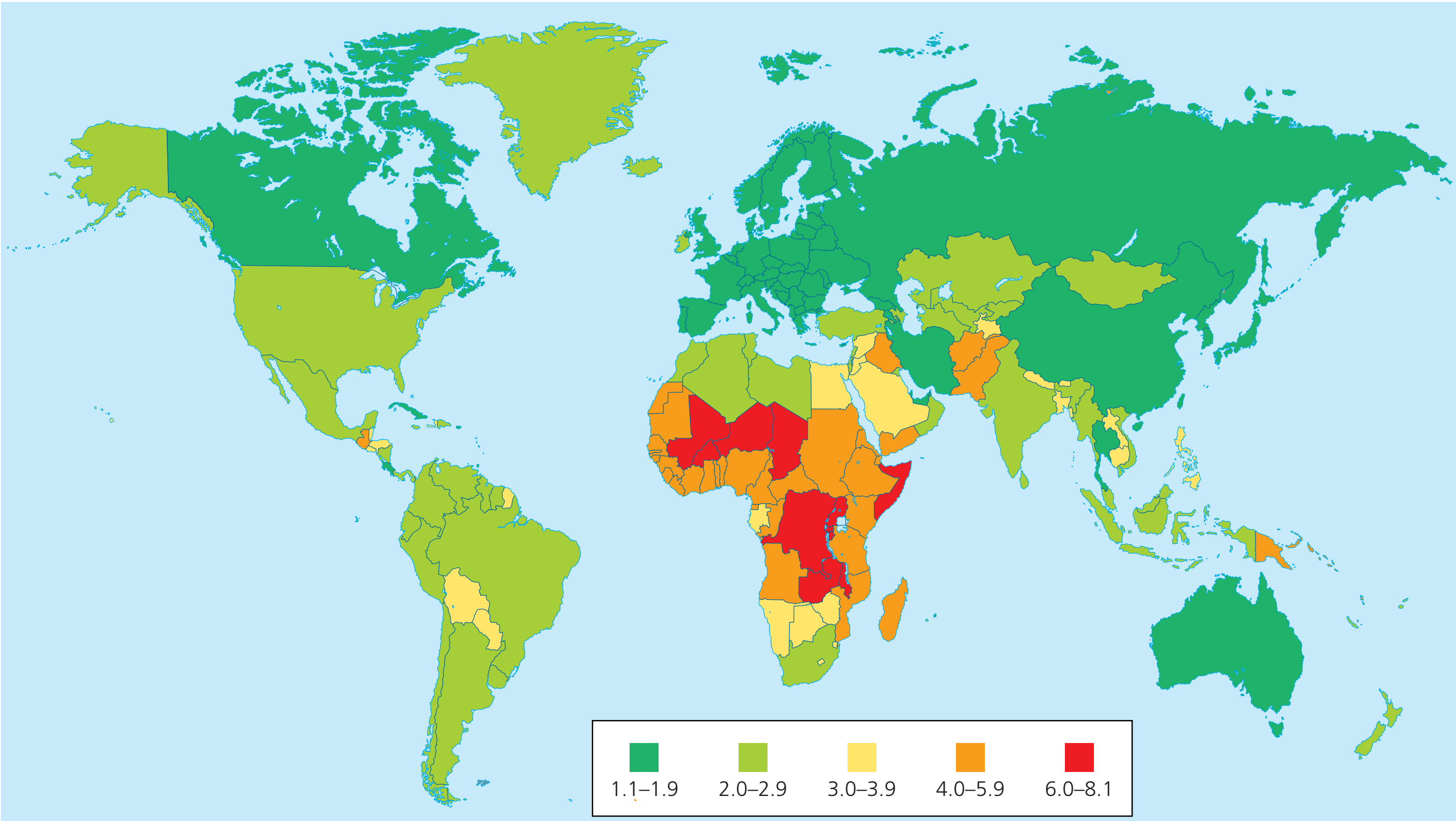


Figure 12 This map represents the total fertility rate (TFR), or average number of children born to the world's women throughout their lifetimes, as measured in 2010. (Data from Population Reference Bureau and United Nations Population Division)

Data and Map Analysis

1. Which country in the highest TFR category borders two countries in the lowest TFR category? What are those two countries? (See Figure 1 of this supplement, p. S30, for country names.)
2. Describe two geographic patterns that you see on this map.

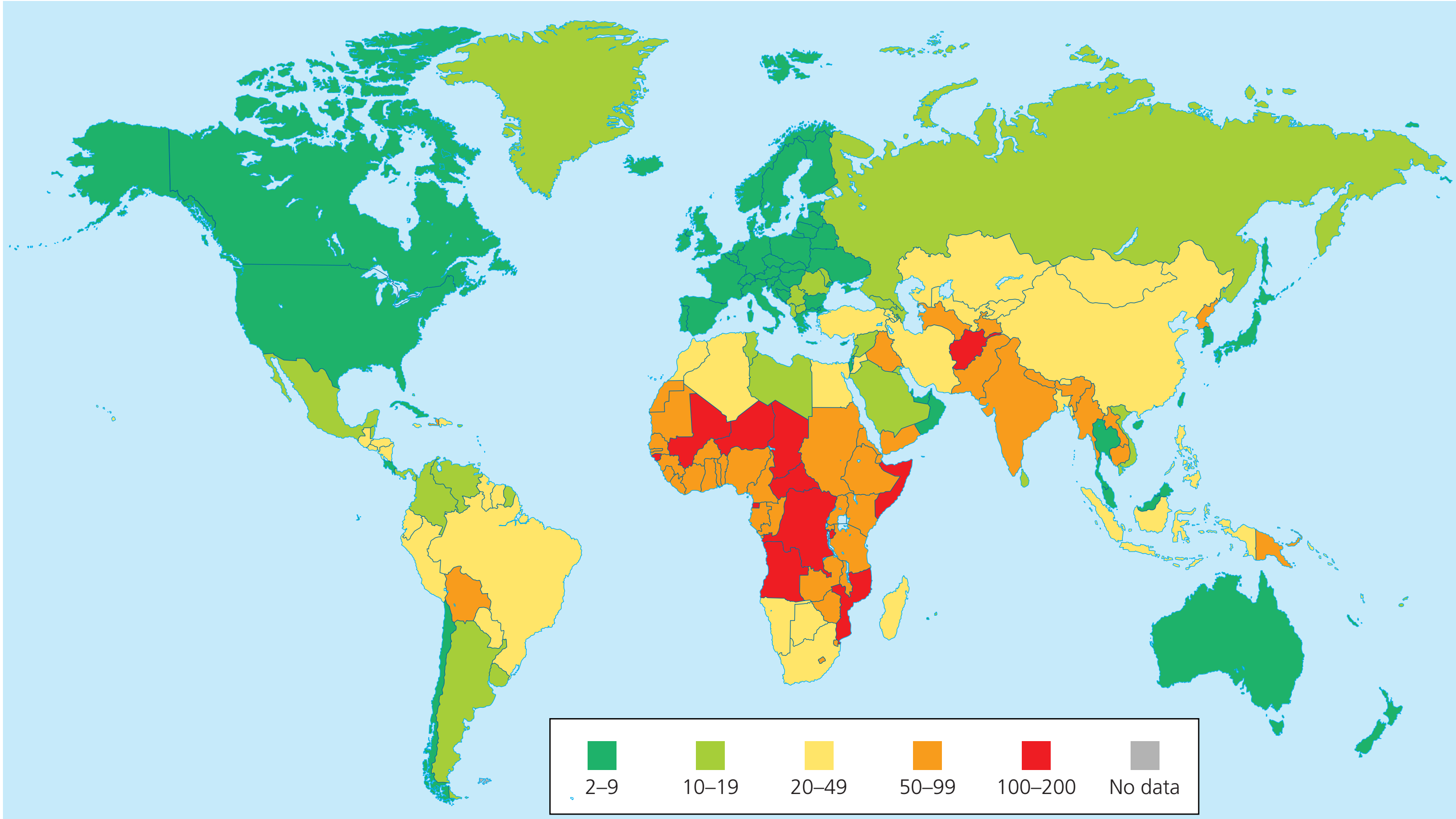


Figure 13 Infant mortality rates in 2010 are shown here. (Data from Population Reference Bureau and United Nations Population Division)

Data and Map Analysis

1. Describe a geographic pattern that you can see related to infant mortality rates as reflected on this map.
2. Describe any similarities that you see in geographic patterns between this map and the one in Figure 11.

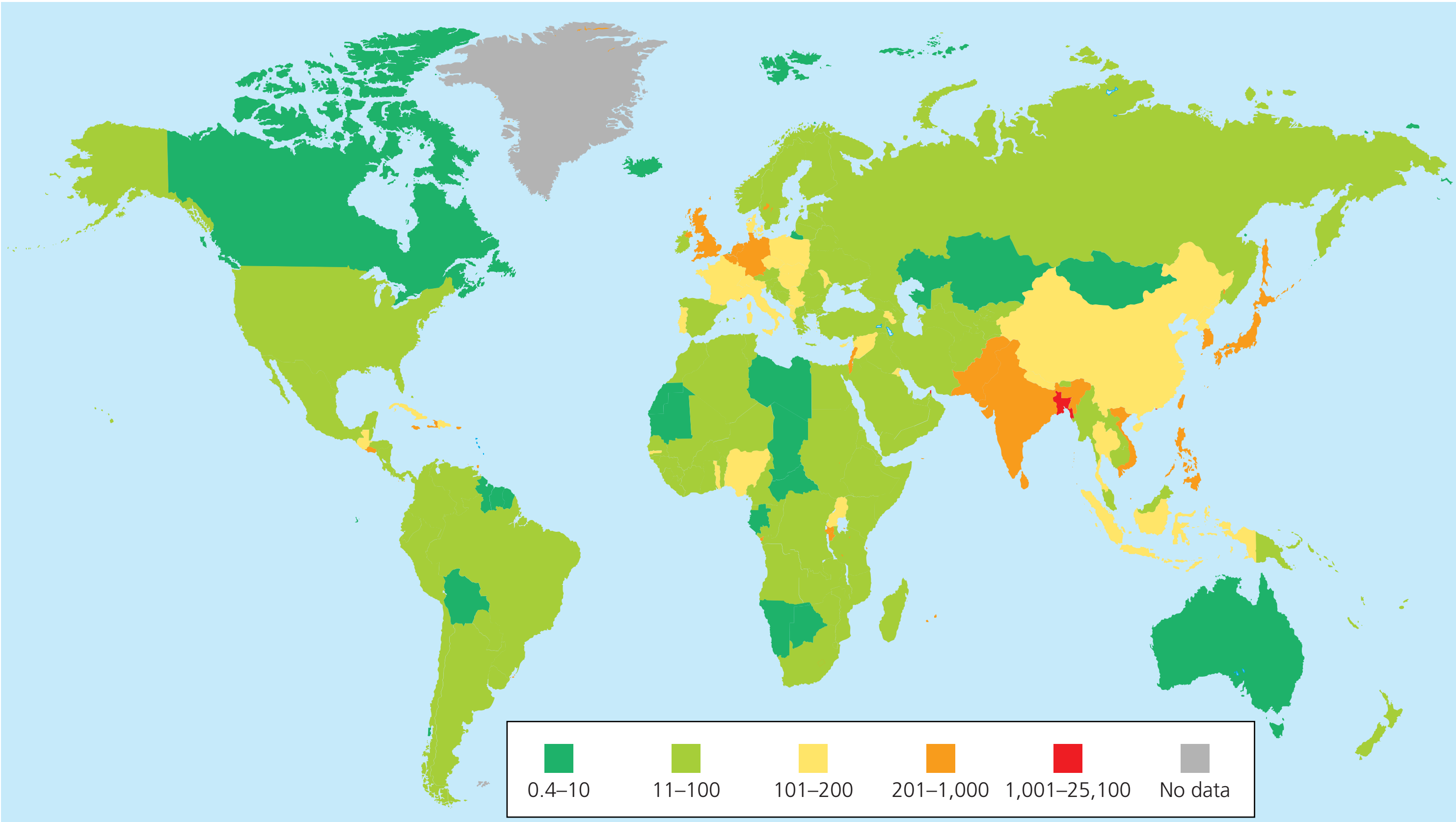
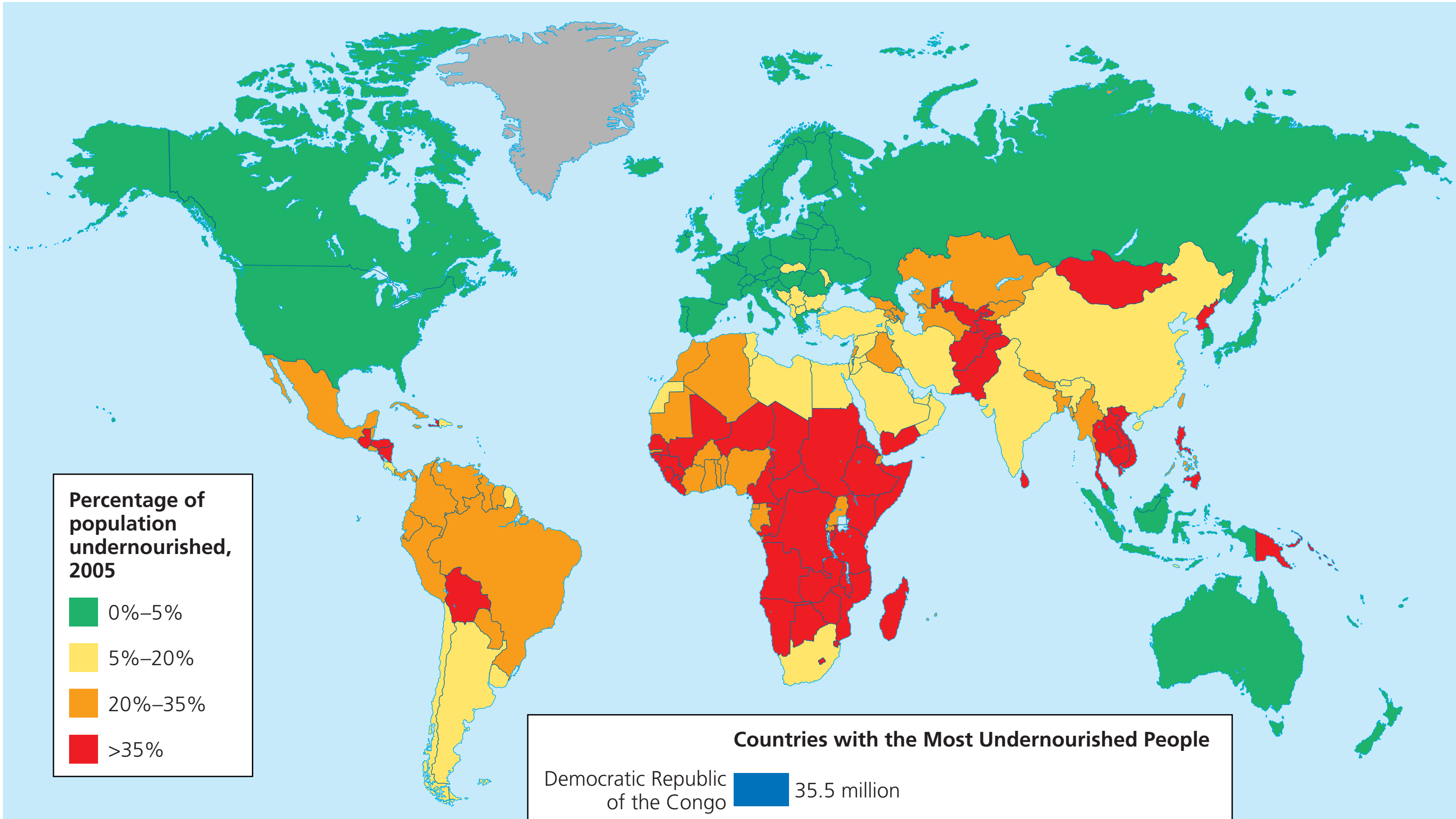


Figure 14 This map reflects global population density per square kilometer in 2008. (Data from Population Reference Bureau and United Nations Population Division)

Data and Map Analysis

1. Which country has the densest population? (See Figure 1 of this supple ment, p. S30, for country names.)
2. List the continents in order from the most densely populated, overall, to the least densely populated, overall. (See Figure 1 of this supplement, p. S30, for continent names.)



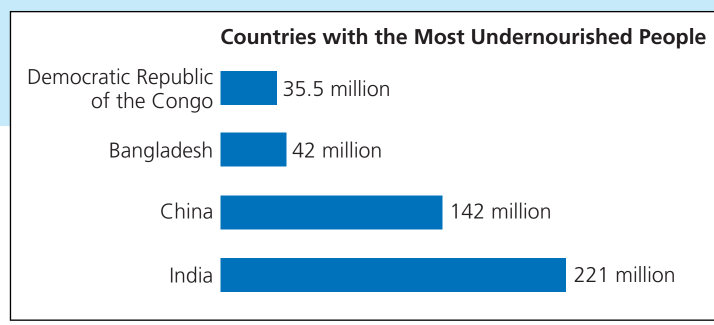


Figure 15 World hunger is shown here as a population percentage that suffered from chronic hunger and malnutrition in 2005. (Data from Food and Agriculture Organization, United Nations)

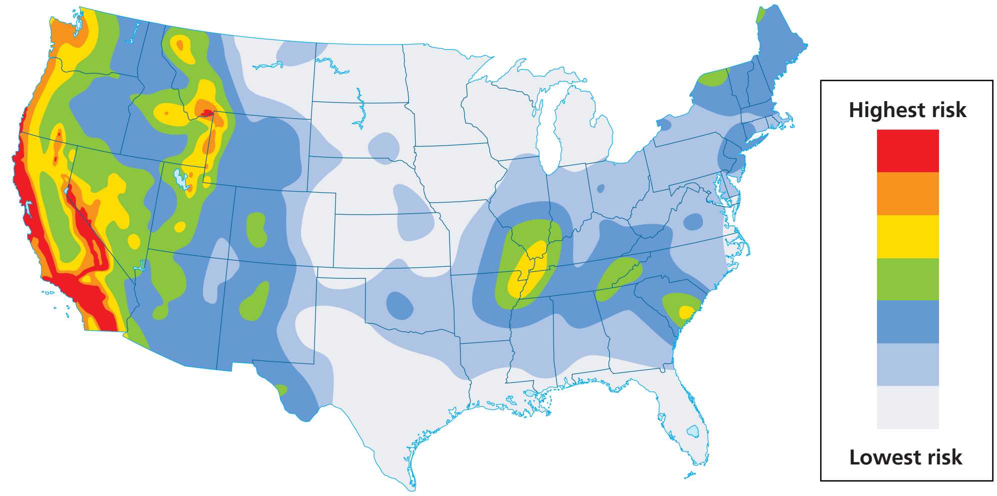
Data and Map Analysis

1. List the continents in order, starting with the one that has the highest percentage of undernourished people and ending with the one that has the lowest such percentage. (See Figure 1 of this supplement, p. S30, for continent names.)
2. On which continent is the largest block of countries that suffer the highest levels of undernourishment? List five of these countries.

Figure 16 This map shows the earthquake (seismic) risk in various areas of the continental United States. In 2008, the U.S. Geological Survey estimated that the U.S. state of California has more than a 99% chance of experiencing a magnitude 6.7 earthquake within 30 years, and that Southern California has a 37% chance of experiencing a magnitude 7.5 earthquake during that period. (Data from U.S. Geological Survey)

Data and Map Analysis

1. Speaking in general terms (northeast, southeast, central, west coast, etc.) which area has the highest earthquake risk and which area has the lowest risk?
2. For each of the categories of risk, list the number of states that fall into the category.



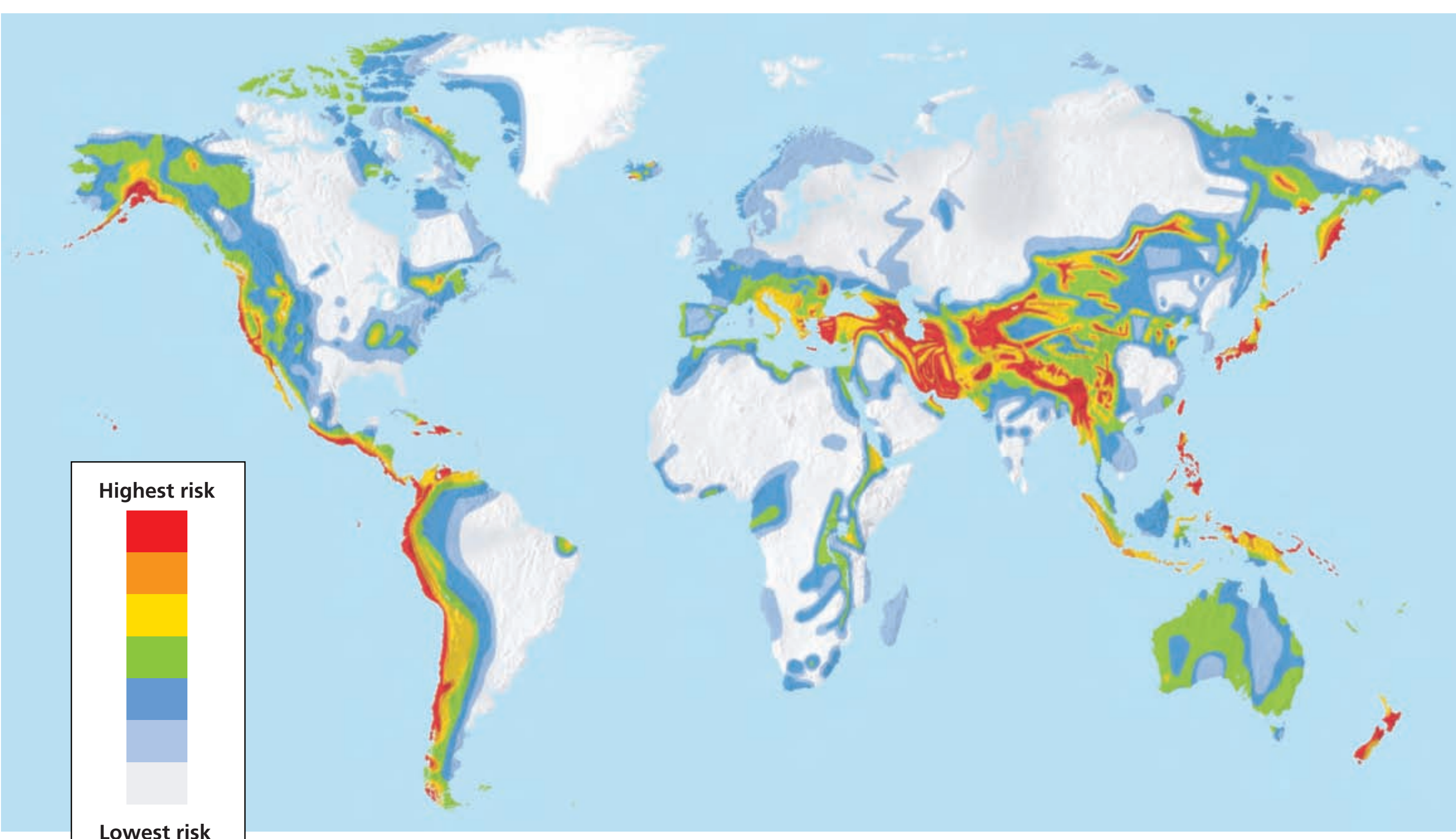
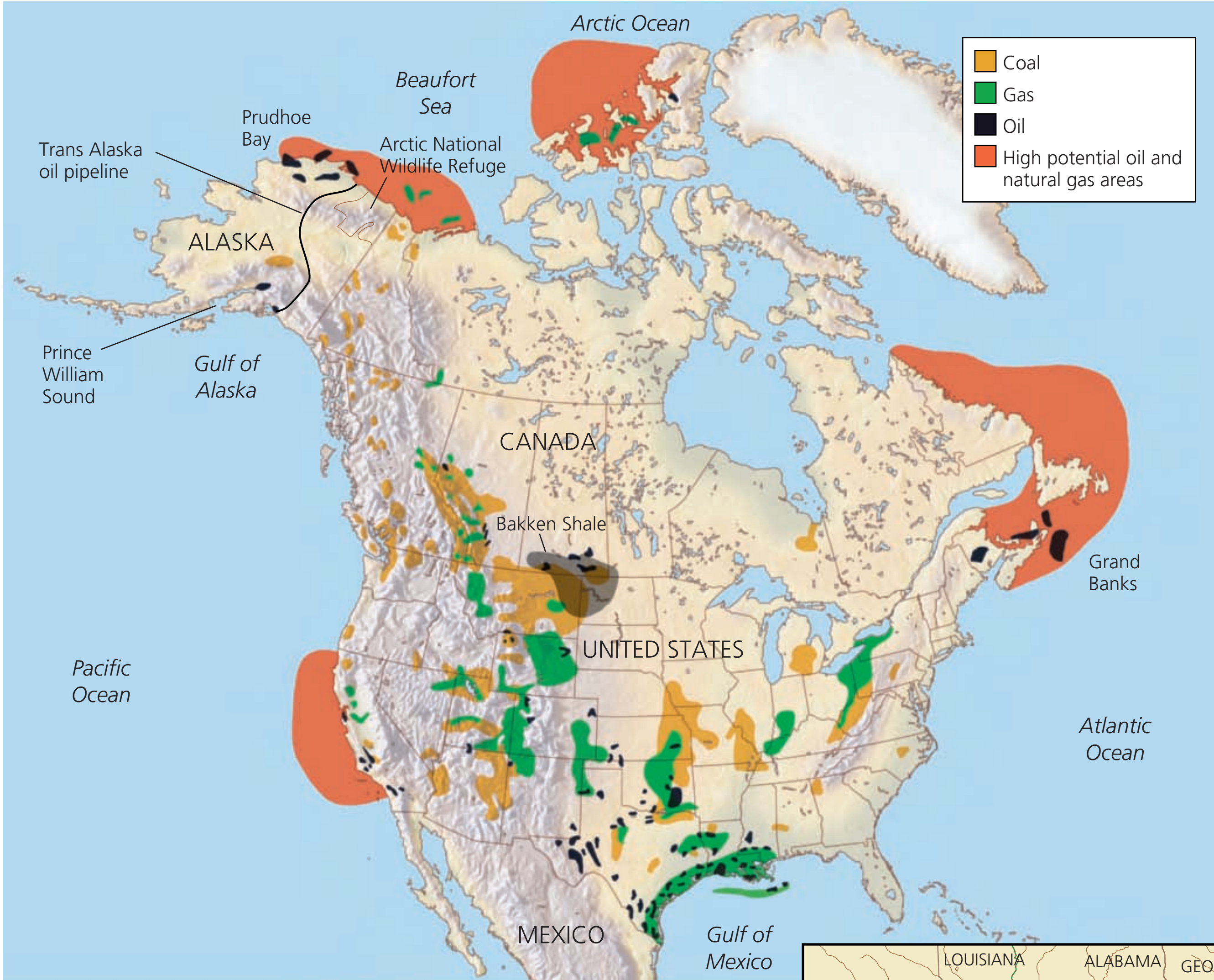


Figure 17 This maps shows earthquake (seismic) risk in the world. (Data from U.S. Geological Survey)

Data and Map Analysis

1. How are these areas related to the boundaries of the earth's major tectonic plates as shown in Figure 14-4, p. 349?
2. Which continent has the longest coastal area subject to the highest possible risk? Which continent has the second-longest such coastal area? (See Figure 1 of this supplement, p. S30, for continent names.)



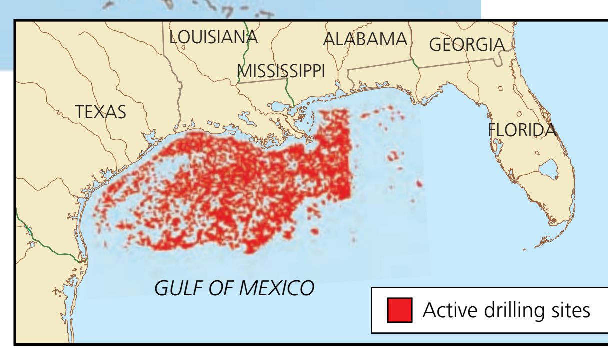


Figure 18 This map indicates the locations of the major, known proven and unproven reserves of oil, natural gas, and coal in North America, as well as offshore areas where more crude oil and natural gas might be found. Geologists do not expect to find very much new oil and natural gas in North America. Offshore drilling for oil accounts for about one-fourth of U.S. oil production. Nine of every ten barrels of this oil come from the Gulf of Mexico, where there are 4,000 oil drilling platforms and 53,000 kilometers (33,000 miles) of underwater pipeline (see insert). (Data from U.S. Geological Survey)

Data and Map Analysis

1. If you live in North America, where are the oil, coal, and natural gas deposits closest to where you live?
2. Which country borders on the largest areas of high potential for oil and natural gas?

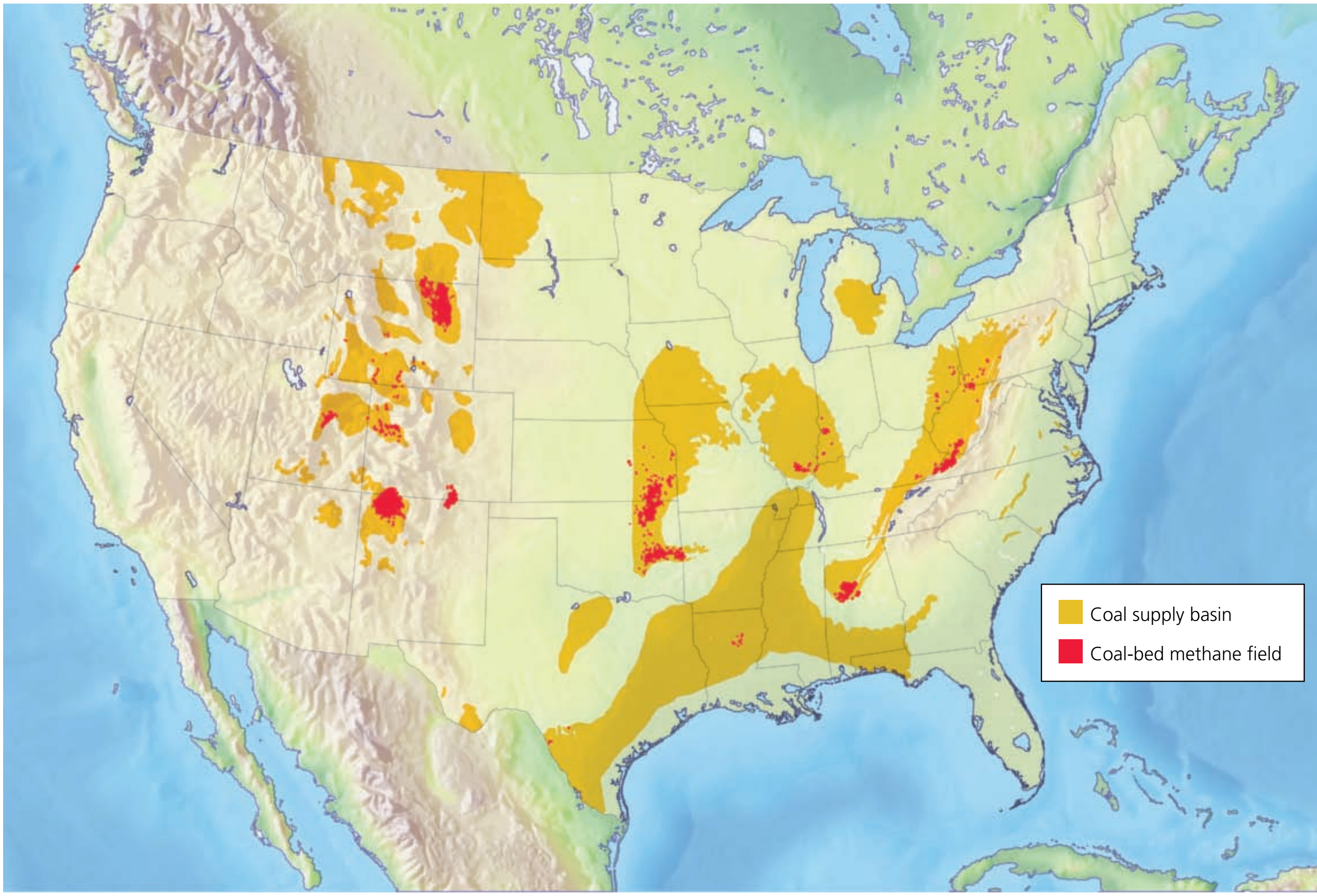


Figure 19 Major coal supply basins and coal-bed methane fields in the lower 48 states of the United States. (Data from U.S. Energy Information based U.S. Geological Survey and various other published studies)

Data and Map Analysis

1. If you live in the United States, where are the coal-bed methane deposits closest to where you live?
2. Removing these deposits requires lots of water. Compare the locations of the major deposits of coal-bed methane with water-deficit areas shown in Figure 13-4, bottom, p. 322, and Figure 13-5, p. 322.

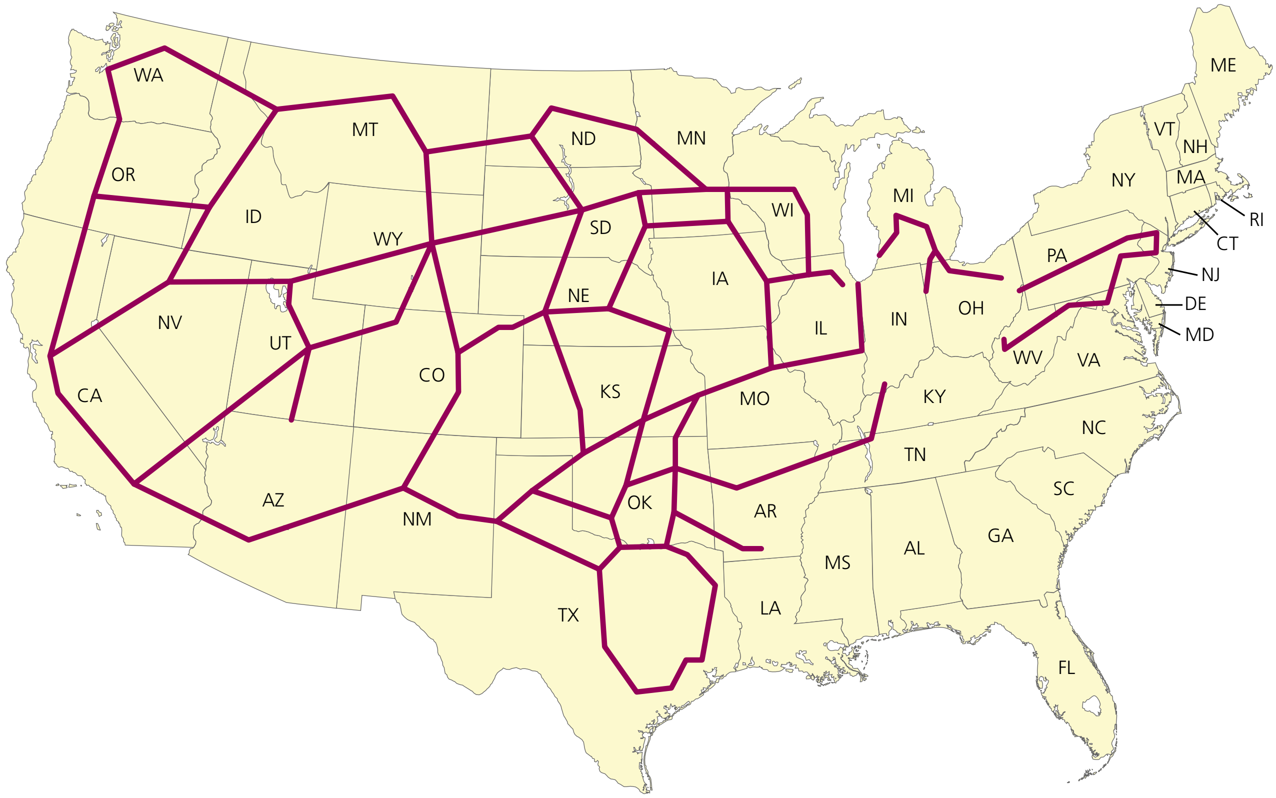


Figure 20 Proposed ultra-high-voltage electric transmission lines in the continental United States. There are numerous other high voltage and lower voltage electrical lines in the existing national grid. (Data from American Electric Power)

Data and Map Analysis

1. According to this map, which two areas of the country are not being considered for new high-voltage transmission lines?
2. Which section of the country would have the highest concentration of new lines?

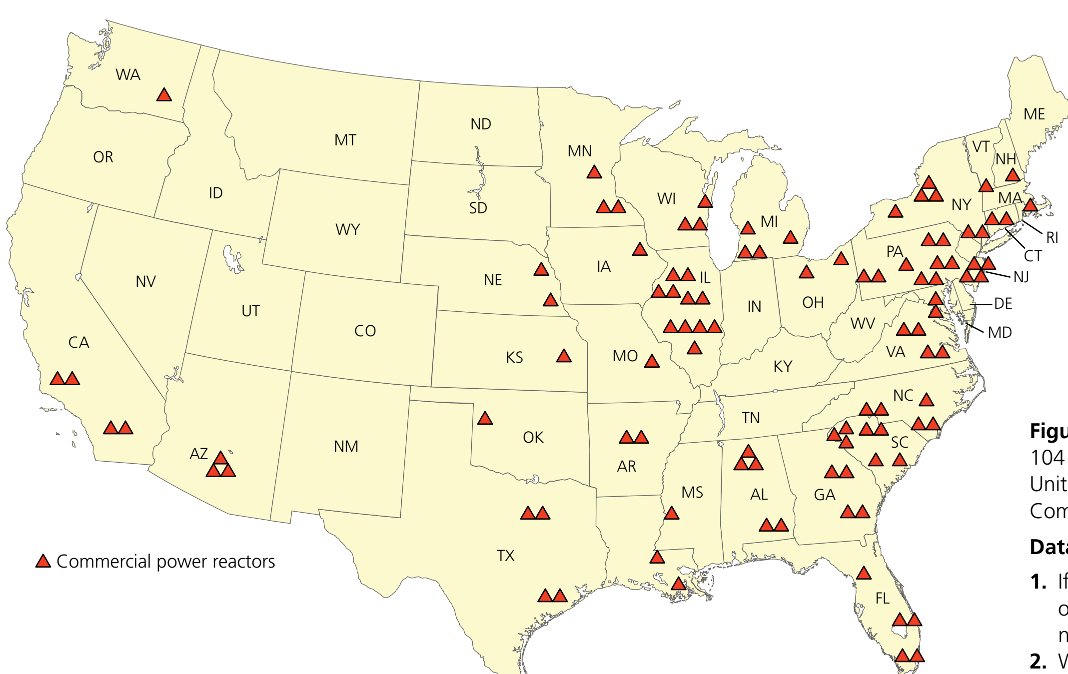


Figure 21 This map shows the locations of the 104 commercial nuclear power reactors in the United States. (Data from U.S. Nuclear Regulatory Commission)

Data and Map Analysis

1. If you live in the Untied States, do you live or go to school in an area near a commercial nuclear power reactor?
2. Which state has the largest number of commercial nuclear power reactors?

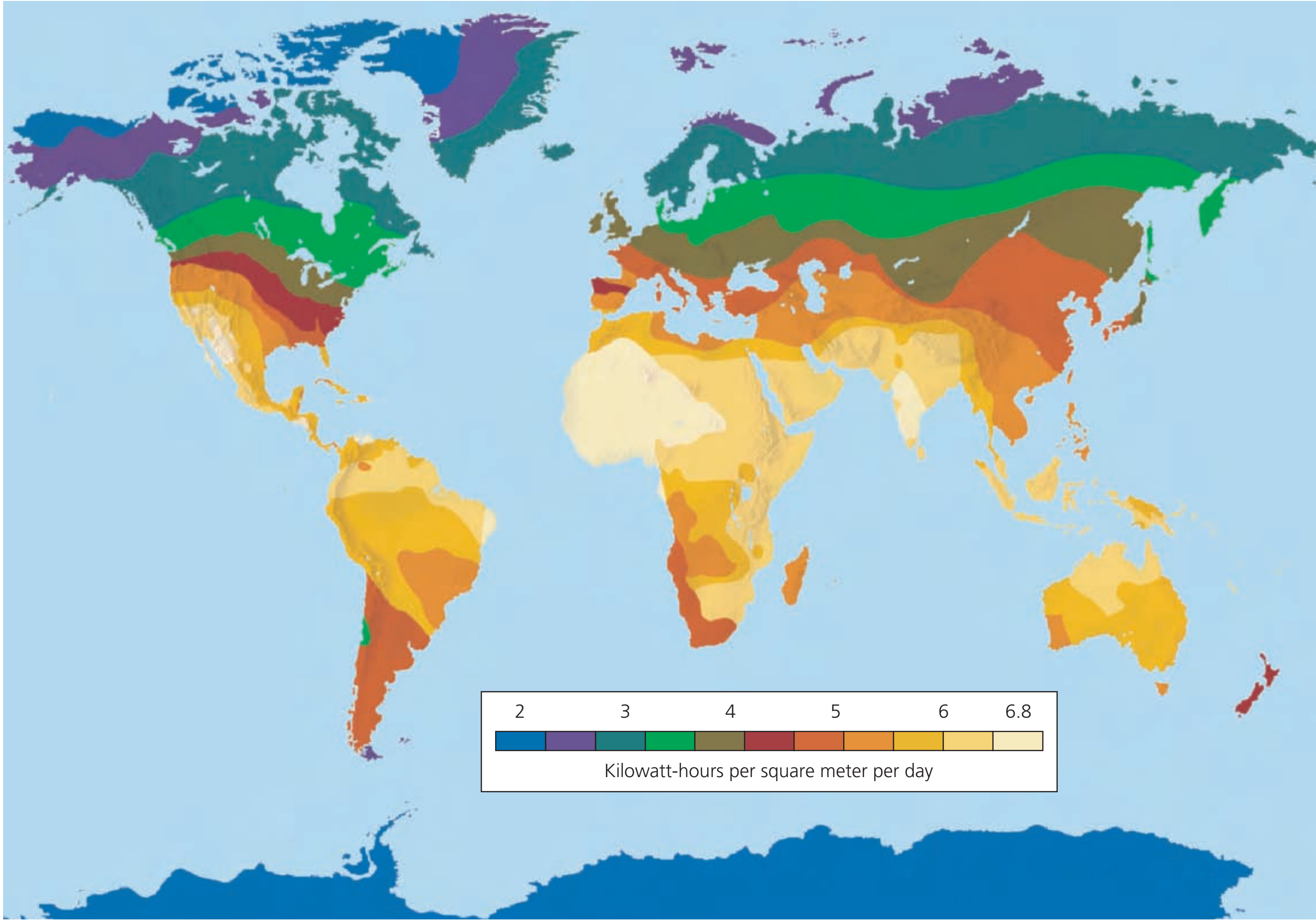


Figure 22 This map shows the global availability of direct solar energy. Areas with more than 3.5 kilowatt-hours per square meter per day (see scale) are good candidates for passive and active solar heating systems and use of solar cells to produce electricity. The United Nations is mapping the potential wind and solar energy resources of 13 developing countries in Africa, Asia, and South and Central America. (Data from U.S. Department of Energy)

Data and Map Analysis

1. What is the potential for making greater use of solar energy to provide heat and produce electricity (with solar cells) where you live or go to school?
2. List the continents in order of overall availability of direct solar energy, from those with the highest to those with the lowest. (See Figure 1 of this supplement, p. S30, for continent names.)

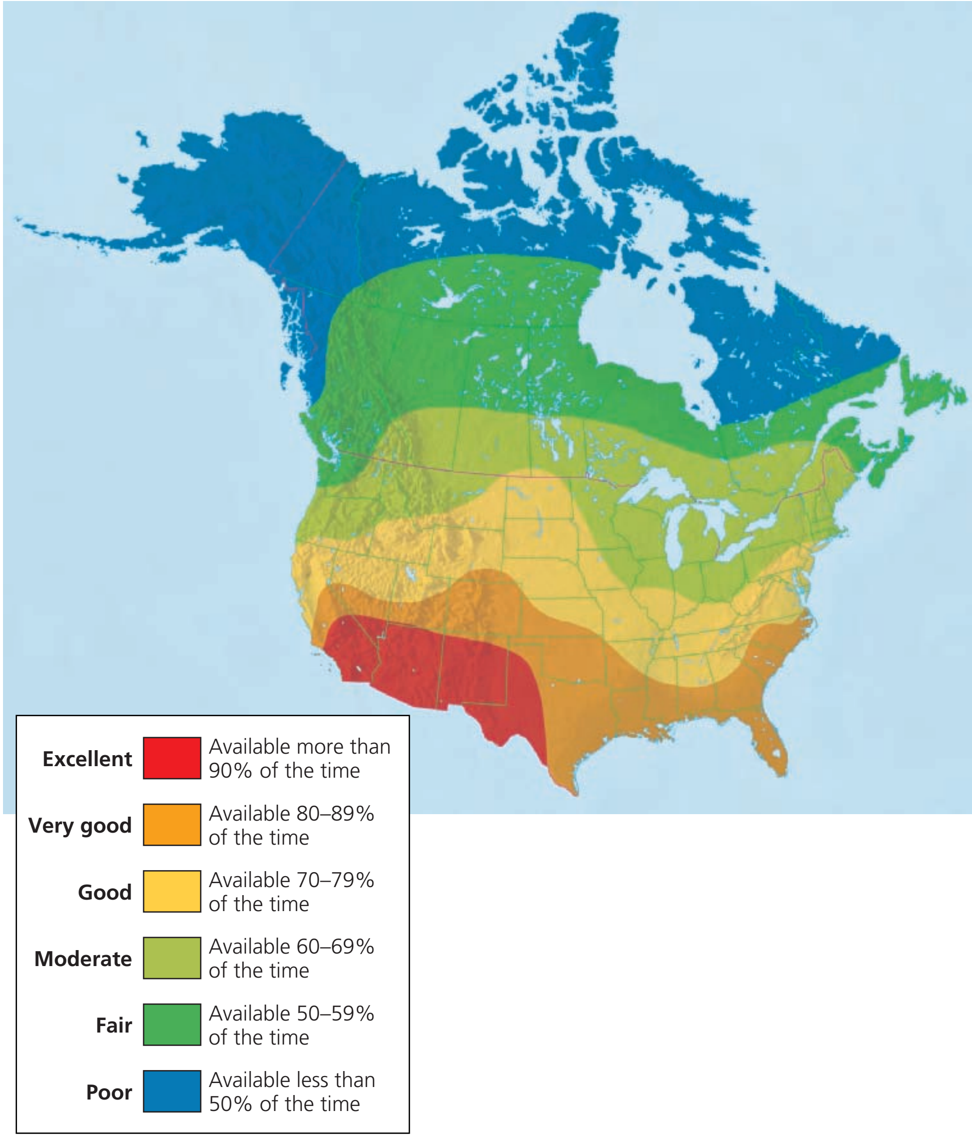


Figure 23 The availability of direct solar energy in the continental United States and Canada is shown here. If prices come down as expected, large banks of solar cells in desert areas of the southwestern United States could produce enough energy to meet all U.S. electricity needs. Electricity produced by such solar-cell power plants would be distributed through the country's electric power grid. (Data from the U.S. Department of Energy and the National Wildlife Federation)

Data and Map Analysis

1. If you live in the United States, what is the potential for making increased use of solar energy to provide heat and electricity (with solar cells) where you live or go to school?
2. How many states have areas with excellent, very good, or good availability of direct solar energy?

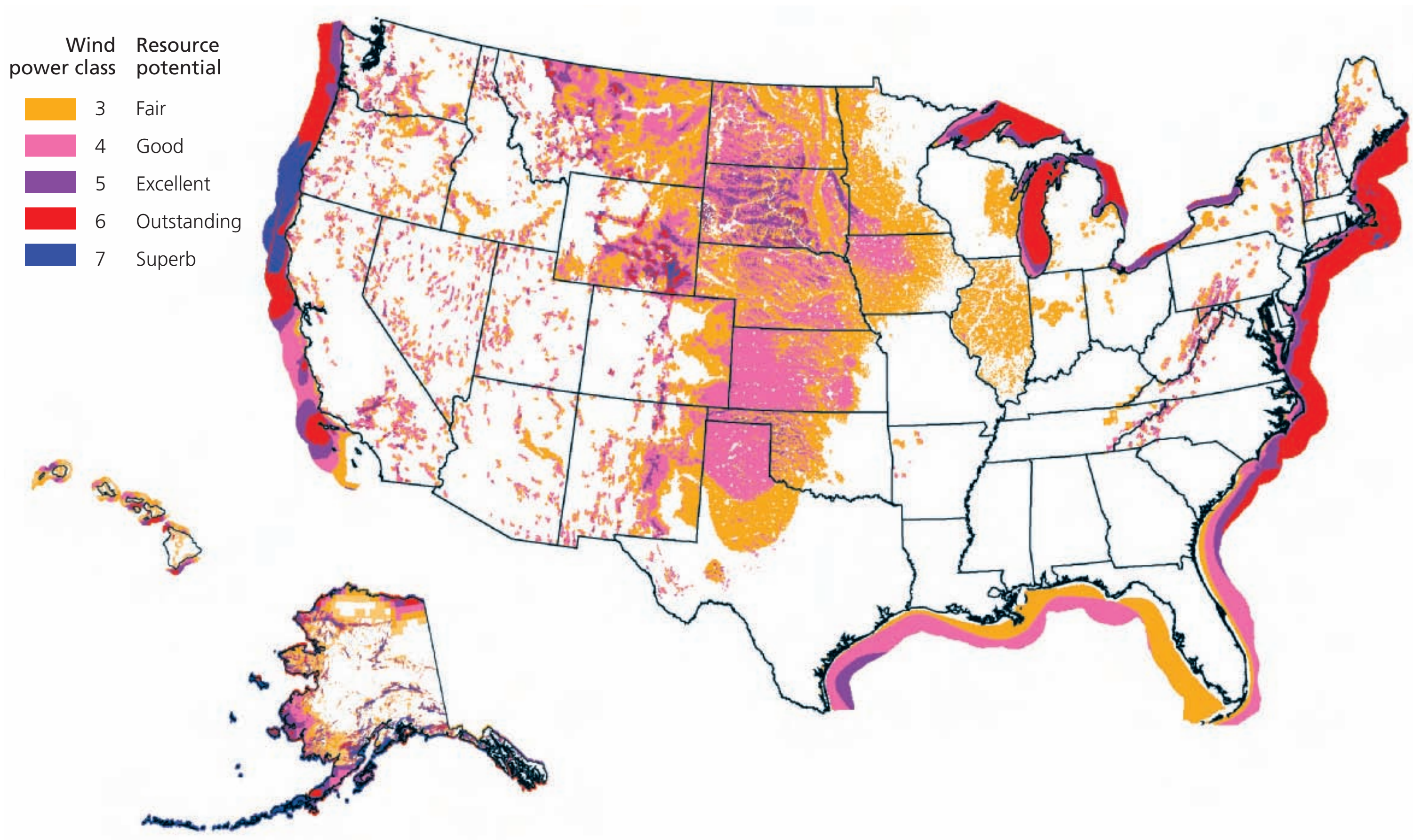


Figure 24 This map indicates the potential supply of land- and ocean-based wind energy (an indirect form of solar energy) in the United States. Locate the land-based and offshore areas with the highest potential for wind power. For more detailed maps by state see the U.S. Department of Energy, National Renewable Energy Laboratory website at **http://www.nrel.gov/wind/resource_assessment.html**.

Data and Map Analysis

1. If you live in the United States, what is the general wind energy potential where you live or go to school?
2. How many states have areas with good or better potential for wind energy?

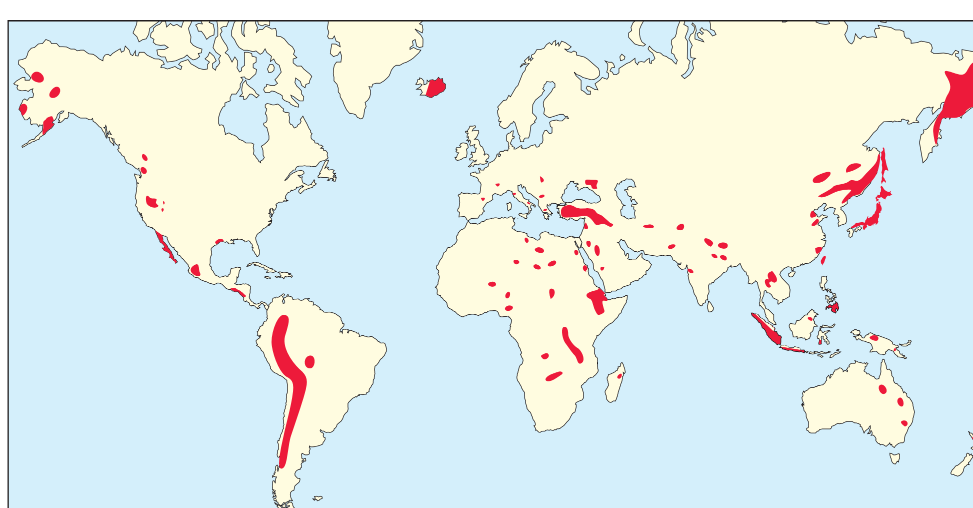


Figure 25 This map illustrates the known global reserves of moderate- to high-temperature geothermal energy. (Data from Canadian Geothermal Resources Council)

Data and Map Analysis

1. Between North and South America, which continent appears to have the greatest total potential for geothermal energy? (See Figure 1 of this supplement, p. S30, for continent names.)
2. Which country in Asia has the greatest known reserves of geothermal energy? (See Figure 1 of this supplement, p. S30, for country names.)

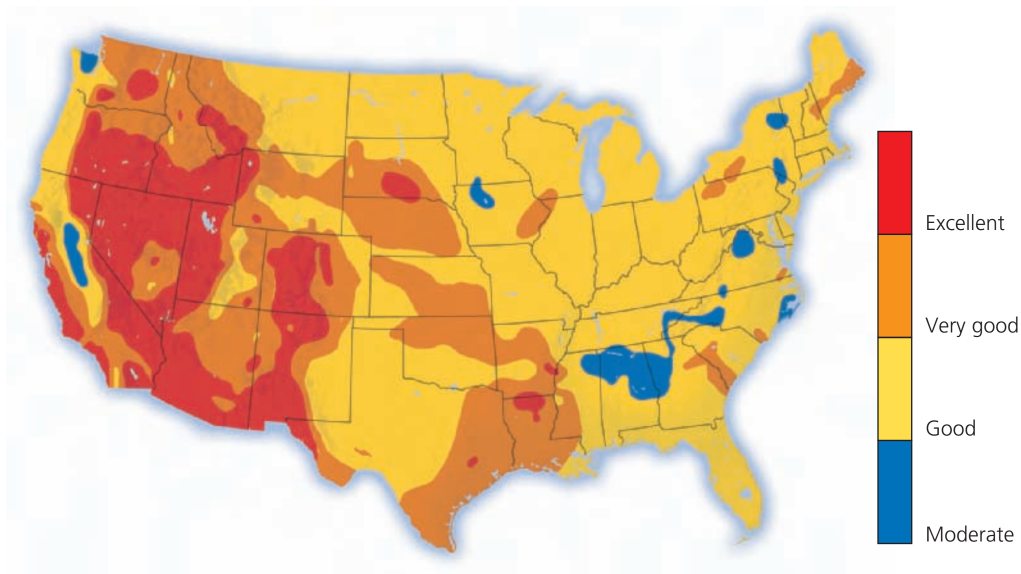


Figure 26 The potential geothermal energy resources in the continental United States are shown here. (Data from U.S. Department of Energy)

Data and Map Analysis

1. If you live in the United States, what is the potential for using geothermal energy to provide heat or to produce electricity where you live or go to school?
2. How many states have areas with very good or excellent potential for using geothermal energy?

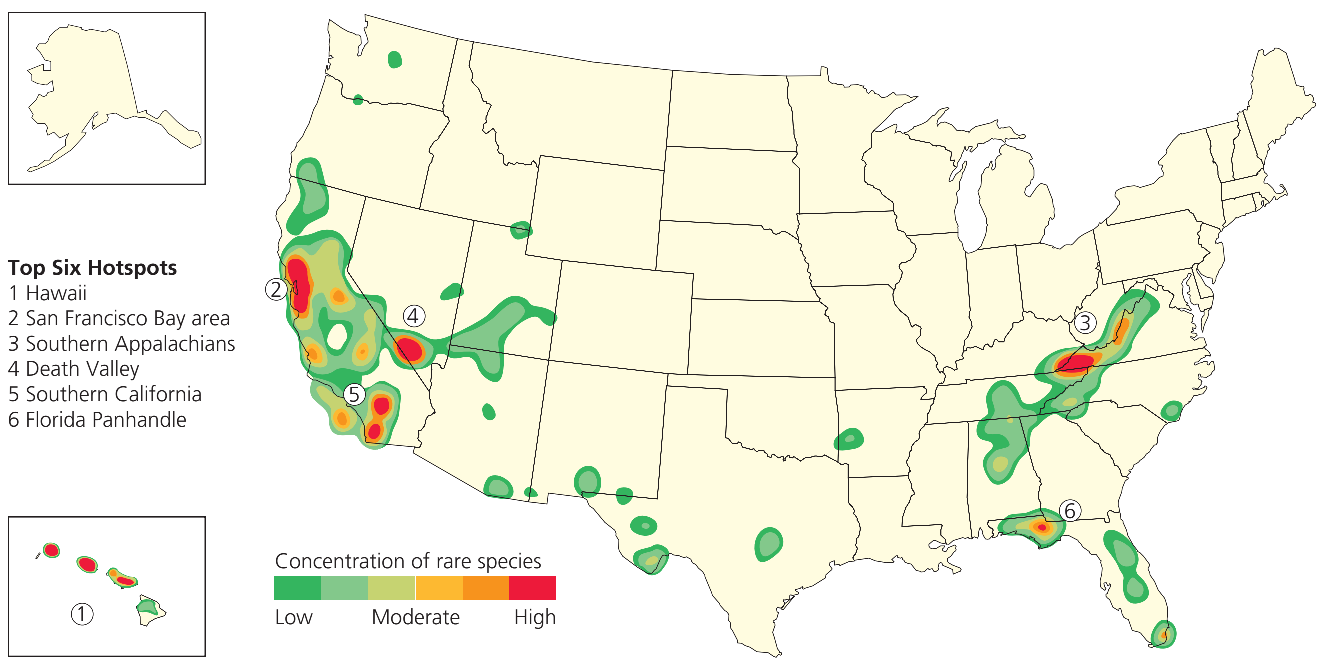


Figure 27 **Endangered natural capital:** This map shows major biodiversity hotspots in the United States that need emergency protection. The shaded areas contain the largest concentrations of rare and potentially endangered species. Compare these areas with those on the map of the human ecological footprint in North America shown in Figure 9 in this supplement. **Question:** Do you think that hotspots near urban areas would be harder to protect than those in rural areas? Explain. (Data from State Natural Heritage Programs, the Nature Conservancy, and Association for Biodiversity Information)

Data and Map Analysis

1. If you live in the United States, which of the top six hotspots is closest to where you live or go to school?
2. Which general part of the country has the highest overall concentration of rare species? Which part has the second-highest concentration?

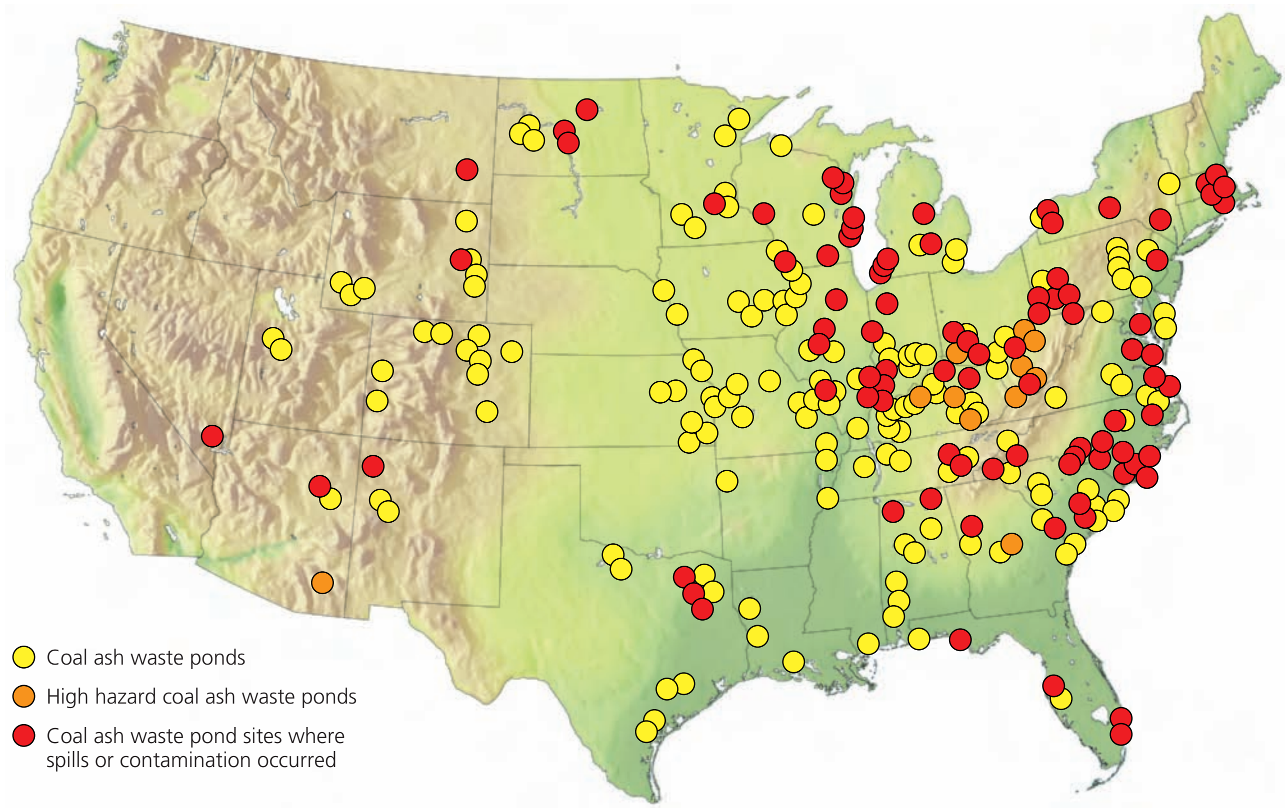


Figure 28 Coal ash waste pond sites in the United States. **Question:** Do you live or go to school near any of these ponds? (Data from U.S. Environmental Protection Agency and the Sierra Club)

Data and Map Analysis

1. In what part of the country (eastern third, central third, or western third) have most of the cases of contamination and spills occured?
2. What state appears to have had the most cases of spills and contamination?
3. In what part of the country are most of the high-hazard coal ash ponds located?

Environmental Data and Data Analysis (Chapters 3, 6, 7, 14–16, 19, 21–23, 25)

SUPPLEMENT 9

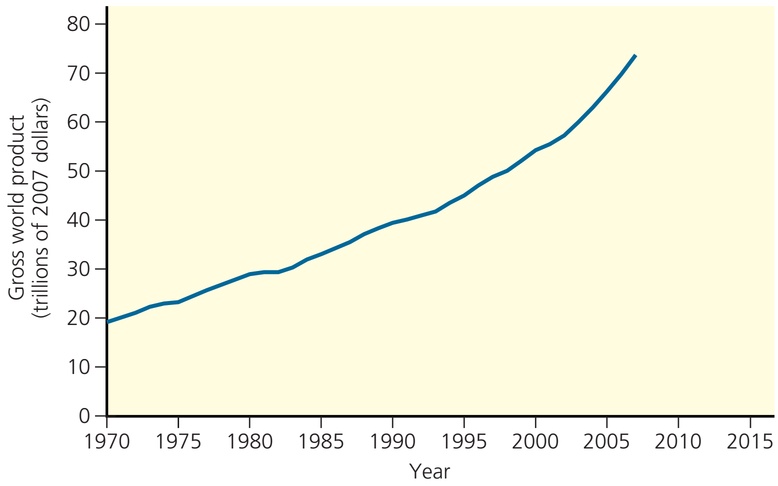


Figure 1 This graph tracks gross world product (GWP), 1970–2008. (Data from International Monetary Fund and the World Bank using purchasing power parity terms)

Data and Graph Analysis

1. Roughly how many times bigger than the gross world product of 1985 was the gross world product in 2008?
2. If the current trend continues, about what do you think the gross world product will be in 2013, in trillions of dollars?

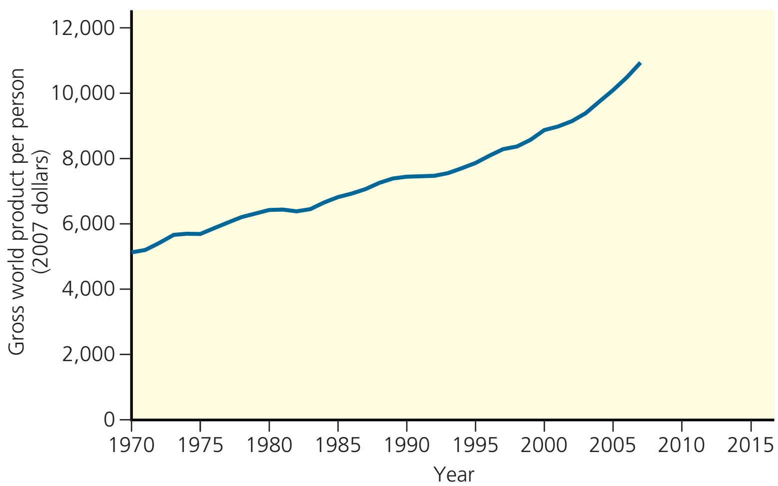


Figure 2 This graph tracks gross world product (GWP) per person, 1970–2008. (Data from International Monetary Fund and the World Bank using purchasing power parity terms)

Data and Graph Analysis

1. Roughly how many years did it take for the GWP per person value in 1970 to double?
2. If the current trend continues, about what do you think the GWP per person will be in 2013, in dollars?

Figure 3 This is a population time line for the period 10,000 BC–2042 AD.

Data and Graph Analysis

1. About how many years did it take the human population to reach 1 billion? How long after that did it reach 2 billion?
2. In about what year was the population half of what it is projected to be in 2011?

Year	Event	Human population (approximate)
50,000 BC	Hunter-gatherer societies	1.2 million
10,000 BC	End of last Ice Age	4 million
8,000 BC	Agricultural Revolution	5 million
500 BC		100 million
1,000 AD		250 million
1347–1351	Black Death (Plague); 75 million people die	
1500		450 million
1750	Industrial Revolution begins in Europe	791 million
1800	Industrial Revolution begins in the United States	
1804		1 billion
1845–1849	Irish potato famine: 1 million people die	
1927		2 billion
1943	Penicillin used against infection helps decrease death rates	
1957	Great famine in China; 20 million die	
1961		3 billion
1974		4 billion
1984		5 billion
1987		6 billion
2011	Projected human population:	7 billion
2024	Projected human population:	8 billion
2042	Projected human population:	9 billion

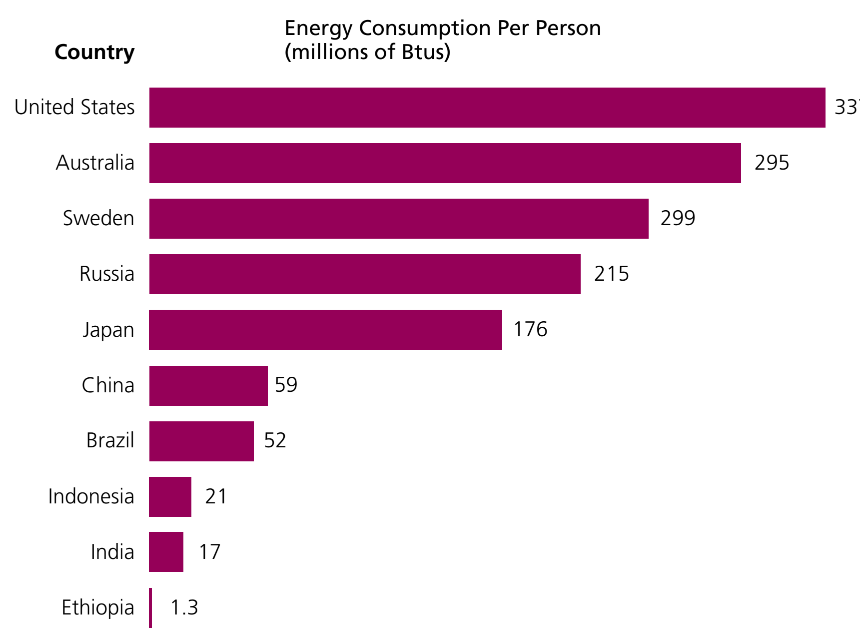
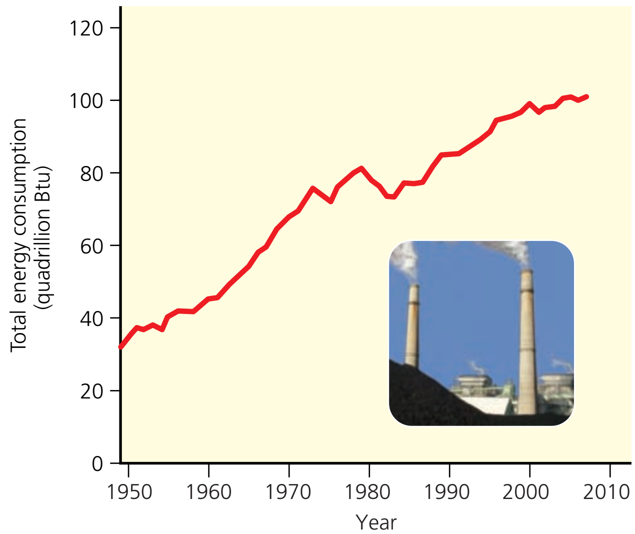


Figure 4 This bar graph represents energy consumption per person in 2007 for selected countries. (Data from World Resources Institute and International Energy Agency)

Data and Graph Analysis

1. On average, how many times more energy does an American consume per year than does a person in **(a)** China, **(b)** India, **(c)** Japan, and **(d)** Ethiopia?
2. On average, how many times more energy does a Chinese citizen consume per year than does a person in **(a)** India and **(b)** Ethiopia?



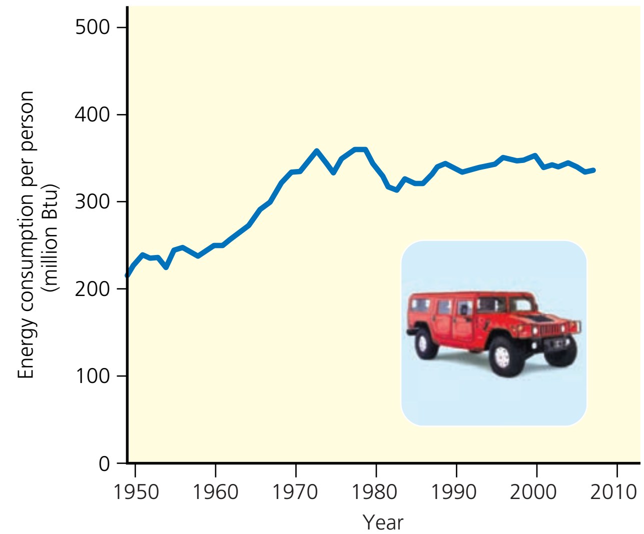


Figure 5 These graphs track total (left) and per capita (right) energy consumption in the United States, 1950–2007. (Data from U.S. Energy Information Administration/Annual Energy Review 2008)

Data and Graph Analysis

1. In what year or years did total U.S. energy consumption reach 80 quadrillion Btus?
2. In what year did energy consumption per person reach its highest level shown on this graph, and about what was that level of consumption?

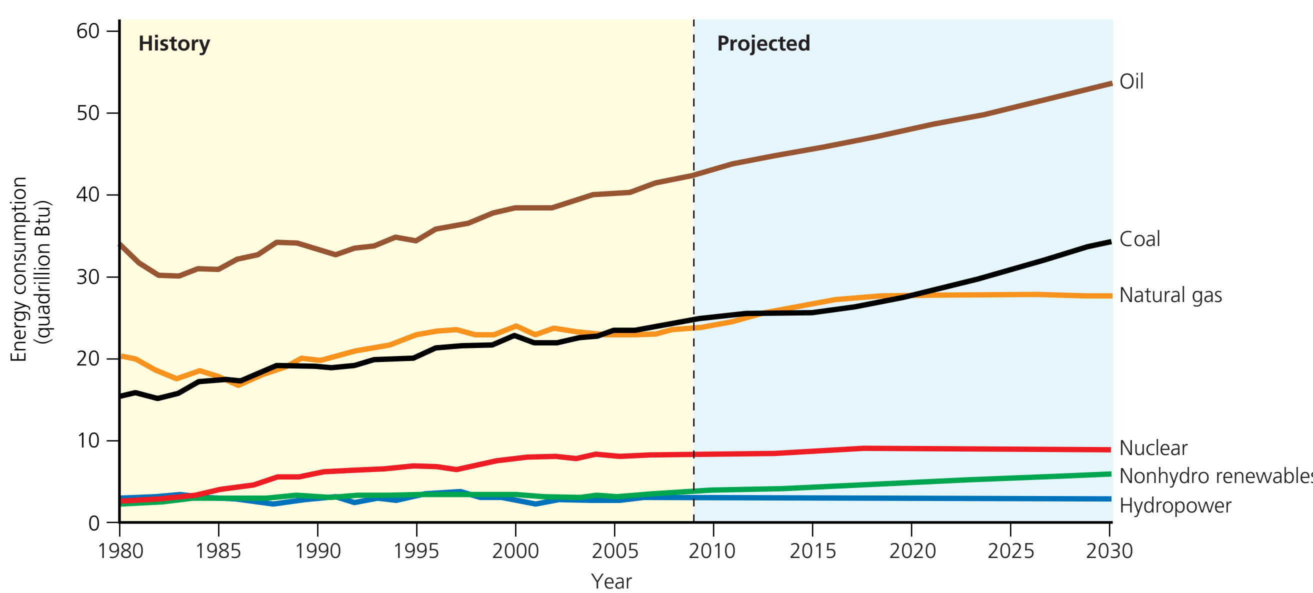


Figure 6 This graph represents energy consumption by fuel in the United States, 1980–2009, with projections to 2030. (Data from U.S. Energy Information Administration/Annual Energy Outlook 2010)

Data and Graph Analysis

1. Which energy source grew the most between 1990 and 2009? How much did it grow (in quadrillion Btus)?
2. In what years after 2007 was it projected that coal use would be higher than natural gas use?

Figure 7 World coal and natural gas consumption for the period 1950–2009 are shown in this graph. (Data from U.S. Energy Information Administration, British Petroleum, International Energy Agency, and United Nations)

Data and Graph Analysis

1. Which energy source has grown more steadily—coal or natural gas? In what years has coal use grown most sharply?
2. In what year did coal use reach a level twice as high as it was in 1960?

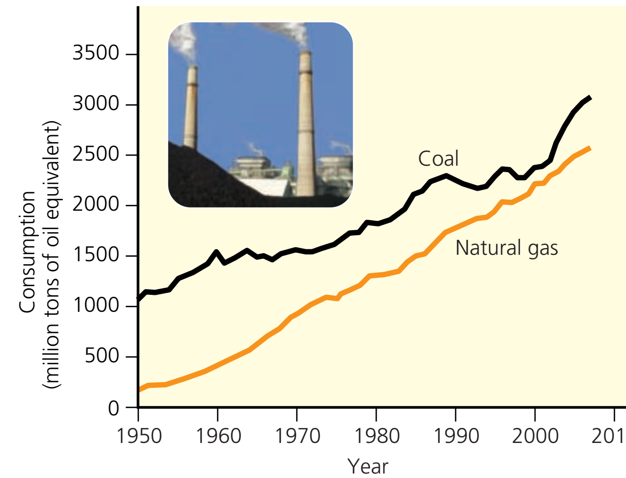
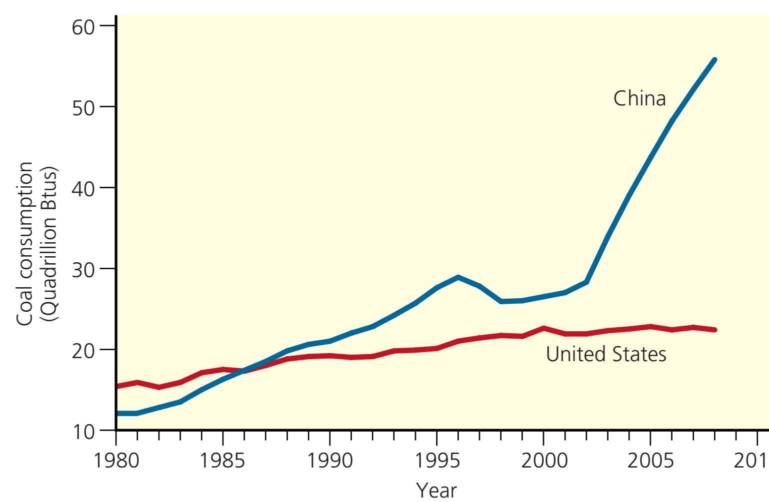


Figure 8 Coal consumption in China and the United States, 1980–2008. (Data from British Petroleum, *Statistical Review of World Energy*, 2009).

Data and Graph Analysis

1. By what percentage did coal consumption increase in China between 1980 and 2008?
2. By what percentage did coal consumption increase in the United States between 1980 and 2008?



Year	Event
1857	First commercial oil well drilled near Titusville, Pennsylvania.
1905	Oil supplies 10% of U.S. energy.
1925	The United States produces 71% of the world's oil.
1930	Because of an oil glut, oil sells for 10¢ per barrel.
1953	U.S. oil companies account for about half the world's oil production, and the United States is the world's leading oil exporter.
1955	The United States has 20% of the world's estimated oil reserves.
1960	OPEC is formed so that developing countries, with most of the world's known oil and projected oil reserves, can get a higher price for their oil.
1973	The United States uses 30% of the world's oil, imports 36% of this oil, and has only 5% of the world's proven oil reserves.
1973–1974	OPEC reduces oil imports to the West and bans oil exports to the United States because of its support for Israel in the 18-day Yom Kippur War with Egypt and Syria. World oil prices rise sharply and lead to double-digit inflation in the United States and many other countries and a global economic recession.
1975	Production of estimated U.S. oil reserves peaks.
1979	Iran's Islamic Revolution shuts down most of Iran's oil production and reduces world oil production.
1981	The Iran-Iraq war pushes global oil prices to an historic high.
1983	Facing an oil glut, OPEC cuts its oil prices.
1985	U.S. domestic oil production begins to decline and is not expected to increase enough to affect the global price of oil or to reduce U.S. dependence on oil imports.
August 1990–June 1991	The United States and its allies fight the Persian Gulf War to oust Iraqi invaders of Kuwait and to protect Western access to Saudi Arabian and Kuwaiti oil supplies.
2004–???	The United States and a small number of allies fight a second Persian Gulf War to oust Saddam Hussein from power in Iraq and to protect Western access to Saudi Arabian, Kuwaiti, and Iraqi oil.
2008	OPEC has 67% of the world oil reserves and produces 40% of the world's oil. The United States has only about 2% of world oil reserves, uses 25% of the world's oil production, and imports 58% of its oil.
2020	The United States could be importing at least 70% of the oil it uses, as consumption continues to exceed production.
2010–2030	Production of conventional oil from the world's estimated oil reserves is expected to peak as half of the world's oil reserves are used up. Oil prices are expected to increase gradually as the demand for oil increasingly exceeds the supply—unless the world decreases its demand by wasting less energy and shifting to other sources of energy.
2010–2048	Domestic U.S. conventional oil reserves are projected to be 80% depleted.
2042–2083	A gradual decline in dependence on conventional oil is expected.

Figure 9 This time line presents a brief history of the Age of Conventional Oil.

Data and Graph Analysis

1. About what year did U.S. oil production begin to decline?
2. When might the U.S. share of only 1.5% of the world's proven conventional oil reserves be about 80% depleted and, therefore, too expensive to justify extracting what remains?

Figure 10 This graph tracks global electrical generating capacity of nuclear power plants for the period 1960–2009. (Data from International Energy Agency and Worldwatch Institute)

Data and Graph Analysis

1. After 1980, how long did it take to double that year's generating capacity?
2. Considering the decades of the 1970s, 1980s, and 1990s, which decade saw the sharpest growth in generating capacity? During which decade did this growth level off?

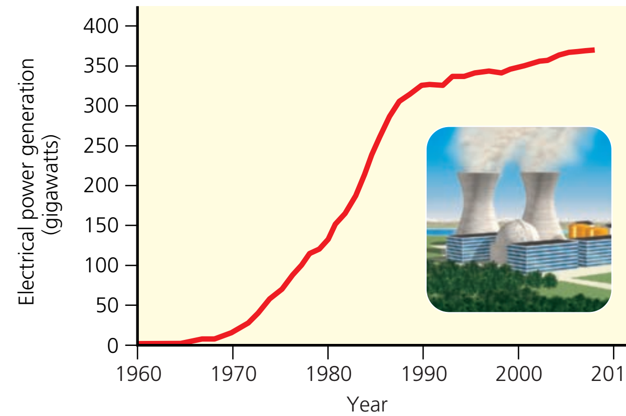
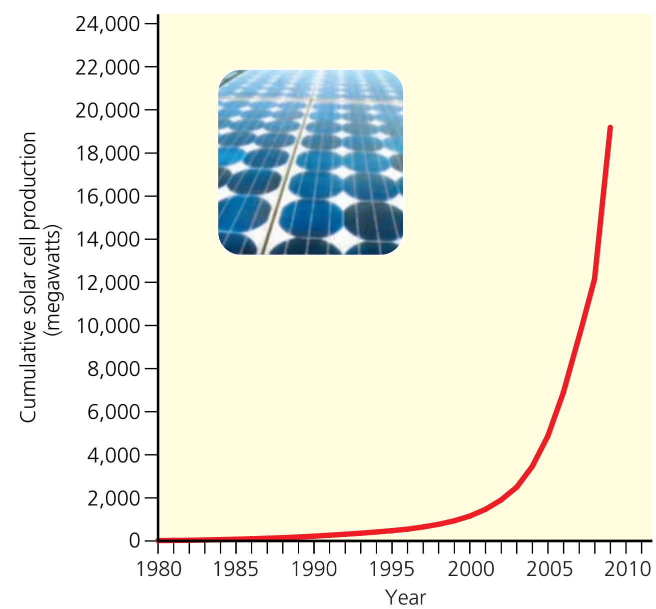


Figure 11 This graph tracks the global cumulative production of electricity by solar (photovoltaic) cells for the period 1980–2008. (Data from PV News, Maycock, Prometheus Institute, and Global Data 2009)

Data and Graph Analysis

1. About how many times more solar cell production had occurred by 2008 than had occurred by 2000?
2. How long did it take the world to go **(a)** from 0 to 6,000 megawatts in its cumulative production of electricity by solar cells and **(b)** from 6,000 to 19,200 megawatts?



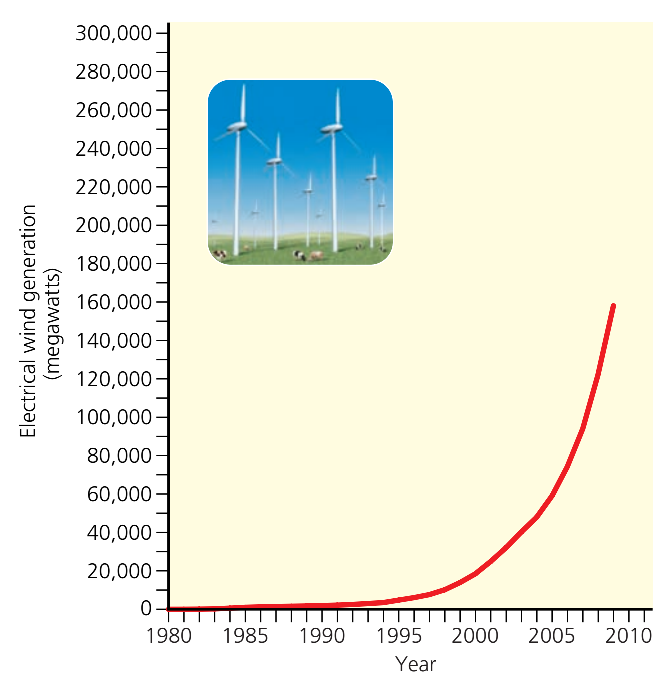


Figure 12 Global installed capacity for generation of electricity by wind energy for the period 1980–2009 is shown in this graph. (Data from Global Wind Energy Council, European Wind Energy Association, American Wind Energy Association, Worldwatch Institute, and World Wind Energy Association, 2010)

Data and Graph Analysis

1. How long did it take for the world to go from zero to 100,000 megawatts of installed capacity for wind-generated electricity?
2. In 2009, the world's installed capacity for generating electricity by wind power was about how many times more than it was in 1995?

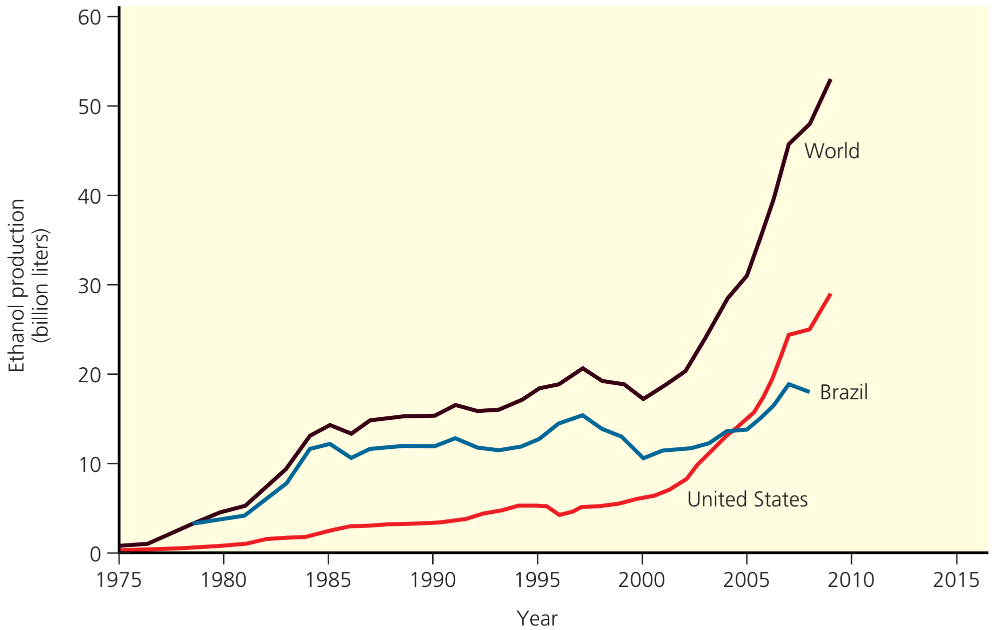


Figure 13 This graph tracks the production of ethanol motor fuel in the world, in Brazil, and in the United States for the period 1975–2009. (Data from F. O. Litch, USDA, and Earth Policy Institute)

Data and Graph Analysis

1. By roughly what percentage did global ethanol production increase between 2000 and 2009?
2. If U.S. production of ethanol continues at its current rate, when is it likely to reach about 50 billion liters?

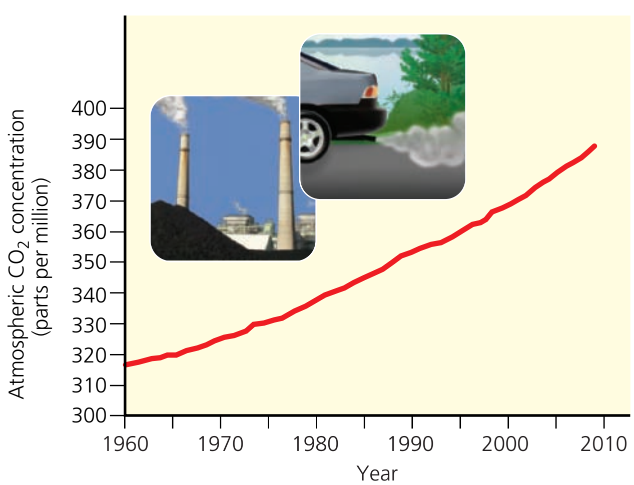


Figure 14 This graph shows the atmospheric concentration of carbon dioxide (CO_2) measured at a major atmospheric research center in Mauna Loa, Hawaii, 1960–2009. The annual fluctuation in CO_2 values occurs because land plants take up varying amounts of CO_2 in different seasons. (Data from Scripps Institute of Oceanography, 2010, and U.S. Energy Information Agency, 2010)

Data and Graph Analysis

1. By how much did atmospheric CO_2 concentrations grow between 1960 and 2009 (in parts per million)?
2. Assuming that atmospheric CO_2 concentrations continue growing as is reflected on this graph, estimate the year in which such concentrations will reach 450 parts per million.

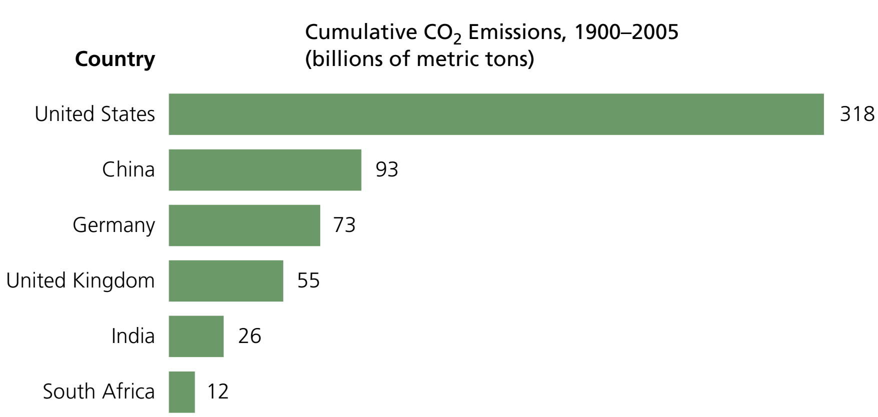


Figure 15 This bar graph shows the cumulative carbon dioxide (CO_2) emissions from use of fossil fuels for selected countries, 1900–2005. (Data from International Panel on Climate Change and the World Resources Institute)

Data and Graph Analysis

1. How many times higher are the cumulative CO_2 emissions of the United States than those of **(a)** China and **(b)** India?
2. How many times higher are the cumulative CO_2 emissions of China than those of **(a)** the United Kingdom and **(b)** India?

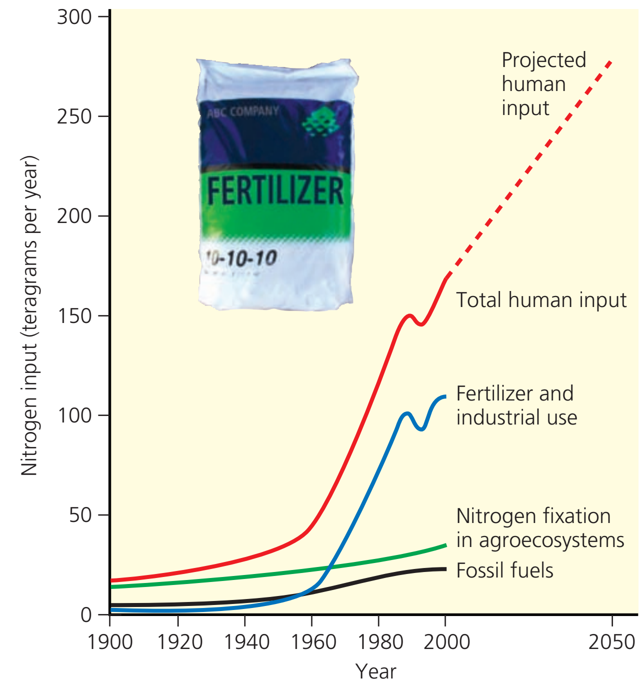


Figure 16 Global trends in the annual inputs of nitrogen into the environment from human activities, with projections to 2050, are shown in this graph. (Data from 2005 Millennium Ecosystem Assessmentt)

Data and Graph Analysis

1. By roughly what percentage did the world's total input of nitrogen into the environment increase between 1960 and 2000?
2. If nitrogen inputs continue as projected, by how many times will the inputs have doubled between 1980 and 2050?

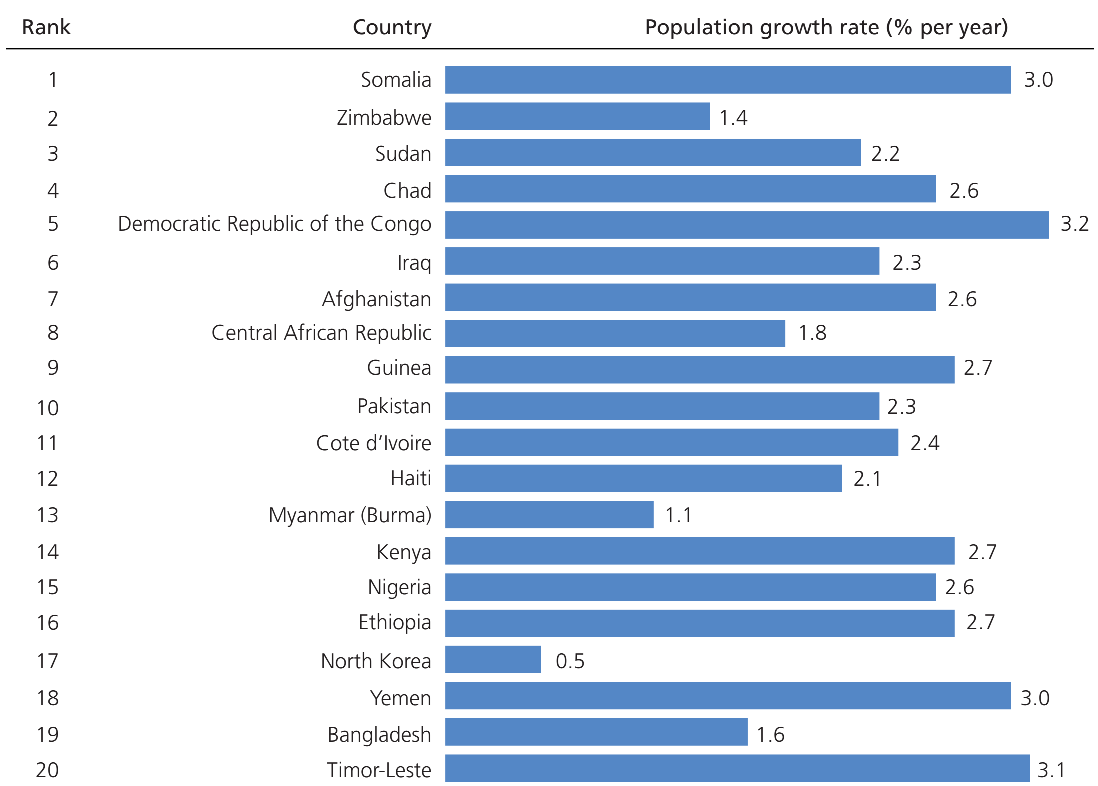


Figure 17 This is a list of the top 20 failing states in 2008. Population growth rate is one factor contributing to these nations' challenges, along with internal strife, corrupt governments, and poor economic management. (Data from Fund for Peace and Foreign Policy, 2009)

Data and Graph Analysis

1. What percentage of these 20 countries has a population growth rate greater than 2.5%?
2. Which three countries have the lowest population growth rates?

Glossary

abiotic Nonliving. Compare *biotic.*

acid See *acid solution.*

acid deposition The falling of acids and acid-forming compounds from the atmosphere to the earth's surface. Acid deposition is commonly known as *acid rain*, a term that refers to the wet deposition of droplets of acids and acid-forming compounds.

acidity Chemical characteristic that helps determine how a substance dissolved in water (a solution) will interact with and affect its environment; based on the comparative amounts of hydrogen ions (H^+) and hydroxide ions (OH^-) contained in a particular volume of the solution. See *pH*.

acid rain See *acid deposition.*

acid solution Any water solution that has more hydrogen ions (H^+) than hydroxide ions (OH^-); any water solution with a pH less than 7. Compare *basic solution, neutral solution.*

active solar heating system System that uses solar collectors to capture energy from the sun and store it as heat for space heating and water heating. Liquid or air pumped through the collectors transfers the captured heat to a storage system such as an insulated water tank or rock bed. Pumps or fans then distribute the stored heat or hot water throughout a dwelling as needed. Compare *passive solar heating system.*

adaptation Any genetically controlled structural, physiological, or behavioral characteristic that helps an organism survive and reproduce under a given set of environmental conditions. It usually results from a beneficial mutation. See *biological evolution, differential reproduction, mutation, natural selection.*

adaptive trait See *adaptation.*

aerobic respiration Complex process that occurs in the cells of most living organisms, in which nutrient organic molecules such as glucose ($C_6H_{12}O_6$) combine with oxygen (O_2) to produce carbon dioxide (CO_2), water (H_2O), and energy. Compare *photosynthesis.*

affluence wealth that results in high levels of consumption and unnecessary waste of resources, based mostly on the assumption that buying more and more material goods will bring fulfillment and happiness.

age structure Percentage of the population (or number of people of each sex) at each age level in a population.

agroforestry Planting trees and crops together.

air pollution One or more chemicals in high enough concentrations in the air to harm humans, other animals, vegetation, or materials. Excess heat is also considered a form of air pollution. Such chemicals or physical conditions are called air pollutants. See *primary pollutant, secondary pollutant.*

albedo Ability of a surface to reflect light.

alien species See *nonnative species.*

alley cropping Planting of crops in strips with rows of trees or shrubs on each side.

alpha particle Positively charged matter, consisting of two neutrons and two protons, which is emitted as radioactivity from the nuclei of some radioisotopes. See also *beta particle, gamma rays.*

altitude Height above sea level. Compare *latitude.*

anaerobic respiration Form of cellular respiration in which some decomposers get the energy they need through the breakdown of glucose (or other nutrients) in the absence of oxygen. Compare *aerobic respiration.*

ancient forest See *old-growth forest.*

animal manure Dung and urine of animals used as a form of organic fertilizer. Compare *green manure.*

annual Plant that grows, sets seed, and dies in one growing season. Compare *perennial.*

anthropocentric Human-centered.

applied ecology See *reconciliation ecology.*

aquaculture Growing and harvesting of fish and shellfish for human use in freshwater ponds, irrigation ditches, and lakes, or in cages or fenced-in areas of coastal lagoons and estuaries or in the open ocean. See *fish farming, fish ranching.*

aquatic Pertaining to water. Compare *terrestrial.*

aquatic life zone Marine and freshwater portions of the biosphere. Examples include freshwater life zones (such as lakes and streams) and ocean or marine life zones (such as estuaries, coastlines, coral reefs, and the open ocean).

aquifer Porous, water-saturated layers of sand, gravel, or bedrock that can yield an economically significant amount of water.

arable land Land that can be cultivated to grow crops.

area strip mining Type of surface mining used where the terrain is flat. An earthmover strips away the overburden, and a power shovel digs a cut to remove the mineral deposit. The trench is then filled with overburden, and a new cut is made parallel to the previous one. The process is repeated over the entire site. Compare *mountaintop removal, open-pit mining, subsurface mining.*

arid Dry. A desert or other area with an arid climate has little precipitation.

artificial selection Process by which humans select one or more desirable genetic traits in the population of a plant or animal species and then use *selective breeding* to produce populations containing many individuals with the desired traits. Compare *genetic engineering, natural selection.*

asexual reproduction Reproduction in which a mother cell divides to produce two identical daughter cells that are clones of the mother cell. This type of reproduction is common in single-celled organisms. Compare *sexual reproduction.*

asthenosphere Zone within the earth's mantle made up of hot, partly melted rock that flows and can be deformed like soft plastic.

atmosphere Whole mass of air surrounding the earth. See *stratosphere, troposphere.* Compare *biosphere, geosphere, hydrosphere.*

atmospheric pressure Force or mass per unit area of air, caused by the bombardment of a surface by the molecules in air.

atom Minute unit made of subatomic particles that is the basic building block of all chemical elements and thus all matter; the smallest unit of an element that can exist and still have the unique characteristics of that element. Compare *ion, molecule.*

atomic number Number of protons in the nucleus of an atom. Compare *mass number.*

atomic theory Idea that all elements are made up of atoms; the most widely accepted scientific theory in chemistry.

autotroph See *producer.*

background extinction rate Normal extinction of various species as a result of changes in local environmental conditions. Compare *mass extinction.*

bacteria Prokaryotic, one-celled organisms. Some transmit diseases. Most act as decomposers and get the nutrients they need by breaking down complex organic compounds in the tissues of living or dead organisms into simpler inorganic nutrient compounds.

basic solution Water solution with more hydroxide ions (OH^-) than hydrogen ions (H^+); water solution with a pH greater than 7. Compare *acid solution, neutral solution.*

benthos Bottom-dwelling organisms. Compare *decomposer, nekton, plankton.*

beta particle Swiftly moving electron emitted by the nucleus of a radioactive isotope. See also *alpha particle, gamma ray.*

bioaccumulation An increase in the concentration of a chemical in specific organs or tissues at a level higher than would normally be expected. Compare *biomagnification.*

biocentric Life-centered. Compare *anthropocentric.*

biodegradable Capable of being broken down by decomposers.

biodegradable pollutant Material that can be broken down into simpler substances (elements and compounds) by bacteria or other decomposers. Paper and most organic wastes such as animal manure are biodegradable but can take decades to biodegrade in modern landfills. Compare *nondegradable pollutant.*

biodiversity Variety of different species (*species diversity*), genetic variability among individuals within each species (*genetic diversity*), variety of ecosystems (*ecological diversity*), and functions such as energy flow and matter cycling needed for the survival of species and biological communities (*functional diversity*).

biodiversity hotspot An area especially rich in plant species that are found nowhere else and are in great danger of extinction. Such areas suffer serious ecological disruption, mostly because of rapid human population growth and the resulting pressure on natural resources.

biofuel Gas (such as methane) or liquid fuel (such as ethyl alcohol or biodiesel) made from plant material (biomass).

biogeochemical cycle Natural processes that recycle nutrients in various chemical forms from the nonliving environment to living organisms and then back to the nonliving environment. Examples include the carbon, oxygen, nitrogen, phosphorus, sulfur, and hydrologic cycles.

biological amplification See *biomagnification.*

biological community See *community.*

biological diversity See *biodiversity.*

biological evolution Change in the genetic makeup of a population of a species in successive generations. If continued long enough, it can lead to the formation of a new species. Note that populations, not individuals, evolve. See also *adaptation, differential reproduction, natural selection, theory of evolution.*

biological extinction Complete disappearance of a species from the earth. It happens when a species cannot adapt and successfully reproduce under new environmental conditions or when a species evolves into one or more new species. Compare *speciation.* See also *endangered species, mass extinction, threatened species.*

biological pest control Control of pest populations by natural predators, parasites, or disease-causing bacteria and viruses (pathogens).

biomagnification Increase in concentration of DDT, PCBs, and other slowly degradable, fat-soluble chemicals in organisms at successively higher trophic levels of a food chain or web. Compare *bioaccumulation.*

biomass Organic matter produced by plants and other photosynthetic producers; total dry weight of all living organisms that can be supported at each trophic level in a food chain or web; dry weight of all organic matter in plants and animals in an ecosystem; plant materials and animal wastes used as fuel.

biome Terrestrial regions inhabited by certain types of life, especially vegetation. Examples include various types of deserts, grasslands, and forests.

biomimicry Process of observing certain changes in nature, studying how natural systems have responded to such changing conditions over many millions of years, and applying what is learned to dealing with some environmental challenge.

biosphere Zone of the earth where life is found. It consists of parts of the atmosphere (the troposphere), hydrosphere (mostly surface water and groundwater), and lithosphere (mostly soil and surface rocks and sediments on the bottoms of oceans and other bodies of water) where life is found. Compare *atmosphere, geosphere, hydrosphere.*

biotic Living organisms. Compare *abiotic.*

biotic pollution The effect of invasive species that can reduce or wipe out populations of many native species and trigger ecological disruptions.

biotic potential Maximum rate at which the population of a given species can increase when there are no limits on its rate of growth. See *environmental resistance.*

birth rate See *crude birth rate.*

bitumen Gooey, black, high-sulfur, heavy oil extracted from tar sand and then upgraded to synthetic fuel oil. See *oil sand.*

broadleaf deciduous plants Plants such as oak and maple trees that survive drought and cold by shedding their leaves and becoming dormant. Compare *broadleaf evergreen plants, coniferous evergreen plants.*

broadleaf evergreen plants Plants that keep most of their broad leaves year-round. An example is the trees found in the canopies of tropical rain forests. Compare *broadleaf deciduous plants, coniferous evergreen plants.*

buffer Substance that can react with hydrogen ions in a solution and thus hold the acidity or pH of a solution fairly constant. See *pH.*

calorie Unit of energy; amount of energy needed to raise the temperature of 1 gram of water by 1 C° (unit on Celsius temperature scale). See also *kilocalorie.*

cancer Group of more than 120 different diseases, one for each type of cell in the human body. Each type of cancer produces a tumor in which cells multiply uncontrollably and invade surrounding tissue.

carbon capture and storage (CCS) Process of removing carbon dioxide gas from coal-burning power and industrial plants and storing it somewhere (usually underground or under the seabed) so that it is not released into the atmosphere, essentially forever.

carbon cycle Cyclic movement of carbon in different chemical forms from the environment to organisms and then back to the environment.

carcinogen Chemicals, ionizing radiation, and viruses that cause or promote the development of cancer. See *cancer.* Compare *mutagen, teratogen.*

carnivore Animal that feeds on other animals. Compare *herbivore, omnivore.*

carrying capacity (*K*) Maximum population of a particular species that a given habitat can support over a given period. Compare *cultural carrying capacity.*

CCS See *carbon capture and storage*.

cell Smallest living unit of an organism. Each cell is encased in an outer membrane or wall and contains genetic material (DNA) and other parts to perform its life function. Organisms such as bacteria consist of only one cell, but most organisms contain many cells.

cell theory The idea that all living things are composed of cells; the most widely accepted scientific theory in biology.

CFCs See *chlorofluorocarbons.*

chain reaction Multiple nuclear fissions, taking place within a certain mass of a fissionable isotope, which release an enormous amount of energy in a short time.

chemical One of the millions of different elements and compounds found naturally and synthesized by humans. See *compound, element.*

chemical change Interaction between chemicals in which the chemical composition of the elements or compounds involved changes. Compare *nuclear change, physical change.*

chemical formula Shorthand way to show the number of atoms (or ions) in the basic structural unit of a compound. Examples include H_2O, NaCl, and $C_6H_{12}O_6$.

chemical reaction See *chemical change.*

chemosynthesis Process in which certain organisms (mostly specialized bacteria) extract inorganic compounds from their environment and convert them into organic nutrient compounds without the presence of sunlight. Compare *photosynthesis.*

chlorinated hydrocarbon Organic compound made up of atoms of carbon, hydrogen, and chlorine. Examples include DDT and PCBs.

chlorofluorocarbons (CFCs) Organic compounds made up of atoms of carbon, chlorine, and fluorine. An example is Freon-12 (CCl_2F_2), which is used as a refrigerant in refrigerators and air conditioners and in making plastics such as Styrofoam. Gaseous CFCs can deplete the ozone layer when they slowly rise into the stratosphere and their chlorine atoms react with ozone molecules. Their use is being phased out.

CHP (Combined heat and power) See *cogeneration*.

chromosome A grouping of genes and associated proteins in plant and animal cells that carry certain types of genetic information. See *genes.*

chronic malnutrition Faulty nutrition, caused by a diet that does not supply an individual with enough protein, essential fats, vitamins, minerals, and other nutrients needed for good health. Compare *overnutrition, chronic undernutrition.*

chronic undernutrition Condition suffered by people who cannot grow or buy enough food to meet their basic energy needs. Most chronically undernourished children live in developing countries and are likely to suffer from mental retardation and stunted growth and to die from infectious diseases. Compare *chronic malnutrition, overnutrition.*

civil suit Court case brought to settle disputes or damages between one party and another.

clear-cutting Method of timber harvesting in which all trees in a forested area are removed in a single cutting. Compare *selective cutting, strip cutting.*

climate Physical properties of the troposphere of an area based on analysis of its weather records over a long period (at least 30 years). The two main factors determining an area's climate are its average *temperature,* with its seasonal variations, and the average amount and distribution of *precipitation.* Compare *weather.*

climate tipping point Point at which an environmental problem reaches a threshold level where scientists fear it could cause irreversible climate disruption.

climax community See *mature community.*

closed-loop recycling See *primary recycling.*

coal Solid, combustible mixture of organic compounds with 30–98% carbon by weight, mixed with various amounts of water and small amounts of sulfur and nitrogen compounds. It forms in several stages as the remains of plants are subjected to heat and pressure over millions of years.

coal gasification Conversion of solid coal to synthetic natural gas (SNG).

coal liquefaction Conversion of solid coal to a liquid hydrocarbon fuel such as synthetic gasoline or methanol.

coastal wetland Land along a coastline, extending inland from an estuary that is covered with salt water all or part of the year. Examples include marshes, bays, lagoons, tidal flats, and mangrove swamps. Compare *inland wetland.*

coastal zone Warm, nutrient-rich, shallow part of the ocean that extends from the high-tide mark on land to the edge of a shelflike extension of continental land masses known as the continental shelf. Compare *open sea.*

coevolution Evolution in which two or more species interact and exert selective pressures on each other that can lead each species to undergo adaptations. See *evolution, natural selection.*

cogeneration Production of two useful forms of energy, such as high-temperature heat or steam and electricity, from the same fuel source.

cold front Leading edge of an advancing mass of cold air. Compare *warm front.*

combined heat and power (CHP) production See *cogeneration.*

commensalism An interaction between organisms of different species in which one type of organism benefits and the other type is neither helped nor harmed to any great degree. Compare *mutualism.*

commercial extinction Depletion of the population of a wild species used as a resource to a level at which it is no longer profitable to harvest the species.

commercial inorganic fertilizer Commercially prepared mixture of inorganic plant nutrients such as nitrates, phosphates, and potassium applied to the soil to restore fertility and increase crop yields. Compare *organic fertilizer.*

commercial forest See *tree plantation.*

common law A body of unwritten rules and principles derived from court decisions along with commonly accepted practices, or norms, within a society. Compare *statutory law.*

common-property resource Resource that is owned jointly by a large group of individuals. One example is the roughly one-third of the land in the United States that is owned jointly by all U.S. citizens and held and managed for them by the government. Another example is an area of land that belongs to a whole village and that can be used by anyone for grazing cows or sheep. Compare *open access renewable resource.* See *tragedy of the commons.*

community Populations of all species living and interacting in an area at a particular time.

competition Two or more individual organisms of a single species (*intraspecific competition*) or two or more individuals of different species (*interspecific competition*) attempting to use the same scarce resources in the same ecosystem.

compost Partially decomposed organic plant and animal matter used as a soil conditioner or fertilizer.

compound Combination of atoms, or oppositely charged ions, of two or more elements held together by attractive forces called chemical bonds. Examples are NaCl, CO_2, and $C_6H_{12}O_6$. Compare *element.*

concentration Amount of a chemical in a particular volume or weight of air, water, soil, or other medium.

coniferous evergreen plants Cone-bearing plants (such as spruces, pines, and firs) that keep some of their narrow, pointed leaves (needles) all year. Compare *broadleaf deciduous plants, broad-leaf evergreen plants.*

coniferous trees Cone-bearing trees, mostly evergreens, that have needle-shaped or scalelike leaves. They produce wood known commercially as softwood. Compare *deciduous plants.*

conservation Sensible and careful use of natural resources by humans. People with this view are called *conservationists.*

conservation biology Multidisciplinary science created to deal with the crisis of maintaining the genes, species, communities, and ecosystems that make up earth's biological diversity. Its goals are to investigate human impacts on biodiversity and to develop practical approaches to preserving biodiversity.

conservationist Person concerned with using natural areas and wildlife in ways that sustain them for current and future generations of humans and other forms of life.

conservation-tillage farming Crop cultivation in which the soil is disturbed little (minimum-tillage farming) or not at all (no-till farming) in an effort to reduce soil erosion, lower labor costs, and save energy. Compare *conventional-tillage farming.*

consumer Organism that cannot synthesize the organic nutrients it needs and gets its organic nutrients by feeding on the tissues of producers or of other consumers; generally divided into *primary consumers* (herbivores), *secondary consumers* (carnivores), *tertiary* (*higher-level*) *consumers, omnivores,* and *detritivores* (decomposers and detritus feeders). In economics, one who uses economic goods. Compare *producer.*

contour farming Plowing and planting across the changing slope of land, rather than in straight lines, to help retain water and reduce soil erosion.

contour strip mining Form of surface mining used on hilly or mountainous terrain. A power shovel cuts a series of terraces into the side of a hill. An earthmover removes the overburden, and a power shovel extracts the coal. The overburden from each new terrace is dumped onto the one below. Compare *area strip mining, mountaintop removal, open-pit mining, subsurface mining.*

controlled burning Deliberately set, carefully controlled surface fires that reduce flammable litter and decrease the chances of damaging *crown fires. See ground fire, surface fire.*

conventional-tillage farming Crop cultivation method in which a planting surface is made by plowing land, breaking up the exposed soil, and then smoothing the surface. Compare *conservation-tillage farming.*

convergent plate boundary Area where the earth's lithospheric plates are pushed together. See subduction zone. *Compare divergent plate boundary, transform fault.*

coral reef Formation produced by massive colonies containing billions of tiny coral animals, called polyps, that secrete a stony substance (calcium carbonate) around themselves for protection. When the corals die, their empty outer skeletons form layers and cause the reef to grow. Coral reefs are found in the coastal zones of warm tropical and subtropical oceans.

core Inner zone of the earth. It consists of a solid inner core and a liquid outer core. Compare *crust, mantle.*

corrective feedback loop See *negative feedback loop.*

cost–benefit analysis A comparison of estimated costs and benefits of actions such as implementing a pollution control regulation, building a dam on a river, or preserving an area of forest.

critical mass Amount of fissionable nuclei needed to sustain a nuclear fission chain reaction.

crop rotation Planting a field, or an area of a field, with different crops from year to year to reduce soil nutrient depletion. A plant such as corn, tobacco, or cotton, which removes large amounts of nitrogen from the soil, is planted one year. The next year a legume such as soybeans, which adds nitrogen to the soil, is planted.

crown fire Extremely hot forest fire that burns ground vegetation and treetops. Compare *controlled burning, ground fire, surface fire.*

crude birth rate Annual number of live births per 1,000 people in the population of a geographic area at the midpoint of a given year. Compare *crude death rate.*

crude death rate Annual number of deaths per 1,000 people in the population of a geographic area at the midpoint of a given year. Compare *crude birth rate.*

crude oil Gooey liquid consisting mostly of hydrocarbon compounds and small amounts of compounds containing oxygen, sulfur, and nitrogen. Extracted from underground accumulations, it is sent to oil refineries, where it is converted to heating oil, diesel fuel, gasoline, tar, and other materials.

crust Solid outer zone of the earth. It consists of oceanic crust and continental crust. Compare *core, mantle.*

cultural carrying capacity The limit on population growth that would allow most people in an area or the world to live in reasonable comfort and freedom without impairing the ability of the planet to sustain future generations. Compare *carrying capacity.*

cultural eutrophication Overnourishment of aquatic ecosystems with plant nutrients (mostly nitrates and phosphates) because of human activities such as agriculture, urbanization, and discharges from industrial plants and sewage treatment plants. See *eutrophication.*

culture Whole of a society's knowledge, beliefs, technology, and practices.

currents See *ocean currents*.

dam A structure built across a river to control the river's flow or to create a reservoir. See *reservoir.*

data Factual information collected by scientists.

DDT Dichlorodiphenyltrichloroethane, a chlorinated hydrocarbon that has been widely used as an insecticide but is now banned in some countries.

death rate See *crude death rate.*

debt-for-nature swap Agreement in which a certain amount of foreign debt is canceled in exchange for local currency investments that will improve natural resource management or protect certain areas in the debtor country from environmentally harmful development.

deciduous plants Trees, such as oaks and maples, and other plants that survive during dry or cold seasons by shedding their leaves. Compare *coniferous trees, succulent plants.*

decomposer Organism that digests parts of dead organisms, and cast-off fragments and wastes of living organisms by breaking down the complex organic molecules in those materials into simpler inorganic compounds and then absorbing the soluble nutrients. Producers return most of these chemicals to the soil and water for reuse. Decomposers consist of various bacteria and fungi. Compare *consumer, detritivore, producer.*

defendant The party in a court case being charged with creating a harm. See *plaintiff* and *civil suit.*

deforestation Removal of trees from a forested area.

degree of urbanization Percentage of the population in the world, or in a country, living in urban areas. Compare *urban growth.*

democracy Government by the people through their elected officials and appointed representatives. In a *constitutional democracy,* a constitution provides the basis of government authority and puts restraints on government power through free elections and freely expressed public opinion.

demographic transition Hypothesis that countries, as they become industrialized, have declines in death rates followed by declines in birth rates.

density Mass per unit volume.

depletion time The time it takes to use a certain fraction (usually 80%) of the known or estimated supply of a nonrenewable resource at an assumed rate of use. Finding and extracting the remaining 20% usually costs more than it is worth.

desalination Purification of salt water or brackish (slightly salty) water by removal of dissolved salts.

desert Biome in which evaporation exceeds precipitation and the average amount of precipitation is less than 25 centimeters (10 inches) per year. Such areas have little vegetation or have widely spaced, mostly low vegetation. Compare *forest, grassland.*

desertification Conversion of rangeland, rain-fed cropland, or irrigated cropland to desertlike land, with a drop in agricultural productivity of 10% or more. It usually is caused by a combination of overgrazing, soil erosion, prolonged drought, and climate change.

detritivore Consumer organism that feeds on detritus, parts of dead organisms, and cast-off fragments and wastes of living organisms. Examples include earthworms, termites, and crabs. Compare *decomposer.*

detritus Parts of dead organisms and cast-off fragments and wastes of living organisms.

detritus feeder See *detritivore.*

deuterium (D; hydrogen-2) Isotope of the element hydrogen, with a nucleus containing one proton and one neutron and a mass number of 2.

developed country See *more-developed country*.

developing country See *less-developed country*.

dieback Sharp reduction in the population of a species when its numbers exceed the carrying capacity of its habitat. See *carrying capacity.*

differential reproduction Phenomenon in which individuals with adaptive genetic traits produce more living offspring than do individuals without such traits. See *natural selection.*

dioxins Family of 75 chlorinated hydrocarbon compounds formed as unwanted by-products in chemical reactions involving chlorine and hydrocarbons, usually at high temperatures.

discount rate An estimate of a resource's future economic value compared to its present value; based on the idea that having something today may be worth more than it will be in the future.

dissolved oxygen (DO) content Amount of oxygen gas (O_2) dissolved in a given volume of water at a particular temperature and pressure, often expressed as a concentration in parts of oxygen per million parts of water.

disturbance An event that disrupts an ecosystem or community. Examples of *natural disturbances* include fires, hurricanes, tornadoes, droughts, and floods. Examples of *human-caused disturbances* include deforestation, overgrazing, and plowing.

divergent plate boundary Area where the earth's lithospheric plates move apart in opposite directions. Compare *convergent plate boundary, transform fault.*

DNA (deoxyribonucleic acid) Large molecules in the cells of living organisms that carry genetic information.

domesticated species Wild species tamed or genetically altered by crossbreeding for use by humans for food (cattle, sheep, and food crops), as pets (dogs and cats), or for enjoyment (animals in zoos and plants in botanical gardens). Compare *wild species.*

dose Amount of a potentially harmful substance an individual ingests, inhales, or absorbs through the skin. Compare *response. See dose-response curve, median lethal dose.*

dose-response curve Plot of data showing the effects of various doses of a toxic agent on a group of test organisms. See *dose, median lethal dose, response.*

doubling time Time it takes (usually in years) for the quantity of something growing exponentially to double. It can be calculated by dividing the annual percentage growth rate into 70.

drainage basin See *watershed.*

drift-net fishing Catching fish in huge nets that drift in the water.

drought Condition in which an area does not get enough water because of lower-than-normal precipitation or higher-than-normal temperatures that increase evaporation.

earthquake Shaking of the ground resulting from the fracturing and displacement of subsurface rock, which produces a fault, or from subsequent movement along the fault.

ecological diversity The variety of forests, deserts, grasslands, oceans, streams, lakes, and other biological communities interacting with one another and with their nonliving environment. See *biodiversity.* Compare *functional diversity, genetic diversity, species diversity.*

ecological footprint Amount of biologically productive land and water needed to supply a population with the renewable resources it uses and to absorb or dispose of the wastes from such resource use. It is a measure of the average environmental impact of populations in different countries and areas. See *per capita ecological footprint.*

ecological niche Total way of life or role of a species in an ecosystem. It includes all physical, chemical, and biological conditions that a species needs to live and reproduce in an ecosystem. See *fundamental niche, realized niche*.

ecological restoration Deliberate alteration of a degraded habitat or ecosystem to restore as much of its ecological structure and function as possible.

ecological succession Process in which communities of plant and animal species in a particular area are replaced over time by a series of different and often more complex communities. See *primary ecological succession, secondary ecological succession.*

ecological tipping point Point at which an environmental problem reaches a threshold level, which causes an often irreversible shift in the behavior of a natural system.

ecologist Biological scientist who studies relationships between living organisms and their environment.

ecology Biological science that studies the relationships between living organisms and their environment; study of the structure and functions of nature.

economic depletion Exhaustion of 80% of the estimated supply of a nonrenewable resource. Finding, extracting, and processing the remaining 20% usually costs more than it is worth. May also apply to the depletion of a renewable resource, such as a fish or tree species.

economic development Improvement of human living standards by economic growth. Compare *economic growth, environmentally sustainable economic development.*

economic growth Increase in the capacity to provide people with goods and services; an increase in gross domestic product (GDP). Compare *economic development, environmentally sustainable economic development.* See *gross domestic product.*

economic resources Natural resources, capital goods, and labor used in an economy to produce material goods and services. See *natural resources.*

economic system Method that a group of people uses to choose which goods and services to produce, how to produce them, how much to produce, and how to distribute them to people.

economy System of production, distribution, and consumption of economic goods.

ecosphere See *biosphere.*

ecosystem One or more communities of different species interacting with one another and with the chemical and physical factors making up their nonliving environment.

ecosystem services Natural services or natural capital that support life on the earth and are essential to the quality of human life and the functioning of the world's economies. Examples are the chemical cycles, natural pest control, and natural purification of air and water. See *natural resources.*

electromagnetic radiation Forms of kinetic energy traveling as electromagnetic waves. Examples include radio waves, TV waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays. Compare *ionizing radiation, nonionizing radiation.*

electron (e) Tiny particle moving around outside the nucleus of an atom. Each electron has one unit of negative charge and almost no mass. Compare *neutron, proton.*

element Chemical, such as hydrogen (H), iron (Fe), sodium (Na), carbon (C), nitrogen (N), or oxygen (O), whose distinctly different atoms serve as the basic building blocks of all matter. Two or more elements combine to form the compounds that make up most of the world's matter. Compare *compound.*

elevation Distance above sea level.

emigration Movement of people out of a specific geographic area. Compare *immigration, migration*.

endangered species Wild species with so few individual survivors that the species could soon become extinct in all or most of its natural range. Compare *threatened species.*

endemic species Species that is found in only one area. Such species are especially vulnerable to extinction.

energy Capacity to do work by performing mechanical, physical, chemical, or electrical tasks or to cause a heat transfer between two objects at different temperatures.

energy conservation Reducing or eliminating the unnecessary waste of energy.

energy efficiency Percentage of the total energy input that does useful work and is not converted into low-quality, generally useless heat in an energy conversion system or process. See *energy quality, net energy.* Compare *material efficiency.*

energy productivity See *energy efficiency.*

energy quality Ability of a form of energy to do useful work. High-temperature heat and the chemical energy in fossil fuels and nuclear fuels are concentrated high-quality energy. Low-quality energy such as low-temperature heat is dispersed or diluted and cannot do much useful work. See *high-quality energy, low-quality energy.*

environment All external conditions, factors, matter, and energy, living and nonliving, that affect any living organism or other specified system.

environmental degradation Depletion or destruction of a potentially renewable resource such as soil, grassland, forest, or wildlife that is used faster than it is naturally replenished. If such use continues, the resource becomes nonrenewable (on a human time scale) or nonexistent (extinct). See also *sustainable yield.*

environmental ethics Human beliefs about what is right or wrong with how we treat the environment.

environmentalism Social movement dedicated to protecting the earth's life support systems for us and other species.

environmentalist Person who is concerned about the impacts of human activities on the environment.

environmental justice Fair treatment and meaningful involvement of all people, regardless of race, color, sex, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.

environmentally sustainable economic development Development that meets the basic needs of the current generations of humans and other species without preventing future generations of humans and other species from meeting their basic needs. It is the economic component of an *environmentally sustainable society.* Compare *economic development, economic growth.*

environmentally sustainable society Society that meets the current and future needs of its people for basic resources in a just and equitable manner without compromising the ability of future generations of humans and other species from meeting their basic needs.

environmental movement Citizens organized to demand that political leaders enact laws and develop policies to curtail pollution, clean up polluted environments, and protect unspoiled areas from environmental degradation.

environmental policy Laws, rules, and regulations related to an environmental problem that are developed, implemented, and enforced by a particular government body or agency.

environmental resistance All of the limiting factors that act together to limit the growth of a population. See *biotic potential, limiting factor.*

environmental revolution Cultural change that includes halting population growth and altering lifestyles, political and economic systems, and the way we treat the environment with the goal of living more sustainably. It requires working with the rest of nature by learning more about how nature sustains itself.

environmental science Interdisciplinary study that uses information and ideas from the physical sciences (such as biology, chemistry, and geology) with those from the social sciences and humanities (such as economics, politics, and ethics) to learn how nature works, how we interact with the environment, and how we can to help deal with environmental problems.

environmental scientist Scientist who uses information from the physical sciences and social sciences to understand how the earth works, learn how humans interact with the earth, and develop solutions to environmental problems. See *environmental science.*

environmental wisdom worldview Worldview holding that humans are part of and totally dependent on nature and that nature exists for all species, not just for us. Our success depends on learning how the earth sustains itself and integrating such environmental wisdom into the ways we think and act. Compare *frontier worldview, planetary management worldview, stewardship worldview.*

environmental worldview Set of assumptions and beliefs about how people think the world works, what they think their role in the world should be, and what they believe is right and wrong environmental behavior (environmental ethics). See *environmental wisdom worldview, frontier worldview, planetary management worldview, stewardship worldview.*

EPA U.S. Environmental Protection Agency; responsible for managing federal efforts to control air and water pollution, radiation and pesticide hazards, environmental research, hazardous waste, and solid waste disposal.

epidemiology Study of the patterns of disease or other harmful effects from exposure to toxins and diseases caused by pathogens within defined groups of people to find out why some people get sick and some do not.

epiphyte Plant that uses its roots to attach itself to branches high in trees, especially in tropical forests.

erosion Process or group of processes by which loose or consolidated earth materials, especially topsoil, are dissolved, loosened, or worn away and removed from one place and deposited in another. See *weathering.*

estuary Partially enclosed coastal area at the mouth of a river where its freshwater, carrying fertile silt and runoff from the land, mixes with salty seawater.

eukaryotic cell Cell that is surrounded by a membrane and has a distinct nucleus. Compare *prokaryotic cell.*

euphotic zone Upper layer of a body of water through which sunlight can penetrate and support photosynthesis.

eutrophication Physical, chemical, and biological changes that take place after a lake, estuary, or slow-flowing stream receives inputs of plant nutrients—mostly nitrates and phosphates—from natural erosion and runoff from the surrounding land basin. See *cultural eutrophication.*

eutrophic lake Lake with a large or excessive supply of plant nutrients, mostly nitrates and phosphates. Compare *mesotrophic lake, oligotrophic lake.*

evaporation Conversion of a liquid into a gas.

evergreen plants Plants that keep some of their leaves or needles throughout the year. Examples include cone-bearing trees (conifers) such as firs, spruces, pines, redwoods, and sequoias. Compare *deciduous plants, succulent plants.*

evolution See *biological evolution.*

exhaustible resource See *nonrenewable resource.*

exotic species See *nonnative species.*

experiment Procedure a scientist uses to study some phenomenon under known conditions. Scientists conduct some experiments in the laboratory and others in nature. The resulting scientific data or facts must be verified or confirmed by repeated observations and measurements, ideally by several different investigators.

exponential growth Growth in which some quantity, such as population size or economic output, increases at a constant rate per unit of time. An example is the growth sequence 2, 4, 8, 16, 32, 64, and so on, which increases by 100% at each interval. When the increase in quantity over time is plotted, this type of growth yields a curve shaped like the letter J. Compare *linear growth.*

external benefit Beneficial social effect of producing and using an economic good that is not included in the market price of the good. Compare *external cost, full cost.*

external cost Harmful environmental, economic, or social effect of producing and using an economic good that is not included in the market price of the good. Compare *external benefit, full cost, internal cost.*

extinction See *biological extinction.*

extinction rate Percentage or number of species that go extinct within a certain period of time such as a year.

family planning Providing information, clinical services, and contraceptives to help people choose the number and spacing of children they want to have.

famine Widespread malnutrition and starvation in a particular area because of a shortage of food, usually caused by drought, war, flood, earthquake, or other catastrophic events that disrupt food production and distribution.

feedback Any process that increases (positive feedback) or decreases (negative feedback) a change to a system.

feedback loop Occurs when an output of matter, energy, or information is fed back into the system as an input and leads to changes in that system. See *positive feedback loop* and *negative feedback loop.*

feedlot Confined outdoor or indoor space used to raise hundreds to thousands of domesticated livestock.

fermentation See *anaerobic respiration.*

fertility rate Number of children born to an average woman in a population during her lifetime. Compare *replacement-level fertility.*

fertilizer Substance that adds inorganic or organic plant nutrients to soil and improves its ability to grow crops, trees, or other vegetation. See *commercial inorganic fertilizer, organic fertilizer.*

first law of thermodynamics Whenever energy is converted from one form to another in a physical or chemical change, no energy is created or destroyed, but energy can be changed from one form to another; you cannot get more energy out of something than you put in; in terms of energy quantity, you cannot get something for nothing. This law does not apply to nuclear changes, in which large amounts of energy can be produced from small amounts of matter. See *second law of thermodynamics.*

fishery Concentration of particular aquatic species suitable for commercial harvesting in a given ocean area or inland body of water.

fish farming See *aquaculture.*

fishprint Area of ocean needed to sustain the consumption of an average person, a nation, or the world. Compare *ecological footprint.*

fissionable isotope Isotope that can split apart when hit by a neutron at the right speed and thus undergo nuclear fission. Examples include uranium-235 and plutonium-239.

floodplain Flat valley floor next to a stream channel. For legal purposes, the term often applies to any low area that has the potential for flooding, including certain coastal areas.

flows See *throughputs.*

food chain Series of organisms in which each eats or decomposes the preceding one. Compare *food web.*

food insecurity Condition under which people live with chronic hunger and malnutrition that threatens their ability to lead healthy and productive lives. Compare *food security.*

food security Condition under which every person in a given area has daily access to enough nutritious food to have an active and healthy life. Compare *food insecurity.*

food web Complex network of many interconnected food chains and feeding relationships. Compare *food chain.*

forest Biome with enough average annual precipitation to support the growth of tree species and smaller forms of vegetation. Compare *desert, grassland.*

fossil fuel Products of partial or complete decomposition of plants and animals; occurs as crude oil, coal, natural gas, or heavy oils as a result of exposure to heat and pressure in he earth's crust over millions of years. See *coal, crude oil, natural gas.*

fossils Skeletons, bones, shells, body parts, leaves, seeds, or impressions of such items that provide recognizable evidence of organisms that lived long ago.

foundation species Species that plays a major role in shaping a community by creating and enhancing a habitat that benefits other species. Compare *indicator species, keystone species, native species, nonnative species.*

free-access resource See *open access renewable resource.*

freons See *chlorofluorocarbons.*

freshwater life zones Aquatic systems where water with a dissolved salt concentration of less than 1% by volume accumulates on or flows through the surfaces of terrestrial biomes. Examples include *standing* (lentic) bodies of freshwater such as lakes, ponds, and inland wetlands and *flowing* (lotic) systems such as streams and rivers. Compare *biome.*

front The boundary between two air masses with different temperatures and densities. See *cold front, warm front.*

frontier science See *tentative science.*

frontier worldview View held by European colonists settling North America in the 1600s that the continent had vast resources and was a wilderness to be conquered by settlers clearing and planting land.

full cost Cost of a good when its internal costs and its estimated short- and long-term external costs are included in its market price. Compare *external cost, internal cost.*

functional diversity Biological and chemical processes or functions such as energy flow and matter cycling needed for the survival of species and biological communities. See *biodiversity, ecological diversity, genetic diversity, species diversity.*

fungicide Chemical that kills fungi.

game species Type of wild animal that people hunt or fish as a food source or for sport or recreation.

gamma ray Form of ionizing electromagnetic radiation with a high energy content emitted by some radioisotopes. It readily penetrates body tissues. See *alpha particle, beta particle.*

GDP See *gross domestic product.*

gene mutation See *mutation.*

gene pool Sum total of all genes found in the individuals of the population of a particular species.

generalist species Species with a broad ecological niche. They can live in many different places, eat a variety of foods, and tolerate a wide range of environmental conditions. Examples include flies, cockroaches, mice, rats, and humans. Compare *specialist species.*

genes Coded units of information about specific traits that are passed from parents to offspring during reproduction. They consist of segments of DNA molecules found in chromosomes.

gene splicing See *genetic engineering.*

genetic adaptation Changes in the genetic makeup of organisms of a species that allow the species to reproduce and gain a competitive advantage under changed environmental conditions. See *differential reproduction, evolution, mutation, natural selection.*

genetically modified organism (GMO) Organism whose genetic makeup has been altered by genetic engineering.

genetic diversity Variability in the genetic makeup among individuals within a single species. See *biodiversity.* Compare *ecological diversity, functional diversity, species diversity.*

genetic engineering Insertion of an alien gene into an organism to give it a beneficial genetic trait. Compare *artificial selection, natural selection.*

genuine progress indicator (GPI) GDP plus the estimated value of beneficial transactions that meet basic needs, but in which no money changes hands, minus the estimated harmful environmental, health, and social costs of all transactions. Compare *gross domestic product*.

geographic isolation Separation of populations of a species into different areas for long periods of time.

geology Study of the earth's dynamic history. Geologists study and analyze rocks and the features and processes of the earth's interior and surface.

geosphere Earth's intensely hot core, thick mantle composed mostly of rock, and thin outer crust that contains most of the earth's rock, soil, and sediment. Compare *atmosphere, biosphere, hydrosphere.*

geothermal energy Heat transferred from the earth's underground concentrations of dry steam (steam with no water droplets), wet steam (a mixture of steam and water droplets), or hot water trapped in fractured or porous rock.

global climate change Broad term referring to long-term changes in any aspects of the earth's climate, especially temperature and precipitation. Compare *weather.*

global warming Warming of the earth's lower atmosphere (troposphere) because of increases in the concentrations of one or more greenhouse gases. It can result in climate change that can last for decades to thousands of years. See *greenhouse effect, greenhouse gases, natural greenhouse effect.*

GMO See *genetically modified organism.*

GPI See *genuine progress indicator*.

GPP See *gross primary productivity.*

grassland Biome found in regions where enough annual average precipitation to support the growth of grass and small plants but not enough to support large stands of trees. Compare *desert, forest.*

greenhouse effect Natural effect that releases heat in the atmosphere near the earth's surface. Water vapor, carbon dioxide, ozone, and other gases in the lower atmosphere (troposphere) absorb some of the infrared radiation (heat) radiated by the earth's surface. Their molecules vibrate and transform the absorbed energy into longer-wavelength infrared radiation in the troposphere. If the atmospheric concentrations of these greenhouse gases increase and other natural processes do not remove them, the average temperature of the lower atmosphere will increase. Compare *global warming.*

greenhouse gases Gases in the earth's lower atmosphere (troposphere) that cause the greenhouse effect. Examples include carbon dioxide, chlorofluorocarbons, ozone, methane, water vapor, and nitrous oxide.

green manure Freshly cut or still-growing green vegetation that is plowed into the soil to increase the organic matter and humus available to support crop growth. Compare *animal manure.*

green revolution Popular term for the introduction of scientifically bred or selected varieties of grain (rice, wheat, maize) that, with adequate inputs of fertilizer and water, can greatly increase crop yields.

greenwashing Deceptive practice that some businesses use to spin environmentally harmful products as green, clean, or environmentally beneficial.

gross domestic product (GDP) Annual market value of all goods and services produced by all firms and organizations, foreign and domestic, operating within a country. See *per capita GDP.* Compare genuine progress indicator (GPI).

gross primary productivity (GPP) Rate at which an ecosystem's producers capture and store a given amount of chemical energy as biomass in a given length of time. Compare *net primary productivity.*

ground fire Fire that burns decayed leaves or peat deep below the ground's surface. Compare *crown fire, surface fire.*

groundwater Water that sinks into the soil and is stored in slowly flowing and slowly renewed underground reservoirs called *aquifers; underground water in the zone of saturation, below the water table. Compare runoff, surface water.*

habitat Place or type of place where an organism or population of organisms lives. Compare *ecological niche.*

habitat fragmentation Breakup of a habitat into smaller pieces, usually as a result of human activities.

hazard Something that can cause injury, disease, economic loss, or environmental damage. See also *risk.*

hazardous chemical Chemical that can cause harm because it is flammable or explosive, can irritate or damage the skin or lungs (such as strong acidic or alkaline substances), or can cause allergic reactions of the immune system (allergens). See also *toxic chemical.*

hazardous waste Any solid, liquid, or containerized gas that can catch fire easily, is corrosive to skin tissue or metals, is unstable and can explode or release toxic fumes, or has harmful concentrations of one or more toxic materials that can leach out. These substances are usually byproducts of manufacturing processes. See also *toxic waste.*

heat Total kinetic energy of all randomly moving atoms, ions, or molecules within a given substance, excluding the overall motion of the whole object. Heat always flows spontaneously from a warmer sample of matter to a colder sample of matter. This is one way to state the *second law of thermodynamics. Compare temperature.*

herbicide Chemical that kills a plant or inhibits its growth.

herbivore Plant-eating organism. Examples include deer, sheep, grasshoppers, and zooplankton. Compare *carnivore, omnivore.*

heterotroph See *consumer.*

high Air mass with a high pressure. Compare *low.*

high-grade ore Ore containing a large amount of a desired mineral. Compare *low-grade ore.*

high-input agriculture See *industrialized agriculture.*

high-quality energy Energy that is concentrated and has great ability to perform useful work. Examples include high-temperature heat and the energy in electricity, coal, oil, gasoline, sunlight, and nuclei of uranium-235. Compare *low-quality energy.*

high-quality matter Matter that is concentrated and contains a high concentration of a useful resource. Compare *low-quality matter.*

high-throughput economy Economic system in most advanced industrialized countries, in which ever-increasing economic growth is sustained by maximizing the rate at which matter and energy resources are used, with little emphasis on pollution prevention, recycling, reuse, reduction of unnecessary waste, and other forms of resource conservation. Compare *low-throughput economy, matter-recycling economy.*

high-waste economy See *high-throughput economy.*

HIPPCO Acronym used by conservation biologists for the six most important secondary causes of premature extinction: **H**abitat destruction, degradation, and fragmentation; **I**nvasive (nonnative) species; **P**opulation growth (too many people consuming too many resources); **P**ollution; **C**limate change; and **O**verexploitation.

host Plant or animal on which a parasite feeds.

human capital People's physical and mental talents that provide labor, innovation, culture, and organization. Compare *manufactured capital, natural capital.*

human resources See *human capital.*

humus Slightly soluble residue of undigested or partially decomposed organic material in topsoil. This material helps retain water and water-soluble nutrients, which can be taken up by plant roots.

hunger See *chronic undernutrition.*

hunter–gatherers People who get their food by gathering edible wild plants and other materials and by hunting wild animals and catching fish.

hydrocarbon Organic compound made of hydrogen and carbon atoms. The simplest hydrocarbon is methane (CH_4), the major component of natural gas.

hydroelectric power plant Structure in which the energy of falling or flowing water spins a turbine generator to produce electricity.

hydrologic cycle Biogeochemical cycle that collects, purifies, and distributes the earth's fixed supply of water from the environment to living organisms and then back to the environment.

hydroponics Form of agriculture in which farmers grow plants by exposing their roots to a nutrient-rich water solution instead of soil.

hydropower Electrical energy produced by falling or flowing water. See *hydroelectric power plant.*

hydrosphere Earth's *liquid water* (oceans, lakes, other bodies of surface water, and underground water), *frozen water* (polar ice caps, floating ice caps, and ice in soil, known as permafrost), and *water vapor* in the atmosphere. See also *hydrologic cycle.* Compare *atmosphere, biosphere, geosphere.*

hypereutrophic Result of excessive inputs of nutrients in a lake. See *cultural eutrophication.*

igneous rock Rock formed when molten rock material (magma) wells up from the earth's interior, cools, and solidifies into rock masses. Compare *metamorphic rock, sedimentary rock.* See *rock cycle.*

immature community Community at an early stage of ecological succession. It usually has a low number of species and ecological niches and cannot capture and use energy and cycle critical nutrients as efficiently as more complex, mature communities. Compare *mature community.*

immigrant species See *nonnative species.*

immigration Migration of people into a country or area to take up permanent residence.

indicator species Species whose decline serves as early warnings that a community or ecosystem is being degraded. Compare *foundation species, keystone species, native species, nonnative species.*

industrialized agriculture Production of large quantities of crops and livestock for domestic and foreign sale; involves use of large inputs of energy from fossil fuels (especially oil and natural gas), water, fertilizer, and pesticides. Compare *subsistence farming.*

industrial smog Type of air pollution consisting mostly of a mixture of sulfur dioxide, suspended droplets of sulfuric acid formed from some of the sulfur dioxide, and suspended solid particles. Compare *photochemical smog.*

industrial solid waste Solid waste produced by mines, factories, refineries, food growers, and businesses that supply people with goods and services. Compare *municipal solid waste.*

infant mortality rate Number of babies out of every 1,000 born each year who die before their first birthday.

infectious disease Disease caused when a pathogen such as a bacterium, virus, or parasite invades the body and multiplies in its cells and tissues. Examples are flu, HIV, malaria, tuberculosis, and measles. See *transmissible disease.* Compare *nontransmissible disease.*

infiltration Downward movement of water through soil.

inherent value See *intrinsic value.*

inland wetland Land away from the coast, such as a swamp, marsh, or bog, that is covered all or part of the time with freshwater. Compare *coastal wetland.*

inorganic compounds All compounds not classified as organic compounds. See *organic compounds.*

inorganic fertilizer See *commercial inorganic fertilizer.*

input Matter, energy, or information entering a system. Compare *output, throughput.*

input pollution control See *pollution prevention.*

insecticide Chemical that kills insects.

instrumental value Value of an organism, species, ecosystem, or the earth's biodiversity based on its usefulness to humans. Compare *intrinsic value.*

integrated pest management (IPM) Combined use of biological, chemical, and cultivation methods in proper sequence and timing to keep the size of a pest population below the level that causes economically unacceptable loss of a crop or livestock animal.

integrated waste management Variety of strategies for both waste reduction and waste management designed to deal with the solid wastes we produce.

intercropping Growing two or more different crops at the same time on a plot. For example, a carbohydrate-rich grain that depletes soil nitrogen and a protein-rich legume that adds nitrogen to the soil may be intercropped. Compare *monoculture, polyculture.*

internal cost Direct cost paid by the producer and the buyer of an economic good. Compare *external benefit, external cost, full cost.*

interspecific competition Attempts by members of two or more species to use the same limited resources in an ecosystem. See *competition, intraspecific competition.*

intertidal zone The area of shoreline between low and high tides.

intraspecific competition Attempts by two or more organisms of a single species to use the same limited resources in an ecosystem. See *competition, interspecific competition.*

intrinsic rate of increase (*r*) Rate at which a population could grow if it had unlimited resources. Compare *environmental resistance.*

intrinsic value Value of an organism, species, ecosystem, or the earth's biodiversity based on its existence, regardless of whether it has any usefulness to humans. Compare *instrumental value.*

invasive species See *nonnative species.*

inversion See *temperature inversion.*

invertebrates Animals that have no backbones. Compare *vertebrates.*

ion Atom or group of atoms with one or more positive (+) or negative (–) electrical charges. Examples are Na^+ and Cl^-. Compare *atom, molecule.*

ionizing radiation Fast-moving alpha or beta particles or high-energy radiation (gamma rays) emitted by radioisotopes. They have enough energy to dislodge one or more electrons from atoms they hit, thereby forming charged ions in tissue that can react with and damage living tissue. Compare *nonionizing radiation.*

IPM See *integrated pest management*.

isotopes Two or more forms of a chemical element that have the same number of protons but different mass numbers because they have different numbers of neutrons in their nuclei.

J-shaped curve Curve with a shape similar to that of the letter J; can represent prolonged exponential growth. See *exponential growth.*

junk science See *unreliable science.*

kerogen Solid, waxy mixture of hydrocarbons found in oil shale rock. Heating the rock to high temperatures causes the kerogen to vaporize. The vapor is condensed, purified, and then sent to a refinery to produce gasoline, heating oil, and other products. See also *oil shale, shale oil.*

keystone species Species that play roles affecting many other organisms in an ecosystem. Compare *foundation species, indicator species, native species, nonnative species.*

kilocalorie (kcal) Unit of energy equal to 1,000 calories. See *calorie.*

kilowatt (kW) Unit of electrical power equal to 1,000 watts. See *watt.*

kinetic energy Energy that matter has because of its mass and speed, or velocity. Compare *potential energy.*

lake Large natural body of standing freshwater formed when water from precipitation, land runoff, or groundwater flow fills a depression in the earth created by glaciation, earth movement, volcanic activity, or a giant meteorite. See *eutrophic lake, mesotrophic lake, oligotrophic lake.*

land degradation Decrease in the ability of land to support crops, livestock, or wild species in the future as a result of natural or human-induced processes.

landfill See *sanitary landfill.*

land-use planning Planning to determine the best present and future uses of each parcel of land.

latitude Distance from the equator. Compare *altitude.*

law of conservation of energy See *first law of thermodynamics.*

law of conservation of matter In any physical or chemical change, matter is neither created nor destroyed but merely changed from one form to another; in physical and chemical changes, existing atoms are rearranged into different spatial patterns (physical changes) or different combinations (chemical changes).

law of nature See *scientific law.*

law of tolerance Existence, abundance, and distribution of a species in an ecosystem are determined by whether the levels of one or more physical or chemical factors fall within the range tolerated by the species. See *threshold effect.*

LD50 See *median lethal dose.*

LDC See *less-developed country.* Compare more-developed country.

leaching Process in which various chemicals in upper layers of soil are dissolved and carried to lower layers and, in some cases, to groundwater.

less-developed country Country that has low to moderate industrialization and low to moderate per capita GDP. Most are located in Africa, Asia, and Latin America. Compare *more-developed country.*

life-cycle cost Initial cost plus lifetime operating costs of an economic good. Compare *full cost.*

life expectancy Average number of years a newborn infant can be expected to live.

limiting factor Single factor that limits the growth, abundance, or distribution of the population of a species in an ecosystem. See *limiting factor principle.*

limiting factor principle Too much or too little of any abiotic factor can limit or prevent growth of a population of a species in an ecosystem, even if all other factors are at or near the optimal range of tolerance for the species.

linear growth Growth in which a quantity increases by some fixed amount during each unit of time. An example is growth that increases by 2 units in the sequence 2, 4, 6, 8, 10, and so on. Compare *exponential growth.*

liquefied natural gas (LNG) Natural gas converted to liquid form by cooling it to a very low temperature.

liquefied petroleum gas (LPG) Mixture of liquefied propane (C_3H_8) and butane (C_4H_{10}) gas removed from natural gas and used as a fuel.

lithosphere Outer shell of the earth, composed of the crust and the rigid, outermost part of the mantle outside the asthenosphere; material found in the earth's plates. See *crust, geosphere, mantle.*

LNG See *liquefied natural gas*.

lobbying Process in which individuals or groups use public pressure, personal contacts, and political action to persuade legislators to vote or act in their favor.

logistic growth Pattern in which exponential population growth occurs when the population is small, and population growth decreases steadily with time as the population approaches the carrying capacity. See *S-shaped curve.*

low Air mass with a low pressure. Compare *high.*

low-grade ore Ore containing a small amount of a desired mineral. Compare *high-grade ore.*

low-input agriculture See *sustainable agriculture.*

low-quality energy Energy that is dispersed and has little ability to do useful work. An example is low-temperature heat. Compare *high-quality energy.*

low-quality matter Matter that is dilute or dispersed or contains a low concentration of a useful resource. Compare *high-quality matter.*

low-throughput economy Economy based on working with nature by recycling and reusing discarded matter; preventing pollution; conserving matter and energy resources by reducing unnecessary waste and use; and building things that are easy to recycle, reuse, and repair. Compare *high-throughput economy, matter-recycling economy.*

low-waste economy See *low-throughput economy.*

LPG See *liquefied petroleum gas.*

magma Molten rock below the earth's surface.

malnutrition See *chronic malnutrition.*

mangrove swamps Swamps found on the coastlines in warm tropical climates. They are dominated by mangrove trees, any of about 55 species of trees and shrubs that can live partly submerged in the salty environment of coastal swamps.

mantle Zone of the earth's interior between its core and its crust. Compare *core, crust.* See *geosphere, lithosphere.*

manufactured capital See *manufactured resources.*

manufactured inorganic fertilizer See *comercial inorganic fertilizer.*

manufactured resources Manufactured items made from natural resources and used to produce and distribute economic goods and services bought by consumers. They include tools, machinery, equipment, factory buildings, and transportation and distribution facilities. Compare *human resources, natural resources.*

manure See *animal manure, green manure.*

marine life zone See *saltwater life zone*.

mass Amount of material in an object.

mass extinction Catastrophic, widespread, often global event in which major groups of species are wiped out over a short time compared with normal (background) extinctions. Compare *background extinction.*

mass number Sum of the number of neutrons (n) and the number of protons (p) in the nucleus of an atom. It gives the approximate mass of that atom. Compare *atomic number.*

mass transit Buses, trains, trolleys, and other forms of transportation that carry large numbers of people.

material efficiency Total amount of material needed to produce each unit of goods or services. Also called *resource productivity.* Compare *energy efficiency.*

matter Anything that has mass (the amount of material in an object) and takes up space. On the earth, where gravity is present, we weigh an object to determine its mass.

matter quality Measure of how useful a matter resource is, based on its availability and concentration. See *high-quality matter, low-quality matter.*

matter-recycling-and-reuse economy Economy that emphasizes recycling the maximum amount of all resources that can be recycled and reused. The goal is to allow economic growth to continue without depleting matter resources and without producing excessive pollution and environmental degradation. Compare *high-throughput economy, low-throughput economy.*

mature community Fairly stable, self-sustaining community in an advanced stage of ecological succession; usually has a diverse array of species and ecological niches; captures and uses energy and cycles critical chemicals more efficiently than simpler, immature communities. Compare *immature community.*

maximum sustainable yield See *sustainable yield.*

MDC See *more-developed country.*

median lethal dose (LD50) Amount of a toxic material per unit of body weight of test animals that kills half the test population in a certain time.

megacity City with 10 million or more people.

meltdown Melting of the highly radioactive core of a nuclear reactor.

mesotrophic lake Lake with a moderate supply of plant nutrients. Compare *eutrophic lake, oligotrophic lake.*

metabolism Ability of a living cell or organism to capture and transform matter and energy from its environment to supply its needs for survival, growth, and reproduction.

metamorphic rock Rock produced when a preexisting rock is subjected to high temperatures (which may cause it to melt partially), high pressures, chemically active fluids, or a combination of these agents. Compare *igneous rock, sedimentary rock.* See *rock cycle.*

metastasis Spread of malignant (cancerous) cells from a tumor to other parts of the body.

metropolitan area See *urban area.*

microorganisms Organisms such as bacteria that are so small that it takes a microscope to see them.

micropower systems Systems of small-scale decentralized units that generate 1–10,000 kilowatts of electricity. Examples include microturbines, fuel cells, wind turbines, and household solar-cell panels and solar-cell roofs.

migration Movement of people into and out of specific geographic areas. Compare *emigration* and *immigration.*

mineral Any naturally occurring inorganic substance found in the earth's crust as a crystalline solid. See *mineral resource.*

mineral resource Concentration of naturally occurring solid, liquid, or gaseous material in or on the earth's crust in a form and amount such that extracting and converting it into useful materials or items is currently or potentially profitable. Mineral resources are classified as *metallic* (such as iron and tin ores) or *nonmetallic* (such as fossil fuels, sand, and salt).

minimum-tillage farming See *conservation-tillage farming.*

mixture Combination of one or more elements and compounds.

model Approximate representation or simulation of a system being studied.

molecule Combination of two or more atoms of the same chemical element (such as O_2) or different chemical elements (such as H_2O) held together by chemical bonds. Compare *atom, ion.*

monoculture Cultivation of a single crop, usually on a large area of land. Compare *polyculture.*

more-developed country Country that is highly industrialized and has a high per capita GDP. Compare *less-developed country.*

mountaintop removal mining Type of surface mining that uses explosives, massive power shovels, and large machines called draglines to remove the top of a mountain and expose seams of coal underneath a mountain. Compare *area strip mining, contour strip mining.*

MSW See *municipal solid waste.*

multiple use Use of an ecosystem such as a forest for a variety of purposes such as timber harvesting, wildlife habitat, watershed protection, and recreation. Compare *sustainable yield.*

municipal solid waste (MSW) Solid materials discarded by homes and businesses in or near urban areas. See *solid waste.* Compare *industrial solid waste.*

mutagen Chemical or form of radiation that causes inheritable changes (mutations) in the DNA molecules in genes. See *carcinogen, mutation, teratogen.*

mutation Random change in DNA molecules making up genes that can alter anatomy, physiology, or behavior in offspring. See *mutagen.*

mutualism Type of species interaction in which both participating species generally benefit. Compare *commensalism.*

native species Species that normally live and thrive in a particular ecosystem. Compare *foundation species, indicator species, keystone species, nonnative species.*

natural capital Natural resources and natural services that keep us and other species alive and support our economies. See *natural resources, natural services.*

natural capital degradation See *environmental degradation*.

natural gas Underground deposits of gases consisting of 50–90% by weight methane gas (CH_4) and small amounts of heavier gaseous hydrocarbon compounds such as propane (C_3H_8) and butane (C_4H_{10}).

natural greenhouse effect See *greenhouse effect.*

natural income Renewable resources such as plants, animals, and soil provided by natural capital.

natural law See *scientific law.*

natural radioactive decay Nuclear change in which unstable nuclei of atoms spontaneously shoot out particles (usually alpha or beta particles) or energy (gamma rays) at a fixed rate.

natural rate of extinction See *background extinction.*

natural recharge Natural replenishment of an aquifer by precipitation, which percolates downward through soil and rock. See *recharge area.*

natural resources Materials such as air, water, and soil and energy in nature that are essential or useful to humans. See *natural capital.*

natural selection Process by which a particular beneficial gene (or set of genes) is reproduced in succeeding generations more than other genes. The result of natural selection is a population that contains a greater proportion of organisms better adapted to certain environmental conditions. See *adaptation, biological evolution, differential reproduction, mutation.*

natural services Processes of nature, such as purification of air and water and pest control, which support life and human economies. See *natural capital.*

negative feedback loop Feedback loop that causes a system to change in the opposite direction from which is it moving. Compare *positive feedback loop*.

nekton Strongly swimming organisms found in aquatic systems. Compare *benthos, plankton.*

net energy Total amount of useful energy available from an energy resource or energy system over its lifetime, minus the amount of energy *used* (the first energy law), *automatically wasted* (the second energy law), and *unnecessarily wasted* in finding, processing, concentrating, and transporting it to users.

net primary productivity (NPP) Rate at which all the plants in an ecosystem produce net useful chemical energy; equal to the difference between the rate at which the plants in an ecosystem produce useful chemical energy (gross primary productivity) and the rate at which they use some of that energy through cellular respiration. Compare *gross primary productivity.*

neurotoxins Chemicals that can harm the human *nervous system* (brain, spinal cord, peripheral nerves).

neutral solution Water solution containing an equal number of hydrogen ions (H^+) and hydroxide ions (OH^-); water solution with a pH of 7. Compare *acid solution, basic solution.*

neutron (n) Elementary particle in the nuclei of all atoms (except hydrogen-1). It has a relative mass of 1 and no electric charge. Compare *electron, proton.*

niche See *ecological niche.*

nitric oxide (NO) Colorless gas that forms when nitrogen and oxygen gas in air react at the high-combustion temperatures in automobile engines and coal-burning plants. Lightning and certain bacteria in soil and water also produce NO as part of the *nitrogen cycle.*

nitrogen cycle Cyclic movement of nitrogen in different chemical forms from the environment to organisms and then back to the environment.

nitrogen dioxide (NO_2) Reddish-brown gas formed when nitrogen oxide reacts with oxygen in the air.

nitrogen fixation Conversion of atmospheric nitrogen gas, by lightning, bacteria, and cyanobacteria, into forms useful to plants; it is part of the nitrogen cycle.

nitrogen oxides (NO_x) See *nitric oxide* and *nitrogen dioxide.*

noise pollution Any unwanted, disturbing, or harmful sound that impairs or interferes with hearing, causes stress, hampers concentration and work efficiency, or causes accidents.

nondegradable pollutant Material that is not broken down by natural processes. Examples include the toxic elements lead and mercury. Compare *biodegradable pollutant.*

nonionizing radiation Forms of radiant energy such as radio waves, microwaves, infrared light, and ordinary light that do not have enough energy to cause ionization of atoms in living tissue. Compare *ionizing radiation.*

nonnative species Species that migrate into an ecosystem or are deliberately or accidentally introduced into an ecosystem by humans. Compare *native species.*

nonpoint sources Broad and diffuse areas, rather than points, from which pollutants enter bodies of surface water or air. Examples include runoff of chemicals and sediments from cropland, livestock feedlots, logged forests, urban streets, parking lots, lawns, and golf courses. Compare *point source.*

nonrenewable resource Resource that exists in a fixed amount (stock) in the earth's crust and has the potential for renewal by geological, physical, and chemical processes taking place over hundreds of millions to billions of years. Examples include copper, aluminum, coal, and oil. We classify these resources as exhaustible because we are extracting and using them at a much faster rate than they are formed. Compare *renewable resource.*

nontransmissible disease Disease that is not caused by living organisms and does not spread from one person to another. Examples include most cancers, diabetes, cardiovascular disease, and malnutrition. Compare *transmissible disease.*

no-till farming See *conservation-tillage farming.*

NPP See *net primary productivity.*

nuclear change Process in which nuclei of certain isotopes spontaneously change, or are forced to change, into one or more different isotopes. The three principal types of nuclear change are natural radioactivity, nuclear fission, and nuclear fusion. Compare *chemical change, physical change.*

nuclear energy Energy released when atomic nuclei undergo a nuclear reaction such as the spontaneous emission of radioactivity, nuclear fission, or nuclear fusion.

nuclear fission Nuclear change in which the nuclei of certain isotopes with large mass numbers (such as uranium-235 and plutonium-239) are split apart into lighter nuclei when struck by a neutron. This process releases more neutrons and a large amount of energy. Compare *nuclear fusion.*

nuclear fusion Nuclear change in which two nuclei of isotopes of elements with a low mass number (such as hydrogen-2 and hydrogen-3) are forced together at extremely high temperatures until they fuse to form a heavier nucleus (such as helium-4). This process releases a large amount of energy. Compare *nuclear fission.*

nucleus Extremely tiny center of an atom, making up most of the atom's mass. It contains one or more positively charged protons and one or more neutrons with no electrical charge (except for a hydrogen-1 atom, which has one proton and no neutrons in its nucleus).

nutrient Any chemical an organism must take in to live, grow, or reproduce.

nutrient cycle See *biogeochemical cycle.*

nutrient cycling The circulation of chemicals necessary for life, from the environment (mostly from soil and water) through organisms and back to the environment.

ocean currents Mass movements of surface water produced by prevailing winds blowing over the oceans.

oil See *crude oil.*

oil reserves See proven oil reserves.

oil sand See *tar sand.*

oil shale Fine-grained rock containing various amounts of kerogen, a solid, waxy mixture of hydrocarbon compounds. Heating the rock to high temperatures converts the kerogen into a vapor that can be condensed to form a slow-flowing heavy oil called shale oil. See *kerogen, shale oil.*

old-growth forest Virgin and old, second-growth forests containing trees that are often hundreds—sometimes thousands—of years old. Examples include forests of Douglas fir, western hemlock, giant sequoia, and coastal redwoods in the western United States. Compare *second-growth forest, tree plantation.*

oligotrophic lake Lake with a low supply of plant nutrients. Compare *eutrophic lake, mesotrophic lake.*

omnivore Animal that can use both plants and other animals as food sources. Examples include pigs, rats, cockroaches, and humans. Compare *carnivore, herbivore.*

open access renewable resource Renewable resource owned by no one and available for use by anyone at little or no charge. Examples include clean air, underground water supplies, the open ocean and its fish, and the ozone layer. Compare *common property resource.*

open dump Fields or holes in the ground where garbage is deposited and sometimes covered with soil. They are rare in developed countries, but are widely used in many developing countries, especially to handle wastes from megacities. Compare *sanitary landfill.*

open-pit mining Removing minerals such as gravel, sand, and metal ores by digging them out of the earth's surface and leaving an open pit behind. Compare *area strip mining, contour strip mining, mountaintop removal, subsurface mining.*

open sea Part of an ocean that lies beyond the continental shelf. Compare *coastal zone.*

ore Part of a metal-yielding material that can be economically extracted from a mineral; typically containing two parts: the ore mineral, which contains the desired metal, and waste mineral material (gangue). See *high-grade ore, low-grade ore.*

organic agriculture Growing crops with limited or no use of synthetic pesticides and synthetic fertilizers; genetically modified crops, raising livestock without use of synthetic growth regulators and feed additives; and using organic fertilizer (manure, legumes, compost) and natural pest controls (bugs that eat harmful bugs, plants that repel bugs and environmental controls such as crop rotation). See *sustainable agriculture.*

organic compounds Compounds containing carbon atoms combined with each other and with atoms of one or more other elements such as hydrogen, oxygen, nitrogen, sulfur, phosphorus, chlorine, and fluorine. All other compounds are called *inorganic compounds.*

organic farming See *organic agriculture* and *sustainable agriculture.*

organic fertilizer Organic material such as animal manure, green manure, and compost applied to cropland as a source of plant nutrients. Compare *commercial inorganic fertilizer.*

organism Any form of life.

output Matter, energy, or information leaving a system. Compare *input, throughput.*

output pollution control See *pollution cleanup.*

overburden Layer of soil and rock overlying a mineral deposit. Surface mining removes this layer.

overfishing Harvesting so many fish of a species, especially immature individuals, that not enough breeding stock is left to replenish the species and it becomes unprofitable to harvest them.

overgrazing Destruction of vegetation when too many grazing animals feed too long on a specific area of pasture or rangeland and exceed the carrying capacity of a rangeland or pasture area.

overnutrition Diet so high in calories, saturated (animal) fats, salt, sugar, and processed foods, and so low in vegetables and fruits that the consumer runs a high risk of developing diabetes, hypertension, heart disease, and other health hazards. Compare *malnutrition, undernutrition.*

oxygen-demanding wastes Organic materials that are usually biodegraded by aerobic (oxygen-consuming) bacteria if there is enough dissolved oxygen in the water.

ozone (O_3) Colorless and highly reactive gas and a major component of photochemical smog. Also found in the ozone layer in the stratosphere. See *photochemical smog.*

ozone depletion Decrease in concentration of ozone (O_3) in the stratosphere. See *ozone layer.*

ozone layer Layer of gaseous ozone (O_3) in the stratosphere that protects life on earth by filtering out most harmful ultraviolet radiation from the sun.

PANs Peroxyacyl nitrates; group of chemicals found in photochemical smog.

parasite Consumer organism that lives on or in, and feeds on, a living plant or animal, known as the host, over an extended period. The parasite draws nourishment from and gradually weakens its host; it may or may not kill the host. See *parasitism.*

parasitism Interaction between species in which one organism, called the parasite, preys on another organism, called the host, by living on or in the host. See *host, parasite.*

particulates Also known as suspended particulate matter (SPM); variety of solid particles and liquid droplets small and light enough to remain suspended in the air for long periods. About 62% of the SPM in outdoor air comes from natural sources such as dust, wild fires, and sea salt. The remaining 38% comes from human sources such as coal-burning electric power and industrial plants, motor vehicles, plowed fields, road construction, unpaved roads, and tobacco smoke.

parts per billion (ppb) Number of parts of a chemical found in 1 billion parts of a particular gas, liquid, or solid.

parts per million (ppm) Number of parts of a chemical found in 1 million parts of a particular gas, liquid, or solid.

parts per trillion (ppt) Number of parts of a chemical found in 1 trillion parts of a particular gas, liquid, or solid.

passive solar heating system System that, without the use of mechanical devices, captures sunlight directly within a structure and converts it into low-temperature heat for space heating or for heating water for domestic use. Compare *active solar heating system.*

pasture Managed grassland or enclosed meadow that usually is planted with domesticated grasses or other forage to be grazed by livestock. Compare *feedlot.*

pathogen Living organism that can cause disease in another organism. Examples include bacteria, viruses, and parasites.

PCBs See *polychlorinated biphenyls.*

peak production Point in time when the pressure in an oil well drops and its rate of conventional crude oil production starts declining, usually a decade or so; for a group of wells or for a nation, the point at which all wells on average have passed peak production.

peer review Process of scientists reporting details of the methods and models they used, the results of their experiments, and the reasoning behind their hypotheses for other scientists working in the same field (their peers) to examine and criticize.

per capita ecological footprint Amount of biologically productive land and water needed to supply each person or population with the renewable resources they use and to absorb or dispose of the wastes from such resource use. It measures the average environmental impact of individuals or populations in different countries and areas. Compare *ecological footprint.*

per capita GDP Annual gross domestic product (GDP) of a country divided by its total population at midyear. It gives the average slice of the economic pie per person. Used to be called per capita gross national product (GNP). See *gross domestic product.* Compare genuine progress indicator (GPI).

per capita GDP PPP (Purchasing Power Parity) Measure of the amount of goods and services that a country's average citizen could buy in the United States.

percolation Passage of a liquid through the spaces of a porous material such as soil.

perennial Plant that can live for more than 2 years. Compare *annual.*

permafrost Perennially frozen layer of the soil that forms when the water there freezes. It is found in arctic tundra.

perpetual resource Essentially inexhaustible resource on a human time scale because it is renewed continuously. Solar energy is an example. Compare *nonrenewable resource, renewable resource.*

pest Unwanted organism that directly or indirectly interferes with human activities.

pesticide Any chemical designed to kill or inhibit the growth of an organism that people consider undesirable. See *fungicide, herbicide, insecticide.*

petrochemicals Chemicals obtained by refining (distilling) crude oil. They are used as raw materials in manufacturing most industrial chemicals, fertilizers, pesticides, plastics, synthetic fibers, paints, medicines, and many other products.

petroleum See *crude oil.*

pH Numeric value that indicates the relative acidity or alkalinity of a substance on a scale of 0 to 14, with the neutral point at 7. Acid solutions have pH values lower than 7; basic or alkaline solutions have pH values greater than 7.

phosphorus cycle Cyclic movement of phosphorus in different chemical forms from the environment to organisms and then back to the environment.

photochemical smog Complex mixture of air pollutants produced in the lower atmosphere by the reaction of hydrocarbons and nitrogen oxides under the influence of sunlight. Especially harmful components include ozone, peroxyacyl nitrates (PANs), and various aldehydes. Compare *industrial smog.*

photosynthesis Complex process that takes place in cells of green plants. Radiant energy from the sun is used to combine carbon dioxide (CO_2) and water (H_2O) to produce oxygen (O_2), carbohydrates (such as glucose, $C_6H_{12}O_6$), and other nutrient molecules. Compare *aerobic respiration, chemosynthesis.*

photovoltaic (PV) cell Device that converts radiant (solar) energy directly into electrical energy. Also called a solar cell.

physical change Process that alters one or more physical properties of an element or a compound without changing its chemical composition. Examples include changing the size and shape of a sample of matter (crushing ice and cutting aluminum foil) and changing a sample of matter from one physical state to another (boiling and freezing water). Compare *chemical change, nuclear change.*

phytoplankton Small, drifting plants, mostly algae and bacteria, found in aquatic ecosystems. Compare *plankton, zooplankton.*

pioneer community First integrated set of plants, animals, and decomposers found in an area undergoing primary ecological succession. See *immature community, mature community.*

pioneer species First hardy species—often microbes, mosses, and lichens—that begin colonizing a site as the first stage of ecological succession. See *ecological succession, pioneer community.*

plaintiff Party in a court case bringing charges or seeking to collect damages for injuries to health or for economic loss; may also seek an injunction, by which the party being charged would be required to stop whatever action is causing harm. See *defendant* and *civil suit.*

planetary management worldview Worldview holding that humans are separate from nature, that nature exists mainly to meet our needs and increasing wants, and that we can use our ingenuity and technology to manage the earth's life-support systems, mostly for our benefit. It assumes that economic growth is unlimited. Compare *environmental wisdom worldview, stewardship worldview.*

plankton Small plant organisms (phytoplankton) and animal organisms (zooplankton) that float in aquatic ecosystems.

plantation agriculture Growing specialized crops such as bananas, coffee, and cacao in tropical developing countries, primarily for sale to developed countries.

plates See *tectonic plates.*

plate tectonics Theory of geophysical processes that explains the movements of lithospheric plates and the processes that occur at their boundaries. See *lithosphere, tectonic plates.*

point source Single identifiable source that discharges pollutants into the environment. Examples include the smokestack of a power plant or an industrial plant, drainpipe of a meatpacking plant, chimney of a house, or exhaust pipe of an automobile. Compare *nonpoint source.*

poison Chemical that adversely affects the health of a living human or animal by causing injury, illness, or death.

policies programs, and the laws and regulations through which they are enacted, that a government enforces and funds.

politics Process through which individuals and groups try to influence or control government policies and actions that affect the local, state, national, and international communities.

pollutant Particular chemical or form of energy that can adversely affect the health, survival, or activities of humans or other living organisms. See *pollution.*

pollution Undesirable change in the physical, chemical, or biological characteristics of air, water, soil, or food that can adversely affect the health, survival, or activities of humans or other living organisms.

pollution cleanup Device or process that removes or reduces the level of a pollutant after it has been produced or has entered the environment. Examples include automobile emission control devices and sewage treatment plants. Compare *pollution prevention.*

pollution prevention Device, process, or strategy used to prevent a potential pollutant from forming or entering the environment or to sharply reduce the amount entering the environment. Compare *pollution cleanup.*

polychlorinated biphenyls (PCBs) Group of 209 toxic, oily, synthetic chlorinated hydrocarbon compounds that can be biologically amplified in food chains and webs.

polyculture Complex form of intercropping in which a large number of different plants maturing at different times are planted together. See also *intercropping.* Compare *monoculture.*

population Group of individual organisms of the same species living in a particular area.

population change Increase or decrease in the size of a population. It is equal to (Births + Immigration) – (Deaths + Emigration).

population crash Dieback of a population that has used up its supply of resources, exceeding the carrying capacity of its environment. See *carrying capacity*.

population density Number of organisms in a particular population found in a specified area or volume.

population dispersion General pattern in which the members of a population are arranged throughout its habitat.

population distribution Variation of population density over a particular geographic area or volume. For example, a country has a high population density in its urban areas and a much lower population density in its rural areas.

population dynamics Major abiotic and biotic factors that tend to increase or decrease the population size and affect the age and sex composition of a species.

population size Number of individuals making up a population's gene pool.

positive feedback loop Feedback loop that causes a system to change further in the same direction. Compare *negative feedback loop*.

potential energy Energy stored in an object because of its position or the position of its parts. Compare *kinetic energy.*

poverty Inability of people to meet their basic needs for food, clothing, and shelter.

ppb See *parts per billion.*

ppm See *parts per million.*

ppt See *parts per trillion.*

prairie See *grassland.*

precautionary principle When there is significant scientific uncertainty about potentially serious harm from chemicals or technologies, decision makers should act to prevent harm to humans and the environment. See *pollution prevention.*

precipitation Water in the form of rain, sleet, hail, and snow that falls from the atmosphere onto land and bodies of water.

predation Interaction in which an organism of one species (the predator) captures and feeds on some or all parts of an organism of another species (the prey).

predator Organism that captures and feeds on some or all parts of an organism of another species (the prey).

predator–prey relationship Relationship that has evolved between two organisms, in which one organism has become the prey for the other, the latter called the predator. See *predator, prey.*

prey Organism that is killed by an organism of another species (the predator) and serves as its source of food.

primary consumer Organism that feeds on some or all parts of plants (herbivore) or on other producers. Compare *detritivore, omnivore, secondary consumer.*

primary pollutant Chemical that has been added directly to the air by natural events or human activities and occurs in a harmful concentration. Compare *secondary pollutant.*

primary productivity See *gross primary productivity, net primary productivity.*

primary recycling Process in which materials are recycled into new products of the same type—turning used aluminum cans into new aluminum cans, for example.

primary sewage treatment Mechanical sewage treatment in which large solids are filtered out by screens and suspended solids settle out as sludge in a sedimentation tank. Compare *secondary sewage treatment.*

primary ecological succession Ecological succession in a area without soil or bottom sediments. See *ecological succession.* Compare *secondary ecological succession.*

principles of sustainability Principles by which nature has sustained itself for billions of years by relying on solar energy, biodiversity, and nutrient recycling.

probability Mathematical statement about how likely it is that something will happen.

producer Organism that uses solar energy (green plants) or chemical energy (some bacteria) to manufacture the organic compounds it needs as nutrients from simple inorganic compounds obtained from its environment. Compare *consumer, decomposer.*

prokaryotic cell Cell containing no distinct nucleus or organelles. Compare *eukaryotic cell.*

proton (p) Positively charged particle in the nuclei of all atoms. Each proton has a relative mass of 1 and a single positive charge. Compare *electron, neutron.*

proven oil reserves Identified deposits from which conventional crude oil can be extracted profitably at current prices with current technology.

PV cell See *photovoltaic cell*.

pyramid of energy flow Diagram representing the flow of energy through each trophic level in a food chain or food web. With each energy transfer, only a small part (typically 10%) of the usable energy entering one trophic level is transferred to the organisms at the next trophic level.

radiation Fast-moving particles (particulate radiation) or waves of energy (electromagnetic radiation). See *alpha particle, beta particle, gamma ray.*

radioactive decay Change of a radioisotope to a different isotope by the emission of radioactivity.

radioactive isotope See *radioisotope.*

radioactive waste Waste products of nuclear power plants, research, medicine, weapon production, or other processes involving nuclear reactions. See *radioactivity.*

radioactivity Nuclear change in which unstable nuclei of atoms spontaneously shoot out "chunks" of mass, energy, or both at a fixed rate. The three principal types of radioactivity are gamma rays and fast-moving alpha particles and beta particles.

radioisotope Isotope of an atom that spontaneously emits one or more types of radioactivity (alpha particles, beta particles, gamma rays).

rain shadow effect Low precipitation on the leeward side of a mountain when prevailing winds flow up and over a high mountain or range of high mountains, creating semiarid and arid conditions on the leeward side of a high mountain range.

rangeland Land that supplies forage or vegetation (grasses, grasslike plants, and shrubs) for grazing and browsing animals and is not intensively managed. Compare *feedlot, pasture.*

range of tolerance Range of chemical and physical conditions that must be maintained for populations of a particular species to stay alive and grow, develop, and function normally. See *law of tolerance.*

recharge area Any area of land allowing water to percolate down through it and into an aquifer. See *aquifer, natural recharge.*

reconciliation ecology Science of inventing, establishing, and maintaining habitats to conserve species diversity in places where people live, work, or play.

recycle To collect and reprocess a resource so that it can be made into new products; one of the three R's of resource use. An example is collecting aluminum cans, melting them down, and using the aluminum to make new cans or other aluminum products. See *primary recycling, secondary recycling.* Compare *reduce and reuse.*

reduce To consume less and live a simpler lifestyle; one of the three R's of resource use. Compare *recycle* and *reuse*.

reforestation Renewal of trees and other types of vegetation on land where trees have been removed; can be done naturally by seeds from nearby trees or artificially by planting seeds or seedlings.

reliable runoff Surface runoff of water that generally can be counted on as a stable source of water from year to year. See *runoff.*

reliable science Concepts and ideas that are widely accepted by experts in a particular field of the natural or social sciences. Compare *tentative science, unreliable science.*

renewable resource Resource that can be replenished rapidly (hours to several decades) through natural processes as long as it is not used up faster than it is replaced. Examples include trees in forests, grasses in grasslands, wild animals, fresh surface water in lakes and streams, most groundwater, fresh air, and fertile soil. If such a resource is used faster than it is replenished, it can be depleted and converted into a nonrenewable resource. Compare *nonrenewable resource* and *perpetual resource*. See also *environmental degradation.*

replacement-level fertility Average number of children a couple must bear to replace themselves. The average for a country or the world usually is slightly higher than two children per couple (2.1 in the United States and 2.5 in some developing countries) mostly because some children die before reaching their reproductive years. See also *total fertility rate.*

reproduction Production of offspring by one or more parents.

reproductive isolation Long-term geographic separation of members of a particular sexually reproducing species.

reproductive potential See *biotic potential.*

reserves Resources that have been identified and from which a usable mineral can be extracted profitably at present prices with current mining or extraction technology.

reservoir Artificial lake created when a stream is dammed. See *dam.*

resource Anything obtained from the environment to meet human needs and wants. It can also be applied to other species.

resource partitioning Process of dividing up resources in an ecosystem so that species with similar needs (overlapping ecological niches) use the same scarce resources at different times, in different ways, or in different places. See *ecological niche.*

resource productivity See *material efficiency.*

respiration See *aerobic respiration.*

response Amount of health damage caused by exposure to a certain dose of a harmful substance or form of radiation. See *dose, dose-response curve, median lethal dose.*

restoration ecology Research and scientific study devoted to restoring, repairing, and reconstructing damaged ecosystems.

reuse To use a product over and over again in the same form. An example is collecting, washing, and refilling glass beverage bottles. One of the 3 Rs. Compare *reduce and recycling.*

riparian zone A thin strip or patch of vegetation that surrounds a streams. These zones are very important habitats and resources for wildlife.

risk Probability that something undesirable will result from deliberate or accidental exposure to a hazard. See *risk analysis, risk assessment, risk management.*

risk analysis Identifying hazards, evaluating the nature and severity of risks associated with the hazards (*risk assessment*), ranking risks (*comparative risk analysis*), using this and other information to determine options and make decisions about reducing or eliminating risks (*risk management*), and communicating information about risks to decision makers and the public (*risk communication*).

risk assessment Process of gathering data and making assumptions to estimate short- and long-term harmful effects on human health or the environment from exposure to hazards associated with the use of a particular product or technology.

risk communication Communicating information about risks to decision makers and the public. See *risk, risk analysis.*

risk management Use of risk assessment and other information to determine options and make decisions about reducing or eliminating risks. See *risk, risk analysis, risk communication.*

rock Any solid material that makes up a large, natural, continuous part of the earth's crust. See *mineral.*

rock cycle Largest and slowest of the earth's cycles, consisting of geologic, physical, and chemical processes that form and modify rocks and soil in the earth's crust over millions of years.

rule of 70 Doubling time (in years) = 70/(percentage growth rate). See *doubling time, exponential growth.*

runoff Freshwater from precipitation and melting ice that flows on the earth's surface into nearby streams, lakes, wetlands, and reservoirs. See *reliable runoff, surface runoff, surface water.* Compare *groundwater.*

salinity Amount of various salts dissolved in a given volume of water.

salinization Accumulation of salts in soil that can eventually make the soil unable to support plant growth.

saltwater intrusion Movement of saltwater or brackish (slightly salty) water into freshwater aquifers in coastal and inland areas as groundwater is withdrawn faster than it is recharged by precipitation.

sanitary landfill Waste disposal site on land in which waste is spread in thin layers, compacted, and covered with a fresh layer of clay or plastic foam each day. Compare *open dump.*

saltwater life zones Aquatic life zones associated with oceans: oceans and their accompanying bays, estuaries, coastal wetlands, shorelines, coral reefs, and mangrove forests.

scavenger Organism that feeds on dead organisms that were killed by other organisms or died naturally. Examples include vultures, flies, and crows. Compare *detritivore.*

science Attempts to discover order in nature and use that knowledge to make predictions about what is likely to happen in nature. See *reliable science, scientific data, scientific hypothesis, scientific law, scientific methods, scientific model, scientific theory, tentative science, unreliable science.*

scientific data Facts obtained by making observations and measurements. Compare *scientific hypothesis, scientific law, scientific methods, scientific model, scientific theory.*

scientific hypothesis An educated guess that attempts to explain a scientific law or certain scientific observations. Compare *scientific data, scientific law, scientific methods, scientific model, scientific theory.*

scientific law Description of what scientists find happening in nature repeatedly in the same way, without known exception. See *first law of thermodynamics, law of conservation of matter, second law of thermodynamics.* Compare *scientific data, scientific hypothesis, scientific methods, scientific model, scientific theory.*

scientific methods The ways scientists gather data and formulate and test scientific hypotheses, models, theories, and laws. See *scientific data, scientific hypothesis, scientific law, scientific model, scientific theory.*

scientific model A simulation of complex processes and systems. Many are mathematical models that are run and tested using computers.

scientific theory A well-tested and widely accepted scientific hypothesis. Compare *scientific data, scientific hypothesis, scientific law, scientific methods, scientific model.*

secondary consumer Organism that feeds only on primary consumers. Compare *detritivore, omnivore, primary consumer.*

secondary pollutant Harmful chemical formed in the atmosphere when a primary air pollutant reacts with normal air components or other air pollutants. Compare *primary pollutant.*

secondary recycling A process in which waste materials are converted into different products; for example, used tires can be shredded and turned into rubberized road surfacing. Compare *primary recycling.*

secondary sewage treatment Second step in most waste treatment systems in which aerobic bacteria decompose as much as 90% of degradable, oxygen-demanding organic wastes in wastewater. It usually involves bringing sewage and bacteria together in trickling filters or in the activated sludge process. Compare *primary sewage treatment.*

secondary ecological succession Ecological succession in an area in which natural vegetation has been removed or destroyed but the soil or bottom sediment has not been destroyed. See *ecological succession.* Compare *primary ecological succession.*

second-growth forest Stands of trees resulting from secondary ecological succession. Compare *old-growth forest, tree farm.*

second law of energy See *second law of thermodynamics.*

second law of thermodynamics Whenever energy is converted from one form to another in a physical or chemical change, we end up with lower-quality or less usable energy than we started with. In any conversion of heat energy to useful work, some of the initial energy input is always degraded to lower-quality, more dispersed, less useful energy—usually low-temperature heat that flows into the environment; you cannot break even in terms of energy quality. See *first law of thermodynamics.*

sedimentary rock Rock that forms from the accumulated products of erosion and in some cases from the compacted shells, skeletons, and other remains of dead organisms. Compare *igneous rock, metamorphic rock.* See *rock cycle.*

selective cutting Cutting of intermediate-aged, mature, or diseased trees in an uneven-aged forest stand, either singly or in small groups. This encourages the growth of younger trees and maintains an uneven-aged stand. Compare *clear-cutting, strip cutting.*

septic tank Underground tank for treating wastewater from a home in rural and suburban areas. Bacteria in the tank decompose organic wastes, and the sludge settles to the bottom of the tank. The effluent flows out of the tank into the ground through a field of drainpipes.

sexual reproduction Reproduction in organisms that produce offspring by combining sex cells or *gametes* (such as ovum and sperm) from both parents. It produces offspring that have combinations of traits from their parents. Compare *asexual reproduction.*

shale oil Slow-flowing, dark brown, heavy oil obtained when kerogen in oil shale is vaporized at high temperatures and then condensed. Shale oil can be refined to yield gasoline, heating oil, and other petroleum products. See *kerogen, oil shale.*

shelterbelt See *windbreak.*

slash-and-burn agriculture Cutting down trees and other vegetation in a patch of forest, leaving the cut vegetation on the ground to dry, and then burning it. The ashes that are left add nutrients to the nutrient-poor soils found in most tropical forest areas. Crops are planted between tree stumps. Plots must be abandoned after a few years (typically 2–5 years) because of loss of soil fertility or invasion of vegetation from the surrounding forest.

sludge Gooey mixture of toxic chemicals, infectious agents, and settled solids removed from wastewater at a sewage treatment plant.

smart growth Form of urban planning that recognizes that urban growth will occur but uses zoning laws and other tools to prevent sprawl, direct growth to certain areas, protect ecologically sensitive and important lands and waterways, and develop urban areas that are more environmentally sustainable and more enjoyable places to live.

smelting Process in which a desired metal is separated from the other elements in an ore mineral.

smog Originally a combination of smoke and fog but now used to describe other mixtures of pollutants in the atmosphere. See *industrial smog, photochemical smog.*

SNG See *synthetic natural gas*.

social capital Result of getting people with different views and values to talk and listen to one another, find common ground based on understanding and trust, and work together to solve environmental and other problems.

soil Complex mixture of inorganic minerals (clay, silt, pebbles, and sand), decaying organic matter, water, air, and living organisms.

soil conservation Methods used to reduce soil erosion, prevent depletion of soil nutrients, and restore nutrients previously lost by erosion, leaching, and excessive crop harvesting.

soil erosion Movement of soil components, especially topsoil, from one place to another, usually by wind, flowing water, or both. This natural process can be greatly accelerated by human activities that remove vegetation from soil. Compare *soil conservation.*

soil horizons Horizontal zones, or layers, that make up a particular mature soil. Each horizon has a distinct texture and composition that vary with different types of soils. See *soil profile.*

soil profile Cross-sectional view of the horizons in a soil. See *soil horizon.*

solar capital Solar energy that warms the planet and supports photosynthesis, the process that plants use to provide food for themselves and for us and other animals. This direct input of solar energy also produces indirect forms of renewable solar energy such as wind and flowing water. Compare *natural capital.*

solar cell See *photovoltaic cell.*

solar collector Device for collecting radiant energy from the sun and converting it into heat. See *active solar heating system, passive solar heating system.*

solar energy Direct radiant energy from the sun and a number of indirect forms of energy produced by the direct input of such radiant energy. Principal indirect forms of solar energy include wind, falling and flowing water (hydropower), and biomass (solar energy converted into chemical energy stored in the chemical bonds of organic compounds in trees and other plants)—none of which would exist without direct solar energy.

solid waste Any unwanted or discarded material that is not a liquid or a gas. See *industrial solid waste, municipal solid waste.*

sound science See *reliable science.*

spaceship-earth worldview View of the earth as a spaceship: a machine that we can understand, control, and change at will by using advanced technology. See *planetary management worldview.* Compare *environmental wisdom worldview, stewardship worldview.*

specialist species Species with a narrow ecological niche. They may be able to live in only one type of habitat, tolerate only a narrow range of climatic and other environmental conditions, or use only one type or a few types of food. Compare *generalist species.*

speciation Formation of two species from one species because of divergent natural selection in response to changes in environmental conditions; usually takes thousands of years. Compare *extinction.*

species Group of similar organisms, and for sexually reproducing organisms, they are a set of individuals that can mate and produce fertile offspring. Every organism is a member of a certain species.

species diversity Number of different species (species richness) combined with the relative abundance of individuals within each of those species (species evenness) in a given area. See *biodiversity, species evenness, species richness.* Compare *ecological diversity, genetic diversity.*

species equilibrium model See *theory of island biogeography.*

species evenness Degree to which comparative numbers of individuals of each of the species present in a community are similar. See *species diversity.* Compare *species richness.*

species richness Variety of species, measured by the number of different species contained in a community. See *species diversity.* Compare *species evenness.*

spoils Unwanted rock and other waste materials produced when a material is removed from the earth's surface or subsurface by mining, dredging, quarrying, or excavation.

S-shaped curve Leveling off of an exponential, J-shaped curve when a rapidly growing population reaches or exceeds the carrying capacity of its environment and ceases to grow.

statistics Mathematical tools used to collect, organize, and interpret numerical data.

statutory laws Laws developed and passed by legislative bodies such as federal and state governments. Compare *common law.*

stewardship worldview Worldview holding that we can manage the earth for our benefit but that we have an ethical responsibility to be caring and responsible managers, or *stewards,* of the earth. It calls for encouraging environmentally beneficial forms of economic growth and discouraging environmentally harmful forms. Compare *worldview, environmental wisdom worldview, planetary management worldview.*

stratosphere Second layer of the atmosphere, extending about 17–48 kilometers (11–30 miles) above the earth's surface. It contains small amounts of gaseous ozone (O_3), which filters out about 95% of the incoming harmful ultraviolet radiation emitted by the sun. Compare *troposphere.*

stream Flowing body of surface water. Examples are creeks and rivers.

strip-cropping Planting regular crops and close-growing plants, such as hay or nitrogen-fixing legumes, in alternating rows or bands to help reduce depletion of soil nutrients.

strip-cutting Variation of clear-cutting in which a strip of trees is clear-cut along the contour of the land, with the corridor being narrow enough to allow natural regeneration within a few years. After regeneration, another strip is cut above the first, and so on. Compare *clear-cutting, selective cutting.*

strip-mining Form of surface mining in which bulldozers, power shovels, or stripping wheels remove large chunks of the earth's surface in strips. See *area strip mining, contour strip mining, surface mining.* Compare *subsurface mining.*

subatomic particles Extremely small particles—electrons, protons, and neutrons—that make up the internal structure of atoms.

subduction zone Area in which the oceanic lithosphere is carried downward (subducted) under an island arc or continent at a convergent plate boundary. A trench ordinarily forms at the boundary between the two converging plates. See *convergent plate boundary.*

subsidence Slow or rapid sinking of part of the earth's crust that is not slope-related.

subsistence farming See *traditional subsistence agriculture.*

subsurface mining Extraction of a metal ore or fuel resource such as coal from a deep underground deposit. Compare *surface mining.*

succession See *ecological succession, primary ecological succession, secondary ecological succession.*

succulent plants Plants, such as desert cacti, that survive in dry climates by having no leaves, thus reducing the loss of scarce water through *transpiration.* They store water and use sunlight to produce the food they need in the thick, fleshy tissue of their green stems and branches. Compare deciduous plants, evergreen plants.

sulfur cycle Cyclic movement of sulfur in various chemical forms from the environment to organisms and then back to the environment.

sulfur dioxide (SO_2) Colorless gas with an irritating odor. About one-third of the SO_2 in the atmosphere comes from natural sources as part of the sulfur cycle. The other two-thirds come from human sources, mostly combustion of sulfur-containing coal in electric power and industrial plants and from oil refining and smelting of sulfide ores.

superinsulated house House that is heavily insulated and extremely airtight. Typically, active or passive solar collectors are used to heat water, and an air-to-air heat exchanger prevents buildup of excessive moisture and indoor air pollutants.

surface fire Forest fire that burns only undergrowth and leaf litter on the forest floor. Compare *crown fire, ground fire.* See *controlled burning.*

surface mining Removing soil, subsoil, and other strata and then extracting a mineral deposit found fairly close to the earth's surface. See *area strip mining, contour strip mining, mountaintop removal, open-pit mining.* Compare *subsurface mining.*

surface runoff Water flowing off the land into bodies of surface water. See *reliable runoff.*

surface water Precipitation that does not infiltrate the ground or return to the atmosphere by evaporation or transpiration. See *runoff.* Compare *groundwater.*

survivorship curve Graph showing the number of survivors in different age groups for a particular species.

suspended particulate matter See *particulates.*

sustainability Ability of earth's various systems, including human cultural systems and economies, to survive and adapt to changing environmental conditions indefinitely.

sustainability revolution Major cultural change in which people learn how to reduce their ecological footprints and live more sustainability, largely by copying nature and using the three principles of sustainability to guide their lifestyles and economies. See *principles of sustainability*.

sustainable agriculture Method of growing crops and raising livestock based on organic fertilizers, soil conservation, water conservation, biological pest control, and minimal use of nonrenewable fossil-fuel energy.

sustainable development See *environmentally sustainable economic development.*

sustainable living Taking no more potentially renewable resources from the natural world than can be replenished naturally and not overloading the capacity of the environment to cleanse and renew itself by natural processes.

sustainable society Society that manages its economy and population size without doing irreparable environmental harm by overloading the planet's ability to absorb environmental insults, replenish its resources, and sustain human and other forms of life over a specified period, indefinitely. During this period, the society satisfies the needs of its people without depleting natural resources and thereby jeopardizing the prospects of current and future generations of humans and other species.

sustainable yield (sustained yield) Highest rate at which a potentially renewable resource can be used indefinitely without reducing its available supply. See also *environmental degradation.*

synergistic interaction Interaction of two or more factors or processes so that the combined effect is greater than the sum of their separate effects.

synergy See *synergistic interaction.*

synfuels Synthetic gaseous and liquid fuels produced from solid coal or sources other than natural gas or crude oil.

synthetic natural gas (SNG) Gaseous fuel containing mostly methane produced from solid coal.

system Set of components that function and interact in some regular and theoretically predictable manner.

tailings Rock and other waste materials removed as impurities when waste mineral material is separated from the metal in an ore.

tar sand Deposit of a mixture of clay, sand, water, and varying amounts of a tarlike heavy oil known as bitumen. Bitumen can be extracted from tar sand by heating. It is then purified and upgraded to synthetic crude oil. See *bitumen.*

tectonic plates Various-sized areas of the earth's lithosphere that move slowly around with the mantle's flowing asthenosphere. Most earthquakes and volcanoes occur around the boundaries of these plates. See *lithosphere, plate tectonics.*

temperature Measure of the average speed of motion of the atoms, ions, or molecules in a substance or combination of substances at a given moment. Compare *heat.*

temperature inversion Layer of dense, cool air trapped under a layer of less dense, warm air. It prevents upward-flowing air currents from developing. In a prolonged inversion, air pollution in the trapped layer may build up to harmful levels.

tentative science Preliminary scientific data, hypotheses, and models that have not been widely tested and accepted. Compare *reliable science, unreliable science.*

teratogen Chemical, ionizing agent, or virus that causes birth defects. Compare *carcinogen, mutagen.*

terracing Planting crops on a long, steep slope that has been converted into a series of broad, nearly level terraces with short vertical drops from one to another that run along the contour of the land to retain water and reduce soil erosion.

terrestrial Pertaining to land. Compare *aquatic.*

tertiary (higher-level) consumers Animals that feed on animal-eating animals. They feed at high trophic levels in food chains and webs. Examples include hawks, lions, bass, and sharks. Compare *detritivore, primary consumer, secondary consumer.*

theory of evolution Widely accepted scientific idea that all life forms developed from earlier life forms. It is the way most biologists explain how life has changed over the past 3.6–3.8 billion years and why it is so diverse today.

theory of island biogeography Widely accepted scientific theory holding that the number of different species (species richness) found on an island is determined by the interactions of two factors: the rate at which new species immigrate to the island and the rate at which species become *extinct,* or cease to exist, on the island. See *species richness.*

thermal inversion See *temperature inversion.*

threatened species Wild species that is still abundant in its natural range but is likely to become endangered because of a decline in numbers. Compare *endangered species.*

threshold effect Harmful or fatal effect of a small change in environmental conditions that exceeds the limit of tolerance of an organism or population of a species. See *law of tolerance.*

throughput Rate of flow of matter, energy, or information through a system. Compare *input, output.*

throwaway society See *high-throughput economy.*

time delay In a complex system, the period of time between the input of a feedback stimulus and the system's response to it. See *tipping point*.

tipping point Threshold level at which an environmental problem causes a fundamental and irreversible shift in the behavior of a system. See *climate tipping point, ecological tipping point.*

tolerance limits Minimum and maximum limits for physical conditions (such as temperature) and concentrations of chemical substances beyond which no members of a particular species can survive. See *law of tolerance.*

total fertility rate (TFR) Estimate of the average number of children who will be born alive to a woman during her lifetime if she passes through all her childbearing years (ages 15–44) conforming to age-specific fertility rates of a given year. More simply, it is an estimate of the average number of children that women in a given population will have during their childbearing years.

toxic chemical See *poison, carcinogen, hazardous chemical, mutagen, teratogen.*

toxicity Measure of the harmfulness of a substance.

toxicology Study of the adverse effects of chemicals on health.

toxic waste Form of hazardous waste that causes death or serious injury (such as burns, respiratory diseases, cancers, or genetic mutations). See *hazardous waste.*

toxin See *poison.*

traditional intensive agriculture Production of enough food for a farm family's survival and a surplus that can be sold. This type of agriculture uses higher inputs of labor, fertilizer, and water than traditional subsistence agriculture. See *traditional subsistence agriculture.* Compare *industrialized agriculture.*

traditional subsistence agriculture Production of enough crops or livestock for a farm family's survival and. Compare *industrialized agriculture, traditional intensive agriculture.*

tragedy of the commons Depletion or degradation of a potentially renewable resource to which people have free and unmanaged access. An example is the depletion of commercially desirable fish species in the open ocean beyond areas controlled by coastal countries. See *common-property resource, open access renewable resource.*

trait Characteristic passed on from parents to offspring during reproduction in an animal or plant.

transform fault Area where the earth's lithospheric plates move in opposite but parallel directions along a fracture (fault) in the lithosphere. Compare *convergent plate boundary, divergent plate boundary.*

transgenic organisms See *genetically modified organisms.*

transmissible disease Disease that is caused by living organisms (such as bacteria, viruses, and parasitic worms) and can spread from one person to another by air, water, food, or body fluids (or in some cases by insects or other organisms). Compare *nontransmissible disease.*

transpiration Process in which water is absorbed by the root systems of plants, moves up through the plants, passes through pores (stomata) in their leaves or other parts, and evaporates into the atmosphere as water vapor.

tree farm See *tree plantation.*

tree plantation Site planted with one or only a few tree species in an even-aged stand. When the stand matures it is usually harvested by clear-cutting and then replanted. These farms normally raise rapidly growing tree species for fuelwood, timber, or pulpwood. Compare *old-growth forest, second-growth forest.*

trophic level All organisms that are the same number of energy transfers away from the original source of energy (for example, sunlight) that enters an ecosystem. For example, all producers belong to the first trophic level and all herbivores belong to the second trophic level in a food chain or a food web.

troposphere Innermost layer of the atmosphere. It contains about 75% of the mass of earth's air and extends about 17 kilometers (11 miles) above sea level. Compare *stratosphere.*

true cost See *full cost.*

tsunami Series of large waves generated when part of the ocean floor suddenly rises or drops.

turbidity Cloudiness in a volume of water; a measure of water clarity in lakes, streams, and other bodies of water.

undernutrition See *chronic undernutrition.*

unreliable science Scientific results or hypotheses presented as reliable science without having undergone the rigors of the peer review process. Compare *reliable science, tentative science.*

upwelling Movement of nutrient-rich bottom water to the ocean's surface. It can occur far from shore but usually takes place along certain steep coastal areas where the warm surface layer of ocean water is pushed away from shore and replaced by cold, nutrient-rich bottom water.

urban area Geographic area containing a community with a population of 2,500 or more. The number of people used in this definition may vary, with some countries setting the minimum number of people at 10,000–50,000.

urban growth Rate of growth of an urban population. Compare *degree of urbanization.*

urbanization Creation or growth of urban areas, or cities, and their surrounding developed land. See *degree of urbanization, urban area.*

urban sprawl Growth of low-density development on the edges of cities and towns. See *smart growth.*

virtual water Water that is not directly consumed but is used to produce food and other products.

volatile organic compounds (VOCs) Organic compounds that exist as gases in the atmosphere and act as pollutants, some of which are hazardous.

volcano Vent or fissure in the earth's surface through which magma, liquid lava, and gases are released into the environment.

warm front Boundary between an advancing warm air mass and the cooler one it is replacing. Because warm air is less dense than cool air, an advancing warm front rises over a mass of cool air. Compare *cold front.*

waste management Managing wastes to reduce their environmental harm without seriously trying to reduce the amount of waste produced. See *integrated waste management.* Compare *waste reduction.*

waste reduction Reducing the amount of waste produced; wastes that are produced are viewed as potential resources that can be reused, recycled, or composted. See *integrated waste management.* Compare *waste management.*

water cycle See *hydrologic cycle.*

water footprint A rough measure of the volume of water that we use directly and indirectly to keep a person or group alive and to support their lifestyles.

waterlogging Saturation of soil with irrigation water or excessive precipitation so that the water table rises close to the surface.

water pollution Any physical or chemical change in surface water or groundwater that can harm living organisms or make water unfit for certain uses.

watershed Land area that delivers water, sediment, and dissolved substances via small streams to a major stream (river).

water table Upper surface of the zone of saturation, in which all available pores in the soil and rock in the earth's crust are filled with water. See *zone of aeration, zone of saturation.*

watt Unit of power, or rate at which electrical work is done. See *kilowatt.*

weather Short-term changes in the temperature, barometric pressure, humidity, precipitation, sunshine, cloud cover, wind direction and speed, and other conditions in the troposphere at a given place and time. Compare *climate.*

weathering Physical and chemical processes in which solid rock exposed at earth's surface is changed to separate solid particles and dissolved material, which can then be moved to another place as sediment. See *erosion.*

wetland Land that is covered all or part of the time with salt water or freshwater, excluding streams, lakes, and the open ocean. See *coastal wetland, inland wetland.*

wilderness Area where the earth and its ecosystems have not been seriously disturbed by humans and where humans are only temporary visitors.

wildlife All free, undomesticated species. Sometimes the term is used to describe animals only.

wildlife resources Wildlife species that have actual or potential economic value to people.

wild species Species found in the natural environment. Compare *domesticated species.*

windbreak Row of trees or hedges planted to partially block wind flow and reduce soil erosion on cultivated land.

wind farm Cluster of wind turbines in a windy area on land or at sea, built to capture wind energy and convert it into electrical energy.

worldview How people think the world works and what they think their role in the world should be. See *environmental wisdom worldview, planetary management worldview, stewardship worldview.*

zone of aeration Zone in soil that is not saturated with water and that lies above the water table. See *water table, zone of saturation.*

zone of saturation Zone where all available pores in soil and rock in the earth's crust are filled by water. See *water table, zone of aeration.*

zoning Designating parcels of land for particular types of use.

zooplankton Animal plankton; small floating herbivores that feed on plant plankton (phytoplankton). Compare *phytoplankton.*

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