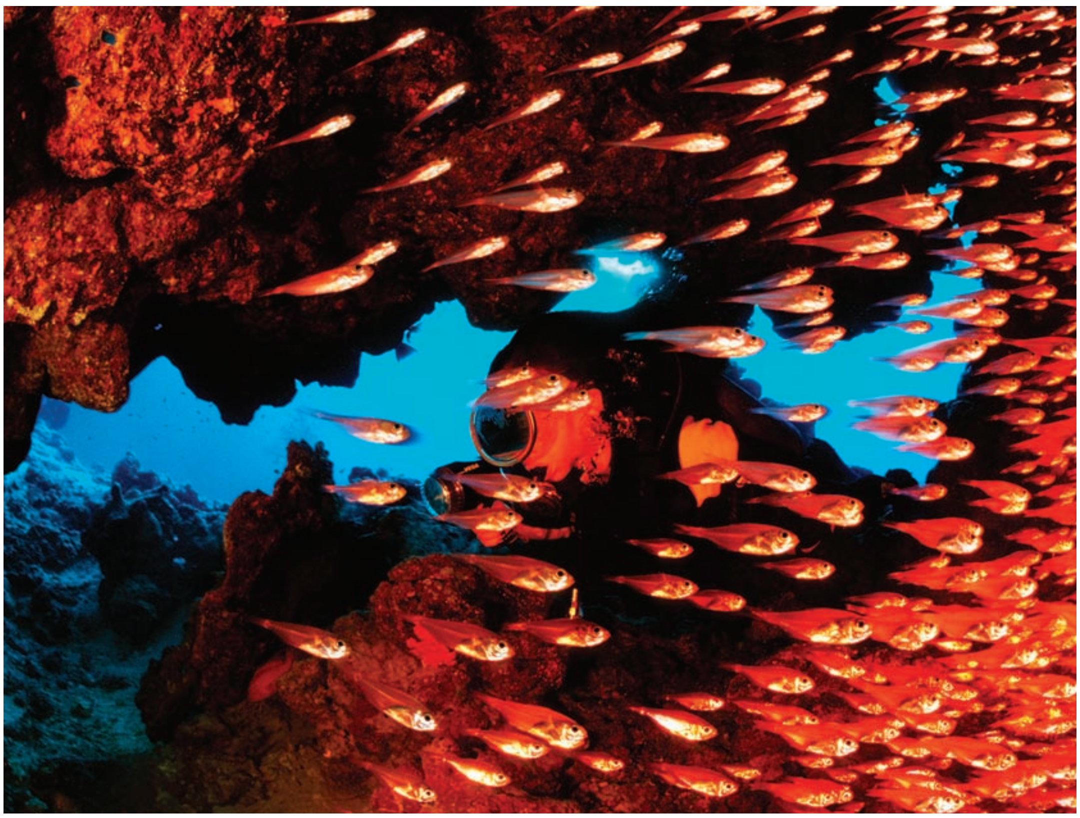

ENVIRONMENTAL SCIENCE | G. TYLER MILLER | SCOTT E. SPOOLMAN

Environmental Science

THIRTEENTH EDITION

G. Tyler Miller, Jr.

Scott E. Spoolman



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About the Cover Photo

The *green sea turtle* is one of seven species of sea turtles, all of which are endangered or threatened. It is the largest of the sea turtles. The adults typically weigh 135–160 kilograms (300–350 pounds) and grow to 0.9 meters (3 feet) in diameter. They get their names from their green body fat, which results from a diet of sea grasses and algae. Green sea turtles live near coral reefs and rocky shorelines of continental coasts and islands in tropical and subtropical waters around the world. And they take an average of 25 years (but as many as 50) to reach sexual maturity.

While these turtles spend most of their lives in the ocean, adult females must lay their eggs on land, and biologists believe they return to beaches where they were born to make their nests. The female lands at night and drags herself ashore using her front flippers. She buries about 100–150 eggs and returns to the sea. The eggs incubate in the sand for about 2 months. Then the cookie-sized baby turtles hatch and dig out from under the sand. Having evolved an ability to sense the heat of sunlight, they wait until dark to emerge and scramble toward the sea. However, artificial lights from a human settlement, can lead them off course, and many then starve or are caught and eaten by predators. Thus small and shrinking numbers of these hatchlings make it to the sea after hatching.

The green sea turtle evolved before dinosaurs arrived on the earth. Now, having survived the entire age of dinosaurs, it is endangered globally because of several human activities. They were hunted nearly to extinction, primarily as a food source. And although they are now protected by laws, poachers still take them for their meat, eggs, and shells. Also, thousands of sea turtles die each year when they are trapped and drowned in commercial fishing nets. Many turtles become entangled in plastic debris (Figure 8-18, p. 171) or ingest plastic litter, which can interfere with their digestion, causing them to starve. Ocean water pollution is another major threat, as is coastal development, which often destroys or degrades their nesting areas.

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Voltchev-UNEP/Peter Arnold, Inc.

Photo 4 Severe desertification threatens an oasis in the Sahel region of West Africa from a combination of severe drought, farming, and overgrazing.

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Martin Bond/Peter Arnold, Inc.

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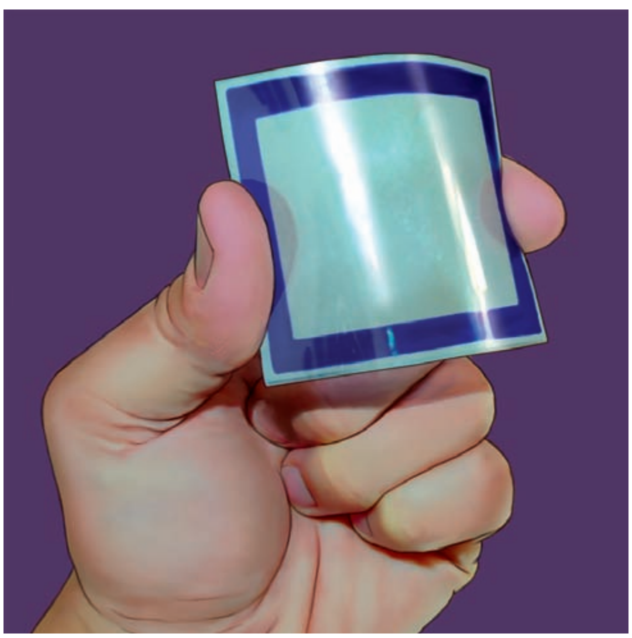

Nanosys

Photo 8 Flexible solar cells using nanotechnology.

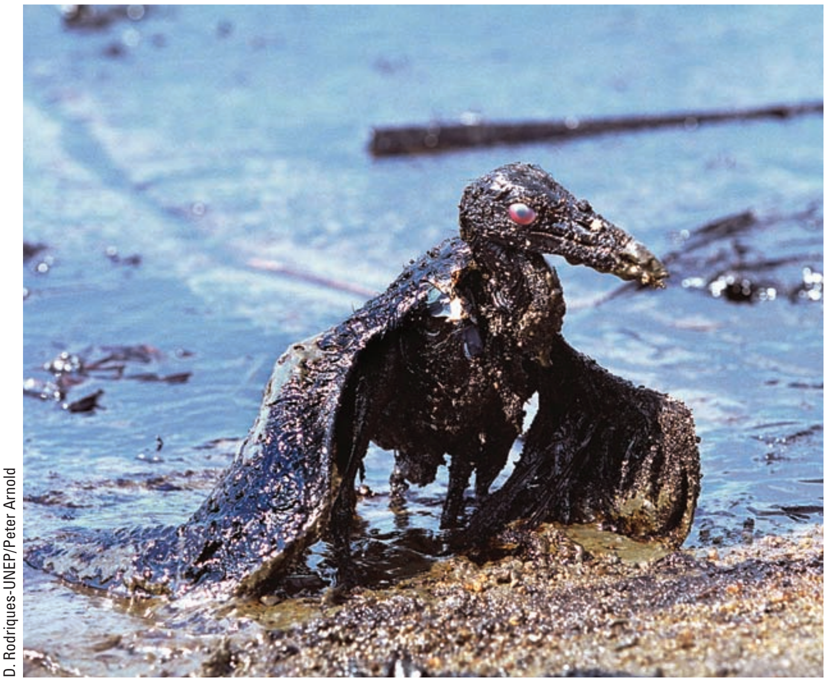

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Photo 14 Children protesting air pollution in Turin, Italy.

PREFACE

For Instructors

The media are full of bad news about the environment. However, environmental science does not have to be all about bad news. We view it as a set of tools with which students can learn to read the bad news objectively and then think about and search for solutions to environmental problems.

We also see environmental science as a field that is rife with good news and promise for a better future. We take this view through the lens of *sustainability*. We truly believe that 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.

Like our other textbooks, this book aims to convey that view of environmental science to students. We seek to leave readers with tools for understanding and thinking critically; to inspire them to take a positive approach toward finding and implementing good environmental solutions in their own lives and in their careers; and to help them to see how promising the future can be if it is framed by goals for more sustainable human communities.

What's New in This Edition?

In this edition, we build on proven strengths of past editions with the following major new features:

- *Good News* logos GOOD NEWS mark areas in this text that present positive developments in our efforts to deal with environmental problems.
- A *Quantitative Data Analysis* or *Ecological Footprint Analysis* exercise appears at the end of each chapter and more than 100 additional Data and Map Analysis exercises have been added to the Environmental Database in the Supplements.
- Each chapter contains new *Connections* boxes that briefly point out connections between human activities and environmental consequences; environmental and social issues; and environmental issues and solutions.
- *Three Big Ideas* at the end of each chapter summarize the three most important ideas of each chapter.
- A number of the chapter-opening *Core Case Studies* are new, providing students with up-to-date illustrative applications threaded throughout the chapters.
- There are almost 40% new, improved, or updated figures, and 30% new photos.
- The chapter review questions at the end of each chapter are more comprehensive and now include all chapter key terms in boldface, to help students better synthesize the information and focus on the key terms and ideas.

Concept-Centered Approach

To help students focus on the main ideas, each major chapter section is built around one to three *key concepts*, which state the most important take-away messages of each chapter. They are listed at the front of each chapter (see p. 40), and each chapter section begins with a key question and concepts (see pp. 42, 45, 48), which are highlighted and referenced throughout each chapter. A logo CONCEPT LINKS in the margin links the material in each chapter to appropriate key concepts in foregoing chapters (see pp. 80, 111, and 155).

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. In this edition, we emphasize three sustainability principles (out of the four from the 12th edition) to make the principles easier to understand, retain, and apply. These principles are introduced in Chapter 1, depicted in Figure 1-1 (p. 5 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 10, pp. 219, 220, and 227).

Core Case Studies and the Sustainability Theme

Each chapter opens with a *Core Case Study* (p. 79), which is applied throughout the chapter. These connections to the Core Case Study are indicated in the page margins by CORE CASE STUDY (see pp. 81, 82, 87, and 88). *Thinking About* exercises strategically placed throughout each chapter (see pp. 187, 202, 219, and 250) challenge students to make these and other connections for themselves. Each chapter ends with a *Revisiting* box (p. 235), 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

In the previous edition of this book, we used five major subthemes, which are carried on in this new edition: *natural capital*, *natural capital degradation*, *solutions*, *trade-offs*, and *individuals matter* (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 1-2 (p. 7), 7-21 (p. 141), and 9-4 (p. 181).
- ***Natural capital degradation***. We describe how human activities can degrade natural capital. Examples of diagrams that illustrate this subtheme are Figures 1-4 (p. 10), 7-19 (p. 139), and 10-7 (p. 215).
- ***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 10-23 (p. 232), 11-17 (p. 253), and 15-13 (p. 381). We also present a number of technologies and social trends that could soon break out and change the world much more rapidly than most people think. The good news is summarized in Figure 17-20 (p. 450).
- ***Trade-Offs***. The search for solutions involves *trade-offs*, because any solution requires weighing advantages against disadvantages. Trade-Offs diagrams present advantages and disadvantages of various environmental technologies and solutions to environmental problems. Examples are Figures 10-15 (p. 222), 13-12 (p. 307), and 16-12 (p. 415).
- ***Individuals Matter***. Throughout the book *Individuals Matter* boxes describe what various concerned citizens and scientists have done to help us achieve sustainability. (See pp. 168, 223, 397, and 433). Also, *What Can You Do?* diagrams describe how readers can deal with the problems we face. Examples are Figures 10-25 (p. 234), 11-30 (p. 269), and 15-25 (p. 396). Twelve especially important steps that individuals can take—the *sustainability dozen*—are summarized in Figure 17-18 (p. 448).

Science-Based Global Coverage

Chapters 2–7 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. 75, 87, and 154). Science is also integrated throughout the book in various *Case Studies* (see pp. 143, 160, and 174) and in figures (see Figures 13-A, p. 299, and 15-17, p. 376). 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. 145, 162, and 249). **GREEN CAREER** notations in the text list various green careers with further information found on the website for this book.

This book also provides a *global perspective* on two levels. *First*, ecological principles reveal how all the world's life is connected and sustained within the biosphere (Chapter 3). *Second*, the book integrates information and images from around the world into its presentation of environmental problems and their possible solutions. This includes many global maps and U.S. maps in the basic text and in Supplements 3, 4, and 9.

CengageNOW, an online visual learning supplement, allows students to enhance their scientific understanding by viewing animations, many of them interactive, available for this book. Some *CengageNOW* notations are related to figures (see Figures 5-11, p. 90, and 7-30, p. 147) and others to text (see pp. 85 and 104).

Three Levels of Flexibility

There are hundreds of ways to organize the content of this course to fit the needs of different instructors having a wide variety of professional backgrounds and 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 would 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 treated 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 2–7, which introduce basic science and ecological concepts. Instructors can then use the remaining chapters in any order desired. Some instructors follow Chapter 1 with Chapter 17 on environmental economics, politics, and worldviews before proceeding to the chapters on basic science and ecological concepts.

We provide a *second level of flexibility* in 9 Supplements (see pp. xii in the Detailed Contents and pp. S1–S44), which instructors can assign as desired to meet the needs of their specific courses. Examples include maps and graphs of global economic and environmental data (Supplement 3), maps of biodiversity and ecological footprints (Supplement 4), environmental history (Supplement 5), basic chemistry (Supplement 6), weather basics (Supplement 8), and graphs and maps related to energy resources (Supplement 9). These supplements contain 18 graphs and 14 U.S. and global maps (each with data analysis or map analysis questions) that make up a unique database of environmental information.

There is also a third level of flexibility. Instructors wanting to emphasize a mastery of basic environmental concepts and information can rely mostly on the detailed review questions at the end of each chapter. Those wanting students to go deeper can use any or all of the book's numerous critical thinking questions found in *Thinking About* boxes, in many figure captions, and at the end of each chapter. And those wanting students to do quantitative analysis can direct them to the chapter ending quantitative problems, and the problems in Supplements 3, 4, and 9.

Case Studies

In addition to the 17 Core Case Studies that are integrated through each chapter, 47 additional *Case Studies* (see pp. 14, 75, and 167) appear throughout the book. (See items in **BOLD** type in the Detailed Contents, pp. v–xii.) These case studies provide in-depth looks at specific environmental problems and their possible solutions.

Critical Thinking

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

- As 61 *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 at the end of chapter (see pp. 187, 219, and 250).
- In all *Science Focus* boxes
- In the captions of most of the book's figures (see Figures 7-13, p. 133; 11-A, p. 265; and 15-5, p. 374).
- As 57 *How Would You Vote?* exercises (see pp. 173, 184, and 221).
- As 50 *Connections* boxes that stimulate critical thinking by exploring often surprising connections related to environmental problems (a new feature in this edition, see pp. 169, 183, and 220).
- As end-of-chapter questions (see pp. 92 and 271)

Visual Learning

This book contains more than 400 diagrams, about 130 of which are new or improved and updated in this edition. They are designed to present complex ideas in understandable ways relating to the real world. (See Figures 1-1, p. 5; 3-13, p. 51; and 4-2, p. 61). We have also carefully selected nearly 200 photographs—34 of them new to this edition—to illustrate key ideas. (See Figures 4-9, p. 70; 9-9, p. 184; and 16-14, p. 417). We have avoided the common practice of including numerous "filler" photographs that are not very effective or that show the obvious.

Finally, to enhance visual learning, 80 *CengageNOW* interactive animations, referenced in the text and diagrams, are available online. This and other features make CengageNOW a learning tool that can help students to assess their unique study needs through pretests, post-tests, and personalized learning plans. The animations are available at no extra cost with new copies of the book. Access may be purchased separately for use with used books. Another feature of this learning tool, *How Do I Prepare?*, allows students to review basic math, chemistry, and other refresher skills.

Major Changes in This Edition: A Closer Look

Major changes in this new edition include the following:

- Almost 40% new, improved, or updated figures (see Figures 1-1, p. 5; 1-5, p. 11; and 17-20, p. 450 for examples of new figures)
- 30% carefully selected new photographs (see Figures 3-1, p. 39; 5-1, p. 79; and 12-18, p. 286)
- Expansion of the sustainability theme built around the three **principles of sustainability** (Figure 1-1, p. 5 and the back cover of the student edition)
- 15 new chapter opening *Core Case Studies* (pp. 5, 178, and 344)
- Several new *Science Focus* boxes that provide greater depth on scientific concepts and on the work of environmental scientists (see pp. 82, 181, and 233)
- 50 *Connections* boxes that explore often surprising environmental connections (see pp. 162, 183, and 220)
- *Three Big Ideas*, a new feature at the end of each chapter that summarizes the most important ideas of each chapter (see pp. 149, 202, and 340)
- 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. (See pp. 144, 160, and 257.)
- Expanded *Review* section at the end of each chapter with comprehensive review questions that include all key terms in boldface (see pp. 77 and 92)

- A Data Analysis or Ecological Footprint Analysis exercise at the end of each chapter (see pp. 93, 177, and 205) and 128 additional exercises analyzing graphs or maps in the book's Supplements (see pp. S3, S11, and S13)
- More than 4,000 updates based on information and data published in 2006, 2007, 2008, and 2009
- Integration of material on the growing ecological and economic impacts of China throughout much of the book (see index citations for China)
- More than 100 new or expanded topics and features, including the tragedy of the commons (p. 9); IPAT model (p. 13); additional maps of global economic, population, hunger, health, and waste production data (Supplement 3, pp. S6–S13); additional energy resource and climate data maps (Supplement 9, pp. S38–S45); subsidies, resource use, and environmental degradation (p. 18); tipping points (p. 12 and throughout the text); scientific consensus over projected climate change (p. 27); tropical forest losses (p. 39); southern sea otters (p. 79 and throughout Chapter 5); mountains and climate (p. 127); polar bears and climate change (p. 152); vultures, wild dogs, and rabies (p. 162); disappearing honeybees (p. 167); effects of gray wolves on the Yellowstone ecosystem (p. 193); climate change and forest fires (p. 183); endangered marine turtles (p. 171 and About Cover Photo, p. iv); cod fishery collapse (p. 199); organic agriculture (p. 206 and throughout Chapter 10); perennial crops (p. 233); Brazil as a food superpower (p. 213); pesticides and organic foods (p. 226); harmful effects of using corn to produce ethanol fuel (pp. 208 and 220); Colorado River (pp. 238 and 246); deep aquifers (p. 245); smart cards and water conservation (p. 252); oil and bottled water (p. 262); LifeStraw water purifier (p. 262); environmental effects of gold mining (pp. 273 and 284); ecological restoration of mining sites (p. 286); coal consumption in China (p. 307); the growing problem of coal ash (p. 307); the clean coal campaign (p. 308); plug-in hybrid cars (p. 320); electric car (p. 320); saving energy in a home (p. 322); oil consumption and terrorism (p. 302); solar cell power plants (pp. 326–327); update on wind energy (pp. 330–331); birds and wind turbines (p. 331); updates on biodiesel (p. 333) and ethanol (p. 333) biofuels; BPA controversy (pp. 344 and 355); MRSA staph infections (p. 348); South Asia's brown cloud (p. 368); updates on projected climate change (pp. 385, 390, and 394); melting ice in Greenland (p. 390); projected flooding in Florida (p. 391); expanded coverage of carbon capture and storage (pp. 394–395); microlending and the Grameen Bank (p. 434); greening American campuses (p. 442); and a possible exponential growth change for the better (p. 450).

In-Text and Online 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. 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 (61 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 chapter key terms in boldface (p. 77), followed by a set of *Critical Thinking* (p. 77) questions to 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.

Qualified users of this textbook have access to the companion website for this book at

www.cengage.com/biology/miller

At this website they will find the following material for each chapter:

- *Learning Objectives* help guide student reading and study of each chapter.
- *Flash cards* allow students to test their mastery of each chapter's Terms and Concepts to Remember.
- *Chapter Tests* provide multiple-choice practice quizzes, with an additional comprehensive exam.
- *Essays and information* introduce a variety of environmental careers.
- *Further Readings* lists major books and articles consulted in writing each chapter and suggestions for articles, books, and websites that provide additional information.
- A brief *What Can You Do?* list addresses key environmental problems.
- *Web Links* offers an extensive list of websites with news, research, and images related to individual sections of the chapter.
- WebTutor on WebCT or Blackboard provides qualified adopters of this textbook with access to a full array of study tools, including flash cards (with audio), practice quizzes, online tutorials, and web links.
- Access to *InfoTrac® College Edition* for a full year for teachers and students using *new* copies of this textbook, provides a fully searchable online library that gives users access to complete environmental

articles from several hundred periodicals dating back over the past 24 years.

Other student learning tools include:

- *Audio Concepts for study and review*. Students can download these study aids containing concept reviews, key terms, questions, and study tips by chapter.
- *What Can You Do?* This guide is designed to help students evaluate their impact on the earth by helping them figure out their carbon footprint and ways to reduce that footprint. Every chapter gives students space to record the steps that they have taken toward this goal so they can track their progress.
- *Laboratory Manual*, by Edward Wells. This new manual includes a variety of laboratory exercises, workbook exercises, and projects, many of which require a minimum of sophisticated equipment.
- *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. Instructors can have this book bundled with the textbook. Please contact your Cengage Learning representative for details.

Supplements for Instructors

- *PowerLecture*. This DVD-ROM, free to adopters, allows you to create custom lectures using over 2,000 pieces of high-resolution artwork, images, and animations from *CengageNOW* and the Web, assemble database files, and create Microsoft® PowerPoint lectures using text slides and figures from the textbook. This program'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.
- *Transparency Masters and Acetates*. Includes 200 printed color acetates of art from the textbook and a CD with 300 electronic color acetates that you can use to create your own overhead transparencies. Free to adopters.
- *ABC Videos for Environmental Science*. These informative news stories, available on DVD, contain 45 short video clips of current news stories on environmental issues from around the world. Free to adopters.
- *Instructor's Manual*. This supplement has been updated and reorganized to help you prepare for your classes more easily. Free to adopters. Also available on PowerLecture.
- *Test Bank*. This test bank contains a variety of question types and will help you develop tests faster. Free to adopters. Also available on PowerLecture.
- *ExamView*. Allows an instructor to easily create and customize tests, see them on the screen exactly as they will print, and print them out.

Other Textbook Options

Instructors wanting 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: *Living in the Environment*, 16th edition (674 pages, Brooks/Cole, 2009); *Sustaining the Earth: An Integrated Approach*, 9th edition (339 pages, Brooks/Cole, 2009); and *Essentials of Ecology*, 5th edition (274 pages, Brooks/Cole, 2009).

Help Us Improve This Book

Let us know how you think this book can be improved. If you find any errors, bias, or confusing explanations, please e-mail us about them at

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Most errors can be corrected in subsequent printings of this edition, as well as in future editions.

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Guest Essayists and Reviewers

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; **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; **Donald Worster**, environmental historian and professor of American history, University of Kansas.

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G. Tyler Miller, Jr.

G. Tyler Miller, Jr., has written 58 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 Ph.D. from the University of Virginia and has received two honorary doctorate degrees for his contributions to environmental education. He taught college for 20 years and developed an innovative interdisciplinary undergraduate science program before deciding to write environmental science textbooks full time since 1975. Currently, he is the President of Earth Education and Research, which is 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.

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 complex field of environmental science. I share Tyler's passion for insuring that these textbooks are valuable tools for students and instructors. This is probably the most exciting time in history for students who want to begin an environmental career. Environmental problems are 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 earth.

I am especially grateful to my family for their generous support. My wife, environmental educator Gail Martinelli, provided good ideas and information for this new edition. My children, Will and Katie, give me inspiration and plenty of (often helpful) daily diversions. To them, I dedicate my work on these books.

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 188 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 the 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 and 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—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. 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 key questions explored in the chapter sections and the corresponding key concepts, which are the critical lessons to be learned in the chapter. Use this list as a chapter roadmap. When you finish a chapter you can also use it 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 being 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 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 each chapter. Writing out your answers to the critical thinking and review questions can reinforce your learning. Save your answers for review and preparation for tests.

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 get 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 nurture feelings of realistic optimism, which can be energizing, and avoid immobilizing feelings of pessimism. This will keep you 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: Becoming a Good Baloney Detector

Critical thinking involves developing skills for analyzing information and ideas, judging their validity, and making 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 making 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 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? 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 (*reliable science*, p. 26) or on preliminary scientific results that may be valid but need further testing (*tentative* or *frontier science*, p. 26)? Is the information based on a few isolated stories or experiences (*anecdotal information*) or on carefully controlled studies with the results reviewed by experts in the field involved (*peer review*)? Is it based on unsubstantiated and dubious scientific information or beliefs (*unreliable science*, p. 26)?

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 can disprove things but they cannot establish absolute proof or certainty. However, the reliable results of science have a high degree of certainty.

Do the arguments used involve logical fallacies or debating tricks? Here are six of many examples. *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, but they can often establish high degrees of certainty, as discussed on p. 27). *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, 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. 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 put it, "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—at the end of each chapter, throughout each chapter in brief boxes labeled *Thinking About*, and in the captions of many figures. 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 from 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 the brain is good at visualizing, synthesizing, and creating. Our goal 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, rest, meditate, take a walk, exercise, or do something to shut down your controlling left-brain activity and 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, advantages and disadvantages of various technologies and proposed solutions to environmental problems, and good and bad news about environmental problems without injecting personal bias.

Studying a subject as important as environmental science and ending up with no conclusions, opinions, or 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 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 and point out any bias, correct any errors you find, and suggest ways to improve this book. Please e-mail your suggestions to Tyler Miller at **mtg89@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

It's All About Sustainability

CORE CASE STUDY

Sustainability—the central integrating theme of this book—is the ability of the earth's various natural systems and human cultural systems and economies to survive and adapt to changing environmental conditions indefinitely.

Why should we care about sustainability? Answer: because we are a species in the process of rapidly degrading our own life support system. In 2005, the United Nations *Millennium Ecosystem Assessment*, a 4-year study by 1,360 environmental experts from 95 countries 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."

Scientific research reveals that life on the earth has sustained itself for at least 3.5 billion years despite being subjected to catastrophic changes in environmental conditions. These changes included collisions between the earth and gigantic meteorites, ice ages lasting for hundreds of millions of years, and warming periods during which melting ice raised sea levels and flooded vast areas.

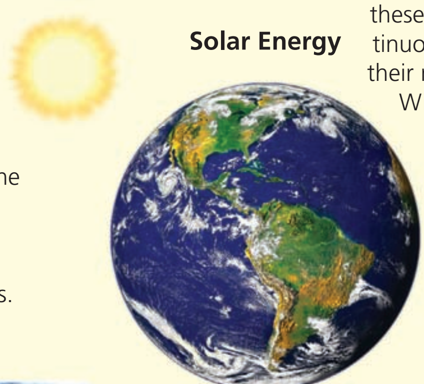
Our species has been around for less than an eye blink of the billions of years that life has existed on the earth. With our big and complex brains we are a very *smart* species. Within only a few hundred years, we have learned how to take over most of the earth to support our basic needs and rapidly growing wants. But it remains to be seen whether we are a *wise* species. 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 for 3.5 billion years. Our research leads us to believe that the long-term sustainability of life on this planet in the face of drastic environmental changes has depended on three key factors: *solar energy*, *biodiversity*, and *chemical cycling*, as summarized in Figure 1-1. These 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 provides energy that plants use to produce food for themselves and for us and most other animals. 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 can be used to produce electricity.
- **Biodiversity** (short for *biological diversity*): It includes the astounding variety of different organisms; the deserts, grasslands, forests, oceans, and other systems in which they exist and interact; and the free natural services, such as soil renewal, pest control, and air and water purification, that these species and systems provide. Without biodiversity, most life would have been wiped out long ago.
- **Chemical Cycling**: Natural processes recycle *nutrients*, or chemicals that plants and animals need to stay alive and reproduce. Because the earth gets no new shipments of these chemicals, they must be continuously cycled from organisms to their nonliving environment and back. Without chemical cycling, there would be no air, no water, no soil, no food, and no life.

Each of us has a role to play in making a transition to more sustainable ways of living during your lifetime. Join us in this exciting adventure.

Solar Energy



Chemical Cycling

Biodiversity

Figure 1-1 *Three principles of sustainability*: These three interconnected principles of sustainability are derived 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. Globe photo used by permission. Image copyright Ragnarock, 2009. Used under license from Shutterstock.com.

Key Questions and Concepts*

1-1 What is an environmentally sustainable society?

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

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

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

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

1-3 What is pollution, and what can we do about it?

CONCEPT 1-3 Preventing pollution is more effective and less costly than cleaning up pollution.

1-4 Why do we have environmental problems?

CONCEPT 1-4 Major causes of environmental problems are population growth, poverty, affluence based on wasteful and unsustainable resource use, and exclusion of harmful environmental costs from the market prices of goods and services.

1-5 How can we live more sustainably?

CONCEPT 1-5 We can live more sustainably by relying more on solar energy, preserving biodiversity, and not disrupting the earth's natural chemical recycling processes.

Note: Supplements 3 (p. S6), 4 (p. S14), and 5 (p. S21) can be used with this chapter.

*This is a *concept-centered* book, with each major chapter section 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 list 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 Is an Environmentally Sustainable Society?

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

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

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 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, political science; and the *humanities*, including 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 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 with their environment. Every organism is a member of a certain **species**: a group of organisms that have distinctive traits and, for sexually reproducing organisms, can mate and produce fertile offspring. A major focus of ecology is the study of ecosystems. An **ecosystem** is a set of organisms within a defined area or volume

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. CONCEPT LINK indicates links to key concepts in earlier chapters. GOOD NEWS refers to good news about the environmental challenges we face.

interacting 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 decomposers that recycle its chemicals, all interacting with one another and with solar energy and the chemicals in its 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.

Sustainability Is the Central Theme of This Book

In economic terms, **capital** is money and other forms of wealth that can be used to support one's lifestyle, providing a sustainable income if used properly, and an economy.

A critical component of sustainability (**Core Case Study***) is **natural capital**—the natural resources and natural services that keep us and other forms of life alive and support our economies (Figure 1-2).

CORE CASE STUDY

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

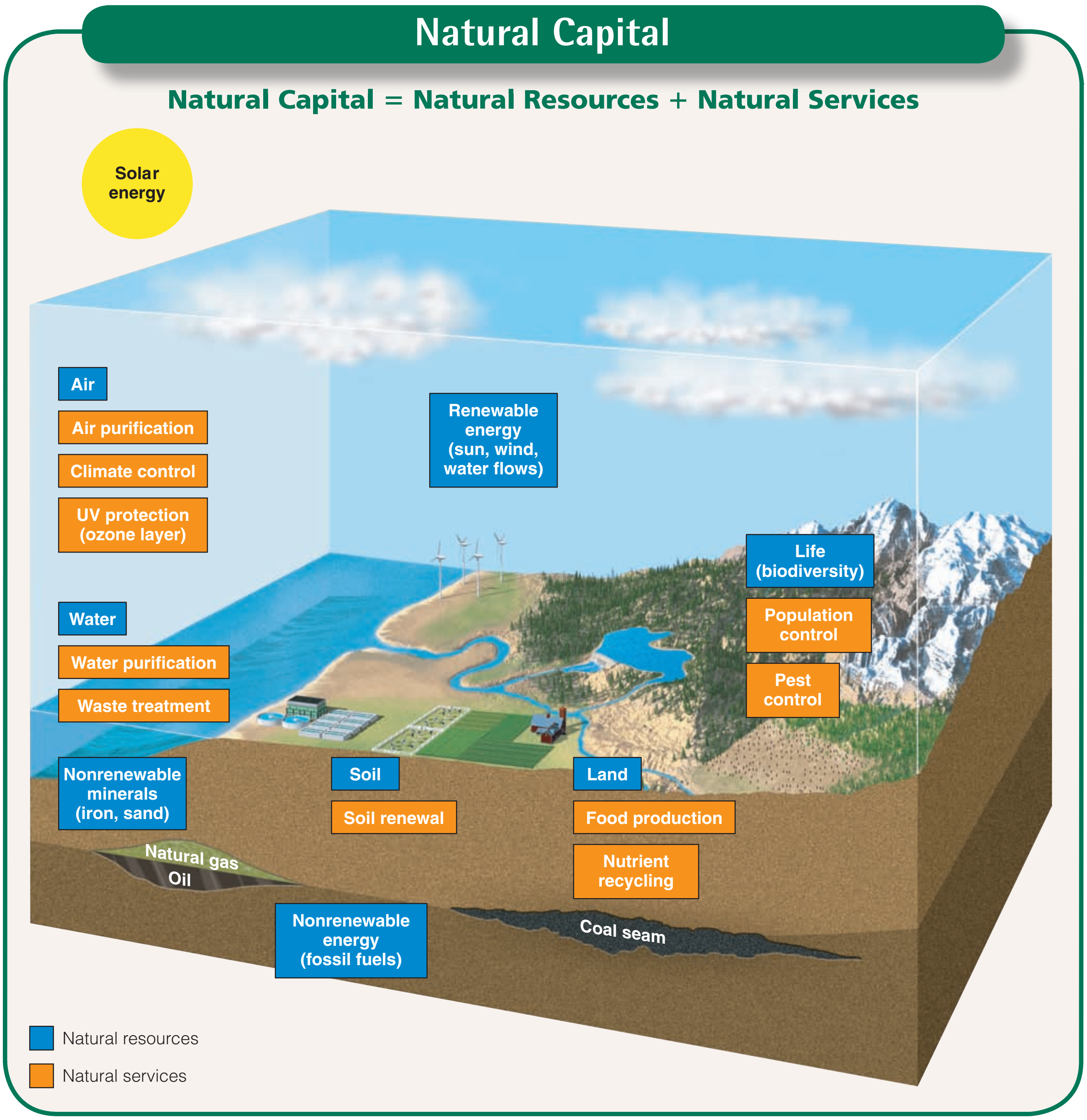


Figure 1-2 *Key natural resources* (blue) and *natural services* (orange) that support and sustain the earth's life and economies (**Concept 1-1A**).

Natural resources are materials and energy in nature that are essential or useful to humans. These resources are often classified as *renewable* (such as air, water, soil, plants, and wind) or *nonrenewable* (such as copper, oil, and coal). **Natural services** are processes in nature such as purification of air and water, which support life and human economies. The earth's biodiversity of species, ecosystems, and interacting components provide us with these essential services at no cost. We can use technology to enhance such services but there are no substitutes for them.

One vital natural service is **nutrient cycling**, the circulation of chemicals necessary for life, from the environment (mostly from soil and water) through organisms and back to the environment (**Core Case Study**, Figures 1-1 and 1-3). *Topsoil*, the upper layer of the earth's crust, is the vital natural resource that provides the nutrients that support the plants, animals, and microorganisms living on land. Without this service, life on land as we know it could not exist.

CORE CASE STUDY

Natural capital is supported by energy from the sun. (Figures 1-1 and 1-2). Take away solar energy and natural capital, and the life it supports would collapse. Solar energy warms the planet and supports *photosynthesis*—a complex chemical process that plants use to provide food for themselves and for us and most other animals. This direct input of solar energy also produces indirect forms of solar energy such as wind, flowing water, and biofuels made from plants and plant residues. Thus, our lives and economies depend on energy from the sun and natural resources and natural services (*natural capital*) provided by the earth (**Concept 1-1A**).

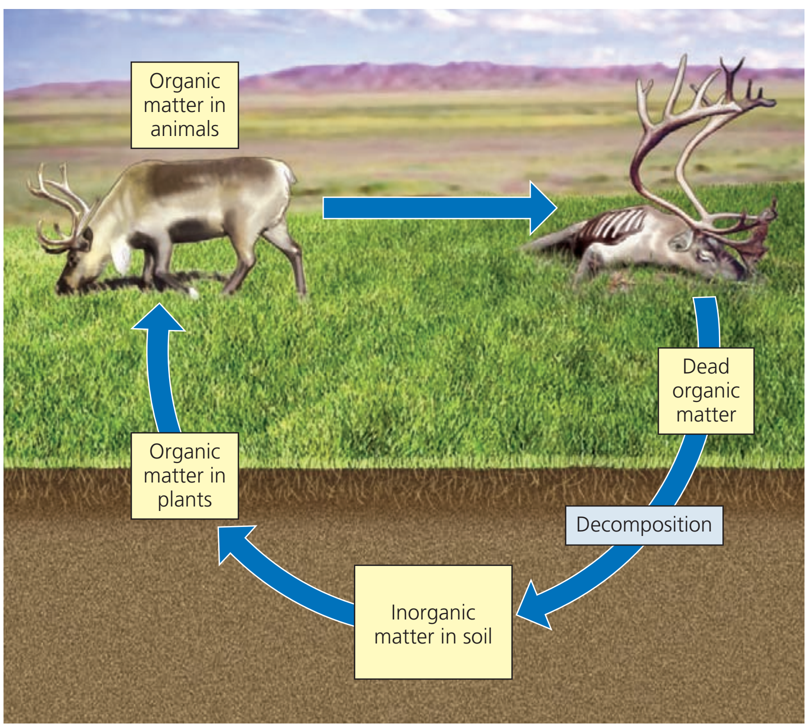


Figure 1-3 *Nutrient cycling*: an important natural service that recycles chemicals needed by organisms from the environment (mostly from soil and water) through organisms and back to the environment.

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 renew them. For example, in parts of the world we are clearing mature forests much faster than they can grow back and eroding topsoil faster that nature can renew it. We are also harvesting many species of ocean fish faster than they can replenish themselves.

This leads us to a third component of sustainability: *solutions*. While environmental scientists search for solutions to problems such as the unsustainable degradation 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, scientific solutions to problems of depletion of trees and fishes might be to stop chopping down biologically diverse, mature forests and to harvest species of fish no faster than they can replenish themselves. But implementing such solutions would probably require government laws and regulations.

The search for solutions often involves conflicts. When a scientist argues for protecting a diverse natural forest to help prevent the premature extinction of various life forms, 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—consisting of neat rows of a particular tree species—in an area that had already been cleared or degraded, in exchange for preserving the more diverse natural forest.

A shift toward environmental sustainability 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. In making such a shift, *individuals matter*—another sustainability subtheme of this book. Some people are good at thinking of new scientific ideas and inventing innovative technologies or solutions. Others are good at putting political pressure on government officials and business leaders, acting either alone or in groups to implement those solutions. In any case, a shift toward sustainability for a society ultimately depends on the actions of individuals within that society, beginning with how and where they live. In the final analysis, *sustainability begins at personal and local levels*.

Environmentally Sustainable Societies Protect Natural Capital and Live Off Its Income

The ultimate goal is 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.

Imagine you win $1 million in a lottery. Suppose you invest this money (your capital), earn 10% interest per year, and allow the interest to accumulate. If you live on just the interest, or income on your capital, you will have a sustainable annual income of at least $100,000 that you can spend each year indefinitely without depleting your capital. However, if you spend $200,000 per year, while 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 provides for us, our children, our grandchildren, and the earth's other species, which help to support us and our economies. *Living sustainably* means living on **natural income**, the renewable resources such as plants, animals, and soil provided by the earth's natural capital.

RESEARCH FRONTIER*

Crash program to gain 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/biology/miller**.

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/biology/miller**.

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

** 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 how you voted with others using this book throughout the United States.

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

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

Some Resources Are Renewable

From a human standpoint, a **resource** is anything obtained from the environment to meet our needs and wants. Some resources such as solar energy, fresh air, fertile soil, and wild edible plants are directly available for use. Other resources such as petroleum, iron, underground water, and cultivated crops are not directly available. They become useful to us only with some effort and technological ingenuity. For example, petroleum was a mysterious fluid until we learned how to find, extract, and convert it into gasoline, heating oil, and other products that could be sold.

Solar energy is called a **perpetual resource** because it is renewed continuously and is expected to last at least 6 billion years as the sun completes its life cycle.

Some resources are renewable. Others are not. A **renewable resource** can be replenished in days to several hundred years through natural processes as long as it is not used up faster than it is renewed. Examples include forests, grasslands, fish populations, freshwater, fresh air, and fertile soil. The highest rate at which a renewable resource can be used indefinitely without reducing its available supply is called its **sustainable yield**. When use of a renewable resource exceeds its natural replacement rate, the available supply begins to shrink, a process known as **environmental degradation**, as shown in Figure 1-4 (p. 10). Such degradation of the natural capital provided by renewable resources is an example of unsustainable living.

Renewable Resources and the Tragedy of the Commons

Some renewable resources can be used by almost anyone. Examples are fresh air, underground water supplies, the earth's climate, and the open ocean and its fish.

We are environmentally degrading many openly shared renewable resources. 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 renewable resource

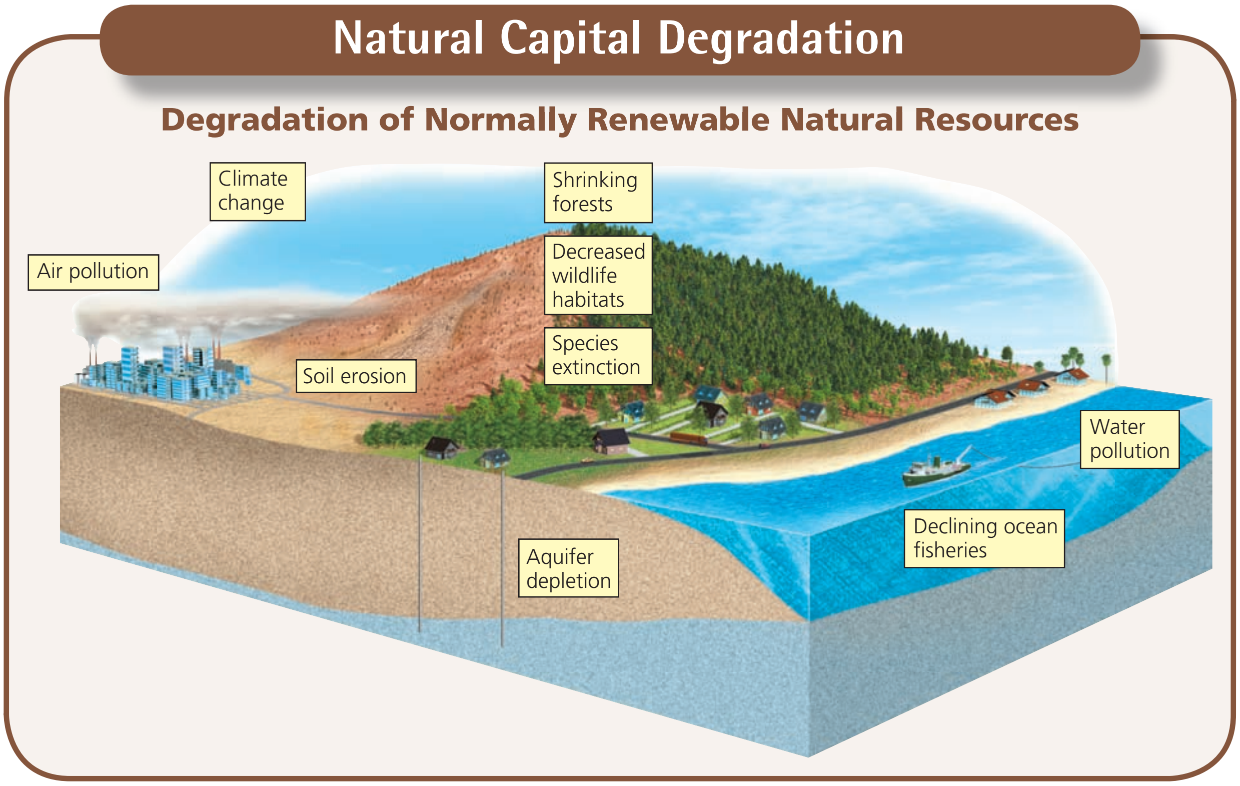


Figure 1-4 Degradation of normally renewable natural resources and services in parts of the world, mostly as a result of rising population and resource use per person.

can exhaust or ruin it. Then no one can benefit from it. That is the tragedy.

There are two major ways to deal with this difficult problem:

- *Use shared renewable resources at rates well below their estimated sustainable yields* by reducing use of the resources, regulating access to the resources, or doing both. For example, governments can establish laws and regulations limiting the annual harvests of various types of ocean fish that are being harvested at unsustainable levels.
- *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 sounds good, but this approach is not practical for global open-access resources such as the atmosphere and the open ocean, which cannot be divided up and sold as private property.

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 (**Core Case Study**). CORE CASE STUDY

In many parts of the world, potentially renewable forests are shrinking, deserts are expanding, soils are eroding, and agricultural lands are being replaced by suburban developments. In addition, the lower atmosphere is warming, glaciers are melting, sea levels are rising, and floods, droughts, and forest fires are increasing. In many areas, potentially renewable water tables are falling, rivers are running dry, fisheries are collapsing, coral reefs are disappearing, and various species are becoming extinct.

The good news* is that we have solutions to these problems that we could implement within a few decades, as you will learn in this book. GOOD NEWS

Ecological Footprints: A Model of the Unsustainable Use of Renewable Resources

Supplying people with renewable resources and producing the resulting wastes and pollution can have a large environmental impact. We can think of it as an **ecological footprint**—the amount of biologically productive land and water needed to indefinitely supply the people in a particular country or area with renewable resources and to absorb and recycle the wastes and pollution produced by such resource use. 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

* There is a lot of bad environmental news. But there is also plenty of good environmental news, as indicted by this logo used throughout this book.

renewable resources and 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 (**Concept 1-1B**). In 2008, the World Wildlife Fund (WWF) and the Global Footprint Network estimated that humanity's global ecological footprint exceeded the *earth's* ecological capacity to indefinitely support humans and other forms of life by at least 30% (Figure 1-5, left). That figure was about 88% in high-income countries such as the United States.

In other words, humanity needs the equivalent of about 1.3 earths to indefinitely supply the current average use of renewable resources per person and to dispose of the resulting pollution and wastes. If the number of people and the average use of renewable resources per person continue growing as projected, by around 2035 supplying such resources indefinitely will require the equivalent of two planet earths (Figure 1-5, right) (**Concept 1-2**). (See Figure 3, p. S18, in Supplement 4 for a map of the human ecological footprints for the world, and Figure 4, p. S20, in Supplement 4 for a map of countries that are ecological debtors and those that are ecological creditors. For more on this subject see the Guest Essay by Michael Cain at CengageNOW™.)

According to William Rees and Mathis Wackernagel, the developers of the ecological footprint concept, 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 with existing technology. 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 6.8 billion. At current levels of resource consumption, the land area of the United States could sustain indefinitely about 186 million people. The actual U.S. population in 2009 was 306 million—64% higher than the nation's estimated natural ecological capacity.

THINKING ABOUT
Your Ecological Footprint

Estimate your own ecological footprint by visiting the website **www.myfootprint.org/**. What are three things you could do to reduce your ecological footprint?

One problem that we face 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

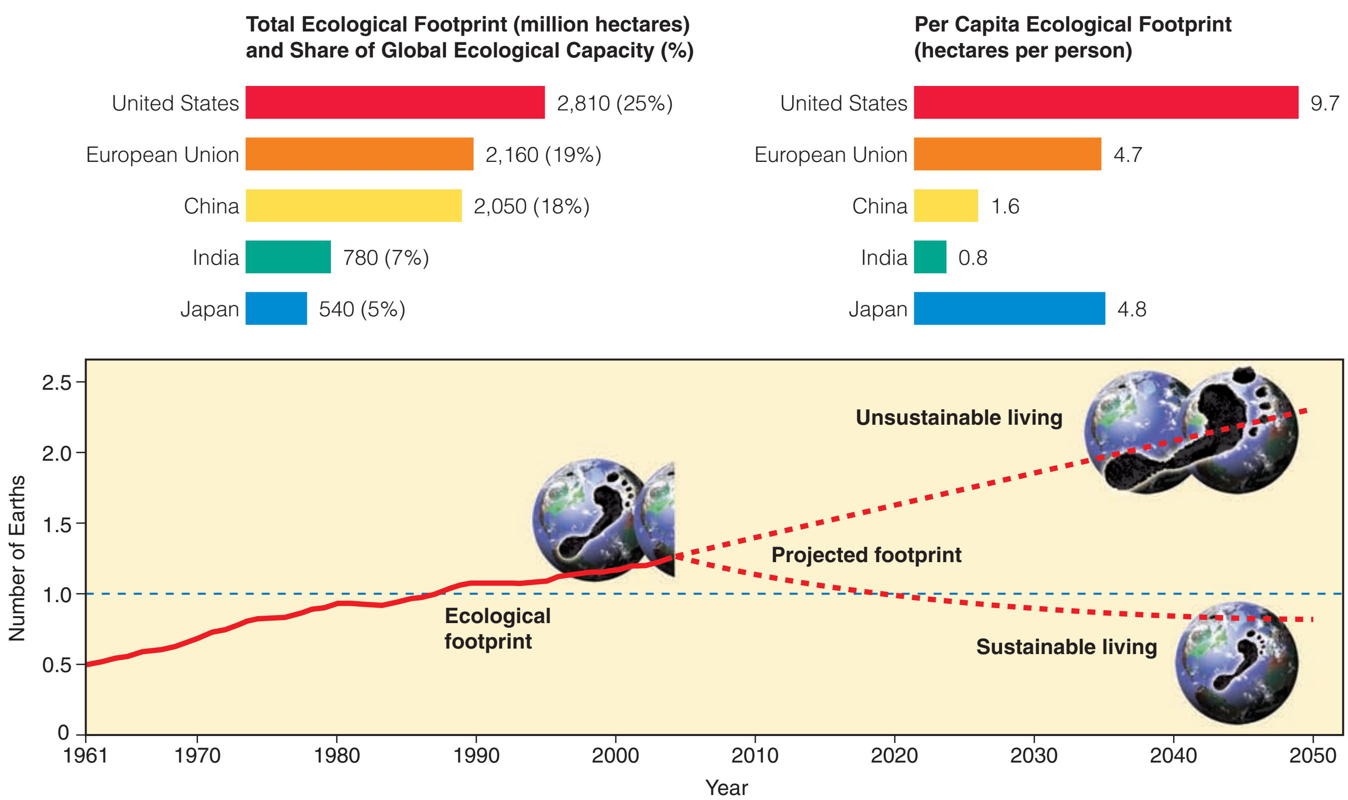


Figure 1-5 **Natural capital use and degradation:** total and per capita ecological footprints of selected countries (top). In 2008, humanity's total, or global, ecological footprint was at least 30% higher than the earth's ecological capacity (bottom) and is projected to be twice the planet's ecological 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/)

until it reaches a *threshold level*, or **ecological tipping point**, which causes an often irreversible shift in the behavior of a natural system.

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

Some Resources Are Not Renewable

Nonrenewable resources exist in a fixed quantity, or *stock*, in the earth's crust. On a time scale of millions to billions of years, geological processes can renew such resources. But on the much shorter human time scale, these resources can be depleted much faster than they are formed. Such exhaustible resources 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 nonrenewable resources are depleted, 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 fossil fuels such as oil and coal. Also, various types of plastics and other synthetic materials can replace certain nonrenewable metals. But sometimes there is no acceptable or affordable substitute.

Some nonrenewable resources such as copper and aluminum can be recycled or reused to extend supplies. **Reuse** means using a resource over and over in the same form. For example, glass bottles can be collected, washed, and refilled many times (Figure 1-6). **Recycling** involves collecting waste materials and processing them into new materials. For example, discarded aluminum cans can be crushed and melted to make new aluminum cans or other aluminum products. But energy resources such as oil and coal cannot be recycled. Once burned, their high-quality energy is no longer available to us.

Recycling nonrenewable metallic resources takes much less energy, water, and other resources and produces much less pollution and environmental degradation than exploiting virgin metallic resources. Reusing such resources takes even less energy and other resources and produces less pollution and environmental degradation than recycling. From an environmental and sustainability viewpoint, the priorities in the use of nonrenewable resources such as metals and plastics more sustainably should be: **R**educe (use less), **R**euse, and **R**ecycle. These are known as the 3Rs of more sustainable use of nonrenewable resources.

Image not available due to copyright restrictions

Rich and Poor Countries Have Different Environmental Impacts

The United Nations classifies the world's countries as economically developed or developing based primarily on their average income per person. The high-income **developed countries** include the United States, Canada, Japan, Australia, New Zealand, and most countries of Europe. According to U.N. and World Bank data, the developed countries, with only 18% of the world's population, use about 88% of the world's resources and produce about 75% of the world's pollution and waste.

All other nations, where 82% of the world's people live, are classified as **developing countries**. Some are *middle-income, moderately developed countries* such as China, India, Brazil, Thailand, and Mexico. Others are *low-income, least developed countries* such as Congo, Haiti, Nigeria, and Nicaragua. (See Figure 2, p. S6, in Supplement 3 for a map of high-, upper middle-, lower middle-, and low-income countries.)

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. This model can be summarized by the simple equation $I = P \times A \times T$.

$$\text{Impact (I)} = \text{Population (P)} \times \text{Affluence (A)} \times \text{Technology (T)}$$

Figure 1-7 shows the relative importance of these three factors in developing and 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.

In most developing countries, the key factors in total environmental impact (Figure 1-7, top) are population size and the degradation of renewable resources as a growing number of poor people struggle to stay alive. In such countries, per capita resource use is low. In developed countries, high rates of per capita resource use and the resulting high levels of pollution and resource depletion and degradation per person usually are the key factors determining overall environmental impact (Figure 1-7 bottom).

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*.

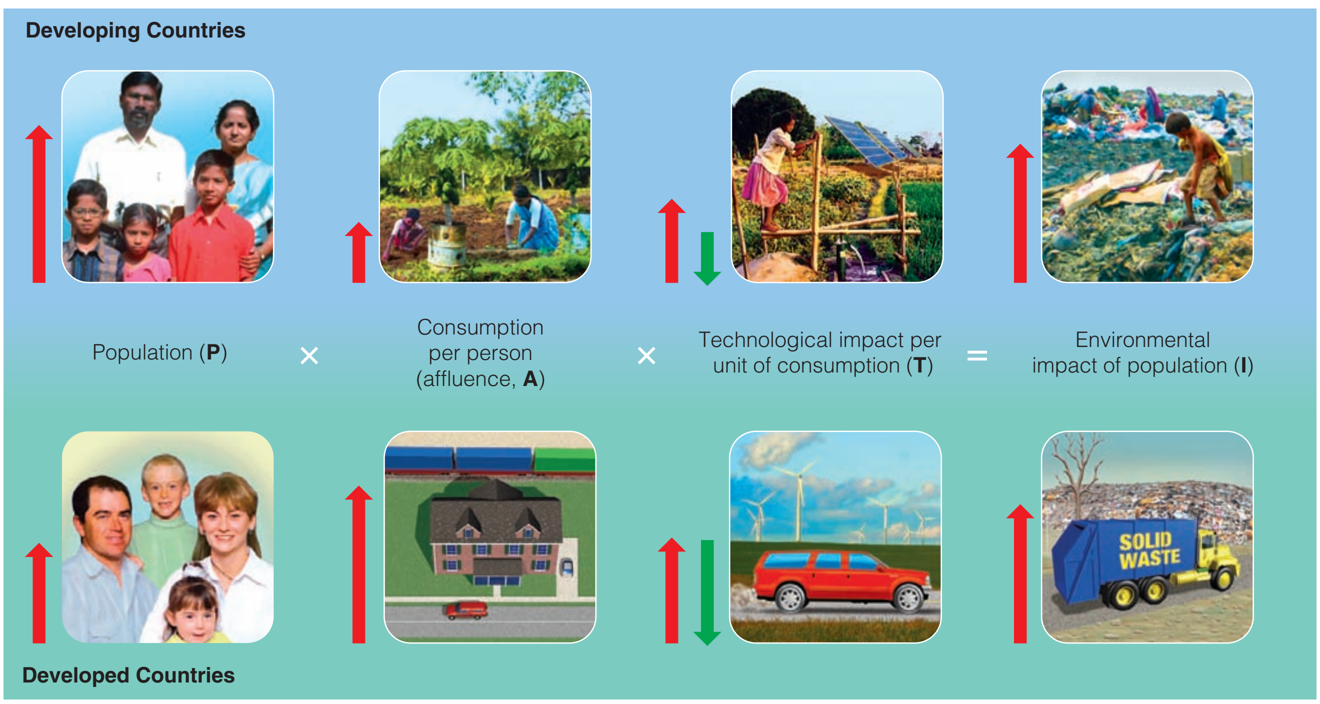


Figure 1-7 *Connections*: simple model of how three factors—number of people, affluence (resource use per person), and technology—affect the environmental impact of populations in developing countries (top) and developed countries (bottom). While many people in affluent countries over-consume, many poor people in developing countries suffer from not having enough resources.

■ CASE STUDY
China's New Affluent Consumers

More than a billion super-affluent consumers in developed countries are putting immense pressure on the earth's potentially renewable natural capital and its nonrenewable resources. And more than a billion new consumers are attaining middle-class, affluent lifestyles in 20 rapidly developing middle-income countries such as China, India, Brazil, South Korea, and Mexico.

Currently, the number of middle-class consumers in China is roughly equal to the size of the entire U.S. population. By 2015, the World Bank projects that China is likely to have 650 million middle-class consumers (more than twice the current U.S. population) and to have the world's leading economy.

According to environmental policy expert Lester R. 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 the growing ecological footprint of China, see the Guest Essay by Norman Myers for this chapter at CengageNOW.

1-3 What Is Pollution and What Can We Do about It?

CONCEPT 1-3 Preventing pollution is more effective and less costly than cleaning up pollution.

Pollution Comes from a Number of Sources

Pollution is contamination of the environment by a chemical or other agent such as noise or heat that is harmful to health, survival, or activities of humans or other organisms. Polluting chemicals can enter the environment naturally, such as from volcanic eruptions, or through human activities, such as burning coal and gasoline and dumping chemicals into rivers and the ocean.

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 1-8 and Photo 1 in the Detailed Contents), the drainpipe of a factory (Photo 2 in the Detailed Contents), 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 and pesticides from farmlands, lawns, gardens, and golf courses into streams and lakes. It is much easier and cheaper to identify and control or prevent pollution from point sources than from widely dispersed nonpoint sources.

Ray Pfortner/Peter Arnold, Inc.

Figure 1-8 *Point-source air pollution* from a pulp mill in New York State (USA).

We Can Clean Up Pollution or Prevent It

Consider the smoke produced by a steel mill. We can try to deal with this air pollution problem by asking two entirely different questions. One question is "how can we clean up the smoke?" The other is "how can we avoid producing the smoke in the first place?"

The answers to these questions involve two different ways of dealing with pollution. One is **pollution cleanup**, which involves cleaning up or diluting pollutants after they have been produced. The other is **pollution prevention**, 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*, perhaps causing air pollution and leaving toxic ash that must be put somewhere; *dumped* on the land, perhaps causing water pollution through runoff or seepage into groundwater; or *buried*, perhaps 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.

Pollution cleanup (end-of-the-pipe) and pollution prevention (front-of-the-pipe) solutions are both needed. 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 (**Concept 1-4**). In other words, making a shift to more sustainable living will require much greater reliance on pollution prevention to keep from upsetting the earth's chemical cycling processes in keeping with one of the three **principles of sustainability** (Figure 1-1).

1-4 Why Do We Have Environmental Problems?

▶ **CONCEPT 1-4 Major causes of environmental problems are population growth, poverty, affluence based on wasteful and unsustainable resource use, and exclusion of harmful environmental costs from the market prices of goods and services.**

Experts Have Identified Four Basic Causes of Environmental Problems

According to various environmental experts, there are four major causes of the environmental problems we face (Figure 1-9).

We discuss all of these causes in detail in later chapters in this book. 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 or pollution increases at a fixed percentage per unit of time, for example, 2% per year. Exponential growth starts off slowly. But after only a few doublings, it grows to enormous numbers because each doubling is twice the total of all earlier growth.

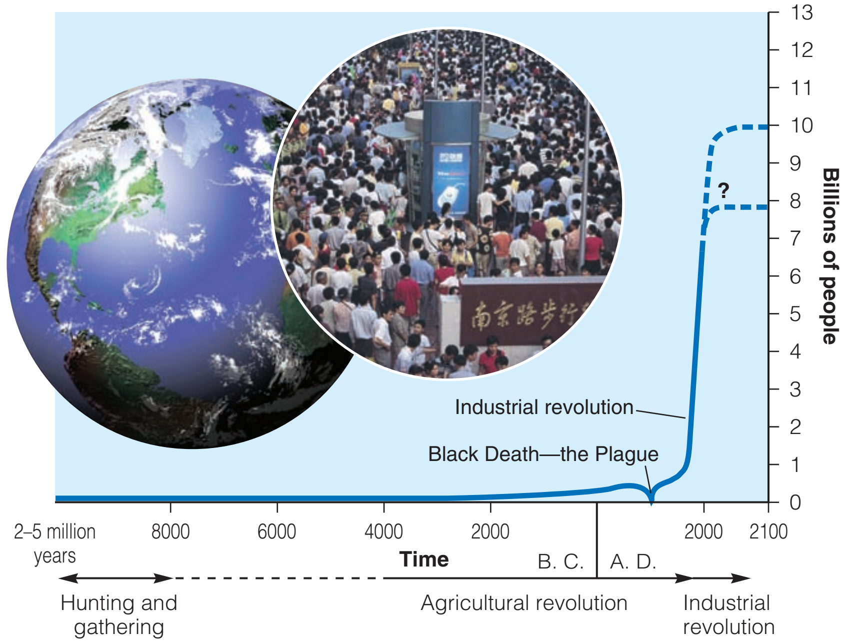
Here is an example of the immense power of exponential growth. Fold a piece of paper in half to double its thickness. If you could continue doubling the thickness of the paper only 50 times, it would be thick enough to reach almost to the sun—149 million kilometers (93 million miles) away! Hard to believe,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

Because of exponential growth in the human population (Figure 1-10, p. 16), in 2009 there were about 6.8 billion people on the planet. Collectively, these people consumed vast amounts of food, water, raw materials, and energy, and in the process produced huge amounts of pollution and wastes. Unless death rates rise sharply, there will probably be 9.3 billion of us by 2050. This projected addition of 2.5 billion more people within your lifetime is equivalent to about 8 times the current U.S. population and more than twice that of China, the world's mot populous nation.

The exponential rate of global population growth has declined some since 1963. Even so, each day we add an average of 227,000 more people on

Figure 1-9 Environmental and social scientists have identified four basic causes of the environmental problems we face (**Concept 1-4**). **Question**: What are two environmental problems that result from each of these causes?

Figure 1-10 *Exponential growth*: the *J*-shaped curve of past exponential world population growth, with projections to 2100 showing possible population stabilization with the J-shaped curve of growth changing 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)



the earth. This is roughly equivalent to adding a new U.S. city of Los Angeles, California, every 2 months, 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 consumption or affluence, without seriously degrading the ability of the planet to support us and other forms of life and our economies. But the world's expanding total and per capita ecological footprints (Figure 1-5) are disturbing warning signs.

Poverty Has Harmful Environmental and Health Effects

Poverty occurs when people are unable to meet their basic needs for adequate food, water, shelter, health, and education (Figure 1-11). According to 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* 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). The good news is that the number of people living in extreme poverty has decreased by 500 million since 1981. GOOD NEWS

Poverty has a number of harmful environmental and health effects (Figure 1-12). The daily lives of the world's poor are focused on getting enough food, water, and cooking and heating fuel to survive. Desperate for short-term survival, some of these individuals degrade forests, soil, 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 developing countries have no choice but to use few resources per person, their large population size leads to a high overall environmental impact (Figure 1-7, top).

Sean Sprague/Peter Arnold, Inc.

Figure 1-11 *Extreme poverty*: This boy is searching in 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.

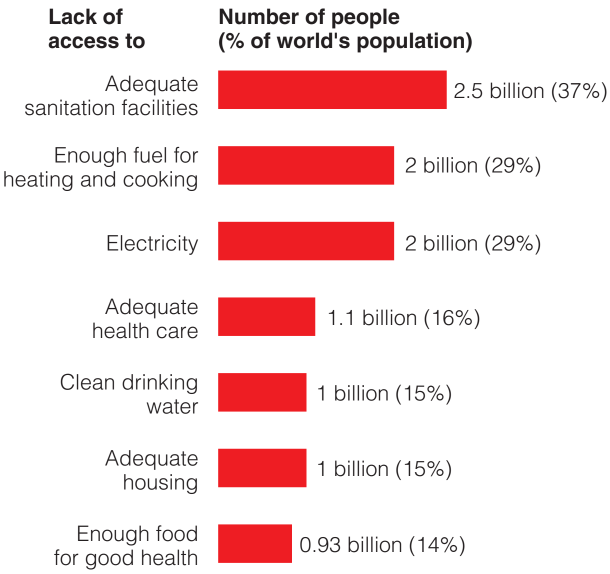


Figure 1-12 Some harmful results of poverty. **Questions**: Which two of these effects do you think are the most harmful? Why? (Data from United Nations, World Bank, and World Health Organization)

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 (which is their 40s or 50s in the poorest countries) because they do not have social security, health care, and retirement funds.

Many of the world's poor people die prematurely from preventable health problems. One such problem is *malnutrition* from a lack of protein and other nutrients needed for good health (Figure 1-13). Their resulting weakened condition can increase their chances of death from normally nonfatal diseases.

A second problem is limited access to adequate sanitation facilities and clean drinking water. More than 2.5 billion people—more than 8 times the population of the United States—have no decent bathroom facilities. They are forced to use backyards, ditches, and streams. As a result, a large portion of these 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 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.

According to the World Health Organization, factors such as those shown in Figures 1-12 and 1-13 cause premature death for at least 7 million people each year. *This number of premature deaths—about 19,200 per day—is equivalent to 96 fully loaded 200-passenger airliners crashing every day with no survivors!* Two-thirds of those dying are children younger than age 5. The daily news rarely covers this ongoing human tragedy. The *great news* is that we have the means to solve the environmental, health, and social problems resulting from poverty within 20–30 years if we can find the political and ethical will to act.

Affluence Has Harmful and Beneficial Environmental Effects

The harmful environmental impacts of poverty are serious, especially in terms of human health, but so are the impacts of the large ecological footprints of individuals in affluent nations (Figure 1-5, top).

The U.S. population is almost one-fourth that of India. But the average American consumes about 30 times as much as the average citizen of India consumes and 100 times as much as the average person in the world's poorest countries consumes. 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 developing countries (Figure 1-5, top and Figure 1-7, bottom).

Tom Koene/Peter Arnold, Inc.

Figure 1-13 *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 13,700 children younger than age 5 die prematurely from malnutrition and infectious diseases, mostly caused by their drinking contaminated water.

For example, according to some ecological footprint calculators, it takes about 27 tractor-trailer loads of resources per year to support one American, or 7.9 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 1-5). Some analysts say that shop-until-they-drop affluent consumers in the United States and elsewhere are afflicted with a social virus called *affluenza*.

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.

GOOD NEWS

In the United States and most other affluent countries, the air is cleaner, drinking water is purer, and most rivers and lakes are cleaner than they were in the 1970s. In addition, the food supply is larger and generally safer, the incidence of life-threatening infectious diseases has been greatly reduced, life spans are longer, and some endangered species are being rescued from premature extinction.

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. But a 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.

THINKING ABOUT

The Poor, the Affluent, and Exponentially Increasing Population Growth

CORE CASE STUDY

Some see rapid population growth of the poor in developing countries as the primary cause of our environmental problems. Others say that the much higher resource use per person in 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

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 not 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 products unless government regulations created an even economic playing field by using taxes or regulations to require all business to do so.

As a result, the prices of goods and services do not include their harmful environmental costs. So consumers have no effective way to evaluate harmful effects on the earth's life-support systems and on their own health resulting from production and delivery of the goods and services they buy.

Another problem is that governments (taxpayers) give companies tax breaks and payments called *subsidies* 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, again, because the value of the natural capital is not included in the market prices of goods and services. Indeed, environmentally harmful, or *perverse*, subsidies encourage the depletion and degradation of natural capital. (See the Guest Essay for this chapter about perverse subsidies by Norman Myers at CengageNOW.)

People Have Different Views about Environmental Problems and Their Solutions

Another challenge is that people differ over the seriousness of the world's environmental problems and what we should do about them. Such differences arise mostly out of differing environmental worldviews. Your **environmental worldview** is a 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. Worldviews involve **environmental ethics**, which are beliefs about what is right and wrong with how we treat the environment. 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 forms of life?
- Do we have an obligation to see that our activities do not cause the premature extinction of other species? Should we try to protect all species or only some? How do we decide which to protect?
- Do we have an ethical obligation to pass on to future generations the extraordinary natural world in a condition 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.)

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.

Environmental worldviews are discussed in detail in Chapter 17, 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. It also calls for encouraging earth-sustaining forms of economic growth and development and discouraging earth-degrading forms. According to this view, our success depends on learning how the earth sustains itself (Figure 1-1) and integrating such *environmental wisdom* into the ways we think and act.

We Can Work Together to Solve Environmental Problems

Solutions to environmental problems are not black and white, but rather all shades of gray, because proponents of all sides of these issues have some legitimate and useful insights. This means that citizens need to work together to find *trade-off solutions* to environmental problems—an important theme of this book.

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 from individuals acting together to bring about change through *bottom-up* grassroots action. In other words, *individuals matter*—another important theme of this book.

GOOD NEWS

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, 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."

1-5 How Can We Live More Sustainably? Three Big Ideas

▶ **CONCEPT 1-5 We can live more sustainably by relying more on solar energy, preserving biodiversity, and not disrupting the earth's natural chemical recycling processes.**

SUSTAINABILITY

Using the three **principles of sustainability** (Figure 1-1) to guide our lifestyles and economies can help us bring about an *environmental* or *sustainability revolution* during your lifetime. (See the Guest Essay by Lester R. Brown at CengageNOW.)

Scientific evidence indicates that we have perhaps 50 years and no more than 100 years to make such crucial cultural changes 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 and must choose a path toward sustainability (Figure 1-5, bottom curve) or continue on our current unsustainable course (Figure 1-5, top curve). One of the goals of this book is to provide a realistic environmental vision of the future that, instead of immobilizing you with fear, gloom, and doom, will energize you by inspiring realistic hope as you play your role in deciding which path to follow.

GOOD NEWS

Based on the three **principles of sustainability** (**Core Case Study** and Figure 1-1), we can use the following strategies to reduce our ecological footprints, help sustain the earth's natural capital, and make the transition to more sustainable lifestyles and economies. They 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 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.
- Do not disrupt the earth's natural chemical cycles by overloading them with harmful chemicals or by removing natural chemicals faster than the cycles can replace them. This requires relying more on pollution prevention and reducing the wasteful use of resources.

REVISITING 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 1-1) to the design of our economic and social systems and to our individual lifestyles. We can use such strategies to help slow human population growth, sharply reduce poverty, curb the unsustainable forms of resource use that are eating away at the earth's natural capital, and create a better world for ourselves, our children, and future generations.

If we make the right choices during this century, we can make 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.

You have the good fortune to be a member of the 21st century *transition generation* that will decide which path humanity takes. What a challenging and exciting time to be alive!

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**? Explain the terms **capital**, **natural capital**, **natural resources**, and **natural services**. Describe **nutrient cycling** and explain why it is important.
3. Describe the importance of finding solutions, making trade-offs, and carrying out individual actions in living more sustainably. Describe the ultimate goal of an **environmentally sustainable society**. What is **natural income**?
4. What is a **resource**? Distinguish between a **renewable resource** and a **perpetual resource** and give an example of each. What is **sustainable yield**? Define and give three examples of **environmental degradation**. What is the *tragedy of the commons*? 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 an **ecological tipping point**?
5. Define and give two examples of a **nonrenewable resource**. Distinguish between **recycling** and **reuse** and give an example of each. What are the 3Rs of more sustainable use of nonrenewable resources? Distinguish between **developed countries** and **developing countries** and give an example of a high-income, middle-income, and low-income country. What is the IPAT model for estimating our environmental impact? Explain how this model can be used to estimate the impacts of the human populations in developing and developed countries. Describe the environmental impacts of China's new affluent consumers.
6. Define **pollution**. Distinguish between **point sources** and **nonpoint sources** of pollution. Distinguish between **pollution cleanup** and **pollution prevention** and give

an example of each. Describe three problems with solutions that rely mostly on pollution cleanup.

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 **poverty** and what are three of its harmful environmental and health effects? Describe the connection between poverty and population growth. Describe the environmental harm and the environmental benefits of affluence. Explain how not including the harmful environmental costs in the prices of goods and services affects the environmental problems we face. What is the connection between government subsidies, resource use, and environmental degradation?

8. What is an **environmental worldview**? What are **environmental ethics**? Distinguish among the **planetary management**, **stewardship**, and **environmental wisdom worldviews**. Explain why individuals matter in dealing with the environmental problems we face.

9. How long do 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?

10. What are this chapter's *three big ideas*? Explain how the three **principles of sustainability** can be used to deal with the four major causes of the environmental problems we face.

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?

2. List two ways in which you could apply each of the three **principles of sustainability** (Figure 1-1) to making your lifestyle more environmentally sustainable.

3. For each of the following actions, state one or more of the three **principles of sustainability** (Figure 1-1) 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 things home in; **(e)** volunteering to help restore a prairie; and **(f)** lobbying elected officials to require that 20% of your country's electricity be produced by 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. Suppose the world's population stopped growing today. What environmental problems might this help solve? What environmental problems would remain? What economic problems might population stabilization make worse?

6. When you read that at least 19,200 people die prematurely 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. 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 help to perpetuate such problems, and which can help to solve them?

8. 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 us; **(d)** because all forms of life eventually become extinct 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.

9. What are the basic beliefs within your environmental worldview (p. 19)? Record your answer and perhaps put it into a sealed envelope. Then at the end of this course return to your answer to see if your environmental worldview has changed. Are the beliefs included in your environmental worldview consistent with your answers to question 8? 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 a country's or the world's *ecological footprint per person* (Figure 1-5) is larger than its *biological capacity per person* to replenish its renewable resources and absorb the resulting waste products and pollution, it is said to have an *ecological deficit*. If the reverse is true, it has an *ecological credit* or *reserve*. Use the data below to calculate the ecological deficit or credit for various countries. (For a map of ecological creditors and debtors see Figure 4, p. S20, in Supplement 4.)

Place	Per Capita Ecological Footprint (hectares per person)*	Per Capita Biocapacity (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

STUDENT COMPANION SITE Visit this book's website at **www.cengage.com/biology/miller** and choose Chapter 1 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, web links, information on Green Careers, and InfoTrac® College Edition articles.

CENGAGENOW™ For students with access, log on at **www.cengage.com/login** for the animations, active figures, activities, and readings indicated within the text by the CengageNOW logo. If your textbook did not come with access, visit **www.iChapters.com** to purchase.

Science, Matter, and Energy

2

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

CORE CASE STUDY

You learn that a logging company 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 the 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 when 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. Their 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 one that was 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 researchers 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 valleys. One winter, they cut down all the trees and shrubs in that valley (the experimental site), left them where they fell, and sprayed the area with herbicides to prevent the regrowth of vegetation. Then they compared outflow of water and nutrients in this experimental site (Figure 2-1, right) with those in the control site (Figure 2-1, left) for 3 years.

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 six to eight 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 world within and around us. You will also learn about three *scientific laws*, or rules of nature, that govern the changes that matter and energy undergo.

Figure 2-1 Controlled field experiment to measure 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. Then all the trees in the other valley (the experimental site, right) were cut and the flows of water and soil nutrients from this experimental valley were measured for 3 years.

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 and how do physical and chemical changes affect it?

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

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

2-3 What is energy and how do physical and chemical changes affect it?

CONCEPT 2-3A 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 2-3B 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).

Note: Supplements 1 (p. S2), 2 (p. S3), 5 (p. S21), and 6 (p. S26) 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 an attempt to discover how nature works and to use that knowledge to make predictions about what is likely to happen in nature. It is based on the assumption that events in the natural world follow cause-and-effect patterns in orderly ways that can be understood through careful observation, measurements, experimentation, and modeling. Figure 2-2 summarizes the scientific process.

There is nothing mysterious about this process. You use it all the time in making decisions. As the famous physicist Albert Einstein put it, "The whole of science is nothing more than a refinement of everyday thinking." Here is an example of applying the scientific process to an everyday situation:

Observation: You try to switch on your flashlight and nothing happens.

Question: Why didn't the light come on?

Hypothesis: Maybe the batteries are dead.

Test the hypothesis with an experiment: Put in new batteries and switch on the flashlight.

Result: Flashlight still does not work.

New hypothesis: Maybe the bulb is burned out.

Experiment: Replace bulb with a new bulb.

Result: Flashlight works when switched on.

Conclusion: Second hypothesis is verified.

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

Here is a more formal outline of steps scientists often take in trying to understand nature. It 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 retention and 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. CONCEPT LINK indicates links to key concepts in earlier chapters. GOOD NEWS refers to good news about the environmental challenges we face.

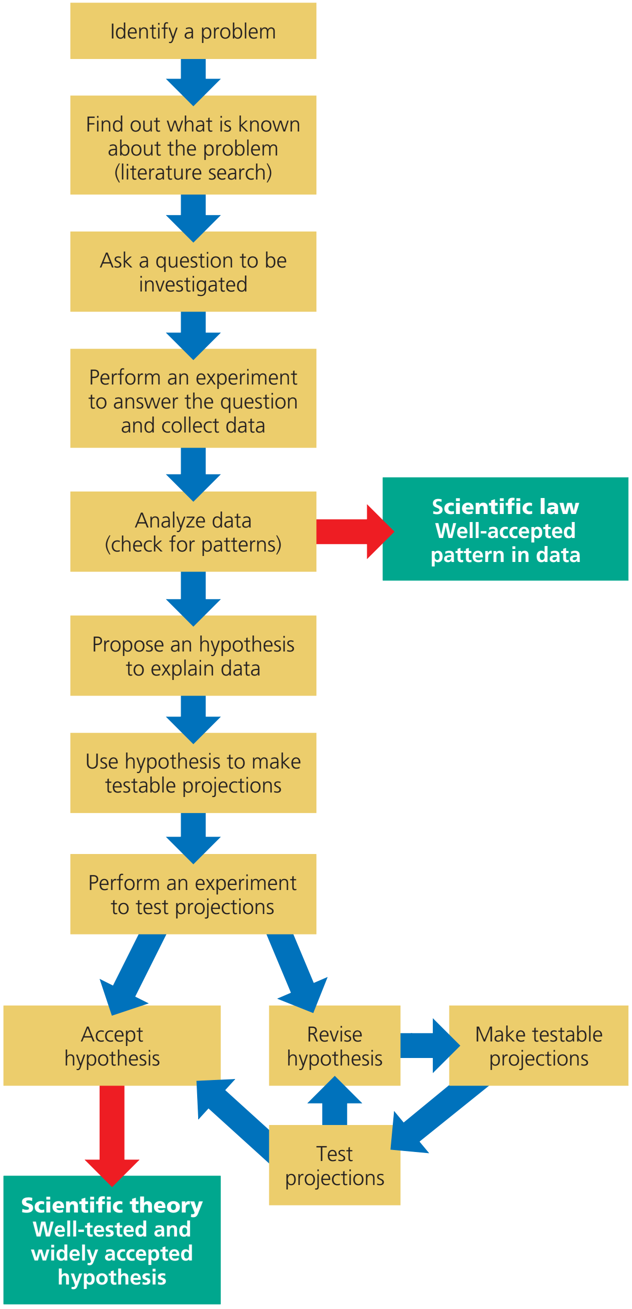


Figure 2-2 *What scientists do*. The essence of science is this process for testing ideas about how nature works. Scientists do not necessarily follow the order of steps shown here. For example, sometimes a scientist might start by formulating a hypothesis to answer the initial question and then run experiments to test the hypothesis.

- *Ask a question to be investigated*. 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 patch of an undisturbed forest (Figure 2-1, left) and from a nearby patch of forest where they had cleared the trees for their experiment (Figure 2-1, right).
- *Propose a hypothesis to explain the data*. Scientists suggest a **scientific hypothesis**—a possible and testable explanation of what they 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 an hypothesis is valid and then run an experiment to test the projections. Bormann and Likens predicted 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 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. These projections can be compared 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 the field being studied 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 also supported their hypothesis. Research and models done by other researchers 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.

Four important features of the scientific process are *curiosity*, *skepticism*, *peer review*, and *reproducibility*. Scientists are curious, and they delight in uncovering new information and ideas about how nature works. But they tend to be highly skeptical of new data, hypotheses, and models until they can be tested and verified.

Science is a community effort. And an important part of the scientific process is **peer review**, in which scientists openly publish 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. Also, any evidence gathered to verify a hypothesis must be reproducible. That is, scientists should repeat and analyze the work to see if the data can be reproduced and whether the proposed hypothesis is reasonable and useful.

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 editors had it reviewed by other soil and forest experts. 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 also been subjected to peer review. In addition, computer models of forest systems have been used to evaluate this problem, with the results subjected to peer review. Scientific knowledge advances in this self-correcting way, with scientists continually questioning measurements, making new measurements, and sometimes coming up with new and better hypotheses. Such skepticism, testing, and debate are essential components of the scientific process.

In this quest, scientists use logic, reasoning, and critical-thinking skills (p. 2). But intuition, imagination, and creativity also play a critical role in science. As American educator John Dewey put it, "Every great advance in science has issued from a new audacity of imagination."

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

Facts and data are essential to science. But the real goal of science is to come up with theories and laws, based on facts, to explain how the physical world works, as pointed out in the quotation that opens this chapter. If an overwhelming body of observations and measurements supports a scientific hypothesis or group of related hypotheses, it becomes a scientific theory. A *scientific theory should be taken very seriously*. It has been tested widely, supported by extensive evidence, and accepted by most scientists in a particular field or related fields of study.

Nonscientists often use the word *theory* incorrectly when they actually mean *scientific hypothesis*, a tentative explanation that needs further evaluation. The statement, "Oh, that's just a theory," made in everyday conversation, implies that the theory was stated without proper investigation and careful testing—the opposite of the scientific meaning of the word.

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 over and over in the same way in nature. An example is the *law of gravity*, based on countless observations and measurements of objects falling from different heights. According to this law, all objects fall to the earth's surface at predictable speeds. *A scientific law cannot be broken as long* as the data used to formulate it are accurate.

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 to establish the reliability of these scientific tools and the resulting conclusions.

Sometimes, preliminary 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.

By contrast, **reliable science** consists of data, hypotheses, theories, models, 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* (Science Focus, p. 27). 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 unless that happens, those views are considered to be the results of reliable science.

Scientific hypotheses and results that are presented as reliable without having undergone the rigors of 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 enough testing? Did it involve a control group? (**Core Case Study**)

SCIENCE FOCUS

Controversy Over Climate Change

Based on numerous measurements and models, it is clear that carbon dioxide and other gases in the atmosphere play a major role in determining the temperature of the atmosphere through a natural warming process called the *natural greenhouse effect*. Without the presence of these *greenhouse gases* in the atmosphere, the earth would be too cold for most life as we know it to exist, and you would not be reading these words. The earth's natural greenhouse effect is one of the most widely accepted theories in the atmospheric sciences and is an example of *reliable science*.

Since 1980, many climate scientists have been focusing their studies on three major questions:

- How much has the earth's atmosphere warmed during the past 50 years?
- How much of the warming is the result of human activities such as the burning of oil, natural gas, and coal, which add carbon dioxide and other greenhouse gases to the atmosphere?
- How much is the atmosphere likely to warm in the future and how might this affect the climate in different parts of the world?

To help clarify these issues, in 1988, the United Nations and the World Meteorological Organization established the Intergovernmental Panel on Climate Change (IPCC) to study how the climate system works, document past climate changes, and project future climate changes. The IPCC network includes more than 2,500 climate experts from 70 nations.

Since 1990, the IPCC has published four major reports summarizing the scientific consensus among these climate experts. In its 2007 report, the IPCC came to three major conclusions:

- It is *very likely* (at least 90% certainty) that the lower atmosphere warmed by about 0.74 C° (1.3 F°) between 1906 and 2005.
- Based on analysis of past climate data and use of 19 climate models, it is *very likely* (at least 90% certainty) that human activities, led by emissions of carbon dioxide from burning fossil fuels, have been the main cause of the observed atmospheric warming between 1957 and 2007.
- It is *likely* (66–89% certainty) that the earth's mean surface temperature will increase by about 3 C° (5.4 F°) between 2005 and 2100, unless the world makes drastic cuts in greenhouse gas emissions from power plants, factories, and vehicles that burn fossil fuels.

This scientific consensus among most of the world's climate experts is currently considered the most *reliable science* we have on this subject. But, as always, there are individual scientists who disagree with the scientific consensus view. Typically, they question the reliability of certain data, say we do not have enough data to come to reliable conclusions, or question some of the hypotheses or models involved. Such questioning helps to advance scientific knowledge. But it is important to know whether such critics are recognized climate experts.

Media reports are sometimes confusing or misleading because they present reliable science along with a quote from a scientist in the field who disagrees with the consensus view, or from someone who is not an expert in the field. This can cause public distrust of well-established reliable science. (See the Guest Essay on environmental reporting by Andrew C. Revkin at CengageNOW™.)

Critical Thinking

Find a newspaper article or other media report that presents the consensus or reliable scientific view on projected climate change and then attempts to balance it with a quote from a scientist who disagrees with the consensus view. Try to determine: **(a)** whether the dissenting scientist is considered an expert in climate science; **(b)** whether the scientist has published any peer-reviewed papers on the subject; and **(c)** what organizations or industries are supporting the dissenting scientist.

- Have the results been reproduced by other scientists?
- Does any proposed hypothesis explain the data? Have projections based on the hypothesis been made and verified?
- Are there no other more reasonable explanations of the data?
- Are the investigators unbiased in their interpretations of the results? Were they funded by an unbiased source?
- 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 the results can be classified as reliable science. Otherwise, the results may represent tentative science that needs further testing and evaluation, or they can be classified as unreliable science.

Science Has Some Limitations

Environmental science and science in general have three 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. Most scientists rarely say something like, "Cigarettes cause lung cancer." Rather, they might say, "Evidence from thousands of studies strongly indicates that people who smoke over a long time have a greatly increased risk of developing lung cancer."

You can usually draw one of two conclusions when someone states that something is not true because it has not been scientifically proven. One conclusion is that the person making the statement does not understand how science works, because scientists can never prove or disprove anything absolutely. An alternative conclusion is that the person is using an old debating trick to make a statement 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 make up their results.

A related problem is that many traditional scientists resist new trailblazing ideas put forth by creative and "boat-rocking" scientists. Using peer review to evaluate scientific results and hypotheses is an important part of the scientific process. But sometimes the personal biases of peer reviewers, threats to profits, or competition for limited research funds can delay serious consideration of new ideas that challenge existing ones.

A *third* limitation—especially important to environmental science—is that many environmental phenomena involve a huge number of interacting variables and complex interactions. This makes it difficult and is 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 include the interactions of many variables. Running such models on high-speed computers can sometimes overcome this limitation and save both time and money. In addition, computer models can be used to simulate global experiments on phenomena like climate change, which are impossible to do in a controlled physical experiment.

CORE CASE STUDY

Despite these three 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 much progress, but we still know too little about how the earth works, its current state of environmental health, and the environmental impacts of our activities. These knowledge gaps point to important *research frontiers*, several of which are highlighted throughout this text.

2-2 What Is Matter and How Do Physical and Chemical Changes Affect It?

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

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

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—and two chemical forms—elements and compounds.

A chemical **element** is a fundamental substance that has a unique set of properties and cannot be broken down into simpler substances by chemical means (**Concept 2-2A**). For example, gold is an element; it cannot be broken down chemically into any other substance.

Some matter is composed of one element such as gold or silver, but most matter consists of **compounds**: combinations of two or more different elements held together in fixed proportions (**Concept 2-2A**). For example, water is a compound made of the elements hydrogen and oxygen, which have chemically combined with one another. (See Supplement 6, p. S26, 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.

Atoms, Ions, and Molecules 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 proper-

Table 2-1

Chemical Elements Important to the Study of Environmental Science

Element	Symbol
Hydrogen	H
Carbon	C
Oxygen	O
Nitrogen	N
Phosphorus	P
Sulfur	S
Chlorine	Cl
Fluorine	F
Bromine	Br
Sodium	Na
Calcium	Ca
Lead	Pb
Mercury	Hg
Arsenic	As
Uranium	U

ties (**Concept 2-2A**). The idea that all elements are made up of atoms is called the **atomic theory**; 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. If you could view them with a supermicroscope, you would find that each different type of atom contains a certain number of three different types of *subatomic particles*: positively charged **protons** (**p**), **neutrons** (**n**) with no electrical charge, and negatively charged **electrons** (**e**).

Each atom consists of an extremely small and dense center called its **nucleus**—which contains one or more protons and, in most cases, one or more neutrons—and one or more electrons moving rapidly somewhere around the nucleus (see Figure 1, p. S26, in Supplement 6). 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, 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. 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 (with 6 protons and 6 neutrons), carbon-13 (with 6 protons and 7 neutrons), and carbon-14 (with 6 protons and 8 neutrons). Carbon-12 makes up about 98.9% of all naturally occurring carbon.

A second building block of some types of matter is an **ion**—an atom or groups of atoms with one or more net positive (+) or negative (–) electrical charges (**Concept 2-2A**). Like atoms, ions are made up of protons, neutrons, and electrons. (For more information, on chemistry fundamentals, see Supplement 6, p. S26.)

The number of positive or negative charges carried by an ion is shown as a superscript after the symbol for an atom or a group of atoms. Examples encountered in this book include a *positive* hydrogen ion (H^+), with one positive charge, an aluminum ion (Al^{3+}) with three positive charges, and a *negative* chloride ion (Cl^-) with one negative charge. These and other ions listed in Table 2-2 are used in other chapters in this book. (A subscript in a chemical symbol shows the number of atoms of each element present in the ion. No subscript means there is one atom.)

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 2-3 (p. 30) shows measurements of the loss of nitrate ions from

Table 2-2

Ions Important to the Study of Environmental Science

Positive Ion	Symbol
hydrogen ion	H^+
sodium ion	Na^+
calcium ion	Ca^{2+}
aluminum ion	Al^{3+}
ammonium ion	NH_4^+
Negative Ion	**Symbol**
chloride ion	Cl^-
hydroxide ion	OH^-
nitrate ion	NO_3^-
carbonate ion	CO_3^{2-}
sulfate ion	SO_4^{2-}
phosphate ion	PO_4^{3-}

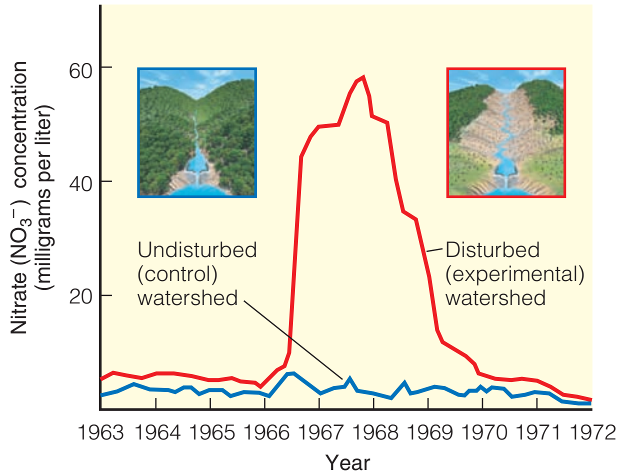


Figure 2-3 Loss of nitrate ions (NO_3^-) from a deforested watershed in the Hubbard Brook Experimental Forest in New Hampshire (Figure 2-1, right). The average concentration of nitrate ions in runoff from the deforested experimental watershed was much higher than in a nearby unlogged watershed used as a control (Figure 2-1, left). (Data from F. H. Bormann and Gene Likens)

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 over the dams of the cleared forest area showed an average 60-fold rise in the concentration of NO_3^- compared to water running off of the uncleared forest area. After a few years, however, vegetation began growing back on the cleared valley and nitrate levels in its runoff returned to normal levels.

CORE CASE STUDY

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. Scientists use **pH** as a measure of acidity, based on the amount of hydrogen ions (H^+) and hydroxide ions (OH^-) contained in a particular volume of a solution. 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 6, p. S28, in Supplement 6 for more details.)

The third 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* (**Concept 2-2A**). Molecules are the basic units of some compounds (called *molecular compounds*). (See Figure 5, p. S27, in Supplement 6 for examples.)

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 and uses subscripts to represent the number of atoms or ions of each element in the compound's basic structural unit. Examples of compounds and their formulas encountered in this book are sodium chloride (NaCl) and water (H_2O, read as "H-two-O"). These and other compounds important to our study of environmental science are listed in Table 2-3.

Table 2-3

Compounds Important to the Study of Environmental Science

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

You may wish to mark this page and those containing Tables 2-1 and 2-2, as they could be useful references for understanding material in other chapters. Think of them as lists of the main chemical characters in the story of matter and life.

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

Table sugar, vitamins, plastics, aspirin, penicillin, and most of the chemicals in your body are **organic compounds**, which 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 8, p. S29, in Supplement 6.)

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 8, p. S29, in Supplement 6)
- *proteins* formed by monomers called *amino acids* (see Figure 9, p. S29, in Supplement 6)
- *nucleic acids* (DNA and RNA) formed by monomers called *nucleotides* (see Figure 10 and 11, p. S30, in Supplement 6)

Lipids, which include fats and waxes, are not made of monomers, but are a fourth type of macromolecule essential for life (see Figure 12, p. S30, in Supplement 6).

Matter Becomes 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 macromolecules and **cells**—the smallest and most 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. Within some DNA molecules are certain sequences of nucleotides called **genes**. Each of these distinct pieces of DNA contains instructions, called *genetic information*, for making specific proteins. Each of these coded units of genetic information concerns a specific **trait**, or characteristic, passed on from parents to offspring during reproduction in an animal or plant.

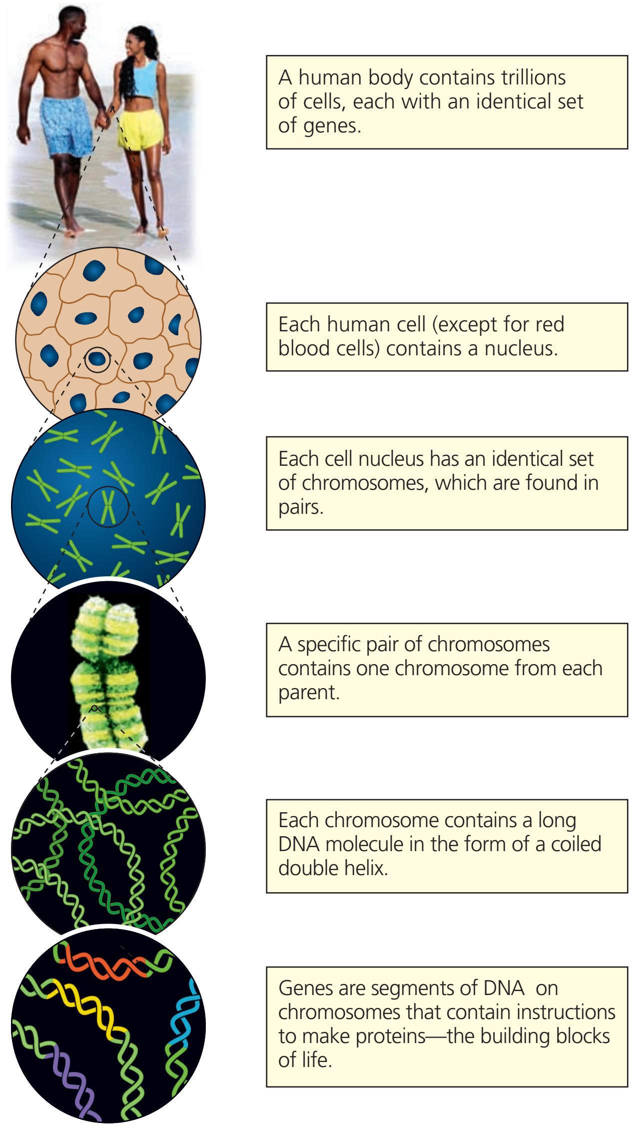


Figure 2-4 Relationships among cells, nuclei, chromosomes, DNA, and genes.

Thousands of genes, in turn, make up a single **chromosome**, a special DNA molecule together with a number of proteins. Genetic information coded in your chromosomal DNA is what makes you different from an oak leaf, an alligator, or a flea, and from your parents. In other words, it makes you human, but it also makes you unique. The relationships of genetic material to cells are depicted in Figure 2-4.

Some Forms of Matter Are More Useful than Others

The study of matter is important for our understanding and use of resources, especially energy resources—the subject of Chapter 13 in this book. **Matter quality** is a measure of how useful a given sample of matter is as a resource for humans. It is based on its availability and *concentration*, or 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. See Figure 2-5 for examples illustrating differences in matter quality.

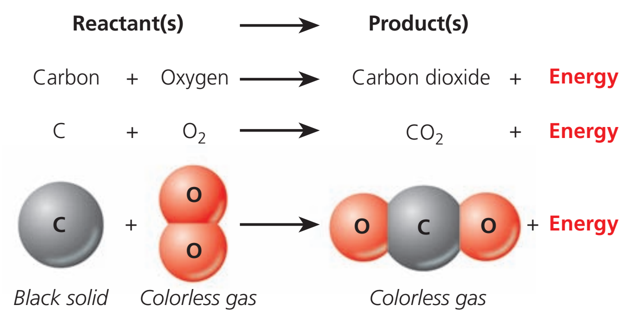
In summary, matter consists of elements and compounds, which in turn are made up of atoms, ions, or molecules (**Concept 2-2A**). And some forms of matter are more useful as resources than others because of their availability and concentrations.

Figure 2-5 Examples of 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.

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.

When a **chemical change**, or **chemical reaction**, takes place there is a change in chemical composition of the substances involved. Chemists use a *chemical equation* to show what happens in a chemical reaction. For example, when coal burns completely, 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).



In addition to physical and chemical changes, matter can undergo three types of *nuclear changes*, or changes in the nuclei of its atoms: **radioactive decay**, **nuclear fission**, and **nuclear fusion** (See Figure 2-6 for definitions).

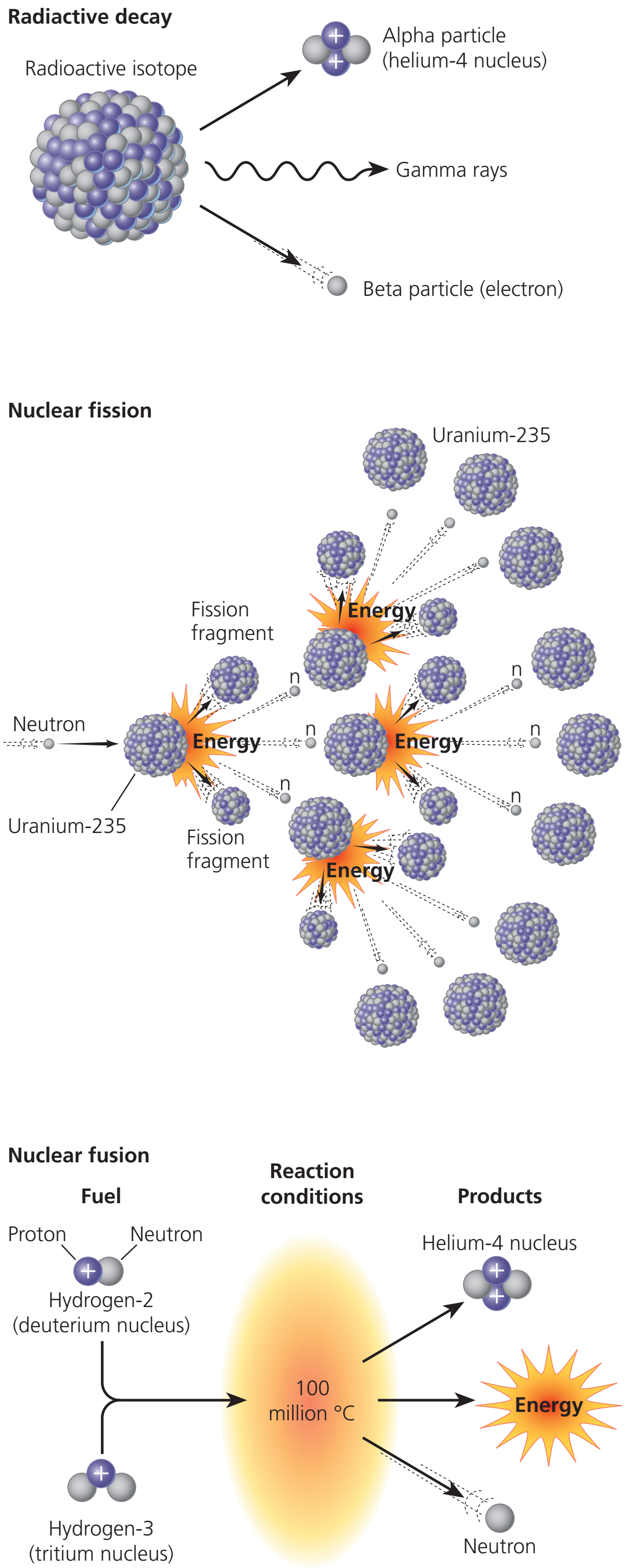
We Cannot Create or Destroy Atoms

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 combinations (chemical changes). These statements, 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 2-2B**).

CONNECTIONS

Waste and the Law of Conservation of Matter

The law of conservation of matter means there is no "away" as in "to throw away." We can bury waste, but it remains where it is buried and sometimes affects the soil. We can burn it, but it then becomes ash, which must be put somewhere, and gases, which can pollute the air. Everything that we think we have thrown away remains here with us in some form.



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 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.

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 2-6 Types of nuclear changes: radioactive decay (top), nuclear fission (middle), and nuclear fusion (bottom).

2-3 What Is Energy and How Do Physical and Chemical Changes Affect It?

▶ **CONCEPT 2-3A 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 2-3B 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).**

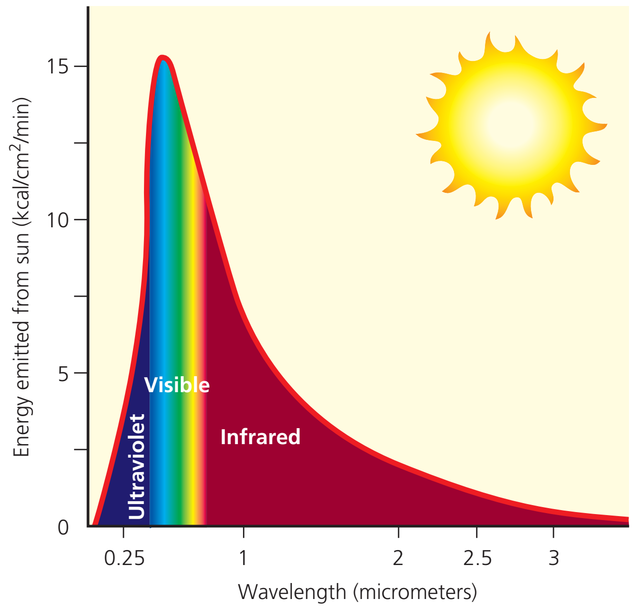
Energy Comes in Many Forms

Energy is the capacity to do work or transfer heat. Work is done when something is moved. The amount of work done is the product of the force applied to an object to move it a certain distance (work = force × distance). For example, it takes a certain amount of muscular force to lift this book from your desk to a certain height.

There are two major types of energy: *moving energy* (called kinetic energy) and *stored energy* (called potential energy). Moving matter has **kinetic energy**, which is energy associated with motion. Examples are wind (a moving mass of air), flowing water, and electricity (flowing electrons).

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 an object such as a hot stove.

In yet another kind of kinetic energy called **electromagnetic radiation**, 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 2-7), each having a different *wavelength* (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 a higher energy content than do forms with longer wavelengths such as visible light and infrared (IR) radiation (Figure 2-7).



CENGAGENOW™ **Active Figure 2-7** The spectrum of electromagnetic radiation released by the sun. *See an animation based on this figure at* CengageNOW.

CENGAGENOW™ Find out how 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 potential energy include a rock held in your hand, the chemical energy stored in gasoline molecules, and the nuclear energy stored in the nuclei of atoms.

Potential energy can be changed to kinetic energy. When you hold this book at a certain height, it has potential energy; drop it on your foot and its potential energy changes to kinetic energy. When a car engine burns gasoline, the potential energy stored in the chemical bonds of gasoline molecules changes into kinetic energy, which propels the car, and heat that flows into the environment. Potential energy stored as chemical energy in the molecules of the carbohydrates you eat becomes kinetic energy when your body uses it to move and do other forms of work.

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 an energy source's capacity to do useful work. **High-quality energy** is concentrated and has a high capacity to do useful work. Examples are very high-temperature heat, nuclear fission, concentrated sunlight, high-velocity wind, and energy released by burning natural gas, gasoline, or coal.

By contrast, **low-quality energy** is dispersed and has little capacity to do useful work. An example is heat dispersed in the moving molecules of a large amount of matter (such as the atmosphere or an ocean) so that its temperature is low. The total amount of heat stored in the Atlantic Ocean is greater than the amount of high-quality chemical energy stored in all the oil deposits of Saudi Arabia. Yet because the ocean's heat is so widely dispersed, it cannot be used to move things or to heat matter to high temperatures.

Energy Changes Are Governed by Two Scientific Laws

Thermodynamics is the study of energy transformations. Scientists have observed energy being changed from one form to another in millions of physical and chemical changes. But they have never been able to detect the creation or destruction of any energy in such changes. The results of these experiments have been summarized in the **first law of thermodynamics**, also known as 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 (**Concept 2-3A**).

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 because energy input always equals energy output. This is one of nature's basic rules that we can never violate.

Because the first law of thermodynamics states that energy cannot be created or destroyed, only converted from one form to another, you may be tempted to think there will always be enough 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 that can perform useful work.

Countless experiments have shown that whenever energy is converted from one form to another, we always end up with a lower quality or less "usable" energy than we started with (**Concept 2-3B**). This is a statement of the **second law of thermodynamics**. This lower-quality energy usually takes the form of heat given off at a low temperature to the environment. There it is dispersed by the random motion of air or water molecules and becomes even less useful as a resource.

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 witnessed a violation of this fundamental scientific law.

Consider three examples of the second law of thermodynamics in action. *First*, when we drive a car, only about 13% of the high-quality energy available in its gasoline fuel actually moves the car. The remaining 87% is degraded to low-quality heat that is released into the environment. Thus, 87% of the money we spend for gasoline is not used to take us anywhere.

Second, when electrical energy in the form of moving electrons flows through filament wires in an incandescent light bulb, about 5% of it is changed into useful light, and 95% flows into the environment as low-quality heat. In other words, the *incandescent lightbulb* is really an energy-wasting *heat bulb*.

Third, in living systems, solar energy is converted into chemical energy (food molecules) and then into mechanical energy (through moving, thinking, and living). During each conversion, high-quality energy is degraded and flows into the environment as low-quality heat. Trace the flows and energy conversions in Figure 2-8 (p. 36) to see how this happens.

CONNECTIONS

Can Energy be Recycled?

We can recycle paper and aluminum. But the second law of thermodynamics means that *we can never recycle or reuse high-quality energy to perform useful work*. Once the concentrated or high-quality 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.

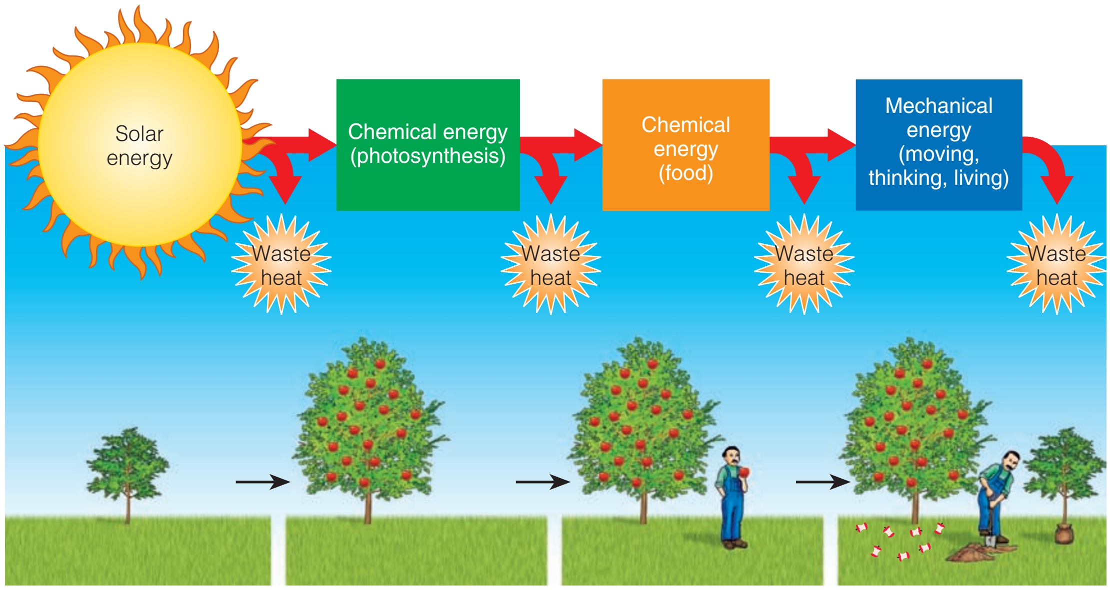
Energy efficiency is a measure of how much useful work is accomplished by a particular input of energy into a system. There is plenty of room for improving energy efficiency. Scientists estimate that only 16% of the energy used in the United States ends up performing useful work. The remaining 84% is either unavoidably wasted because of the second law of thermodynamics (41%) or unnecessarily wasted (43%). Thus, thermodynamics teaches us an important lesson: the cheapest and quickest way to get more energy is to stop wasting almost half the energy we use. We explore energy efficiency in depth in Chapter 13.

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

Three Scientific Laws Govern What We Can and Cannot Do with Matter and Energy

The following highly reliable 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 chemicals; we can only change them from one physical state or chemical form to another.
- **You cannot get something for nothing**. According to the *first law of thermodynamics*, or *law*



CENGAGENOW™ **Active Figure 2-8** The second law of thermodynamics in action in living systems. Whenever energy is changed from one form to another, some of the initial input of high-quality energy is degraded, usually to low-quality heat that is dispersed into the environment. *See an animation based on this figure at* CengageNOW. **Question**: What are three things that you did during the past hour that degraded high-quality energy?

of conservation of energy, no energy is created or destroyed whenever energy undergoes a physical or chemical change. 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, or rules of nature.

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 degraded some of its natural capital (Figure 1-2, p. 7). 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 back cover). In other words, the uncleared forest was a more sustainable system than a similar area of cleared forest (Figures 2-1 and 2-3).

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

Humans clear forests to get wood, grow food, and build cities. The key question is how far can we go in expanding our ecological footprints (Figure 1-5, p. 11, and **Concept 1-2**, p. 9) and environmental impact (Figure 1-7, p. 13) without threatening the quality of life for our own species and for the other species that help to keep us alive and support our economies? To live sustainably, we need to find and maintain a balance between preserving undisturbed natural systems and modifying others for our use.

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.

ARTHUR S. EDDINGTON

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 24. 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**, **scientific theory**, and **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.

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

4. Distinguish among **tentative science** (**frontier science**), **reliable science**, and **unreliable science**. Describe the scientific consensus over projected climate change. What are three limitations of science and environmental science?

5. What is **matter**? Distinguish between an **element** and a **compound** and give an example of each. Distinguish among **atoms**, **ions**, and **molecules** 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. Define **cell** and briefly describe cell theory. Distinguish among **genes**, **traits**, and **chromosomes**. 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. 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 is **energy quality**? Distinguish between **high-quality energy** and **low-quality energy** and give an example of each.

9. 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.

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

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?

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 pp. 24–25 to determine the cause of this fish kill.

3. Describe a way in which you have applied the scientific process described in this chapter (Figure 2-2) in your own life, and state the conclusion you drew from this process. Describe another 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 phenomenon 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, 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 stored in the fuel used to run it. What is your response? Explain.

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

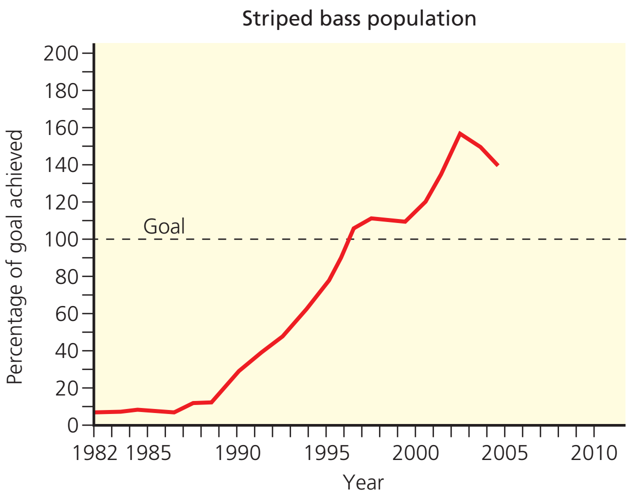
9. a. Imagine you have the power to revoke the law of conservation of matter for one day. What are three things you would do with this power?

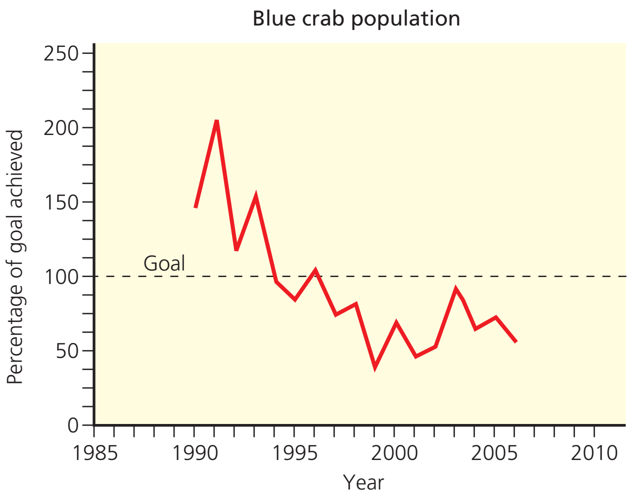
b. Imagine you have the power to violate the first law of thermodynamics for one day. What are three things you would do with this power?

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

DATA ANALYSIS

Marine scientists from the U.S. state of Maryland have produced the following two graphs as part of a report on the current health of the Chesapeake Bay. They are pleased with the recovery of the striped bass population, but they are concerned about the decline of the blue crab population, because blue crabs are consumed by mature striped bass. Their hypothesis is that as the population of striped bass rises, the population of blue crab decreases.





Using the data in the above graphs, answer the following questions:

1. Which years confirm their hypothesis?
2. Which years do not support their hypothesis?
3. If the crab population reaches 100% of its goal, what percentage of its goal would the striped bass population achieve, by your projection?

LEARNING ONLINE

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

CENGAGENOW™ For students with access, log on at **www.cengage.com/login** for the animations, active figures, activities, and readings indicated within the text by the CengageNOW logo. If your textbook did not come with access, visit **www.iChapters.com** to purchase.

Ecosystems: What Are They and How Do They Work?

3

Tropical Rain Forests Are Disappearing

CORE CASE STUDY

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 no more than 6% 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 life (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*, it will reduce the earth's vital biodiversity by destroying or degrading the habitats of many of the unique plant and animal species found in these forests, thereby causing their premature extinction. *Second*, it will help to accelerate projected climate change (Science Focus, p. 27), by eliminating large areas of trees faster than they can grow back, thereby degrading the forests' abilities to remove the greenhouse gas carbon dioxide (CO_2) from the atmosphere.

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

Ecologists study an ecosystem to learn how its variety of organisms interact with their living (*biotic*) environment of other organisms and with their nonliving (*abiotic*) environment of soil, water, other forms of matter, and energy, mostly from the sun. In effect, ecologists study *connections in nature*. Tropical rain forests and other ecosystems recycle nutrients and provide humans and other organisms with essential natural services (Figure 1-2, p. 7) and natural resources such as nutrients (Figure 1-3, p. 8). In this chapter, we look more closely at how ecosystems work and 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.

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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, 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 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 succeeding 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 field research, laboratory research, and mathematical and other models to learn about ecosystems.

Note: Supplements 4 (p. S14), 5 (p. S21), 6 (p. S26), and 7 (p. S32) can be used with this chapter.

The great ecosystems are like complex tapestries—a million complicated threads, interwoven, make up the whole picture.

GERALD DURRELL

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, 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.**

The Earth's Life-Support System Has Four Major Components

Scientific studies reveal that 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, sediment), and the biosphere (living things) (Figure 3-2 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 the majority of the 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 most 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 *liquid water* (on the surface and underground), *ice* (polar ice, icebergs, and ice in frozen soil layers called *permafrost*), and *water vapor* in the atmosphere. The oceans, which 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

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. CONCEPT LINK indicates links to key concepts in earlier chapters. GOOD NEWS refers to good news about the environmental challenges we face.

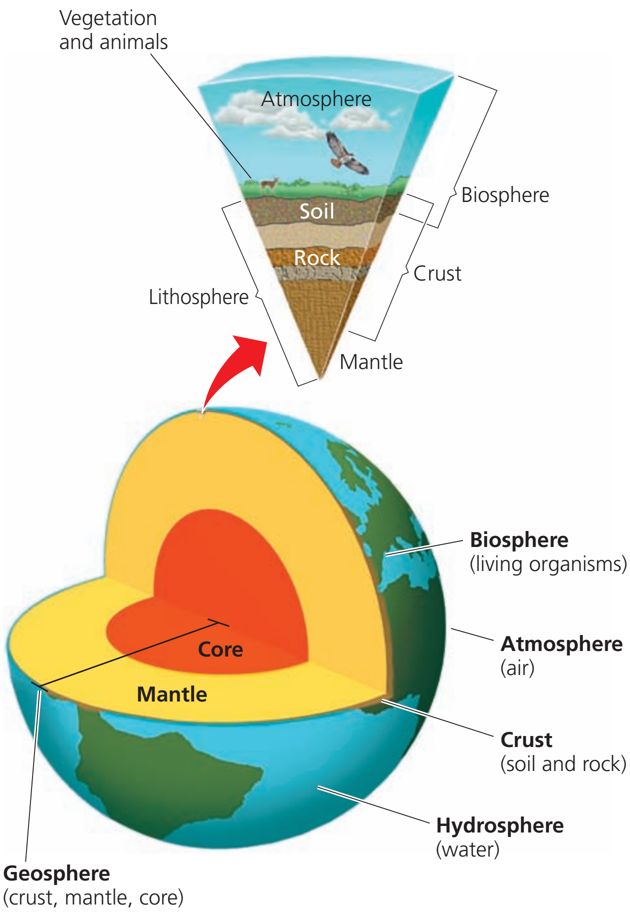


Figure 3-2 **Natural capital:** general structure of the earth showing that it consists of a land sphere (*geosphere*), air sphere (*atmosphere*), water sphere (*hydrosphere*), and life sphere (*biosphere*) (**Concept 3-1A**).

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 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. *The goal of ecology 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**):

- 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 (Figure 3-3). No round-trips are allowed because high-quality energy cannot be recycled. The two laws of thermodynamics (**Concepts 2-3A** and **2-3B**, p. 34) govern this energy flow.

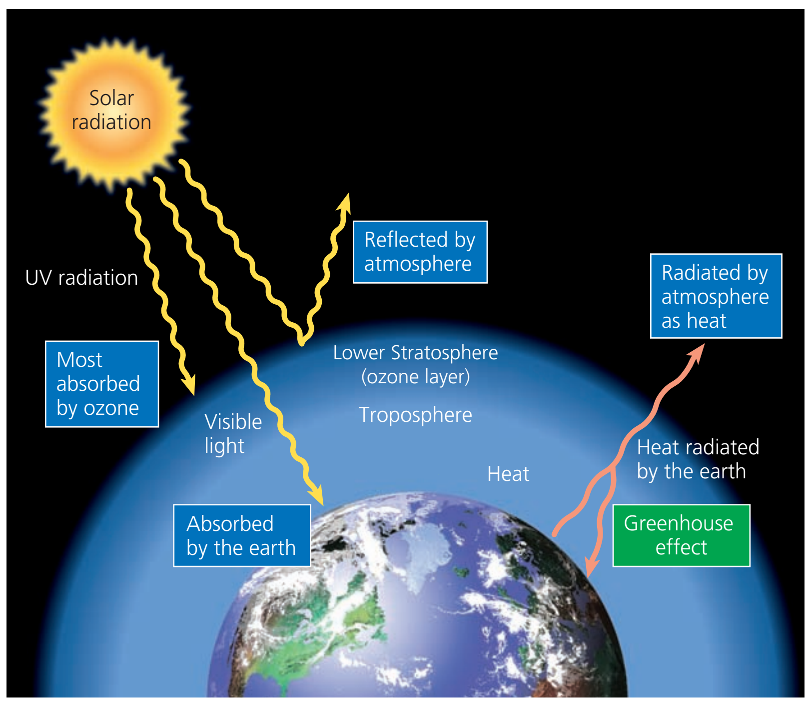
CONCEPT LINK

- The *cycling of nutrients* (the atoms, ions, or molecules needed for survival by living organisms) through parts of the biosphere. Because the earth is closed to significant inputs of matter from space, its essentially fixed supply of nutrients must be continually recycled to support life (Figure 1-3, p. 8). Nutrient movements in ecosystems and in the biosphere are round-trips, which can take from seconds to centuries to complete. The law of conservation of matter (**Concept 2-2B**, p. 28) governs this nutrient cycling process.

CONCEPT LINK

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

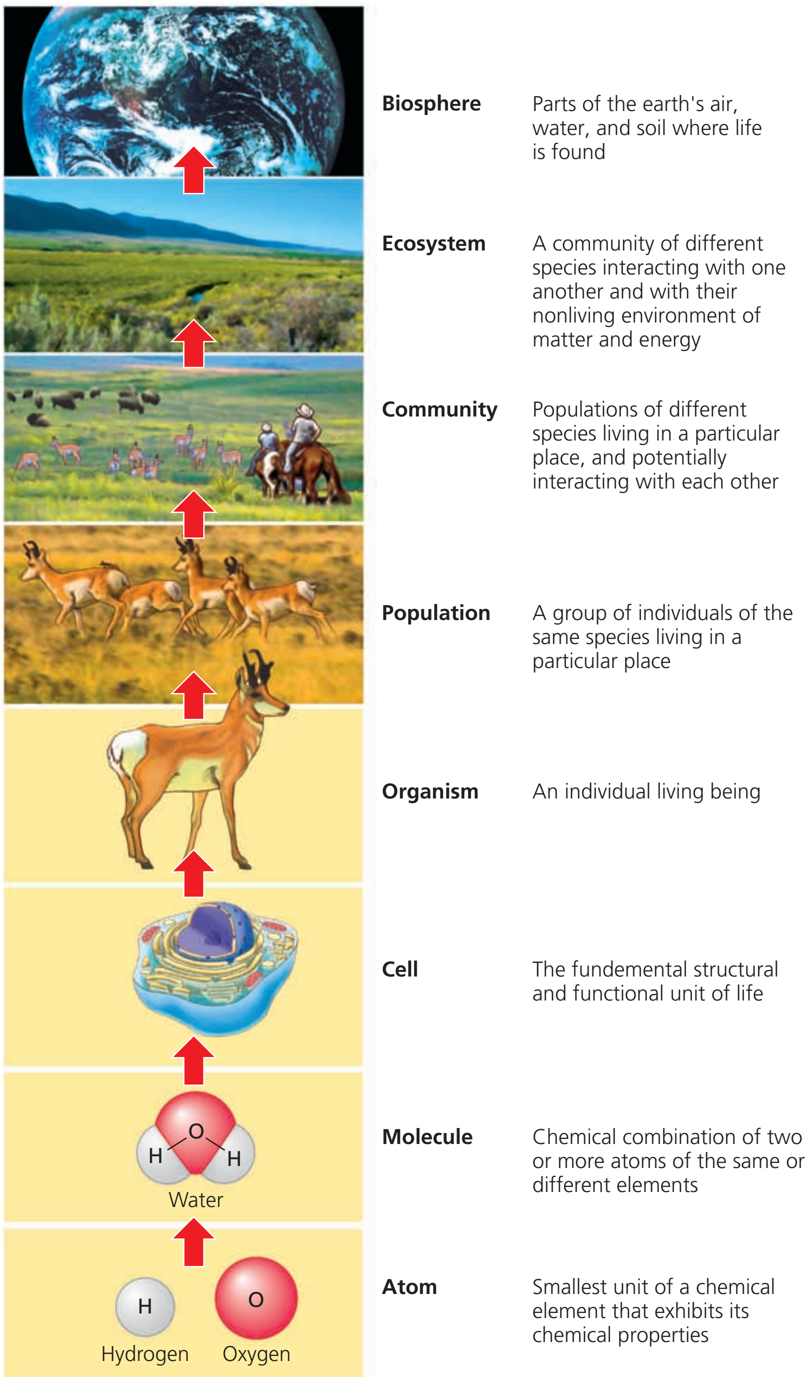
CENGAGENOW™ Learn more about the flow of energy—from sun to earth and within the earth's systems—at CengageNOW.



CENGAGENOW™ **Active Figure 3-3** *Solar energy:* flow of energy to and from the earth. About one-third of the incoming solar radiation is reflected back into space by clouds, particles in the atmosphere, and the earth's surface. Another fifth of the incoming radiation is absorbed by ozone in the lower stratosphere (mostly UV radiation) and clouds and water vapor in the troposphere. Most of the remaining half of incoming solar radiation is absorbed by land and water on the earth's surface. Carbon dioxide and other gases in the troposphere lead to a warming of the troposphere known as the *natural greenhouse effect* (Science Focus, p. 27). *See an animation based on this figure 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 organisms.**



CENGAGENOW™ **Active Figure 3-4** Some levels of organization of matter in nature. Ecology focuses on the top five of these levels. *See an animation based on this figure at* CengageNOW.

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. Ecologists classify matter into levels of organization ranging from the atomic level to the level of the biosphere. They study interactions within and among five of these levels—*organisms*, *populations*, *communities*, *ecosystems*, and the *biosphere*—which are defined in Figure 3-4.

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

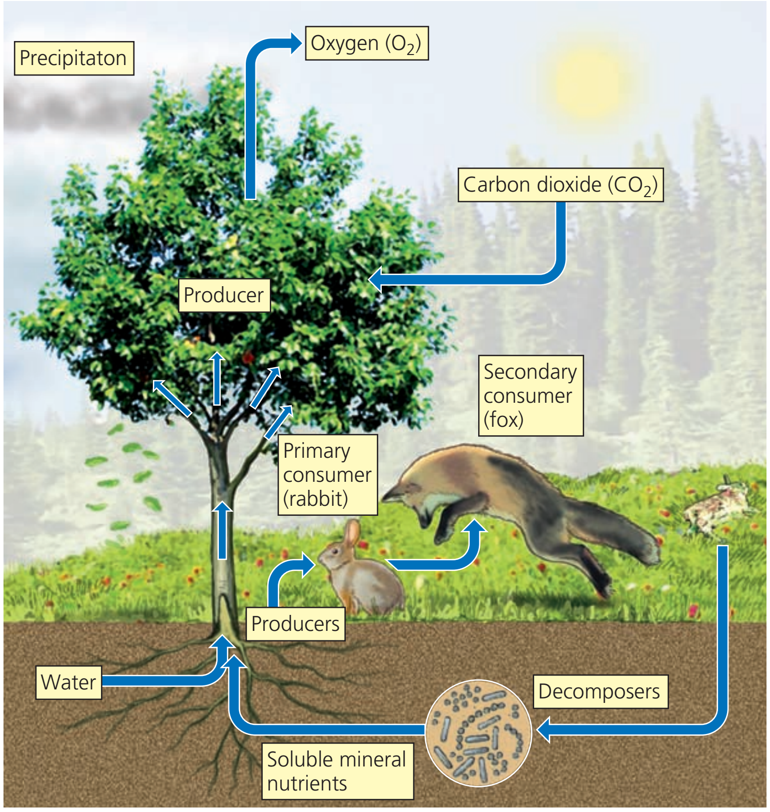
Ecosystems Have Living and Nonliving Components

Two types of components make up the biosphere and its ecosystems: One type, called **abiotic**, consists of nonliving components such as water, air, nutrients, rocks, heat, and solar energy (**Concept 3-1A**). The other type, called **biotic**, consists of living biological components—plants, animals, and microbes. Biotic factors also include dead organisms, dead parts of organisms, and the waste products of organisms. Figure 3-5 is a greatly simplified diagram of some of the biotic and abiotic components of a terrestrial ecosystem.

Producers and Consumers Are the Living Components of Ecosystems

Ecologists assign every type of organism in an ecosystem to a *feeding level*, or **trophic level**, depending on its source of food or nutrients. The living (biotic) organisms that transfer energy and nutrients from one trophic level to another in an ecosystem can be broadly classified 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**). On land, most producers are green plants. In a process called **photosynthesis**, plants typi-



CENGAGENOW™ **Active Figure 3-5** Major living (biotic) and nonliving (abiotic) components of an ecosystem in a field. *See an animation based on this figure at* CengageNOW.

cally capture about 1% of the solar energy that falls on their leaves and use it to combine 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, the overall reaction can be summarized as follows:

carbon dioxide + water + solar energy → glucose + oxygen

In freshwater and marine ecosystems, algae and aquatic plants growing near shorelines are the major producers. 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**).

All other organisms in an ecosystem are **consumers**, or **heterotrophs** ("other-feeders"), which 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 producers, feeding mostly on green plants. Examples are caterpillars, deer, and zooplankton. **Carnivore**s (meat eaters) are animals that feed on the flesh of other animals. Some carnivores such as spiders, robins, and tuna are **secondary consumers** that feed on the flesh of herbivores. Other carnivores such as tigers, hawks, and killer whales (orcas) are **tertiary** (or higher) **consumers** that feed on the flesh of other carnivores. Some of these relationships are shown in Figure 3-5. **Omnivores** such as pigs, foxes, and humans can eat plants and other animals.

THINKING ABOUT
What You Eat

When you had 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 release nutrients from the dead bodies of plants and animals and return them to the soil, water, and air for reuse by producers (**Concept 3-2**). Most consumers are bacteria and fungi. Other consumers, called **detritus feeders**, or **detritivores**, feed on the wastes or dead bodies of other organisms, called *detritus* ("di-TRI-tus," meaning debris). Examples are earthworms, some insects, and vultures.

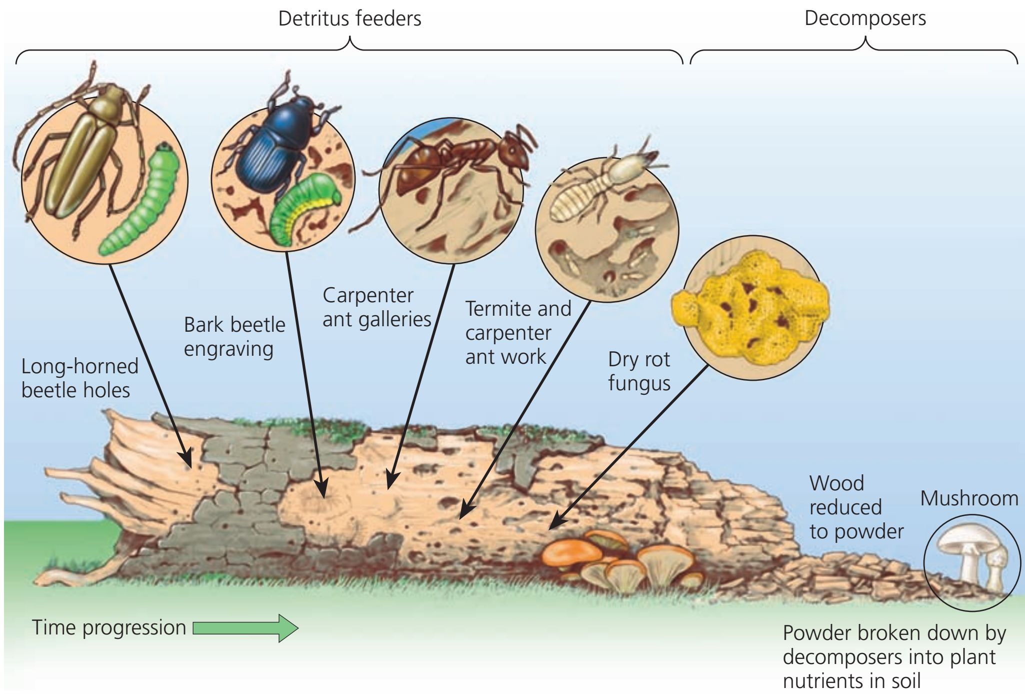
Hordes of decomposers and detritus feeders can transform a fallen tree trunk into a powder and, finally, into simple inorganic molecules that plants can absorb as nutrients (Figure 3-6, p. 44). Thus, in natural ecosystems, the wastes and dead bodies of organisms serve as resources for other organisms, as the nutrients that make life possible are recycled again and again—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. 44), are the key to nutrient cycling. Without them, the planet would be overwhelmed with plant litter, dead animal bodies, animal wastes, 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 molecules) back into carbon dioxide and water. The net effect of the hundreds of steps in this complex process is represented by the following reaction:

glucose + oxygen → carbon dioxide + water + energy

Figure 3-6 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.



Energy Flow and Nutrient Cycling Sustain Ecosystems and the Biosphere

Ecosystems and the biosphere are sustained through a combination of *one-way energy flow* from the sun through these systems and *nutrient cycling* of key materials within them (**Concept 3-1B**)—two of the **principles of sustainability** (Figure 3-7).

THINKING ABOUT
Chemical Cycling and the Law of Conservation of Matter

CONCEPT LINK

Explain the relationship between chemical cycling in ecosystems and the biosphere and the law of conservation of matter (**Concept 2-2B**, p. 28).

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

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 mostly 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.

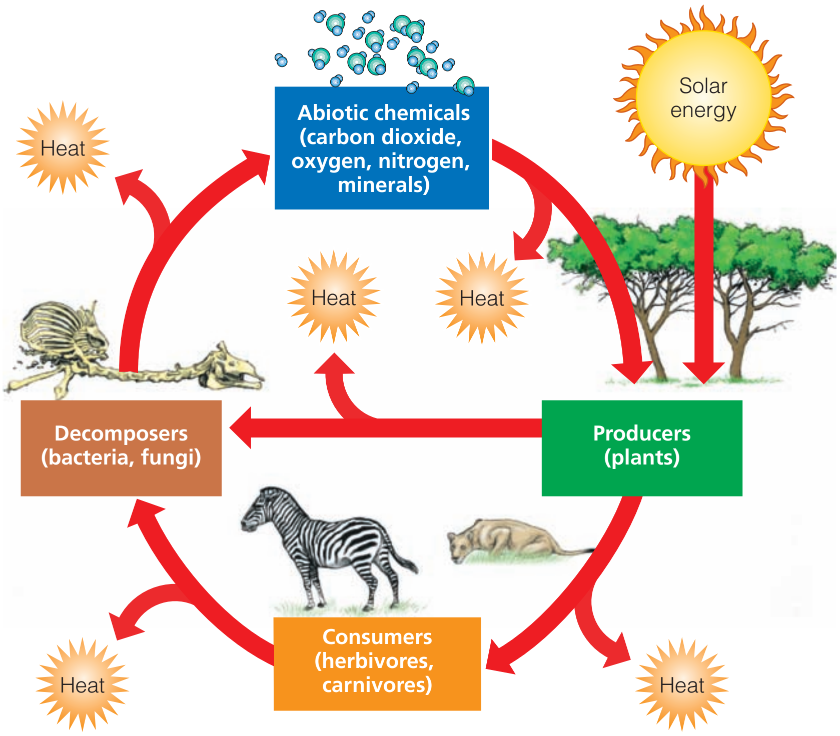
Bacteria and other microbes help to purify the water we drink by breaking down wastes. Bacteria also help to produce foods such as bread, cheese, yogurt, soy sauce, beer, and wine. Bacteria and fungi in the soil decompose organic wastes into nutrients that can be taken up by plants that we and most other animals eat (Figure 3-5). 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 slow atmospheric warming 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 microbes to convert them to microbes that can be used to clean up polluted water and soils.

Some microbes assist us in controlling diseases that affect plants and 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 ways in which microbes helped you today?



CENGAGENOW™ **Active Figure 3-7** **Natural capital:** 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 succeeding 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 remains of the leaf, caterpillar, robin, and hawk after they die and return their nutrients to the soil for reuse by producers.

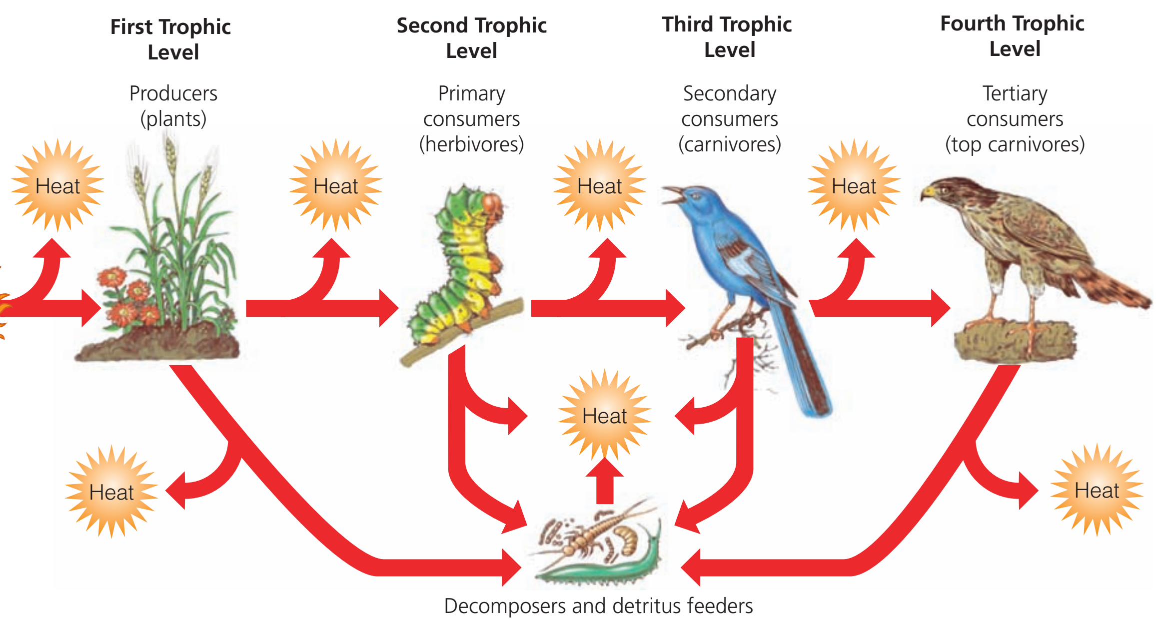
A sequence of organisms, each of which serves as a source of food or energy for the next, is called a **food chain**. It determines how chemical energy and nutrients move from one organism to another through the trophic levels in an ecosystem along the same pathways—primarily through photosynthesis, feeding, and decomposition—as shown in Figure 3-8 (p. 46). 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 3-9, p. 46). Trophic levels can be assigned in food webs just as 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.

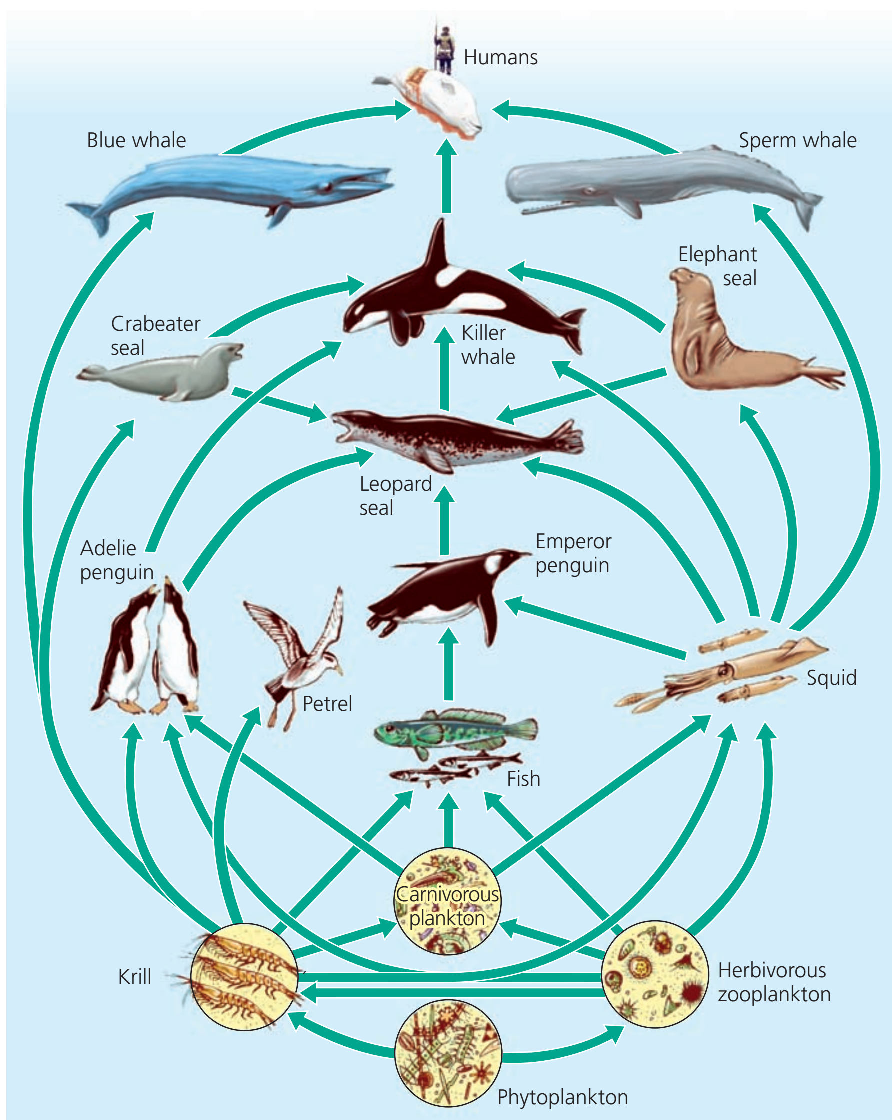
Usable Energy Decreases with Each Link in a Food Chain or Web

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.

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, as a result of the second law of thermodynamics. In other words, as energy flows through ecosystems in food chains and webs, there is a



CENGAGENOW™ **Active Figure 3-8**
A *food chain*. The arrows show how 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 (**Concept 2-3B**, p. 34). *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 3-9**
Greatly simplified *food web* in the Antarctic. Many more participants in the web, including an array of decomposer and detritus feeder organisms, are not depicted 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.

decrease in the amount of chemical energy available to organisms at each succeeding feeding level (**Concept 3-3**).

The percentage of usable chemical energy transferred as biomass from one trophic level to the next ranges from 1.3% to 56% (resulting in an energy loss at each step of 44–98.7%) 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 3-10 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

CONCEPT LINK

Explain the relationship between the second law of thermodynamics (**Concept 2-3B**, p. 34) 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 in the world than there are insects.

CONNECTIONS
Energy Flow and Feeding People

Energy flow pyramids explain why the earth could support more people if they 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 and 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.

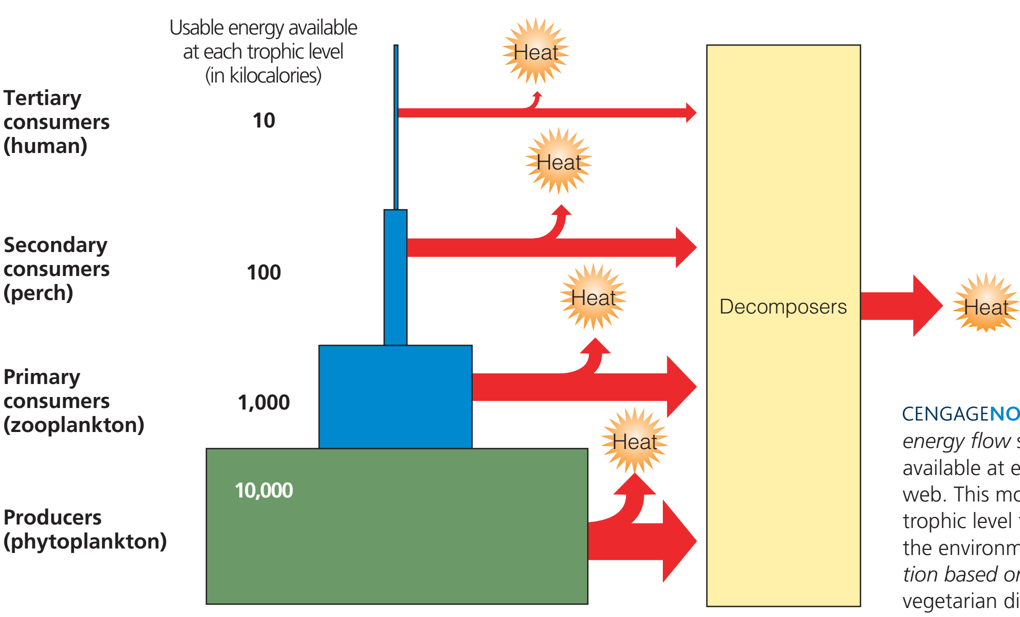
Some Ecosystems Produce Plant Matter Faster Than Others Do

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 produce the chemical energy that is stored in their tissue and potentially available to other organisms (consumers) in an ecosystem.

Ecosystems and life zones differ in their NPP as illustrated in Figure 3-11 (p. 48). 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.

As we have seen, the nutrients that producers provide must serve the needs of all producers, consumers,



CENGAGENOW™ **Active Figure 3-10** Generalized *pyramid of energy flow* showing the decrease in usable chemical energy available at each succeeding trophic level in a food chain or web. This 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. *See an animation based on this figure at* CengageNOW. **Question**: Why is a vegetarian diet more energy efficient than a meat-based diet?

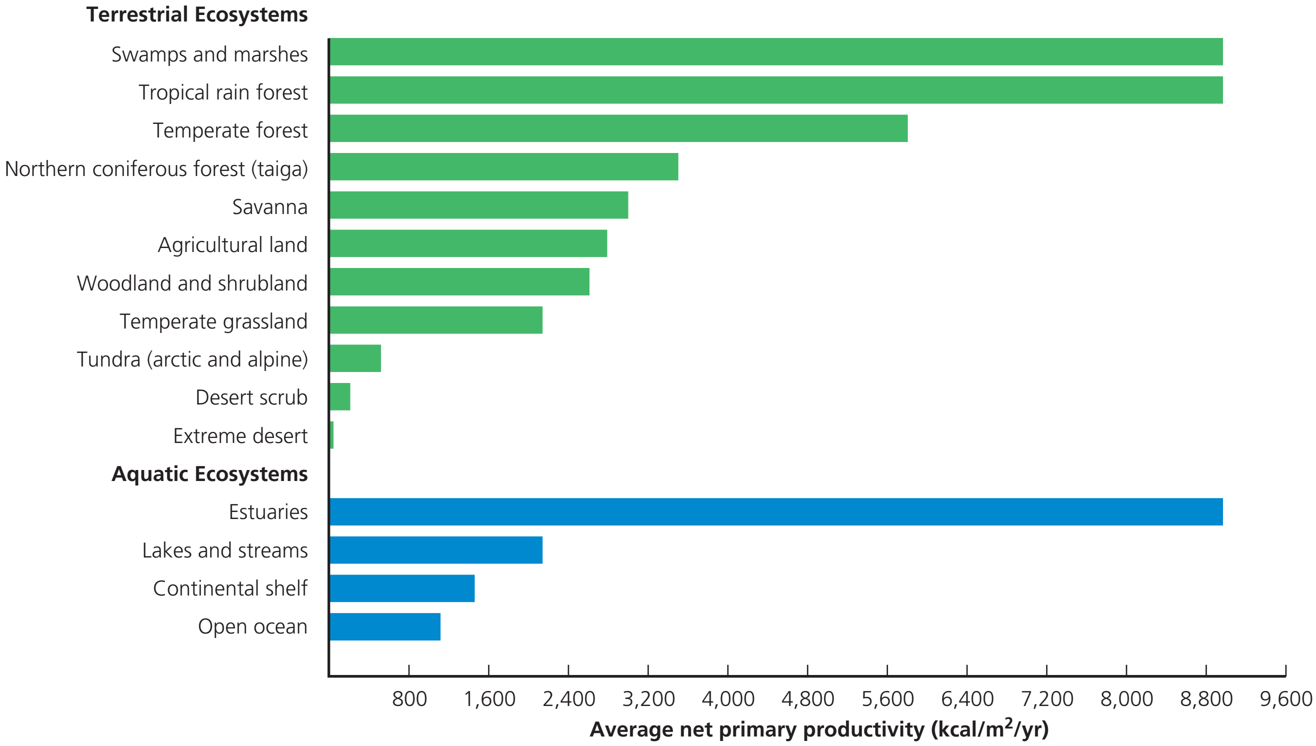


Figure 3-11 Estimated annual average *net primary productivity* in major life zones and ecosystems, expressed as kilocalories of energy produced per square meter per year (kcal/m^2/yr). **Question**: What are nature's three most productive and three least productive systems? (Data from R. H. Whittaker, *Communities and Ecosystems*, 2nd ed., New York: Macmillan, 1975)

and decomposers in any ecosystem. 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.

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.

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 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 gravity, include the hydrologic (water), carbon, nitrogen, phosphorus, and sulfur cycles. These cycles are an important component of the earth's natural capital (Figure 1-2, p. 7), and human activities are altering them (**Concept 3-4**).

As nutrients move through the biogeochemical cycles, they may accumulate in one portion of the cycle and remain there for different periods of time. These temporary storage sites such as the atmosphere, the oceans and other waters, 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, Attila the Hun, 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. 50) that is necessary for life on the earth, and there is a fixed supply of it on our planet. The **hydrologic cycle**, or **water cycle**, collects, purifies, and distributes this supply of water, as shown in Figure 3-12.

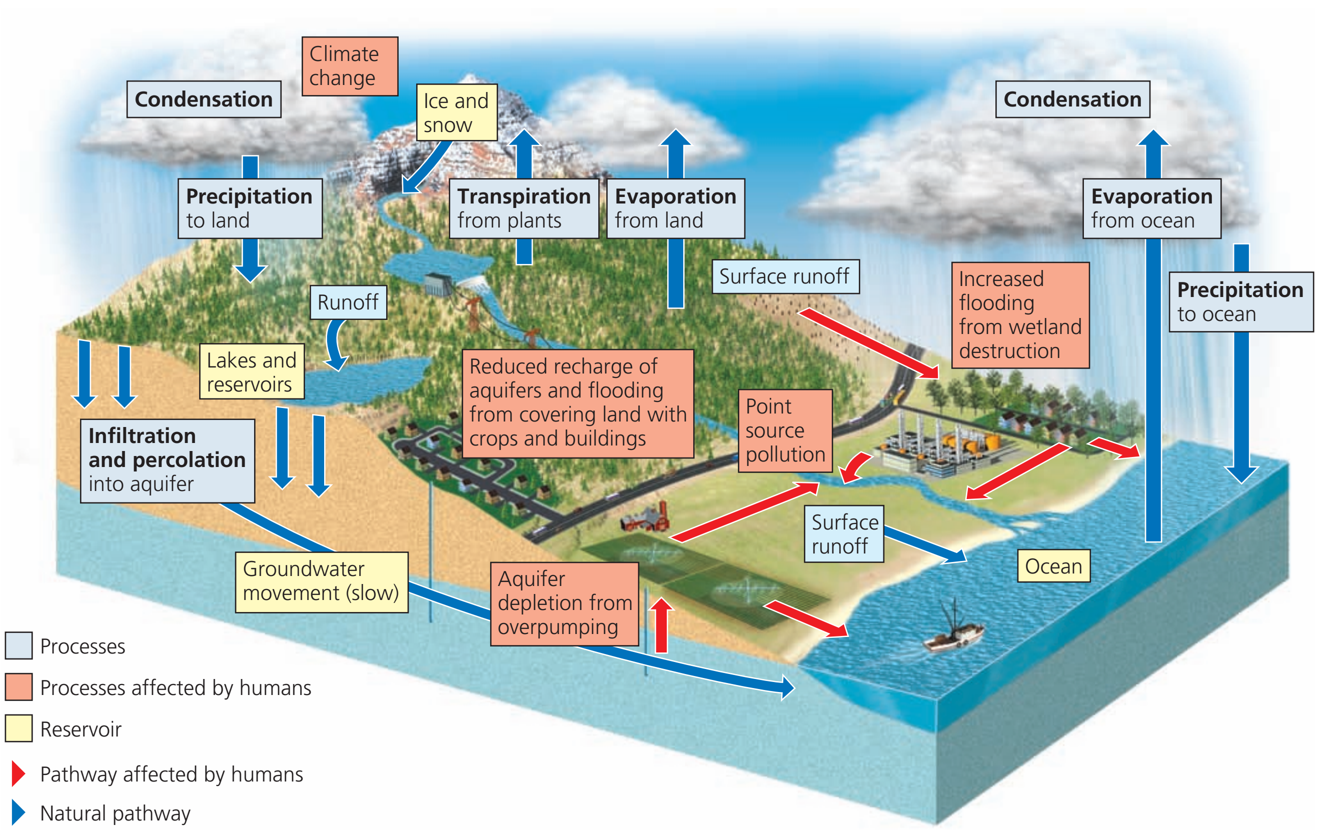
The water cycle is powered by energy from the sun and involves three major processes—evaporation, precipitation, and transpiration. Incoming solar energy causes *evaporation* of water from the oceans, lakes, rivers, and soil. Evaporation changes liquid water into water vapor in the atmosphere, and gravity 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 and lakes, which eventually carry water back to the oceans, from which it can evaporate to repeat the cycle. Some surface water also seeps into the upper layer of soils and some evaporates from soil, lakes, and streams back into the atmosphere.

Some precipitation is converted to ice that is stored in *glaciers*, usually for long periods of time. Some precipitation sinks through soil and 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. Roots of plants absorb some of this water, most of which evaporates from plant leaves back into the atmosphere. Some 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 water back into the environment. Consumers get their water from their food and by drinking it.

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



CENGAGENOW™ **Active Figure 3-12** **Natural capital:** simplified model of the *water* or hydrologic *cycle* with major harmful impacts of human activities shown by 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?

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 7, p. S29, in Supplement 6), *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 weather and 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 4, p. S27, in Supplement 6). 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* (Figure 2-7, p. 34) *that would harm some aquatic organisms.* However, up to a certain depth it is transparent to visible light 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 street pavements, 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?

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 us 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 (see red arrows and boxes in Figure 3-12) by withdrawing large quantities of freshwater faster than it can be replaced and by clearing vegetation. We also cover land with buildings and pavement, which reduces the recharge of aquifers by holding water above ground and increases runoff, which in turn increases flooding and soil erosion.

CONNECTIONS

Clearing a Rainforest Can Affect Local Weather CORE CASE STUDY

Clearing vegetation 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.

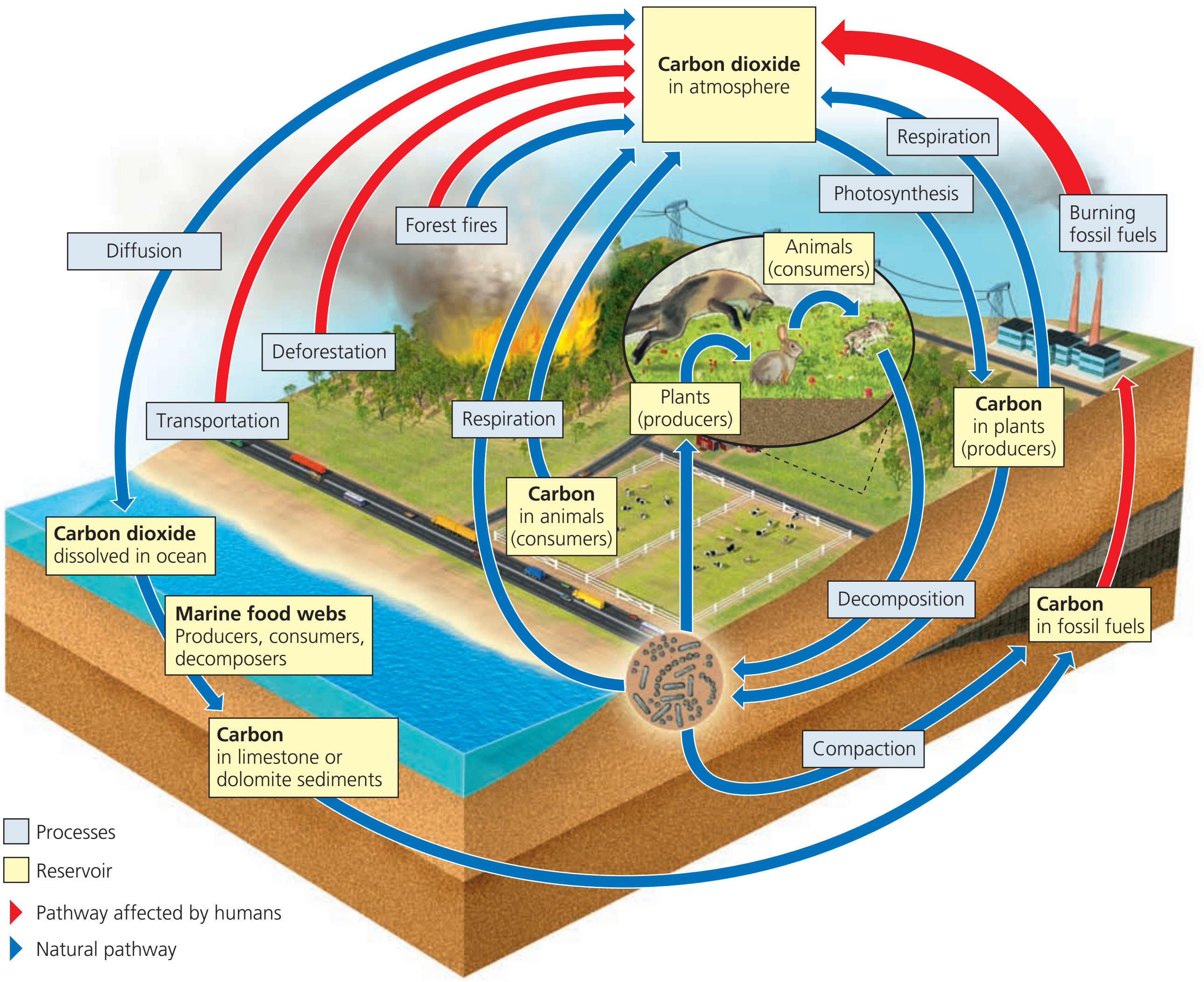
The Carbon Cycle

Carbon is the basic building block of the carbohydrates, fats, proteins, DNA, and other organic compounds necessary for life. It circulates through the biosphere, the atmosphere, and parts of the hydrosphere, in the **carbon cycle** shown in Figure 3-13.

The carbon cycle is based on carbon dioxide (CO_2) gas, which makes up 0.038% of the volume of the atmosphere and is also dissolved in water. Carbon dioxide 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 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 3-13 Natural capital:** simplified model of the global *carbon cycle*, with major harmful impacts of human activities shown by 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 and converts the carbon back to CO_2 in the atmosphere or 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 (Figure 3-13). 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 3-13) mostly by adding large amounts of carbon dioxide to the atmosphere when we burn carbon-containing fossil fuels and clear carbon-absorbing vegetation from forests (especially tropical forests) faster than it can grow back (**Core Case Study**).

CORE CASE STUDY

THINKING ABOUT

The Carbon Cycle, Tropical Deforestation, and Projected Climate Change

CORE CASE STUDY

Use Figure 3-13 and Figure 3-3 to explain why clearing tropical rain forests faster than they can grow back (**Core Case Study**) can help to warm the earth's atmosphere. What are two ways in which this could affect the survival of remaining tropical forests? What are two ways in which it could affect your lifestyle?

Computer models of the earth's climate system indicate that increased concentrations of atmospheric CO_2 and other gases are very likely (with at least a 90% certainty) to warm the atmosphere by enhancing the planet's natural greenhouse effect, and thus to change the earth's climate (See Science Focus, p. 27).

The Nitrogen Cycle: Bacteria in Action

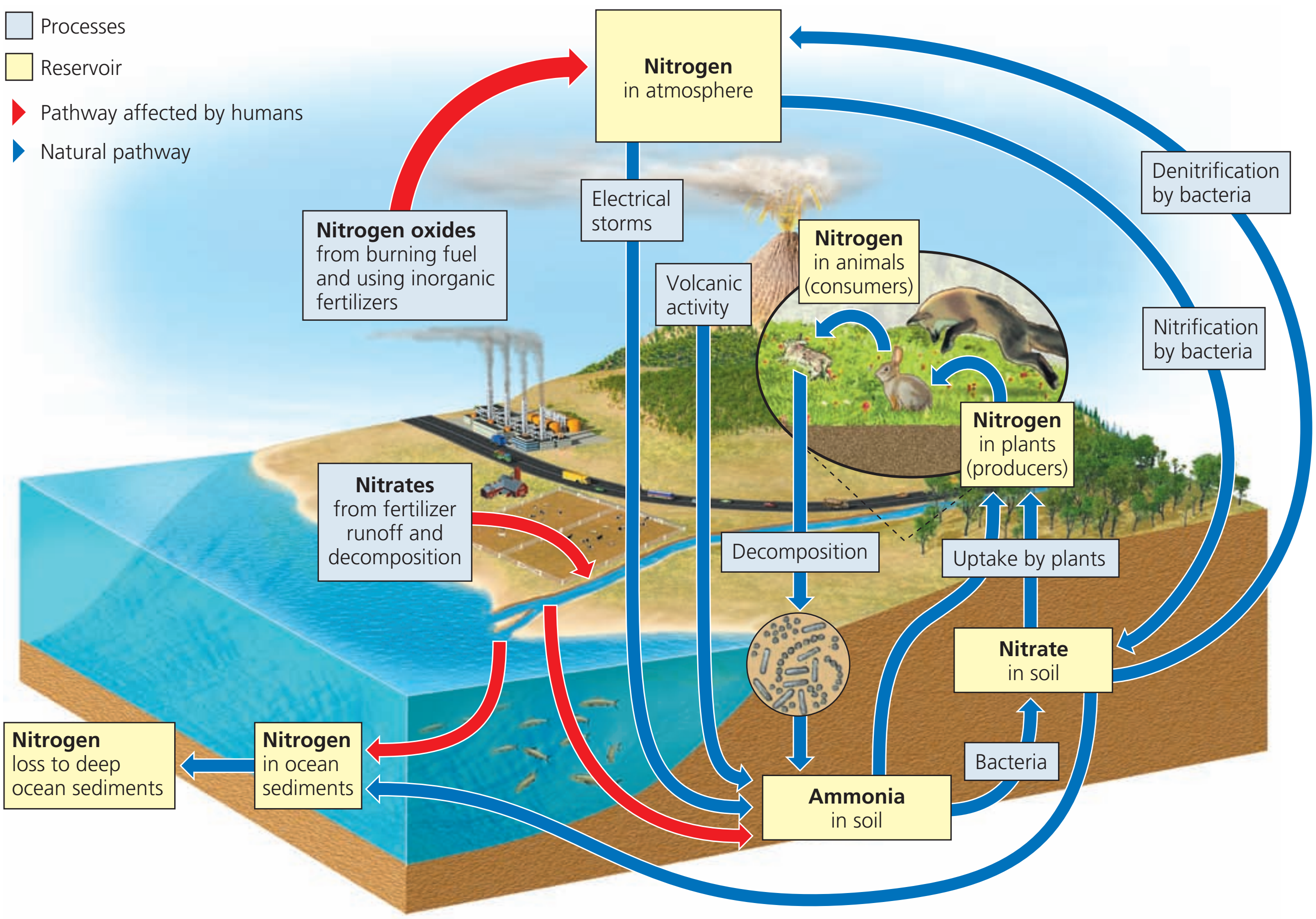
The major reservoir for nitrogen is the atmosphere. Chemically unreactive nitrogen gas (N_2) makes up 78% of the volume of the atmosphere. Nitrogen is a crucial component of proteins, many vitamins, and nucleic acids such as DNA. (See Figure 10, p. S30, in Supplement 6.) However, N_2 cannot be absorbed and used directly as a nutrient by multicellular plants or animals.

Fortunately, two natural processes convert, or *fix*, N_2 into compounds that can be used as nutrients by plants and animals. One is electrical discharges, or lightning, taking place in the atmosphere. The other takes place in aquatic systems, soil, and 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 3-14.

The nitrogen cycle consists of several major steps. In *nitrogen fixation*, specialized bacteria in soil and 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 to the soil or water. Some of the ammonia is converted to ammonium ions (NH_4^+) that can be used as a nutrient by plants.

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 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 wastes and cast-off particles and through their bodies when they die and are decomposed or eaten by detritus feeders. In *ammonification*, vast armies of specialized decomposer bacteria



CENGAGENOW™ **Active Figure 3-14** **Natural capital:** simplified model of the *nitrogen cycle* in a terrestrial ecosystem, with major harmful human impacts shown by 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?

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 several ways (as shown by red arrows in Figure 3-14). 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 is from the greatly increased use of inorganic fertilizer to grow crops, and the amount released is projected to double again by 2050.

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. 23, and Figure 2-3, p. 30).

The Phosphorus Cycle

Phosphorus circulates through water, the earth's crust, and living organisms in the **phosphorus cycle**, depicted in Figure 3-15. 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 also slow compared to the water, carbon, and nitrogen cycles.

As water runs over exposed phosphorus-containing rocks, it slowly erodes away inorganic compounds that contain phosphate ions. The dissolved phosphate can be absorbed by the roots of plants and by other producers. Phosphorous is transferred by food webs from producers to consumers, eventually including detritus feeders and decomposers. In both producers and consumers,

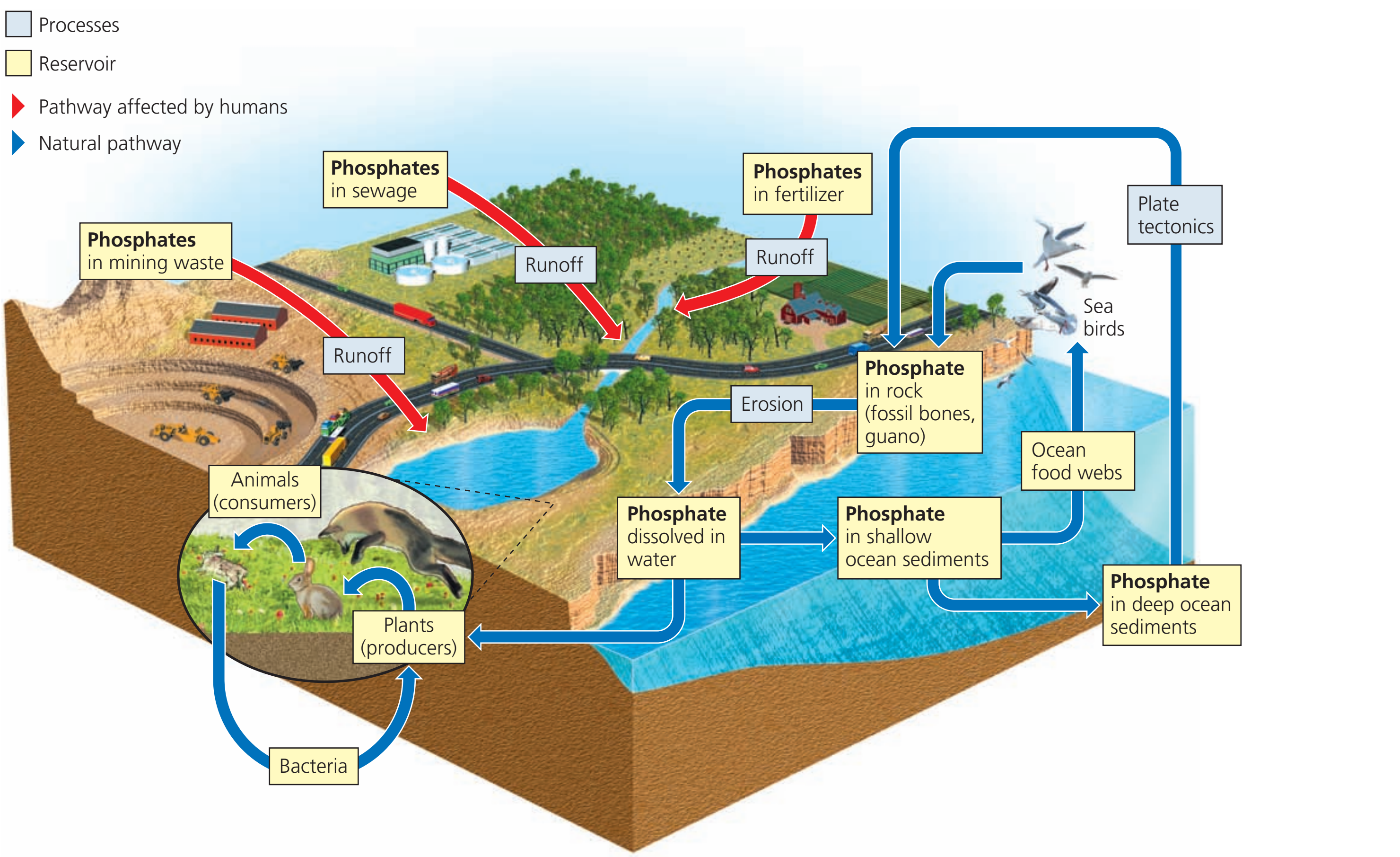


Figure 3-15 **Natural capital:** simplified model of the *phosphorus cycle*, with major harmful human impacts shown by red arrows. **Question**: What are three ways in which you directly or indirectly affect the phosphorus cycle?

phosphorous is a component of biologically important molecules such as nucleic acids (Figure 10, p. S30, in Supplement 6) and energy transfer molecules such as ADP and ATP (Figure 14, p. S31, in Supplement 6). It is also a major component of vertebrate bones and teeth.

Phosphate can be lost from the cycle for long periods when it washes 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, it often limits plant growth on land unless phosphorus (as phosphate salts mined from the earth) is applied to the soil as a fertilizer. Phosphorus also limits the growth of producer populations in many freshwater streams and lakes because phosphate salts are only slightly soluble in water.

Human activities are affecting the phosphorous cycle (as shown by red arrows in Figure 3-15). This includes removing large amounts of phosphate from the earth to make fertilizer and reducing phosphorus in tropical soils by clearing forests (**Core Case Study**). Soil that is eroded from fertilized crop fields, lawns, and golf courses carries large quantities of phosphates into streams, lakes, and the ocean, where it stimulates the growth of producers. Phosphorous-rich runoff from the land can produce huge populations of algae, which can upset chemical cycling and other processes in lakes.

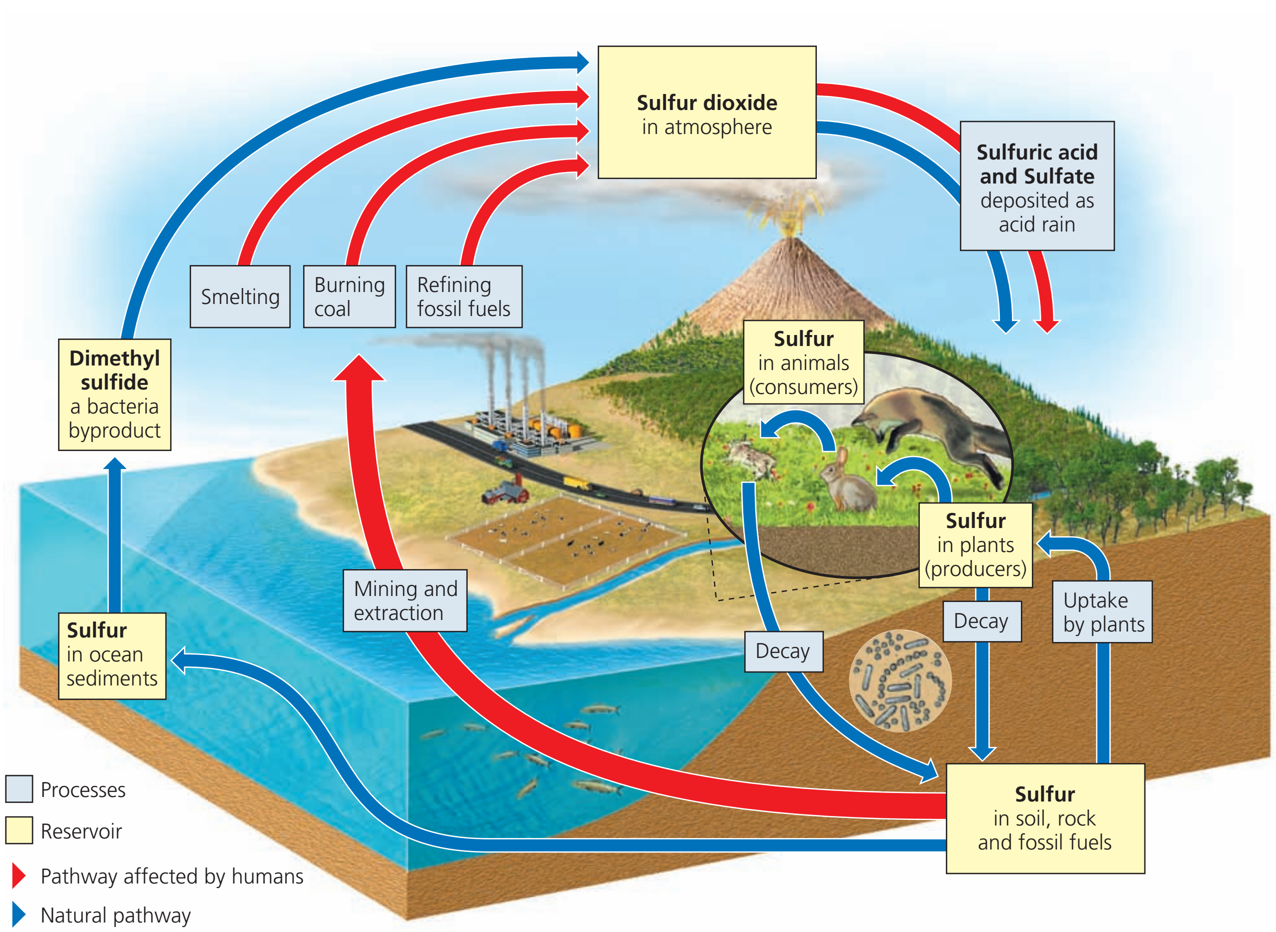
CORE CASE STUDY

The Sulfur Cycle

Sulfur circulates through the biosphere in the **sulfur cycle**, shown in Figure 3-16. Much of the earth's sulfur is stored underground in rocks and minerals, including 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 salts enter the atmosphere from sea spray, dust storms, and forest fires. Plant roots absorb



CENGAGENOW™ **Active Figure 3-16** **Natural capital:** simplified model of the *sulfur cycle*, with major harmful impacts of human activities shown by 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?

sulfate ions and incorporate the sulfur as an essential component of many proteins.

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 red arrows in Figure 3-16). We add sulfur dioxide to the atmosphere in three ways. *First*, we burn sulfur-containing coal and oil to produce electric power. *Second*, we refine sulfur-containing petroleum to make gasoline, heating oil, and other useful products. *Third*, we convert sulfur-containing metallic mineral ores into free metals such as copper, lead, and zinc.

RESEARCH FRONTIER

The effects of human activities on the major nutrient cycles and how we can reduce these effects. See **www.cengage.com/biology/miller**.

CENGAGE**NOW**™ 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 field research, laboratory research, and mathematical and other models to learn about ecosystems.**

Some Scientists Study Nature Directly

Scientists use field research, laboratory research, and mathematical and other models to learn about ecosystems (**Concept 3-6**). *Field research*, sometimes called "muddy-boots biology," involves going into natural settings and observing and measuring the structure of ecosystems and what happens within 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. 23, 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 stretch over the canopies of tropical forests to identify and observe the rich diversity of species living or feeding in these treetop habitats.

Increasingly, new technologies are being used 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. Then they use *geographic information system (GIS)* software to capture, store, analyze, and display such information.

In a GIS, geographic and ecological spatial data can be stored electronically 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 (Figure 1, p. S14, in Supplement 4), gross primary productivity, temperature patterns, air pollution emissions, and many other variables. **GREEN CAREERS:** GIS analyst; remote sensing analyst

Some Scientists Study Ecosystems in the Laboratory

During the past 50 years, ecologists have increasingly supplemented field research by using *laboratory research* to set up, observe, and make measurements of model ecosystems and populations under laboratory conditions. Such simplified systems have been created in containers such as culture tubes, bottles, aquaria tanks, and greenhouses, and in indoor and outdoor chambers where temperature, light, CO_2, humidity, and other variables can be controlled.

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 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, which 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 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 variables being studied. They also must determine the 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/biology/miller**.

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, as revealed 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 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 call for a massive program to develop baseline data for the world's ecosystems.

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/biology/miller**.

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.

REVISITING 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*, ecosystems *recycle the chemical nutrients* that their organisms need for survival, growth, and reproduction. These two principles 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**), 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 cycling of nutrients in the biosphere and the flow of energy through the biosphere. Tropical 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 B.C.)

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 40. What are three harmful effects resulting from the clearing and degradation of tropical rain forests?

2. Distinguish among the **atmosphere**, **troposphere**, **stratosphere**, **hydrosphere**, and **geosphere**. 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. Define **ecology**. Distinguish among an **organism**, a **population**, a **community**, an **ecosystem**, and the **biosphere**.

4. Distinguish between the **abiotic** and **biotic components** in ecosystems and give two examples of each.

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

6. Distinguish between **photosynthesis** and **aerobic respiration**. 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**?

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 unique properties of water. What is **transpiration**? Describe the **hydrologic** (**water**), **carbon**, **nitrogen**, **phosphorus**, and **sulfur cycles** and explain how human activities are affecting each cycle.

10. Describe three ways in which scientists study ecosystems. 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?

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?

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 food 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 (**Concept 2-3B**, p. 34) to explain why many poor people in developing 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 its decomposers and detritus feeders were eliminated, **(b)** all its producers were eliminated, or **(c)** all 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 **Concepts 3-3** and **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 2007 population data, answer the questions below.

Country	Total Carbon Footprint—Carbon Dioxide Emissions in Metric Gigatons per Year*	Population in billions (2007)	Per Capita Carbon Footprint — Per Capita Carbon Dioxide Emissions per year
China	5.0	1.3	
India	1.3	1.1	
Japan	1.3	0.13	
Russia	1.5	0.14	
United States	6.0	0.30	
WORLD	29	6.6	

(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 world-wide 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.cengage.com/biology/miller** and choose Chapter 3 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, web links, information on Green Careers, and InfoTrac® College Edition articles.

CENGAGENOW™ For students with access, log on at **www.cengage.com/login** for the animations, active figures, activities, and readings indicated within the text by the CengageNOW logo. If your textbook did not come with access, visit **www.iChapters.com** to purchase.

Biodiversity and Evolution

4

Why Are Amphibians Vanishing? Unraveling a Mystery

CORE CASE STUDY

Amphibians (frogs, toads, and salamanders) live part of their lives in water and part on land. They were the first animals with backbones (the first *vertebrates*) to set foot on the earth and they have been better at adapting to environmental changes than many other species have been.

But many amphibian species apparently are having difficulty adapting to some of the rapid environmental changes that have taken place during the past few decades—changes resulting mostly from human activities.

Since 1980, populations of hundreds of the earth's almost 6,000 amphibian species have been vanishing (Figure 4-1) or declining in almost every part of the world, even in protected wildlife reserves and parks. According to scientists who study amphibians, about 33% of all known amphibian species (and more than 80% of those in the Caribbean) are threatened with *extinction*—in which whole species cease to exist—and populations of another 43% of these species are declining.

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 inland wetlands, deforestation, and urban development
- *Prolonged drought*, which can dry up breeding pools so that few tadpoles survive
- *Increases in ultraviolet (UV) radiation* due to reductions in stratospheric ozone during the past few decades, caused by ozone-depleting chemicals we have put into the air. Higher doses of UV radiation can harm amphibian embryos lying in shallow ponds and adults exposing themselves to the sun for warmth.
- *Parasites* such as trematode flatworms, which feed on the amphibian eggs laid in water, apparently have caused an increase in births of amphibians with missing or extra limbs and other deformities
- *Viral and fungal diseases*, especially the chytrid fungus that attacks the skin of frogs, apparently reducing their ability to take in water; this leads to death from dehydration. Such diseases can spread among adults of many amphibian species that 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*, which has been identified as the primary cause of the extinction of the golden toad in Costa Rica (Figure 4-1).
- *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 the decline or disappearance of most amphibian species.

In this chapter, we will examine the major components of biodiversity, the scientific theory of how the earth's diverse species arose, how species become extinct from natural and human-related causes, how human activities affect biodiversity, and the ecological roles that species play.

Michael P. Fogden/Bruce Coleman USA

Figure 4-1 Male golden toad in Costa Rica's high-altitude Monteverde Cloud Forest Reserve. This species has recently become extinct primarily because changes in climate dried up its habitat.

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 changes 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 4-4 Human activities can decrease biodiversity by causing the premature extinction of 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 4-6 Each species plays a specific ecological role called its niche.

Note: Supplements 2 (p. S3), 4 (p. S14), 6 (p. S26), and 7 (p. S32) 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

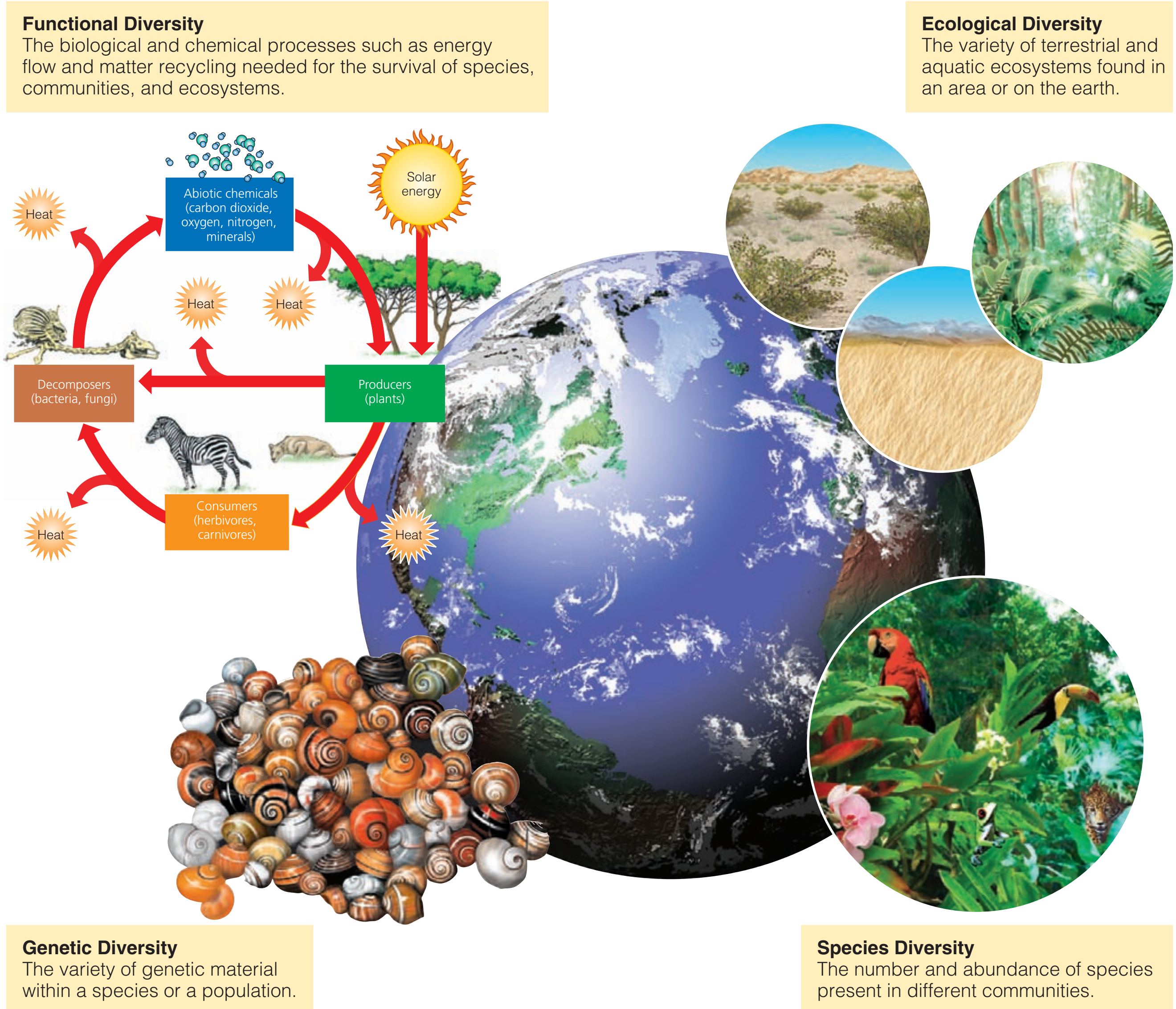
Biological diversity, or **biodiversity**, is the variety of the earth's species, the genes they contain, the ecosystems in which they live, and the ecosystem processes of energy flow and nutrient cycling that sustain all life (Figure 4-2).

Species Make Up the Encyclopedia of Life

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 in Supplement 7, p. S32.

We do not know how many species 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 2 million. These and millions of species still to be discovered and classified are the entries in the encyclopedia of life found on the earth. Up to half of the world's plant and animal species live in tropical rain forests that are being cleared rapidly (Figure 3-1, p. 39). Insects make up most of the world's known species (Science Focus, p. 62).

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. CONCEPT LINK indicates links to key concepts in earlier chapters. GOOD NEWS refers to good news about the environmental challenges we face.



CENGAGENOW™ **Active Figure 4-2** **Natural capital:** the major components of the earth's *biodiversity*—one of the earth's most important renewable resources (**Concept 4-1**). *See an animation based on this figure at* CengageNOW. **Question**: Give two examples of how people, in their daily living, intentionally or unintentionally degrade each of these types of biodiversity?

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 4-3). The earth's variety of species contains an even greater variety of genes (Figure 2-4, p. 31). This genetic diversity enables life on the earth to adapt to and survive dramatic environmental changes.

Figure 4-3 *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.

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 plants to reproduce sexually when pollen grains are transferred from one plant to a receptive part of another plant. Many of the earth's plant species depend on insects to pollinate their flowers (Figure 4-A, top).

Insects that eat other insects—such as the praying mantis (Figure 4-A, bottom)—help 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 4,000 times longer than the latest versions 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 new 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, parts of the life support systems for us and other species would be greatly disrupted.

The environmental lesson: although insects do not need newcomer species such as us, we and most other land organisms need them.

John Henry Williams/Bruce Coleman USA

Peter J. Bryant/Biological Photo Service

Figure 4-A *Importance of insects*: The monarch butterfly, which feeds on pollen in a flower (top), and other insects pollinate flowering plants that serve as food for many plant eaters. The praying mantis, which is eating a house cricket (left), and many other insect species help control the populations of most of the insect species we classify as pests.

Critical Thinking

Identify three insect species not discussed above that benefit your life.

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.

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 4-4 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 (Figure 3-7, p. 45) as species interact with one another in food chains and webs.

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 it 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 soils, decomposing and recycling waste, and controlling populations of pests. 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 chapter and Chapters 7–9.

THINKING ABOUT
Amphibians

CORE CASE STUDY

What difference would it make if most of the world's amphibian species (**Core Case Study**) became extinct?

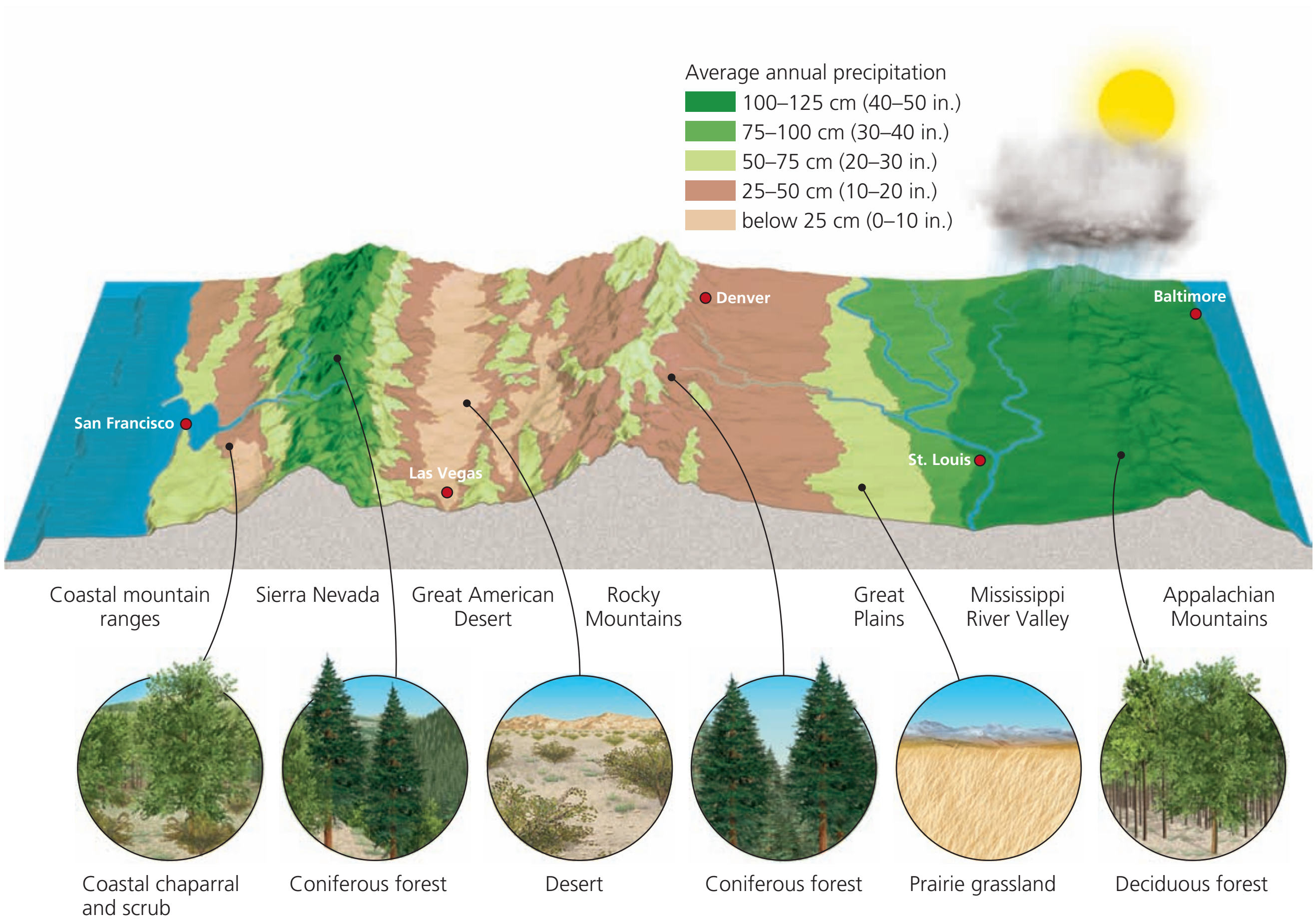


Figure 4-4 Major biomes found along the 39th parallel across the United States. The differences reflect changes in climate, mainly differences in average annual precipitation and temperature.

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 Is the Scientific Explanation of How the Earth's 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. 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 in these ways, called the *fossil record*, is uneven and incomplete. Some forms of life left no fossils, and some fossils have decomposed. The fossils found so far represent probably only 1% of all species that have ever lived. But we know with great certainty that the earth has hosted a huge and extremely diverse number of different species over time.

How did we end up with the current amazing array of 8 million to 100 million species? The scientific answer involves **biological 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.

In 1858 naturalists Charles Darwin (1809–1882) and Alfred Russel Wallace (1823–1913) independently proposed the concept of *natural selection* as a mechanism for biological evolution. However, 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 constantly struggle to survive by getting enough food 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 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.

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.

A huge body of field and laboratory 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. However, there are still many unanswered questions that generate scientific debate about the details of evolution by natural selection.

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 of a gene in any cell. Mutations can result from random changes that occur spontaneously within a cell or from exposure to external agents such as radioactivity.

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 (Figure 4-3).

The next step in biological evolution is *natural selection*, in which environmental conditions favor some individuals over others. The favored individuals possess heritable traits (resulting from mutations) that give them some advantage over other individuals. Such a trait is called an **adaptation**, or **adaptive trait**. It is 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 can under prevailing environmental conditions.

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.

CENGAGE**NOW**™ How many moths can you eat? Find out and learn more about adaptation at CengageNOW.

Another important example of natural selection at work is the evolution of *genetic resistance* to widely used antibacterial drugs, or antibiotics. These drugs are administered by doctors with the goal of controlling 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 4-5).

Here is one way to summarize the process of biological evolution by natural selection: 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 evolution by natural selection is human beings (Science Focus, p. 65). We have evolved certain traits that have allowed us to take over much of the world.

CENGAGE**NOW**™ Get a detailed look at early biological evolution by natural selection—the roots of the tree of life—at CengageNOW.

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

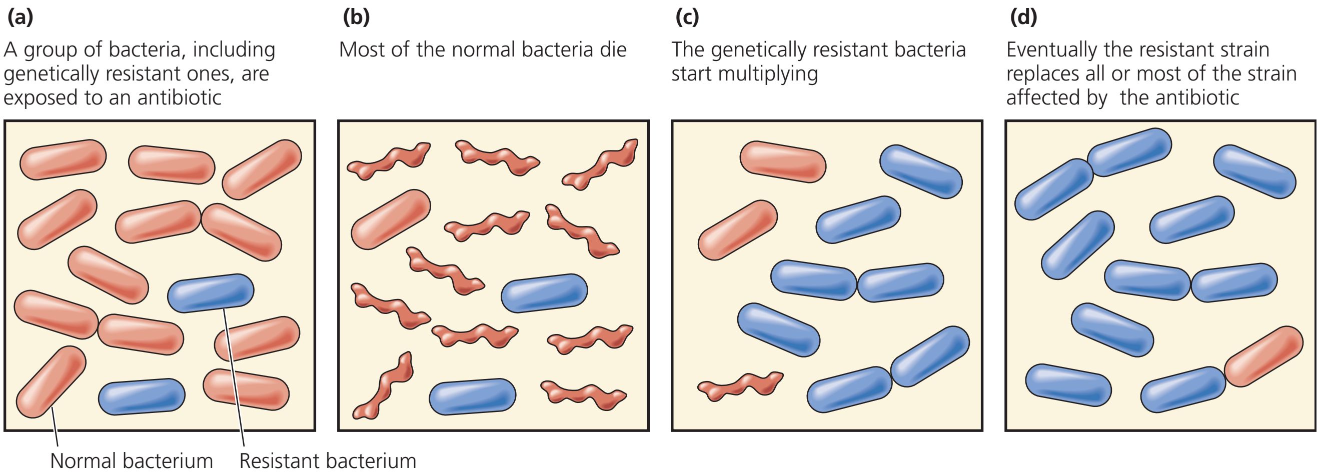


Figure 4-5 *Evolution by natural selection.* **(a)** A population of bacteria is exposed to an antibiotic, which **(b)** kills all individuals except those possessing a trait that makes them resistant to the drug. **(c)** The resistant bacteria multiply and eventually **(d)** replace all or most of the nonresistant bacteria.

effects of UV radiation, 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 limits to adaptations in nature 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.

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

SCIENCE FOCUS

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 allow us to grip and use tools better than the few other animals that have thumbs can 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 weapons, protective devices, and technologies that extend our limited senses and make up for some of our deficiencies. Thus, in an eye blink 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 (Figure 1-5, p. 11).

But adaptations that make a species successful during one period of time may not be enough to ensure the species' survival when environmental conditions 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 (see back cover and **Concept 1-5**, p. 19).

GOOD NEWS

CONCEPT LINK

Critical Thinking

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 without the use of your thumbs. You can find out what these are by taping up your thumbs for a day.

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.**

Geologic 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 4-6).

This process has had two important effects on the evolution and distribution of life on the earth. *First*, the locations (latitudes) of continents and oceanic basins

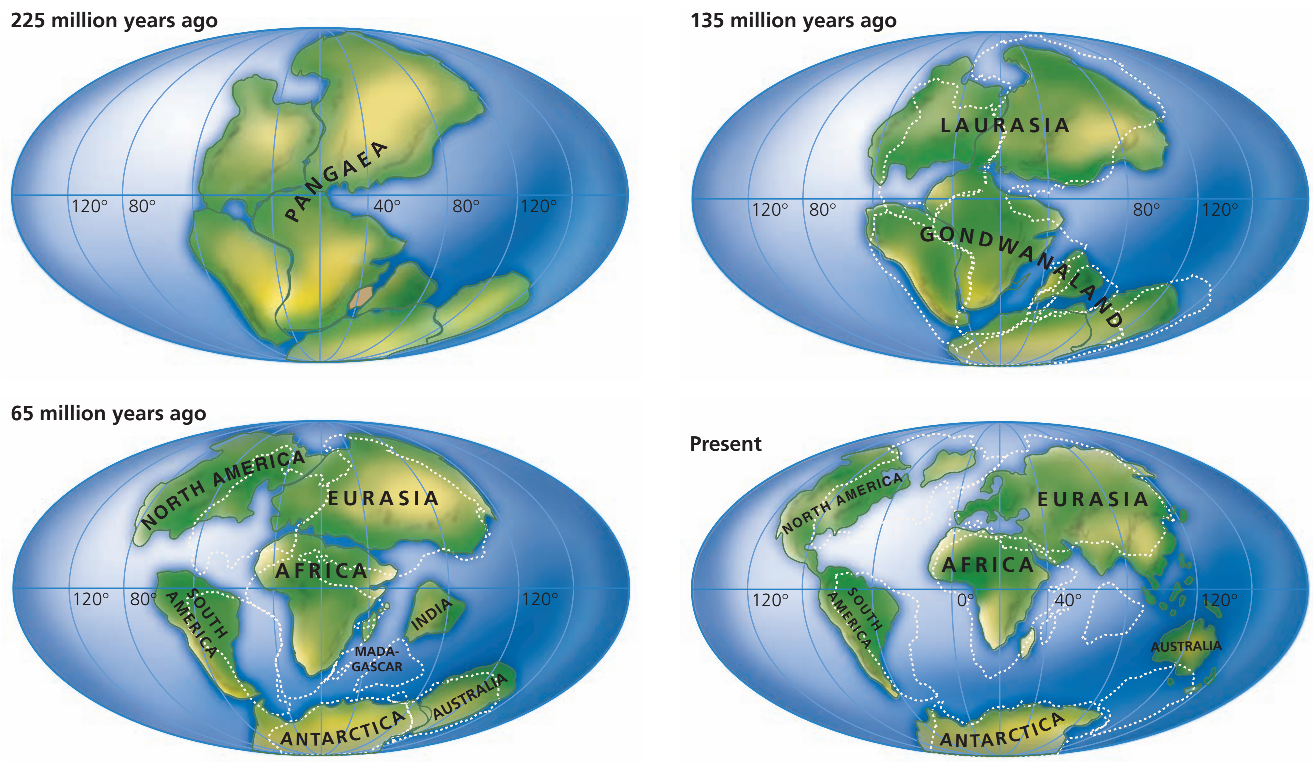


Figure 4-6 Over millions of years, the earth's continents have moved very slowly on several gigantic tectonic plates. This process plays a role in the extinction of species, as continental areas split apart, and also in the rise of new species when isolated island areas such as the Hawaiian Islands and 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). About 180 million years ago, Pangaea began splitting apart as the earth's tectonic plates separated, eventually resulting in today's locations of the continents (bottom). **Question**: How might an area of land splitting apart cause the extinction of a species?

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.

The shifting of tectonic plates, which results in earthquakes, 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. And *volcanic eruptions* affect biological evolution by destroying habitats and reducing or wiping out populations of species (**Concept 4-3**).

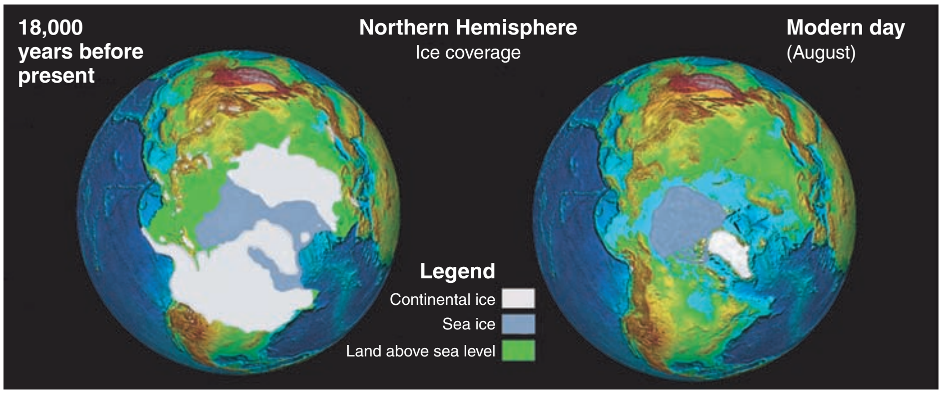


Figure 4-7 Changes in ice coverage in the northern hemisphere during the past 18,000 years. (Data from the National Oceanic and Atmospheric Administration)

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 ice. At other times it has warmed, melted ice, and drastically raised sea levels, which in turn increased the total area covered by oceans and decreased the earth's total land area. Such alternating periods of cooling and heating have led to advances and retreats of ice sheets at high latitudes over much of the northern hemisphere. The most recent advance occurred about 18,000 years ago (Figure 4-7).

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 survive and new species evolved to fill their ecological roles.

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, which depends on 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, water-based life could not exist.

The size of the earth is also just right for life. It has enough gravitational mass to keep its iron and nickel core molten and to keep the atmosphere—made up of light gaseous molecules required for life (such as N_2, O_2, CO_2, and H_2O)—from flying off into space.

Although life on earth has been enormously resilient and adaptive, it has benefitted 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 levels of the temperature-regulating gas carbon dioxide in the atmosphere as a part of the carbon cycle (Figure 3-13, p. 51).

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, an ozone sunscreen in the stratosphere protects us and many other forms of life from an overdose of UV 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?

Another force affecting natural selection has been catastrophic events such as collisions between the earth and large asteroids. There probably have been many of these collisions during the earth's 3.5 billion years of life. 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, p. 67 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 4-4 Human activities can decrease biodiversity by causing the premature extinction of 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 is formed 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 in a different way.

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: geographic isolation and 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. Then one species has become two, and speciation has occurred (Figure 4-8).

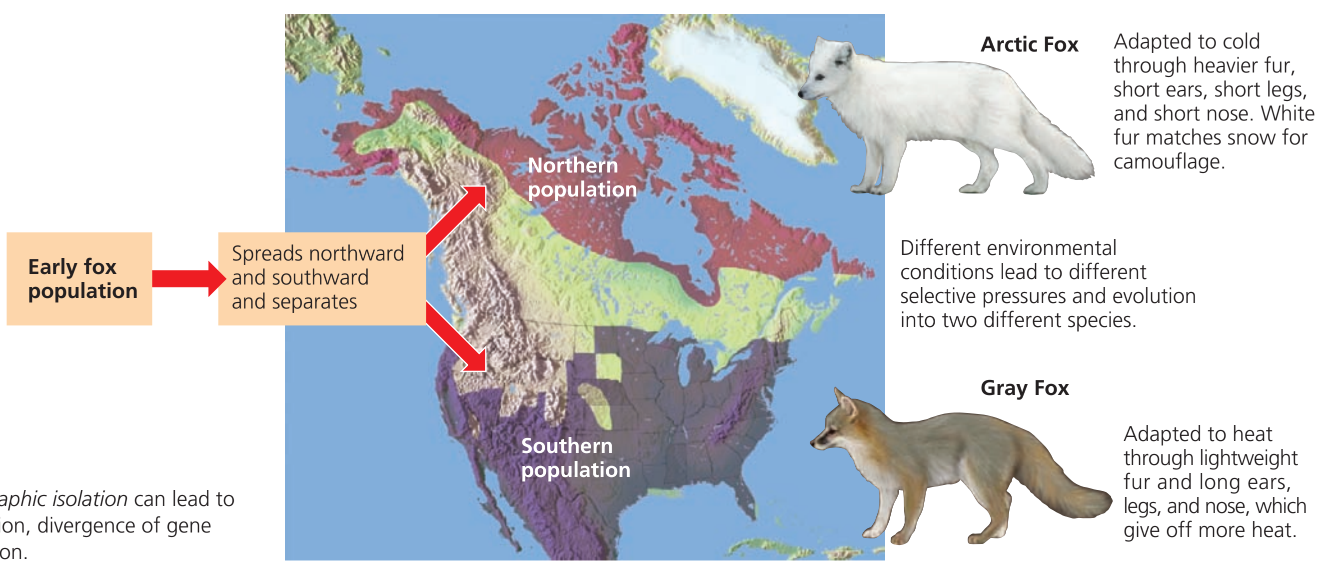


Figure 4-8 *Geographic isolation* can lead to reproductive isolation, divergence of gene pools, and speciation.

CENGAGENOW™ Learn more about different types of speciation and 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 (Science Focus, below).

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, *migrate* (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 small 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.

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 is 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 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.

SCIENCE FOCUS

We Have Developed Two Ways to Change 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, or dog. Then we use *selective breeding* 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 and thus 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 combine traits only from 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, through adding, deleting, or changing segments of its DNA to produce desirable traits or eliminate undesirable ones. It enables scientists to transfer genes between different species that would not interbreed in nature. For example, genes from a fish species can be put into a tomato plant to give it certain properties.

R. L. Brinster and R. E. Hammer/School of Veterinary Medicine, University of Pennsylvania

Figure 4-B An example of genetic engineering. The 6-month-old mouse on the left is normal; the same-age mouse on the right has a human growth hormone gene inserted in its cells. Mice with the human growth hormone gene grow two to three times faster than, and twice as large as, mice without the gene. **Question**: How do you think the creation of such species might change the process of evolution by natural selection?

Scientists have used genetic engineering to develop modified crop plants, new drugs, pest-resistant plants, and animals that grow rapidly (Figure 4-B). 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.

Critical Thinking

What might be some beneficial and harmful effects on the evolutionary process if genetic engineering is widely applied to plants and animals?

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 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 exploit new ways of life. As environmental conditions change, the balance between formation of new species (speciation) and extinction of existing species determines the earth's biodiversity. 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.

Extinction is a natural process. But much evidence indicates that humans have become a major force in the premature extinction of a growing number of species, as discussed further in Chapter 8.

CONNECTIONS

Endemic Species, Climate Change, and Extinction

CORE CASE STUDY

The brilliantly colored golden toad (**Core Case Study**, Figure 4-1) was once found only in a small area of lush rain forests in Costa Rica. Although it lived in the well-protected Monteverde Cloud Forest Reserve, this endemic species had apparently become extinct by 1989. Much of the moisture that supported its habitat came in the form of moisture-laden clouds blowing in from the Caribbean Sea. But warmer air resulting from global climate change caused these clouds to rise, depriving the forests of moisture, and the habitat for the golden toad and many other species dried up.

THINKING ABOUT

Amphibians and Your Lifestyle

CORE CASE STUDY

List two ways in which your lifestyle could be contributing to the decline of some amphibian species (**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**: the number of different species it contains (**species richness**) combined with the relative abundance of individuals within each of those species (**species evenness**).

For example, a biologically diverse community such as a tropical rain forest or a coral reef (Figure 4-9, left) with a large number of different species (high species richness) generally has a relatively low number of members of each species (low species evenness). Biologist Terry Erwin found an estimated 1,700 different beetle species in a

Reinhard Dirscherl/Bruce Coleman USA

Alan Majchrowicz/Peter Arnold

Figure 4-9 *Variations in species richness and species evenness.* A coral reef (left), with a large number of different species (high species richness), generally has only a few members of each species (low species evenness). In contrast, a grove of aspen trees in Alberta, Canada, (right) has a small number of different species (low species richness), but large numbers of individuals of each species (high species evenness).

single tree in a tropical forest in Panama, but only a few individuals of each species. On the other hand, an aspen forest community in Canada (Figure 4-9, right) may have only ten plant species (low species richness), but large numbers of each species (high species evenness).

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 2, p. S16, in Supplement 4). The most species-rich environments are tropical rain forests, coral reefs, the ocean bottom zone, and large tropical lakes.

Species-Rich Ecosystems Tend to Be Productive and Sustainable

How does species richness affect an ecosystem? In trying to answer this question, ecologists have been conducting research to answer two related questions: Is plant productivity higher in species-rich ecosystems? And 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 the 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."

There are exceptions, but many studies support the idea that some level of species richness and productivity can provide insurance against catastrophe. In one 11-year study, 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 new insect species. Because of their higher level of biomass, the species-rich communities also took up more carbon dioxide and more nitrogen, thus playing more robust roles in the carbon and nitrogen cycles (**Concept 3-4**, p. 48).

CONCEPT LINK

Later laboratory studies involved setting up artificial ecosystems in growth chambers where key variables such as temperature, light, and atmospheric gas concentrations could be controlled and varied. 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 topsoils, and others use deeper 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 are still 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.

RESEARCH FRONTIER

Learning more about how biodiversity is related to ecosystem stability and sustainability. See **www.cengage.com/biology/miller**.

4-6 What Roles Do Species Play in an Ecosystem?

▶ **CONCEPT 4-6 Each species plays a specific ecological role called its niche.**

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 4-6**). Scientists describe the role that a species plays in its ecosystem as its **ecological niche**, or simply **niche** (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, and the temperatures it can tolerate. A species' niche should not

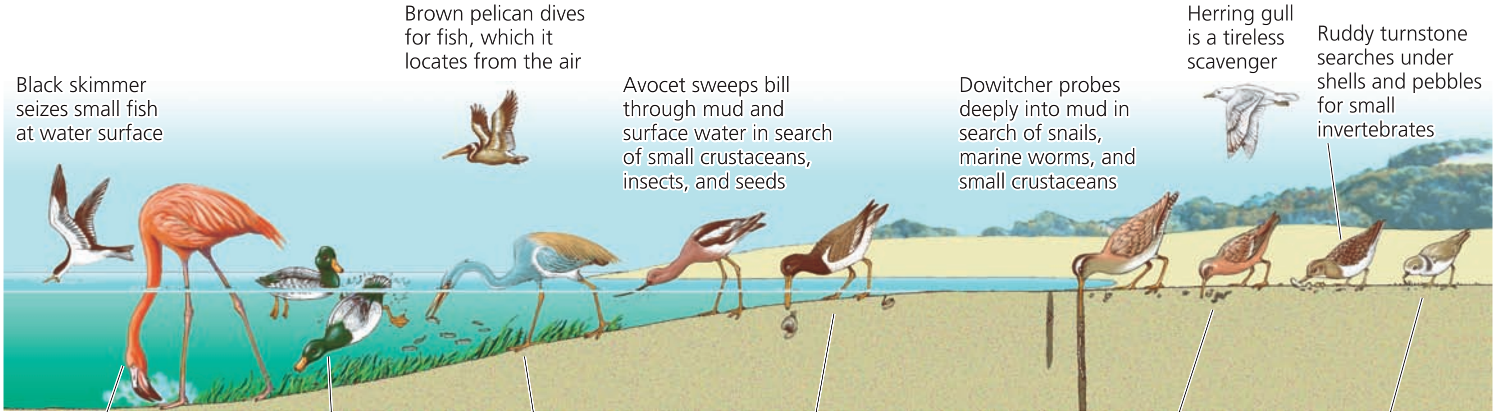


Figure 4-10 Specialized feeding niches of various bird species in a coastal wetland. This specialization reduces competition and allows sharing of limited resources.

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. 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, below), mice, rats, white-tailed deer, raccoons, and humans are generalist species.

In contrast, **specialist species** occupy narrow niches. They may be able to live in only one type of habitat, use one or a few types of food, or tolerate a narrow range of climatic and other environmental conditions. For example, *tiger salamanders* breed only in fishless ponds where their larvae will not be eaten. Some shorebirds occupy specialized niches, feeding on crustaceans, insects, and other organisms on sandy beaches and their adjoining coastal wetlands (Figure 4-10).

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 to be 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 4-11), 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 rapidly reproducing *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 a month 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

Clemson University–USDA Cooperative Extension Slide Series

Figure 4-11 As generalists, cockroaches are among the earth's most adaptable and prolific species. This is a photo of an American cockroach.

that allow them to see in almost all directions at once. Each eye has about 2,000 lenses, compared to 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.

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.

Niches Can Be Occupied by Native and Nonnative Species

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 community.

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 species of crops and animals such as chickens, cattle, and fish from around the world are beneficial to us. However, some nonnative species can reduce a community's native species and cause unintended and unexpected consequences. In 1957, for example, Brazil imported wild African bees to help increase honey production. Instead, the bees displaced domestic honeybees and reduced the honey supply.

GOOD NEWS

Since then, these nonnative bee 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**. For example, the presence or absence of trout species is an indicator of water quality, because trout need clean water with high levels of dissolved oxygen.

Birds are excellent biological indicators because they are found almost everywhere and are affected quickly by environmental changes such as loss or fragmentation of their habitats and 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.

CONNECTIONS

Coal Mining and Canaries

Using a living organism to monitor environmental quality is not new. Coal mining is a dangerous occupation, partly because of the underground presence of poisonous and explosive gases, many of which have no detectable odor. In the 1800s and early 1900s, coal miners took caged canaries into mines to act as early-warning sentinels. These birds normally sing loudly and often. But in the mines, if they quit singing for a long period and appeared to be distressed, miners took this as an indicator of the presence of poisonous or explosive gases and got out of the mine.

Revisiting Amphibian Species

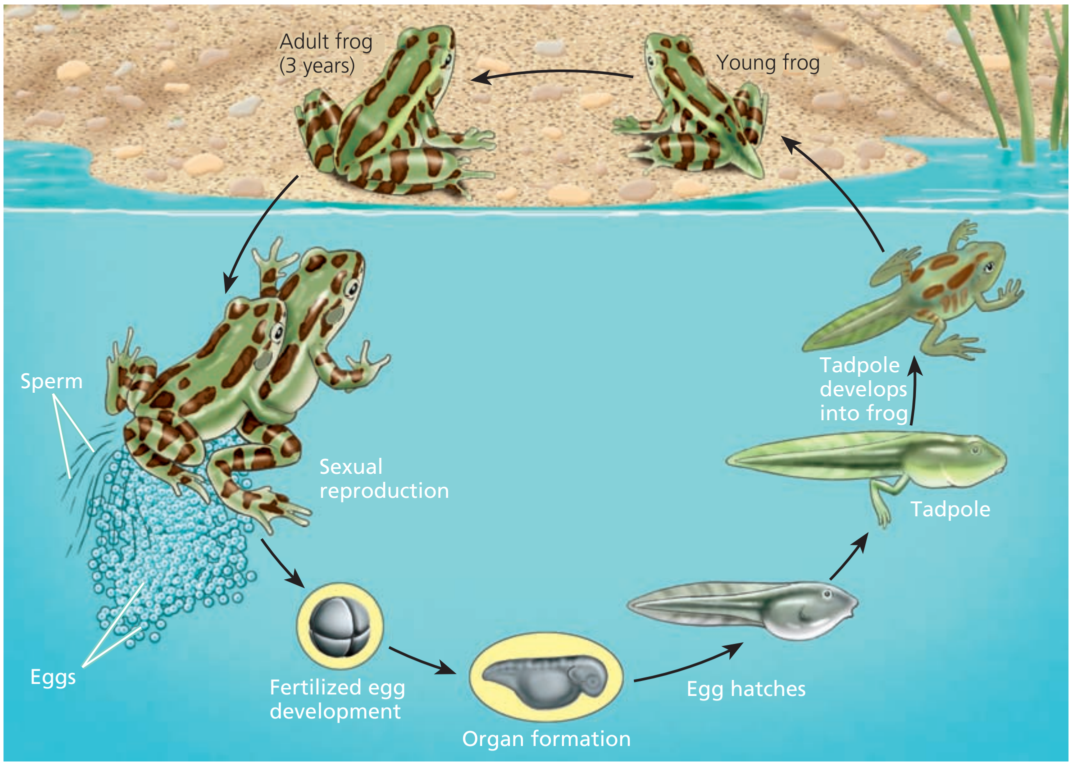
Frogs are especially sensitive and vulnerable to environmental disruption at various points in their life cycle (Figure 4-12, p. 74).

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 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.

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, increased exposure to UV radiation, and climate change. Their possible extinction suggests that environmental health is deteriorating in 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, 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.

Figure 4-12 *Life cycle of a frog.* Populations of various frog species can decline because of the effects of harmful environmental factors at different points in their life cycle. Such environmental factors include habitat loss, drought, pollution, increased UV radiation, parasitism, disease, overhunting for food (frog legs), and nonnative predators and competitors.



Third, amphibians represent a genetic storehouse from which hundreds of pharmaceutical products could be developed. For example, compounds in secretions from amphibian skin have been isolated and used as painkillers and antibiotics and as treatment 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. Like canaries in a coal mine, these indicator species are sending us urgent distress signals.

RESEARCH FRONTIER

Learning more about why amphibians are disappearing and applying this knowledge to other threatened species. See **www.cengage.com/biology/miller**.

Keystone and Foundation Species Play Important 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 abundances 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 others are. As was shown by the near extinction of the American alligator in the southeastern United States (Science Focus, p. 75), eliminating a keystone species may dramatically alter an ecosystem.

THINKING ABOUT
The American Alligator

What difference would it make if the American alligator became extinct?

Keystone species can play several critical roles in helping to sustain ecosystems. One such role is *pollination* of flowering plant species by bees, butterflies, 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 alligator, wolf, leopard, lion, and some shark species (see Case Study, right).

The loss of a keystone species can lead to population crashes and extinctions of other species in a community that depends on it for certain ecological services. This is why it so important for scientists to identify and protect keystone species.

Another important type of species in some ecosystems is a **foundation species**, which plays a major role

SCIENCE FOCUS

Why Should We Care about the American Alligator?

The American alligator, North America's largest reptile, has no natural predators except for humans and plays a number of important roles in the ecosystems where it is found. This species outlived the dinosaurs and survived many challenges to its existence.

But 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 shoes, belts, and pocketbooks. Other people hunted alligators for sport or out of hatred. 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, which hold freshwater during dry spells, serve as refuges for aquatic life, and supply freshwater and food for fish, insects, snakes, turtles, birds, and other animals. Large alligator nesting mounds provide nesting and feeding sites for species of herons and egrets, and red-bellied turtles use old gator nests for incubating their eggs. Alligators eat large numbers of gar, a predatory fish. This helps to maintain populations of game fish such as bass and bream.

As alligators move from gator holes to nesting mounds, they help to keep areas of open water free of invading vegetation. Without these free ecosystem services, 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.

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 where it is found.

In 1967, the U.S. government placed the American alligator on the endangered species list. Protected from hunters, the population made a strong comeback in many areas by 1975—too strong, according to homeowners who 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 1–2 million alligators in Florida, and the state now allows property owners to kill alligators that stray onto their land. To biologists, the comeback of the American alligator is an important success story in wildlife conservation. GOOD NEWS

Critical Thinking

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?

in shaping communities by creating and enhancing their habitats in ways that benefit other species. For example, elephants push over, break, or uproot trees, creating forest 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 are another good example of a foundation species. Acting as "ecological engineers," they build dams in streams to create ponds and other wetlands used by other species.

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). On the other hand, keystone species can do this and more. They sometimes play this foundation role (as do alligators), but they also play an active role in maintaining the ecosystem and keeping it functioning in a way that serves many of the other species living there.

RESEARCH FRONTIER

Identifying and protecting keystone and foundation species. See **www.cengage.com/biology/miller**.

CASE STUDY

Why Should We Protect Sharks?

The world's 370 shark species vary widely in size. The smallest is the dwarf dog shark, about the size of a large goldfish. The largest, the whale shark, can grow to 15 meters (50 feet) long and weigh as much as two full-grown African elephants.

Shark species, feeding at or near the tops of food webs (Figure 3-9, p. 46), remove injured and sick animals from the ocean, and thus play an important ecological role. Without the services provided by these keystone shark species, the oceans would be teeming with dead and dying fish.

In addition to their important ecological roles, sharks could 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—influenced by movies, popular novels, and widespread media coverage of a fairly small number of shark attacks per year—think of sharks as people-eating monsters. In reality, the three largest species—the whale shark, basking shark, and megamouth shark—are gentle giants. They swim through the water with their mouths open, filtering out and swallowing huge quantities of plankton.

Media coverage of shark attacks greatly distorts the danger from sharks. Every year, members of a few species—mostly great white, bull, tiger, gray reef, lemon, hammerhead, shortfin mako, and blue sharks—injure 60–75 people worldwide. Between 1998 and 2007, sharks killed an average of 5 people per year and injured an average of 63 per year, worldwide. Most attacks involve great white sharks, which feed on sea lions and other marine mammals and sometimes mistake divers and surfers for their usual prey.

Does swimming in the ocean make you nervous? Compare some risks. The estimated lifetime risk of being killed by a shark in U.S. waters is 1 in 3,750,000, compared with the risk of dying in a car accident, 1 in 84, and the risk of death by common flu, 1 in 63 (see the Data Analysis exercise at the end of this chapter).

Now, consider the fact that *for every shark that injures one person, we kill at least 500,000 sharks*. Sharks are caught mostly 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. A top (dorsal) fin from a large whale shark can fetch up to $10,000. In high-end restaurants in China, a bowl of shark fin soup can cost $100 or more. Ironically, shark fins have been found to contain dangerously high levels of toxic mercury.

Sharks are also killed for their livers, meat, hides, and jaws, and because we fear them. Some sharks die when they are trapped in nets or lines deployed to catch swordfish, tuna, shrimp, and other species. Sharks are especially vulnerable to overfishing 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.

Mostly because of the increased demand for shark fins and meat, 81 of the world's shark species are threatened with extinction. In response to a public outcry over depletion of some species, the United States and several other countries have banned the hunting of sharks for their fins. But such bans apply only in each country's territorial waters and are difficult to enforce. Scientists call for banning shark finning in international waters and establishing a network of fully protected marine reserves to help protect coastal shark species and other aquatic species from overfishing.

Sharks have been around for more than 400 million years. Sustaining this portion of the earth's biodiversity begins with the knowledge that sharks may not need us, but that, because sharks are keystone species, we and other species need them.

THINKING ABOUT
Sharks

What difference would it make if most of the world's shark species became extinct? What are three ways in which you may be contributing to the premature extinction of some shark species?

HOW WOULD YOU VOTE?

Do we have an ethical obligation to protect shark species from premature extinction and to treat them humanely? Cast your vote online at **www.cengage.com/biology/miller**.

Here are the *three big ideas* in this chapter.

- 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 premature extinction of species and by disrupting habitats needed for the development of new species.
- Each species plays a specific ecological role in the ecosystem where it is found (ecological niche).

REVISITING Amphibians and Sustainability

CORE CASE STUDY

SUSTAINABILITY

The **Core Case Study** at the beginning of this chapter, which describes the decline of many amphibian species, illustrates the power humans have over their environment—the power both to do harm and to make amends. As more amphibians were being eliminated from their natural areas, scientists began pointing out the ecological services these animals provide to their ecosystems and to humans (pp. 73–74). Scientific understanding of these ecological connections can help us to protect vulnerable amphibian species from premature extinction and to help those with declining populations recover.

In this chapter, we studied the importance of biodiversity, especially the numbers and varieties of species (species richness) found in different parts of the world. We looked at other forms of biodiversity as well—genetic, ecosystem, and functional diversity (Figure 4-2). We also studied the process whereby all species came to be, according to the scientific theory of biological evolution through natural selection. Taken together, biodiversity and evolution represent irreplaceable components of the earth's natural capital that must be protected from harmful human activities. Finally, we examined the variety of roles played by species in ecosystems.

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 provide functional biodiversity in the form of energy flow and the chemical cycling of nutrients. Ecosystems also sustain biodiversity in all its forms. In the next chapter, we delve further into how species interact and how their interactions result in natural regulation of populations and maintenance of biodiversity.

Somewhere, something incredible is waiting to be known.

CARL SAGAN

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 59. List possible causes of the decline in the populations of many amphibian species.
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 in understanding the history of life? What is **biological evolution**? State 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**)? How did humans 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 and climate change can 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. Explain why species-rich ecosystems tend to be productive and stable.
8. What is an **ecological niche**? Distinguish between **specialist species** and **generalist species** and give an example of each.
9. Distinguish among **native**, **nonnative**, **indicator**, **keystone**, and **foundation** species and give an example of each type. Explain why birds are excellent indicator species. What major ecological roles do amphibian species play and why should we protect them? Why should we protect shark species from being driven to extinction as a result of our activities?
10. What are this chapter's *three big ideas*? How is biodiversity related to the three **principles of sustainability**? 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 amphibian species (**Core Case Study**) were to become 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? SUSTAINABILITY
3. How would you respond to someone who tells you that:
   a. he or she does not believe in biological evolution because it is "just a theory"?
   b. 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 forms of life in competition? If so, how do they manage to coexist?
5. How would you experimentally determine whether an organism is a keystone species?
6. Is the human species a keystone species? Explain. If humans were to become extinct, what are two species that might also become extinct and two species whose populations might grow?
7. Explain how you would respond to someone who says that because extinction is a natural process, we should not worry about the loss of biodiversity when species become prematurely extinct as a result of our activities.
8. List three ways in which you could apply **Concept 4-4** to live a more environmentally sustainable lifestyle.
9. Congratulations! You are in charge of the future evolution of life on the earth. What are the three most important things you will do?
10. List two questions that you would like to have answered as a result of reading this chapter.

DATA ANALYSIS

Injuries and deaths from shark attacks are highly publicized by the media. However, the risk of injury or death from a shark attack for people going into coastal waters as swimmers, surfers, or divers is extremely small (See Case Study, pp. 75–76). For example, according to the National Safety Council, the Centers for Disease Control and Prevention, and the International Shark Attack File, the estimated lifetime risk of dying from a shark attack in the United States is about 1 in 3,750,000 compared to 1 in 1,130 from drowning, 1 in 218 from a fall, 1 in 84 from a car accident, 1 in 63 from the flu, and 1 in 38 from a hospital infection.

Between 1998 and 2007, the United States had world's highest percentage of deaths and injuries from unprovoked shark attacks. The following table shows numbers of deaths in the United States from various accidental causes, compared with the number of deaths from shark attacks, in 2004 (the latest year for which these data are all available from the U.S. National Safety Council). Study the table and answer the questions that follow.

Selected Causes of Accidental Death in the United States, 2004

Cause of death	Number of deaths	Percent of total
Shark attack	7	
Lightning strike	46	
Sting of wasp or bee	52	
Accidental shooting	649	
Drowning	3,308	2.95%
Falling	18,807	
Accidental poisoning	20,950	
Motor vehicle accident	44,933	
Total accidental deaths	112,012	100%

Source: U.S. National Safety Council.

1. For every person who was killed by a shark in 2004 in the United States, about how many people died by **(a)** lightning strike, **(b)** drowning, and **(c)** motor vehicle accident?

2. Fill in the right-hand column by determining the percentage of total deaths for each of the listed causes. (For example, the percentage of the total for drowning deaths is $3{,}308 \div 112{,}012 = 0.0295 \times 100 = 2.95\%$)

LEARNING ONLINE

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Biodiversity, Species Interactions, and Population Control

5

The Southern Sea Otter: A Species in Recovery

CORE CASE STUDY

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 between the U.S. state of California's coastal cities of Santa Cruz and Santa Barbara.

Southern sea otters are fast and agile swimmers that dive to the ocean bottom looking for shellfish and other prey. These tool-using marine mammals use stones to pry shellfish off rocks under water. When they return to the surface they break open the shells while swimming on their backs, using their bellies as a table (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.

Between 16,000 and 17,000 southern sea otters are believed to have populated the waters along their habitat area of the California coast. But by the early 1900s, the species was hunted almost to extinction in this region because fur traders had killed them for their thick, luxurious fur. Others had killed otters because they were competing with commercial fishers for valuable abalone and other shellfish.

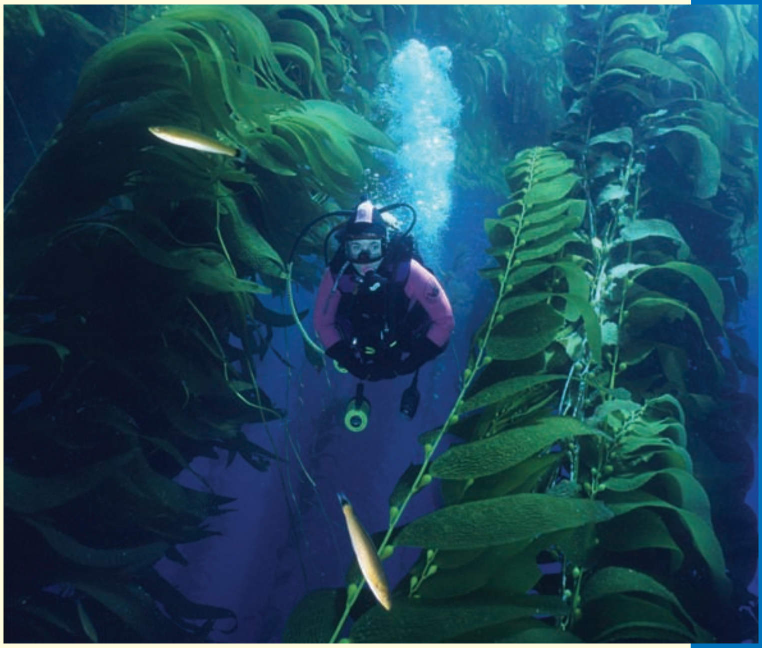
Between 1938 and 2008 the population of southern sea otters off California's coast increased from about 50 to about 2,760. Their partial recovery got a boost in 1977 when the U.S. Fish and Wildlife Service declared the species endangered in most of its range with a population of only 1,850. But this 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 that people love to look at these charismatic, cute, and cuddly animals as they play in the water. As a result, they help to generate millions of dollars a year in tourism income in coastal areas where they are found. Another reason is *ethical:* Some people believe it is wrong to cause the premature extinction of any species.

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* (p. 74). Without southern sea otters, scientists hypothesize 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



Bruce Coleman USA

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 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), 4 (p. S14), 5 (p. S21), and 6 (p. S26) 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 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 the 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, if any, 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 or other resources.

Recall that each species plays a role in its ecosystem called its *ecological niche* (**Concept 4-6**, p. 71). CONCEPT LINK 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, the other competing species must **(1)** migrate to another area (if possible), **(2)** shift its feeding habits or behavior through natural selection to reduce or alter its niche, **(3)** suffer a sharp population decline, **(4)** or become extinct in that area.

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

Figure 5-2 *Sharing the wealth: resource partitioning* by five species of insect-eating warblers in the spruce forests of the U.S. state of Maine. Each species minimizes competition for food with the others by spending at least half its feeding time in a distinct portion (shaded 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.)

other species for the same 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 use shared resources at different times, in different ways, or in different places.

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 4-11 (p. 72) shows how the evolution of specialized feeding niches of bird species in a coastal wetland has reduced their competition for the same resources.

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 of another plant or animal species (the **prey**) as part of a food web (**Concept 3-3**, p. 45). Together, the two different species such as lions (the predator, or hunter) and zebras (the prey, or hunted) form a **predator–prey relationship**. Such relationships are shown in Figures 3-8 and 3-9 (p. 46).

CONCEPT LINK

In giant kelp forest ecosystems, sea urchins prey on kelp, a form of seaweed (**Core Case Study**, Figure 5-1, right). However, as keystone species, southern sea otters (Figure 5-1, left) prey on the sea urchins and thus keep them from destroying the kelp forests (Science Focus, p. 82).

CORE CASE STUDY

Predators have a variety of methods that help them capture prey. *Herbivores* can simply walk, swim, or fly up to the plants they feed on. For example, sea urchins (Science Focus, p. 82, Figure 5-A) can move along the ocean bottom to feed on the bases of giant kelp plants (**Core Case Study**). *Carnivores* feeding on mobile prey have two main options: *pursuit* and *ambush*. Some predators such as the cheetah catch prey by running fast; others such as the American bald eagle can fly and have keen eyesight; still others such as wolves and African lions cooperate in capturing their prey by hunting in packs.

CORE CASE STUDY

Other predators use *camouflage* to hide in plain sight and ambush their prey. For example, praying mantises (Figure 4-A, bottom, p. 62) sit in flowers of a similar color 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 ambush wild game.

Some predators use *chemical warfare* to attack their prey. For example, spiders and poisonous snakes use venom to paralyze their prey and to deter their predators.

Prey species have evolved many ways to avoid predators, including the ability to run, swim, or fly fast, and a highly developed sense of sight or smell that alerts them to the presence of predators. Other avoidance adaptations include protective shells (turtles), thick bark (giant sequoia), spines (porcupines), and thorns (cacti and rose bushes). Many lizards have brightly colored tails that break off when they are attacked, often giving them enough time to escape.

SCIENCE FOCUS

Threats to Kelp Forests from Predators and Climate Change

A kelp forest is a forest of seaweed called *giant kelp* whose large 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.

CORE CASE STUDY

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.

Deborah Meeks/SuperStock

Figure 5-A Purple sea urchin in coastal waters of the U.S. state of California.

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. Male southern sea otters, a keystone species, help to control populations of sea urchins. An adult male 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.

A second threat to kelp forests is projected climate change. Giant kelp forests require fairly cool water. If coastal waters warm up during this century, as projected in 2007 by climate experts on the Intergovernmental Panel on Climate Change (IPCC), many—perhaps most—of the kelp forests off the coast of California will disappear. The southern sea otter and many other species will also disappear, unless they can migrate to other locations, which are few and far between on the earth.

Critical Thinking

What are three ways to protect giant kelp forests and southern sea otters?

Other prey species use the camouflage of certain shapes or colors or the ability to change color (chameleons and cuttlefish). Some insect species have shapes that look like twigs (Figure 5-3a), bark, thorns, or even bird droppings on leaves. A leaf insect can be almost invisible against its background (Figure 5-3b), 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 5-3c), *foul smelling* (skunks, skunk cabbages, and stinkbugs), or *foul tasting* (buttercups and monarch butterflies, Figure 5-3d). 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 enables experienced predators to recognize and avoid them. They flash a warning: "Eating me is risky." Examples are brilliantly colored poisonous frogs (Figure 5-3e) and foul-tasting monarch butterflies (Figure 5-3d). For example, 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 an 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 5-3f) 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 5-3h). Some moths have wings that look like the eyes of much larger animals (Figure 5-3g). 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.

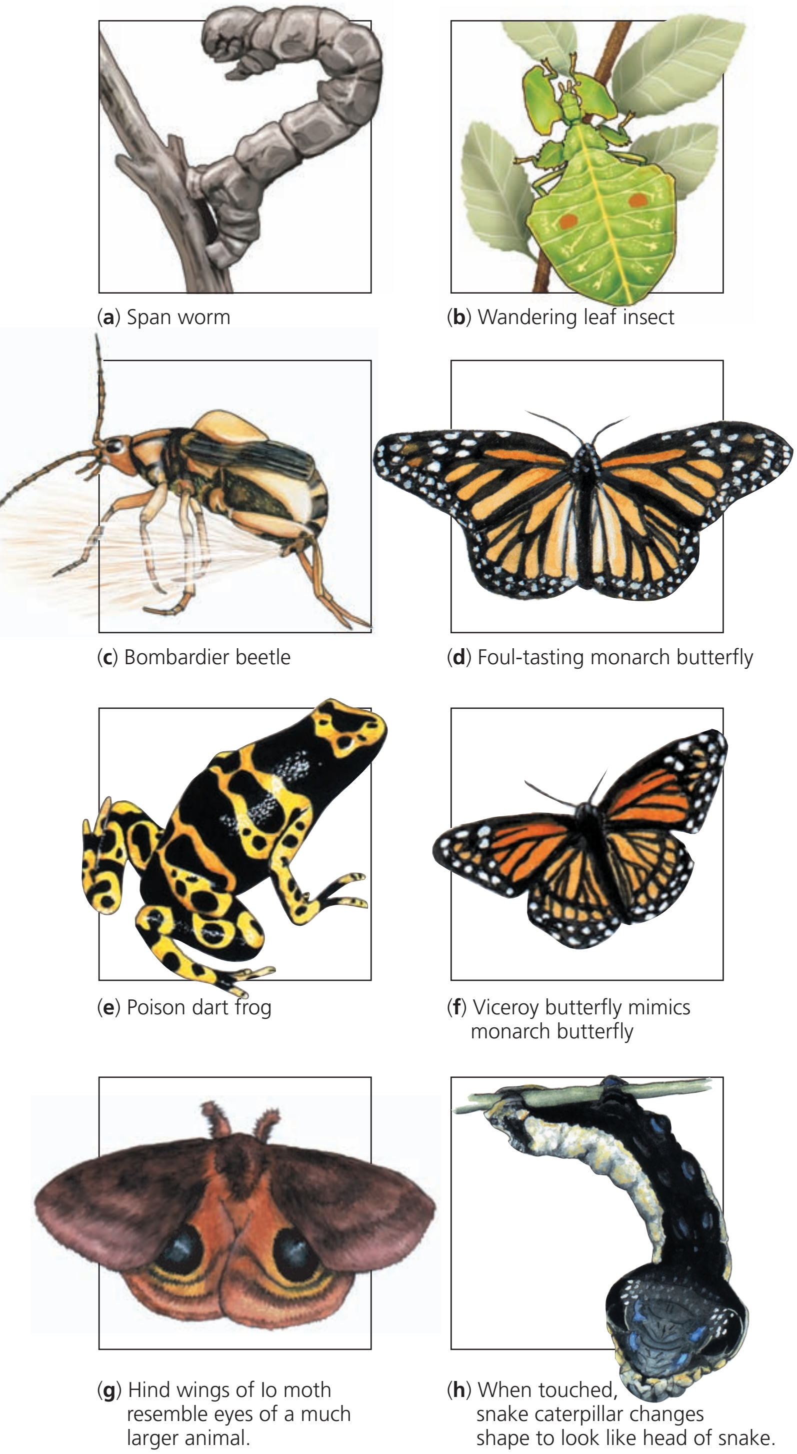


Figure 5-3 Some ways in which prey species avoid their predators: **(a, b)** *camouflage,* **(c–e)** *chemical warfare,* **(d, e)** *warning coloration,* **(f)** *mimicry,* **(g)** *deceptive looks,* and **(h)** *deceptive behavior.*

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 (**Concept 4-2B**, p. 63). CONCEPT LINK 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 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 that increase 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 5-4) and use echolocation to navigate and

ullstein-Nill/Peter Arnold, Inc.

Figure 5-4 *Coevolution.* A Langohrfledermaus bat 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 chances of getting a meal and the moths evolve traits that help them avoid being eaten.

to locate their prey, emitting pulses of extremely high-frequency and high-intensity sound. They capture and analyze the returning echoes and create a sonic "image" of their prey.

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.

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 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 in Them

Parasitism occurs when one species (the *parasite*) feeds on the body of, or the energy used by, another organism (the *host*), usually by living on or in the host. In this relationship, the parasite benefits and the host is harmed but not immediately killed.

Unlike the typical predator in relation to its prey, a parasite usually is much smaller than its host and rarely kills its host. Also, most parasites remain closely associated with their hosts, draw nourishment from them, and may gradually weaken them over time.

Some parasites such as tapeworms and some disease-causing microorganisms (pathogens) live *inside* their hosts. Other parasites attach themselves to the *outsides* of their hosts. Examples of the latter include mosquitoes, mistletoe plants (Figure 5-5, right), and sea lampreys that use their sucker-like mouths to attach themselves to fish and feed on their blood (Figure 5-5, left). Some parasites move from one host to another, as fleas and ticks do; others such as tapeworms spend their adult lives with a single host.

From the host's point of view, parasites are harmful. But at the population level, parasites can promote biodiversity by increasing species richness, and they help to keep the populations of their hosts in check.

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. Such interactions can affect an ecosystem by helping to sustain the populations of the participating species and by providing favorable habitats for certain organisms and influencing their distribution.

Figure 5-6 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 5-6a). 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 approach.

A second example involves the clownfish species (Figure 5-6b). 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

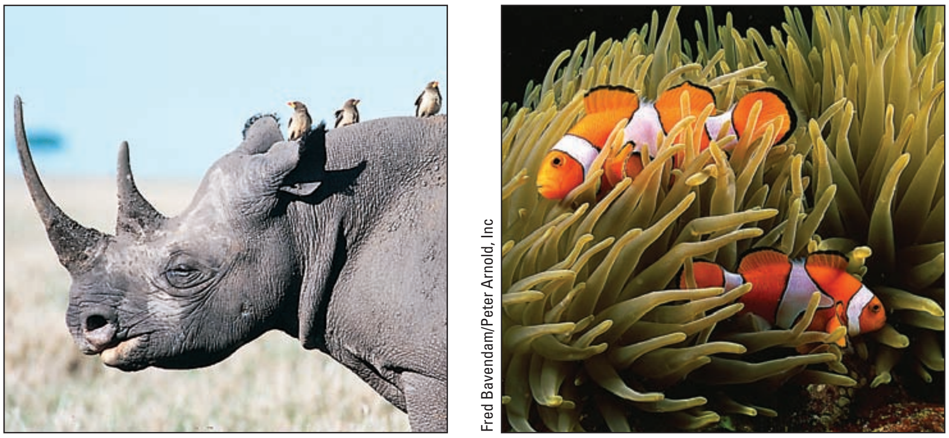
U.S. Fish and Wildlife Service

(a)

PhotoAlto/SuperStock

(b)

Figure 5-5 *Parasitism:* **(a)** Blood-sucking parasitic sea lampreys attached to an adult lake trout from the Great Lakes (USA). **(b)** Healthy tree on the left and an unhealthy one on the right that is infested with parasitic mistletoe.



Joe McDonald/Tom Stack & Associates

Fred Bavendam/Peter Arnold, Inc

(a) Oxpeckers and black rhinoceros

(b) Clownfish and sea anemone

Figure 5-6 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.

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 break down (digest) their food. The bacteria receive a sheltered habitat and food from their host. In turn, they help to digest their host's food. 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 5-7). 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 5-7 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 water, other nutrient debris, and sunlight; 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.**

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):

$$\text{Population change} = (\text{Births} + \text{Immigration}) - (\text{Deaths} + \text{Emigration})$$

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 to begin this reproductive pattern again. 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 to begin the cycle again.

Most large mammals (such as elephants, whales, and humans), birds of prey, and large and long-lived plants (such as the saguaro cactus and most tropical rain forest trees) follow this reproductive pattern. Many of these species—especially those with long times between generations and low reproductive rates like elephants, rhinoceroses, and sharks—are vulnerable to extinction. Most organisms have reproductive patterns between these two extremes.

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, reproduce many times, and have a short time between each successive generation. 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!

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, space, or nutrients, or by exposure to predators, infectious diseases, or too many competitors.

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, right). CORE CASE STUDY

Environmental resistance is the combination of all factors that act to limit the growth of a population. It largely determines a population'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 5-8, left half of curve).

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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.

Another factor may be parasites known to breed in cats. Scientists hypothesize that some sea otters may be dying because northern California 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 prove 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 help to reveal the condition of coastal waters in their habitat.

Some southern sea otters also 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).

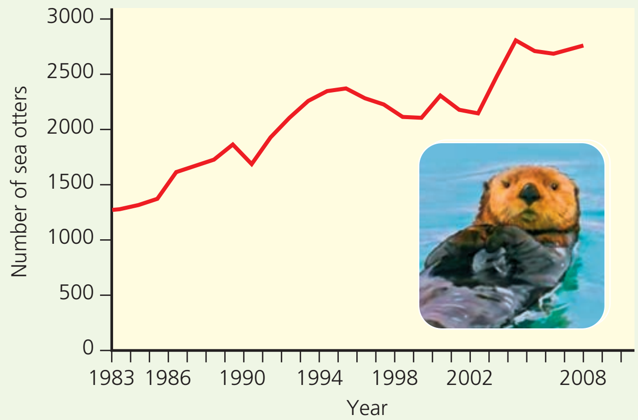
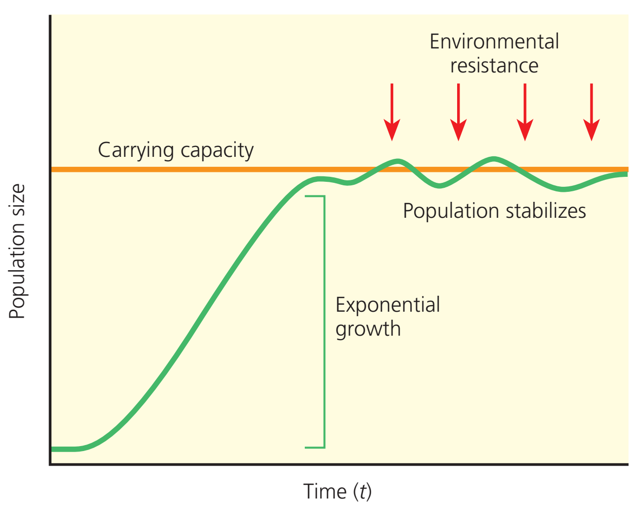


Figure 5-B Population size of southern sea otters off the coast of the U.S. state of California, 1983–2008. According to the U.S. Geological Survey, the California southern sea otter population would have to reach at least 3,090 animals for 3 years in a row before it could be considered for removal from the endangered species list. (Data from U.S. Geological Survey).

Critical Thinking

Design a controlled experiment to test the hypothesis that cat litter flushed down toilets may be killing sea otters.



CENGAGENOW™ **Active Figure 5-8** 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 limitless resources to support its growth. Such exponential growth is 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 the carrying capacity. However, a population may temporarily exceed the 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?

Changes in the population sizes of keystone species such as the southern sea otter (**Core Case Study**) and the American alligator (Science Focus, p. 75) 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, p. 82). This reduced species diversity of the kelp forest and altered its functional biodiversity by upsetting its food webs and reducing energy flows and nutrient cycling within the forest.

THINKING ABOUT
California Southern Sea Otters

Name a species whose population is likely to decline if the population of California southern sea otters in kelp beds declines sharply. Name a species whose population would likely increase if this happened.

When a Population Exceeds Carrying Capacity Its Population Can Crash

Some species do not make a smooth transition from *exponential growth* to *logistic growth* (Figure 5-8). 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 the death rate to rise in response to resource overconsumption.

In such cases, the population suffers a *dieback*, or **population crash**, unless the excess individuals can switch to new resources or move to an area with more resources. Such a crash occurred when reindeer were introduced onto a small island in the Bering Sea (Figure 5-9).

The carrying capacity of an area or volume 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 decreases available vegetation. Other factors include the presence or absence of predators and an abundance or scarcity of competitors.

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, mostly the United States.

During the 14th century the *bubonic plague* spread through densely populated European cities and killed at

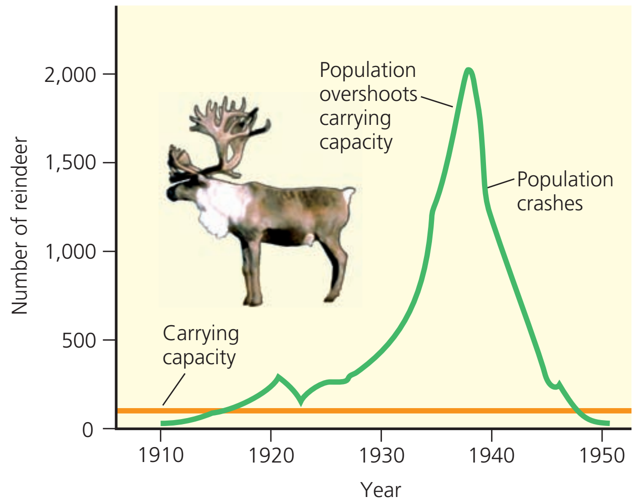


Figure 5-9 Exponential growth, overshoot, and population crash of reindeer introduced to the small Bering Sea island of St. Paul. When 26 reindeer (24 of them female) were introduced in 1910, lichens, mosses, and other food sources were plentiful. By 1935, the herd size had soared to 2,000, overshooting 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 one in this example exceed their environments' carrying capacities and crash?

least 25 million people, about the same number as the combined populations of the U.S. states of New York and North Carolina. 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 rapidly through crowded cities, where sanitary conditions were poor and rats were abundant.

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 claims 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, expand agriculture, and control the populations of other species that compete with us for resources.

Some say we can keep expanding our ecological footprint (See Figure 3, p. S18, in Supplement 4) indefinitely, mostly because of our technological ingenuity. Others say that sooner or later we will reach the limits that nature always imposes on 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/biology/miller**.

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 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 beginning of the process. **Primary 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 5-10), 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 to provide the nutrients needed to establish a plant community.

The other, more common type of ecological succession is called **secondary 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 5-11, p. 90), burned or cut forests, 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

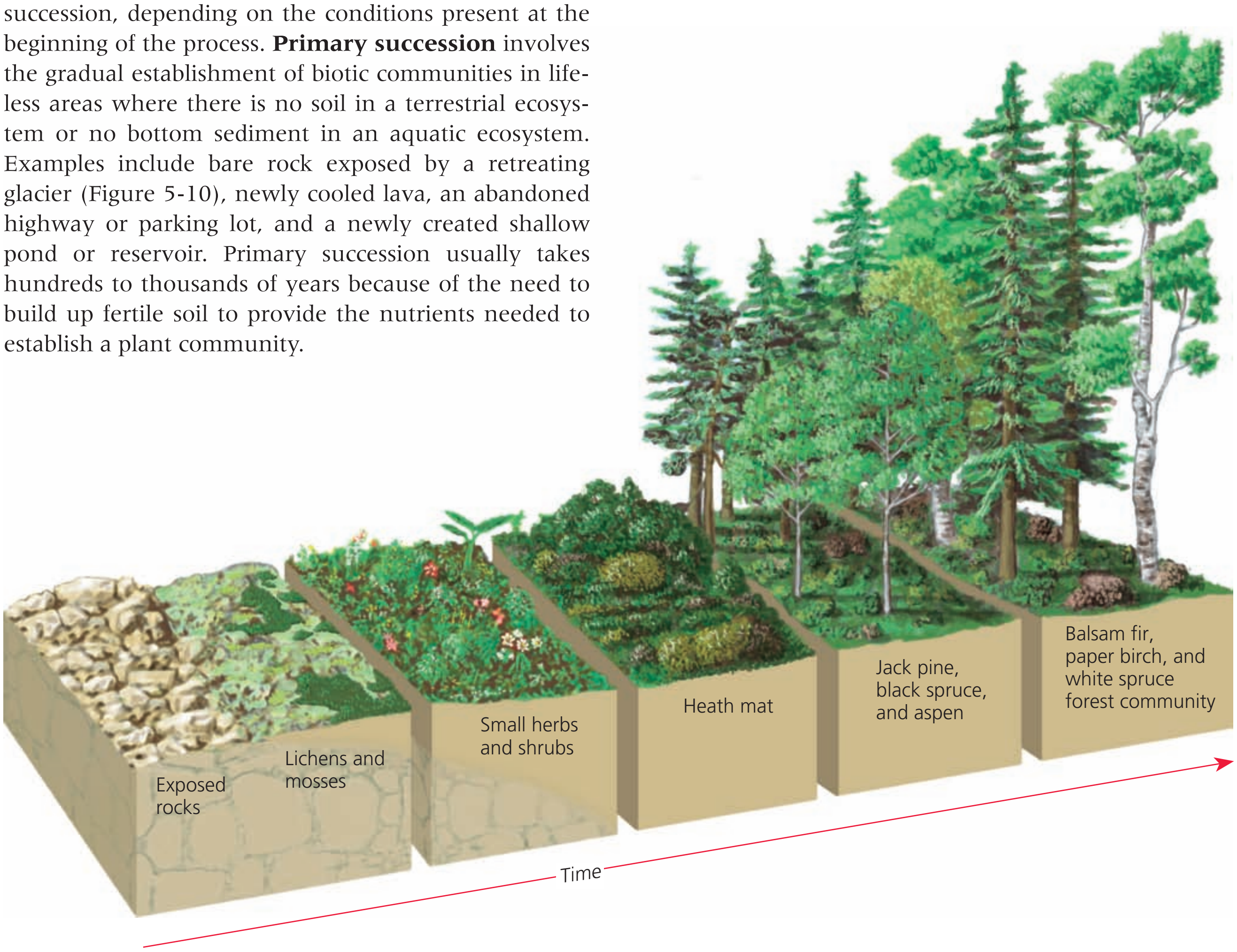
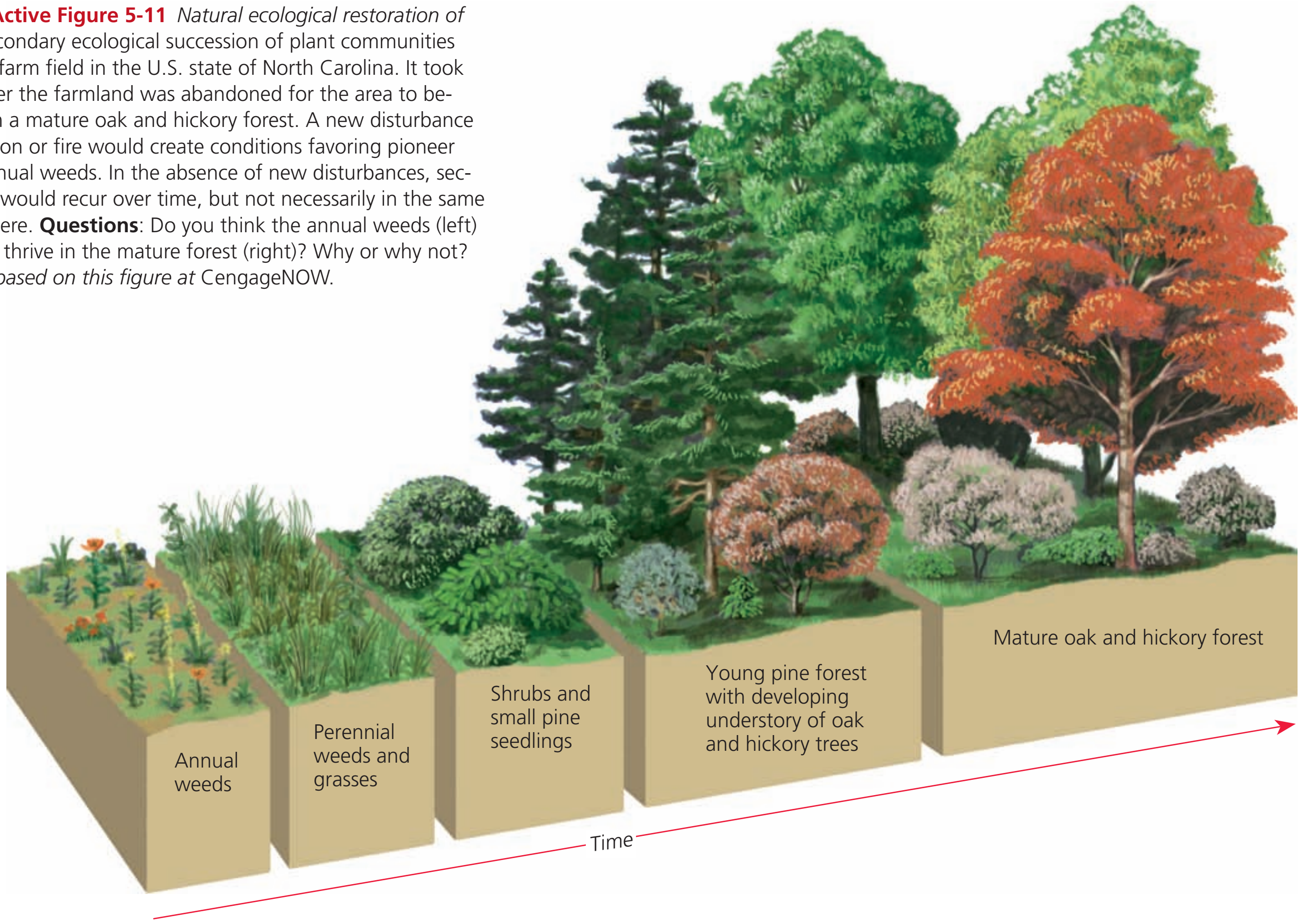


Figure 5-10 *Primary ecological succession.* Over almost a thousand years, plant communities developed, starting on bare rock exposed by a retreating glacier on Isle Royal, Michigan (USA) in northern Lake Superior. The details of this process vary from one site to another. **Question**: What are two ways in which lichens, mosses, and plants might get started growing on bare rock?

CENGAGENOW™ **Active Figure 5-11** *Natural ecological restoration of disturbed land.* 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. **Questions**: Do you think the annual weeds (left) would continue to thrive in the mature forest (right)? Why or why not? *See an animation based on this figure at* CengageNOW.



seeds already in the soil and seeds imported by wind or by 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 allows for the energy flow and nutrient cycling that make up the functional component of biodiversity (Figure 4-2, p. 61). As part of the earth's natural capital, both types of succession are examples of *natural ecological restoration*. GOOD NEWS

CENGAGENOW™ Explore the difference between primary and secondary succession at CengageNOW.

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 5-10 and 5-11). 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 at 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, but There Are Limits

All living systems from a cell to the biosphere are constantly changing in response to changing environmental conditions. Continents move, the climate changes, and disturbances and succession change the composition of communities and ecosystems.

Living systems contain complex parts and processes that interact to provide some degree of 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 destruction. But once a large tract of tropical rain forest is severely damaged, the resilience of the resulting degraded ecosystem may be so low that the forest may reach 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 soil, as in most other terrestrial ecosystems. After the nutrient-rich vegetation is gone, there may not be enough nutrients left in the soil to enable a tropical rain forest to grow again in 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.

Variations among species in resilience and inertia are yet another example of biodiversity that has allowed life on earth to sustain itself for billions of years. Such variations illustrate one aspect of the biodiversity **principle of sustainability** (see back cover).

Here are the *three big ideas* in this chapter:

- Interactions between species affect their use of resources and their population sizes.
- There are always limits to population growth in nature.
- Changes in environmental conditions alter the composition of species and their population sizes in communities and ecosystems (ecological succession).

REVISITING Southern Sea Otters and Sustainability

CORE CASE STUDY

Before the arrival of European settlers on the North American west coast, 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 others.

When humans 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 each population plays a role 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. 80. Explain how southern sea otters act as a keystone species in kelp beds. Explain why we should care about protecting this species from premature extinction that could result mostly because of our activities.

2. Define **interspecific competition**, **predation**, **parasitism**, **mutualism**, 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** and give an example of each. What is a **predator–prey relationship**? Explain why we should help preserve kelp forests. Describe three ways in which prey species can avoid their predators and three ways that predators can increase their chances of feeding on their prey.

4. Define and give an example of **coevolution**.

5. Describe four variables that govern changes in population size and write an equation showing how they interact. Describe two different reproductive strategies that can enhance the long-term survival of a species.

6. Distinguish between the **environmental resistance** and **carrying capacity**, and use these concepts to explain why there are always limits to population growth in nature. Why is the future of California's southern sea otters in doubt? What factors are threatening their recovery?

7. Define and give an example of a **population crash**. Explain why humans are not exempt from nature's population controls.

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**.

10. What are this chapter's *three big ideas*? Explain how changes in the sizes 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 prematurely extinct because of human activities? What are three things we could do to help prevent the premature extinction of this species?

2. Use the second law of thermodynamics (**Concept 2-3B**, p. 35) 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.

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?

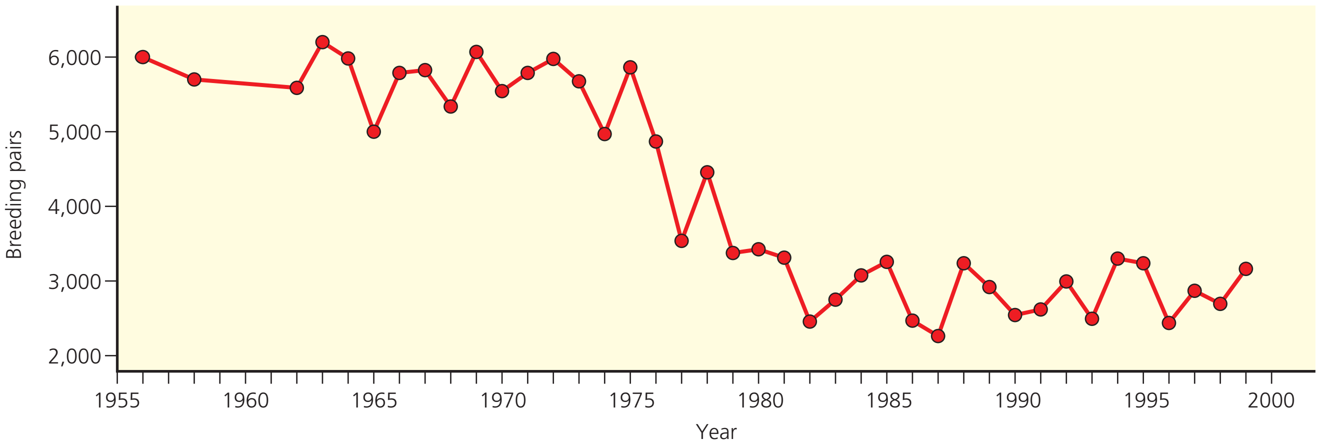
8. How would you reply to someone who contends that efforts to preserve natural systems are not worthwhile because nature is largely unpredictable?

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 Terre Adelie in the Antarctic. (Based on data from *Nature*, May 10, 2001.) Use the graph to answer the questions below.



Source: Data from *Nature*, May 10, 2001.

1. What was the approximate carrying capacity for the penguin population on the island from 1960 to 1975? (*Hint:* see Figure 5-9.) What was the approximate carrying capacity for the penguin population on the island from 1980 to 2000?

2. What was the percentage decline in the penguin population from 1975 to 2000?

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengage.com/biology/miller** and choose Chapter 5 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, web links, information on Green Careers, and InfoTrac® College Edition articles.

CENGAGENOW™ For students with access, log on at **www.cengage.com/login** for the animations, active figures, activities, and readings indicated within the text by the CengageNOW logo. If your textbook did not come with access, visit **www.iChapters.com** to purchase.

6 The Human Population and Urbanization

CORE CASE STUDY Are There Too Many of Us?

There are about 6.8 billion of us. Each year, we add about 83 million more people to the word's population—an average of 227,000 each day or almost 9,500 during your lunch hour. If such growth continues, the number of people on the earth is projected to increase from 6.8 to 9.5 billion between 2009 and 2050, with most of this growth occurring in the world's middle- and low-income countries (Figure 6-1). This raises an important question: *Can we provide an adequate standard of living for a projected 2.7 billion more people by 2050 without causing widespread environmental damage?* There is disagreement over the answer to this question.

According to one view, the planet already has too many people collectively degrading the earth's life-support system. To some analysts, the key problem is *overpopulation* because of the sheer number of people in developing countries, which have 82% of the world's population (Figure 6-1 and Figure 1-7, top, p. 13). To others, the key factor is *overconsumption* in affluent developed countries because of their high rates of resource use per person (Figure 1-7, bottom, p. 13).

L. Young/UNEP/Peter Arnold, Inc.

Figure 6-1 Crowded street in China, which has the largest population of all countries—1.3 billion people. Together, China and India are home to one of every three people on the earth and the resource use per person in these two countries is projected to grow rapidly as they become more industrialized (Case Study, p. 14).

Excessive and wasteful resource consumption per person in developed countries—and to an increasing extent in rapidly developing countries such as China and India—magnify the environmental impact, or ecological footprint, of each person (Figure 1-5, bottom, p. 11, and Case Study, p. 14). 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. By 2050, with the projected population increase, we will likely need 1.5 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 or overconsumption are causing major environmental problems argue that slowing human population growth is an important priority.

Another view is that technological advances have allowed us to overcome the environmental resistance that all populations face (Figure 5-8, p. 87) and to increase 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. They also contend that population growth stimulates economic growth by increasing the number of resource consumers. As a result, they see no need to slow the world's population growth.

Some people view efforts to slow population growth as a violation of their religious or moral beliefs. Others see it as an intrusion into their privacy and personal freedom to have as many children as they want. These people also tend to oppose efforts to slow human population growth.

Proponents of slowing and eventually stopping population growth point out that we are not providing the basic necessities for about one of every five people—who struggle to survive on the equivalent of $1.25 per day (Figure 1-12, p. 17). The number of people living in extreme poverty today—1.4 billion—is larger than China's entire population and 4.6 times the population of the United States. This raises a serious question: If we fail to meet the basic needs for 1.4 billion people today, what will happen in 2050 when there may be 2.7 billion more of us?

They also warn of two serious consequences if we do not sharply *lower* birth rates. First, death rates may increase because of declining health and environmental conditions in some areas, as is already happening in parts of Africa. Second, resource use and degradation of normally renewable resources (Figure 1-4, p. 10) may intensify as more *consumers* increase their already large ecological footprints in developed countries and in rapidly developing countries.

This debate over whether there are limits on human population growth and resource consumption is one of the most important and controversial issues in environmental science.

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, encouraging family planning, and elevating the status of women.

6-5 **What are the major urban resource and environmental problems?**

CONCEPT 6-5 Most cities are unsustainable because of high levels of resource use, waste, pollution, and poverty.

6-6 **How does transportation affect urban environmental impacts?**

CONCEPT 6-6 In some countries, most people live in dispersed urban areas and depend mostly on motor vehicles for their transportation.

6-7 **How can cities become more sustainable and livable?**

CONCEPT 6-7 An *ecocity* allows people to choose walking, biking, or mass transit for most transportation needs; recycle or reuse most of their wastes; grow much of their food; and protect biodiversity by preserving surrounding land.

Note: Supplements 2 (p. S3), 3 (p. S6), 4 (p. S14), and 5 (p. S21) can be used with this chapter.

The problems to be faced are vast and complex, but come down to this: 6.8 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 It Is Unevenly Distributed

For most of history, the human population grew slowly (Figure 1-10, p. 16, 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 (Figure 1-10, 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 6.8 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)—an illustration of the awesome power of exponential growth (p. 15). By 2012 we will be trying to support 7 billion people and perhaps 9.5 billion by 2050. (See Figure 4, p. S8, in Supplement 3 for a timeline of key events related to human population growth.)

The rate of population growth has slowed (See Figure 3, p. S4, in Supplement 2). But the world's population is still growing exponentially at a rate of about 1.22% a year. This means that 83 million people were added to the world's population during 2009—an average of more than 227,000 people each day, or 2 more people every time your heart beats. This is roughly equal of adding all of the people in the U.S. states of a California, Texas, New York, and New Mexico to the world every year. (See *The Habitable Planet*, Video 5, at **www.learner.org/resources/series209.html** for a discussion of how demographers measure population size and growth.).

Geographically this growth is unevenly distributed. About 2 million of these people were added to the world's developed countries, growing at 0.16% a year. About 81 million were added to the world's middle- and low-income developing countries, growing 9 times faster at 1.46% a year. In other words, most of the world's population growth takes place in already heavily populated parts of world, most of which are the least equipped to deal with the pressures of such rapid growth.

Estimates of how many of us are likely to be here in 2050 range from 7.8–10.8 billion people, depending mostly on projections about the average number of babies women are likely to have. The medium projection is 9.5 billion people (Figure 6-2).

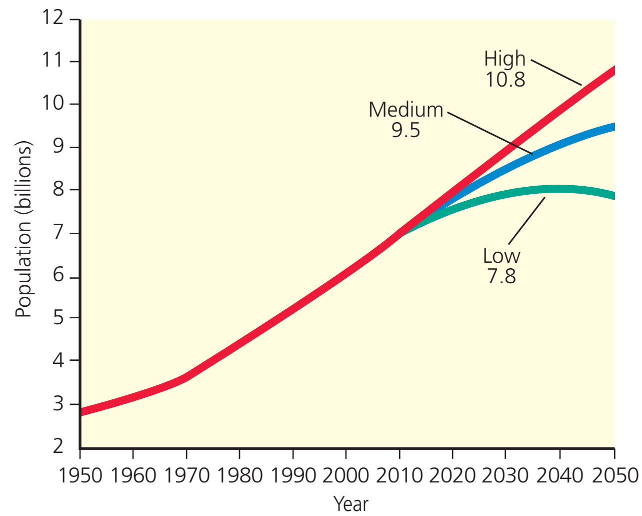


Figure 6-2 *Global connections:* U.N. world population projections, assuming that by 2050, women will have an average of 2.5 children (high estimate), 2.0 children (medium), or 1.5 children (low). The most likely projection is the medium one—9.5 billion by 2050. (Data from United Nations).

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/biology/miller**.

We Do Not Know How Long the Human Population Can 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 (Figure 3, p. S18, in Supplement 4), as our ecological footprints have spread across the globe (**Concept 1-2**, p. 9, and Figure 1-5, p. 11).

CONCEPT LINK

We have used technology to alter natural systems to meet our growing needs and wants in eight major ways (Figure 6-3). Scientific studies of populations of other species tell us that *no population can continue growing indefinitely*. How long can we continue to increase the earth's carrying capacity for our species by sidestepping many of the factors that sooner or later limit the growth of any population?

No one knows how close we are to environmental limits that will control the size of the human population, but mounting evidence indicates that we are steadily degrading the natural capital that keeps us and other species alive and supports our economies (**Concept 6-1**).

How many people can the earth support indefinitely? Some say about 2 billion. Others say as many as 50 billion.

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 that the earth could support at a reasonable level of comfort and freedom without impairing the planet's ability to sustain future generations in the same way. (See the Guest Essay by Garrett Hardin at CengageNOW™.) Choosing whether or not and how to reach such a goal is primarily an ethical decision based on values that differ widely.

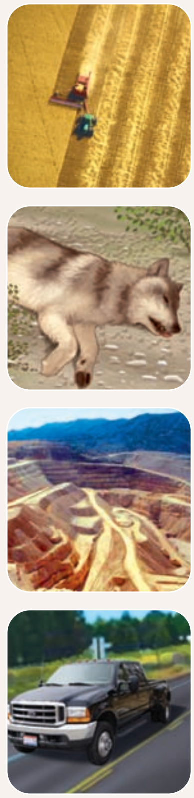
RESEARCH FRONTIER

Determining the cultural carrying capacity of the earth and of various regions. See **www.cengage.com/biology/miller**.

Natural Capital Degradation

Altering Nature to Meet Our Needs

- Reduction of biodiversity
- Increasing use of the earth's net primary productivity
- Increasing genetic resistance of pest species and disease-causing bacteria
- Elimination of many natural predators
- Introduction of potentially harmful species into communities
- Using some renewable resources faster than they can be replenished
- Interfering with the earth's chemical cycling and energy flow processes
- Relying mostly on polluting and climate-changing fossil fuels



CENGAGENOW™ **Active Figure 6-3** Major ways in which 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, population size does not change.

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 **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**).

$$\text{Population change} = (\text{Births} + \text{Immigration}) - (\text{Deaths} + \text{Emigration})$$

When births plus immigration exceed deaths plus emigration, population increases; when the reverse is true, population declines. (Figure 5, p. S9, in Supplement 3 is a map of the percent rate of population change in the world's countries in 2009.)

Instead of using the total numbers of births and deaths per year, population experts (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).

What three countries had the largest numbers of people in 2009? Number 1 was China with 1.3 billion people, or one of every 5 people in the world (Figure 6-1). Number 2 was India with 1.2 billion people, or one of every 6 people. Together China and India have 37% of the world's population. The United States, with 307 million people in 2009—had the world's third largest population, but only 4.5% of its people, or one of every 22 people on the planet.

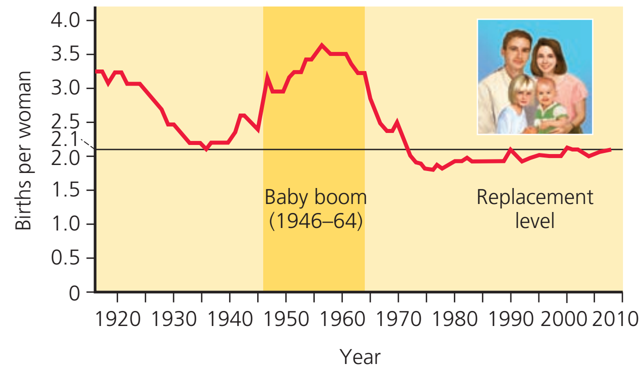


Figure 6-4 Total fertility rates for the United States between 1917 and 2009. **Question**: The U.S. fertility rate has declined and remained at or below replacement levels since 1972. So why is the population of the United States still increasing? (Data from Population Reference Bureau and U.S. Census Bureau)

Women Are Having Fewer Babies but Not Few Enough to Stabilize the World's Population

A key factor affecting human population growth and size is the **total fertility rate** (**TFR**): the average number of children born to women in a population during their reproductive years (**Concept 6-2B**). Here is some good news for those who would like to slow the world's population growth. Between 1950 and 2009, the average global TFR dropped from 2.5 to 1.7 children per woman in developed countries and from 6.5 to 2.8 in developing countries (See Figure 6, p. S9, and Figure 7, p. S10, in Supplement 3). This decline in the world's average TFR is impressive but it will have to drop to around 2.1 to eventually halt the world's population growth.

CASE STUDY

The U.S. Population Is Growing Rapidly

The population of the United States grew from 76 million in 1900 to 307 million in 2009, despite oscillations in the country's TFR (Figure 6-4) and birth rates. 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 2008, as in most years since 1972, it has been at or below 2.1 children per woman, compared to 1.6 in China in 2009.

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 developed countries and that of China, and it is not close to leveling off. According to the U.S. Census Bureau, about 2.14 million people were added to the U.S. population in 2009. About 1.24 million of these people were added because there were that many more births than deaths. About 900,000 migrated into the United States.

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 6-5), which led to dramatic increases in per capita resource use and a much larger U.S. ecological footprint (**Concept 1-2**, p. 9, and Figure 1-5, top, p. 11).

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 $200–400 per year and the average daily wage was 22 cents per hour; 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; most women washed their hair only once a month; marijuana, heroin, and morphine were available over the counter at local drugstores; and there were only 230 reported murders in the entire country.

According to U.S. Census Bureau, the U.S. population is likely to increase from 307 million in 2009 to 439 million by 2050. In contrast, since 1950, population growth has slowed in other major developed countries, most of which are expected to have declining populations after 2010. 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 (Figure 1-7, bottom, p. 13, and Figure 3, pp. S18–19, in Supplement 4). In terms of environmental impact per person, many analysts con-

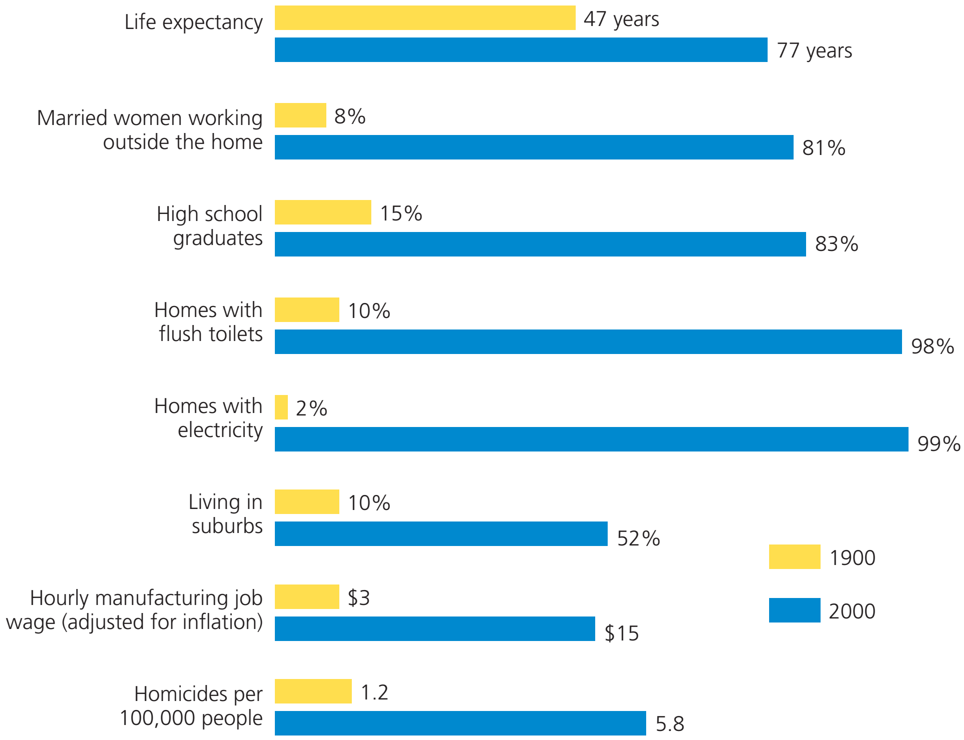


Figure 6-5 Some major changes that took place in the United States between 1900 and 2000. **Question**: Which two of these changes do you think were the most important? (Data from U.S. Census Bureau and Department of Commerce)

sider 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 if U.S. Census Bureau projections are correct, by 2050 there will be about 132 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 developing countries.

Another economic factor is the *cost of raising and educating children*. Birth and fertility rates tend to be lower in 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 about $290,000 to raise a middle-class child from birth to age 18.) By contrast, many children in poor countries have to work to help their families survive.

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 developing countries. Pensions reduce a couple's need to have many children to help support them in old age.

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.

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 developing countries, a woman with no 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 World Bank estimate that at least 46 million of these women get abortions—26 million of them legal and 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. In some countries, these factors favor large families and strongly oppose abortion and some forms of birth control.

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 developing countries. More people in these countries started living longer and fewer infants died 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 expect to live) and the **infant mortality rate** (the number of babies out of every 1,000 born who die before their first birthday). Between 1955 and 2009, the global life expectancy at birth increased from 48 years to 69 years (77 years in developed countries and 67 years in developing countries) and is projected to reach 74 by 2050. Between 1900 and 2009, life expectancy at birth in the United States increased from 47 to 78 years and, by 2050, is projected to reach 82 years. In the world's poorest countries, however, life expectancy is 49 years or less and may fall further in some countries because of more deaths from AIDS and internal strife.

GOOD NEWS

The United States spends more on health care per person than any other country, but 41 other countries including Canada, Japan, Singapore, and a number of European countries have longer life expectancies. Analysts cite two major reasons for this. First, more than 45 million Americans lack health care insurance, while Canada and many European countries have universal health care. Second, adults in the United States have one of the world's highest obesity rates.

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 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 developed and developing countries have declined dramatically since 1965, as shown in Figures 8 and 9, pp. S10 and S11, in Supplement 3. But despite this sharp drop each year more than 4 million infants (most in developing countries) die of preventable causes during their first year of life—an average of 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 *each day* with no survivors!

The U.S. infant mortality rate declined from 165 in 1900 to 6.6 in 2009. This sharp decline was a major factor in the marked increase in U.S. average life expectancy during this period. Still, some 40 countries, including Taiwan, Cuba, and most of Europe, had lower infant mortality rates than the United States had in 2009. Three factors helped to keep the U.S. infant mortality rate higher than it could be: *inadequate health care for poor women during pregnancy and for their babies after birth; drug addiction among pregnant women;* and *a high birth rate among teenagers* (although this rate dropped by about 40% between 1991 and 2008).

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.

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 U.N. study and a 2008 study by environmental scientist Norman Myers, there were at least 40 million *environmental refugees* in 2008 and a million more are added each year.

CONNECTIONS

Projected Climate Change and Environmental Refugees

Environmental scientist Norman Myers warns that if the world's climate changes as projected during this century, the number of *environmental refugees*—people who have to leave their homes because of water or food shortages, drought, flooding, or other crises caused mostly by climate change—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 annual number of legal immigrants (including refugees) has varied among different periods because of changes in immigration laws and rates of economic growth. Currently, legal and illegal immigration account for about 42% of the country's annual population growth.

Between 1820 and 1960, most legal immigrants to the United States came from Europe. Since 1960, most have come from Latin America (53%) and Asia (25%), followed by Europe (14%). In 2008, Hispanics (67% of them from Mexico) made up 15% of the U.S. population, and by 2050, are projected to make up 30% of the population. The U.S. Census Bureau projects that, between 2008 and 2050, the proportion of non-Hispanic whites in the U.S. population will drop from 66% to 46%.

There is controversy over whether to reduce legal immigration to the United States. Some analysts would accept 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 (Figure 1-5, p. 11).

Polls show that almost 60% of the U.S. public strongly supports reducing legal immigration. There is also intense political controversy over what to do about illegal immigration. In 2008, there were an estimated 11.2 million illegal immigrants in the United States, with about 58% of them from Mexico and 22% from other Latin American countries.

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 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, immigrants and their descendants pay taxes. They also take many menial and low-paying jobs that most other Americans shun, start new businesses, create jobs, add cultural vitality, and help the United States to succeed in the global economy.

Also, 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 U.N. 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 8 times the current immigration level—through 2050. At that point, the U.S. population could total 1.1 billion people, 73% of them being 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.

HOW WOULD YOU VOTE? ✓

Should legal immigration into the United States be reduced? Cast your vote online at **www.cengage.com/biology/miller**.

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.**

Populations Made Up Mostly of Young People Can Grow Rapidly: Teenagers Rule

An important factor determining whether the population of a country increases or decreases is its **age structure**: the number or percentage of males and females in young, middle, and older age groups (**Concept 6-3**).

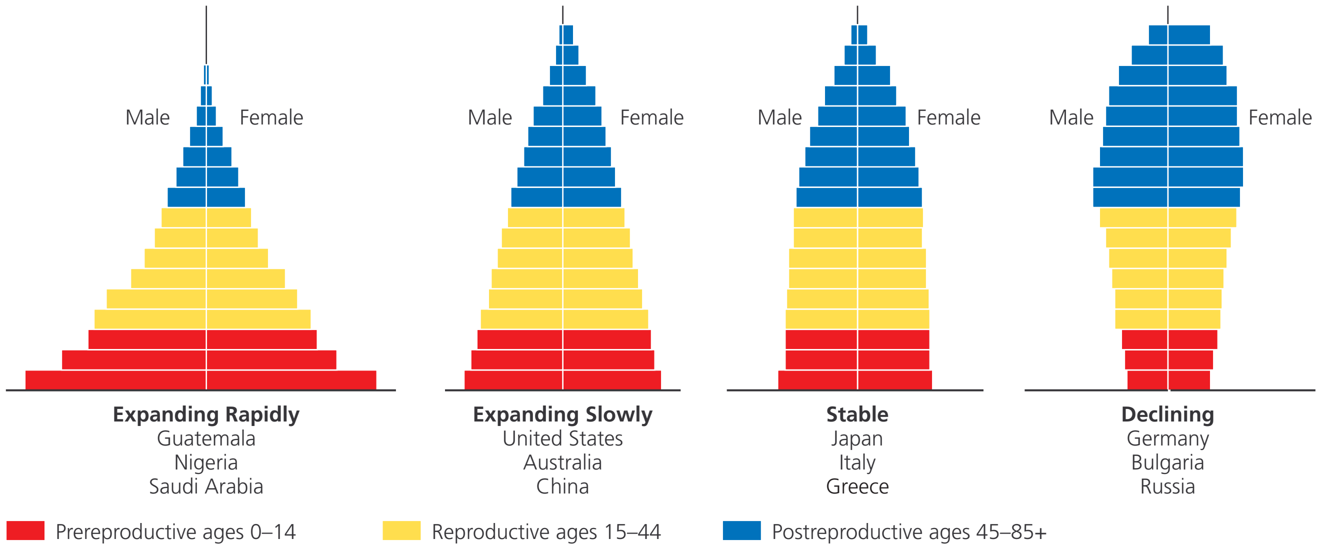
Population experts construct a population age-structure diagram by plotting the percentages or numbers of males and females in the total population in each of three age categories: prereproductive (ages 0–14) consisting of individuals normally too young to have children; reproductive (ages 15–44), consisting of those normally able to have children; and postreproductive (ages 45 and older) with individuals normally too old to have children.

A country with a large percentage of its people younger than age 15 (represented by a wide base in Figure 6-6, far left, p. 102) 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, because of the large number of girls entering their prime reproductive years.

In 2009, nearly 28% of the world's population—30% in the developing countries and 17% in developed countries—was younger than age 15. These 1.9 billion young people—amounting to more than 1 of every 4 persons on the planet—are poised to move into their prime reproductive years over the next 14 years. These dramatic differences in population age structure between developed and developing countries (Figure 6-7, p. 102) show why almost all future human population growth will take place in developing countries.

We Can Use Age-Structure Information to Make Population and Economic Projections

Changes in the distribution of a country's age groups have long-lasting economic and social impacts. Between 1946 and 1964, the United States had a baby boom that



CENGAGE**NOW**™ **Active Figure 6-6** 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 large 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)

added 79 million people to its population. Over time, this group looks like a bulge moving up through the country's age structure, as shown in Figure 6-8.

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. In addition to dominating the population's demand for goods and services, they play increasingly important roles in deciding who gets elected to public office and what laws are passed. Baby boomers who created the youth market in their teens and twenties are now creating the 50-something market and are moving on to create a 60-something market. After 2011, when the first baby boomers will turn 65, the number of Americans older than age 65 will grow sharply through 2029 in what has been called the graying of America.

CONNECTIONS

Baby Boomers, the U.S. Work Force, and Taxes

The large-scale retirement of baby boomers is likely to create a shortage of workers in the United States, unless immigrant workers or various forms of automation replace some of them, or unless many retired baby boomers go back to work to help make ends meet. Retired baby boomers may also use their political clout to have the smaller number of people in the baby-bust generation that followed them pay higher income, health-care (Medicare and Medicaid), and social security taxes. However, the rapidly increasing number of immigrants and their descendants may dilute the boomers' political power.

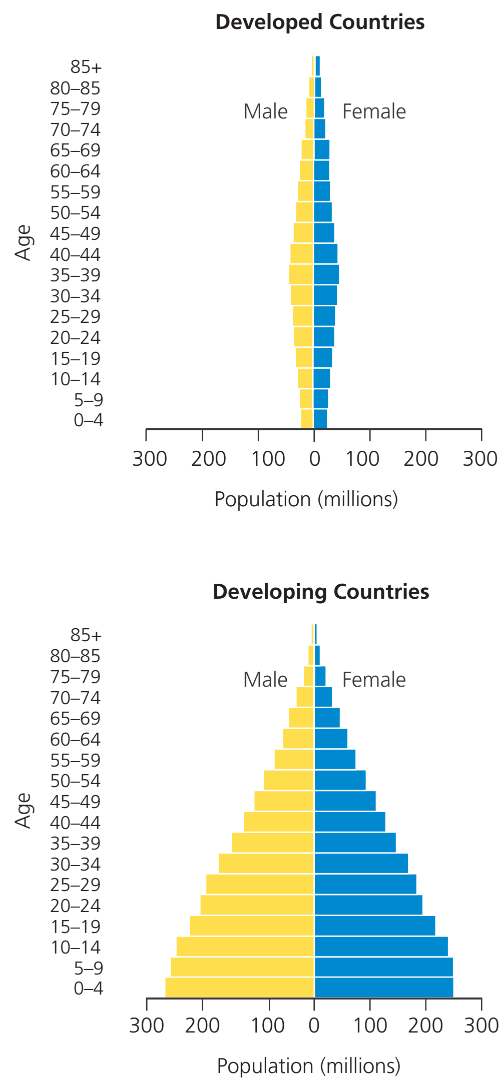
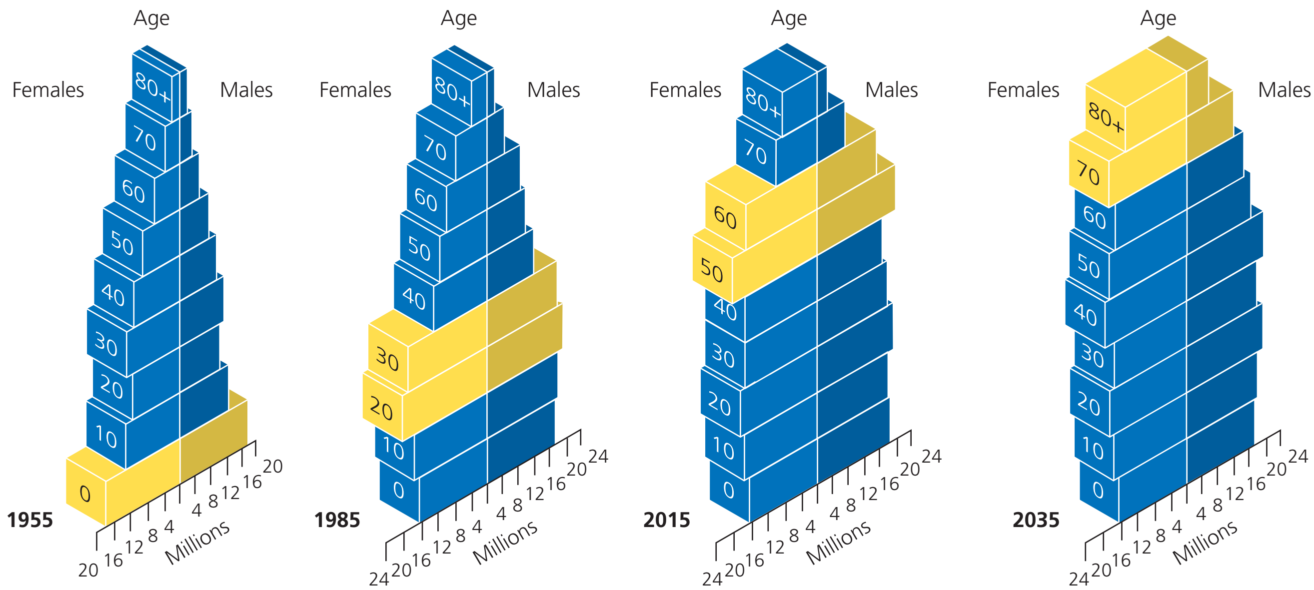


Figure 6-7 *Global outlook:* population structure by age and sex in developing countries and developed countries, 2009. **Question**: If all girls under 15 had only one child during their lifetimes, how do you think these structures would change over time? (Data from United Nations Population Division and Population Reference Bureau)



CENGAGENOW™ **Active Figure 6-8** Tracking the baby-boom generation in the United States. U.S. population by age and sex, 1955, 1985, 2015 (projected), and 2035 (projected). *See an animation based on this figure at* CengageNOW. (Data from U.S. Census Bureau)

CENGAGENOW™ Examine how the baby boom affects the U.S. age structure over several decades at CengageNOW.

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 or 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 had dropped to 128 million by 2009 and is projected to shrink to about 95 million by 2050.

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, social security 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. Countries faced with a rapidly declining population include Japan, Russia, Germany, Bulgaria, the Czech Republic, Hungary, Poland, Ukraine, Greece, Italy, and Spain.

Populations Can Decline from 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 age structure. According to the World Health Organization, between 1981 and 2008 AIDS killed more than 27 million people and it takes about 2 million more lives each year (15,000 in the United States).

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. In 8 African countries, where 16–39% of the adult population is infected with HIV, life expectancy could drop to 34–40 years.

Another effect of the AIDS pandemic is the loss of productive young adult workers and trained personnel such as scientists, farmers, engineers, teachers, and government, business, and health-care workers. The essential services they provide are therefore lacking, and there are fewer of them available to support the very young and the elderly. Within a decade, countries such as Zimbabwe and Botswana in sub-Saharan Africa could lose more than a fifth of their adult population. Such death rates drastically alter a country's age structure (Figure 6-9, p. 104).

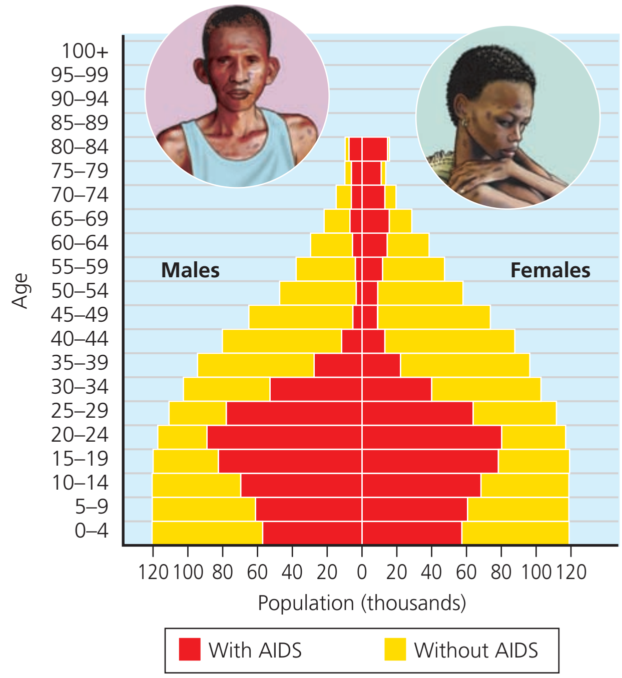


Figure 6-9 *Global outlook:* Worldwide, AIDS is the leading cause of death for people of ages 15–49. This loss of productive working adults can affect the age structure of a population. In Botswana, more than 24% of this age group is infected with HIV. This figure shows the projected age structure of Botswana's population in 2020 with and without AIDS. 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?

Analysts call for the international community to create and fund a massive program to help countries ravaged by AIDS. This program would have two major goals. First, reduce the spread of HIV through a combination of improved education and health care. Second, provide financial assistance for education and health care as well as volunteer teachers and 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, encouraging family planning, and elevating the status of women.**

Promote Economic Development

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, their populations tend to grow more slowly. Figure 6-10 shows the four proposed stages of such a transition.

Some analysts believe that most of the world's developing 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 growth, extreme poverty, and increasing environmental degradation in some low-income developing countries—especially in Africa—could leave these countries stuck in stage 2 of the demographic transition.

Other factors that could hinder the demographic transition in some developing countries are shortages of scientists, engineers, and skilled workers, insufficient financial capital, large debts to developed countries, and a drop in economic assistance from developed countries since 1985.

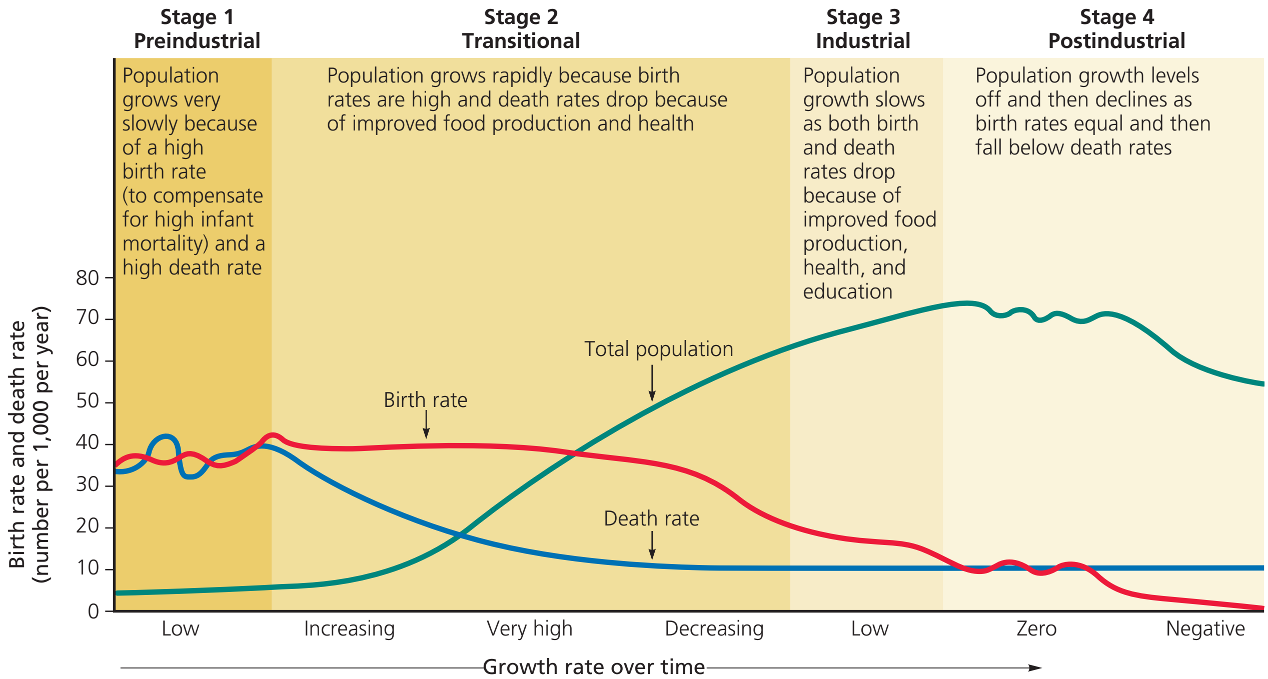
CENGAGENOW™ Explore the effects of economic development on birth and death rates and population growth at CengageNOW.

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.

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 deaths of mothers and fetuses during pregnancy. GOOD NEWS

Studies by the U.N. 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 developing countries, from 6.0 in 1960 to 2.8 in 2009. Between 1971 and 2009, for example, Thailand used family planning to cut its annual population growth rate from 3.2% to 0.6% and its TFR from



CENGAGENOW™ **Active Figure 6-10** The *demographic transition* that the population of a country can experience as it becomes industrialized 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?

6.4 to 1.8 children per family. According to the U.N., had there not been the sharp drop in TFRs since the 1970s, with all else equal, the world's population today would be about 8.5 billion instead of 6.8 billion.

Family planning also has financial benefits. Studies have shown that each dollar spent on using family planning to prevent one unwanted birth in countries such as Thailand, Egypt, and Bangladesh saves $10–16 in health, education, and social service costs. GOOD NEWS

Despite such successes, two problems remain. *First*, according to the U.N. Population Fund, 42% of all pregnancies in developing countries are unplanned and 26% end with abortion. And 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 developing countries want to limit their number of children and to determine their spacing, but they lack access to family planning services. According to a recent study by the U.N. 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 by more than 1 billion people, at an average cost of $20 per couple per year. According to James Grant, former head of the United Nations Children's Fund (UNICEF), "Family planning could bring more benefit to more people at less cost than any other single technology available to the human race."

The experiences of countries such as Japan, Thailand, South Korea, Taiwan, Iran, and China (see Case Study, p. 106) 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 *reducing poverty*, *encouraging family planning*, and *elevating the social and economic status of women* (**Concept 6-4**). GOOD NEWS

Empowering Women Can 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, hold a paying job outside the home, 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.

Women do almost all of the world's domestic work and child care for little or no pay and provide more unpaid health care than do all of the world's organized health services combined. They also do 60–80% of the work associated with growing food, gathering and hauling wood and animal dung for use as fuel, and hauling water in rural areas of Africa, Latin America, and Asia. As one Brazilian woman put it, "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.

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, some 900 million school age girls—almost three times the entire U.S. population—do not attend elementary school. 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 in societies where almost all women can read.

According to Thorya Obaid, executive director of the U.N. 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."

An increasing number of women in developing 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 population, reducing poverty and environmental degradation, and expanding human freedom.

GOOD NEWS

■ **CASE STUDY**

Slowing Population Growth in China: The One-Child Policy

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 was to sharply reduce fertility 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 program began, China has made impressive efforts to feed its people, bring its population growth under control, and encourage economic growth. Between 1972 and 2009, the country cut its crude birth rate in half and trimmed its TFR from 5.7 to 1.6 children per woman, compared to 2.0 in the United States. As a result, China's population is growing at a slower rate than the population of the United States.

Despite this success, China has the world's largest population and in 2009 added about 6.7 million people to its population (compared to an increase of 2.1 million in the United States and 18 million in India). If current trends continue, the United Nations projects that China's population will peak around 2033 at around 1.46 billion and then to begin a slow decline.

Since 1980, China has undergone rapid economic growth and in 2009, was the world's third largest economy (after the United States and Japan). This has helped an estimated 400 million Chinese to work their way out of poverty and become middle-class consumers. However, about 45% of its people are still struggling to live on an equivalent of less than $1.25 a day.

In China, there is a strong preference for male children, because unlike sons, daughters are likely to marry and leave their parents. Some pregnant Chinese women use ultrasound to determine the gender of their fetuses, and some get an abortion if it is female. The result: a rapidly growing "bride shortage" in China's population. As a consequence, young girls in some parts of rural China are being kidnapped and sold as brides for single men in other parts of the country.

Because there are fewer children, the average age of China's population is increasing rapidly. By 2020, 31% of the Chinese population will be over 60 years old, compared to 8% in 2009. This graying of the Chinese population could lead to a declining work force, limited funds for supporting continuing 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.

China's economy is growing at one of the world's highest rates as the country undergoes rapid industrialization. More middle class Chinese (Case Study, p. 14) will consume more resources per person, increasing China's ecological footprint (Figure 1-5, p. 11) within its own borders and in other parts of the world that provide it with resources (**Concept 1-2**, p. 9). This will put a strain on the earth's natural capital unless China steers a course toward more sustainable economic development.

CONCEPT LINK

■ **CASE STUDY**

Slowing Population Growth in India

For more than 5 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 2009, after 56 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 2009, it added 18 million—more than any other country. The United Nations projects that by 2015, India will be the world's most populous country, and by 2050 will have a population of 1.78 billion.

India faces a number of serious poverty, malnutrition, and environmental problems that could worsen as its population continues to grow rapidly. It has a thriving and rapidly growing middle class of more than 100 million people—roughly equal to a third of the U.S. population—a number of them highly skilled software developers and entrepreneurs. On the other hand, nearly half of the country's labor force is unemployed or underemployed, and 80% of its people are struggling to live on the equivalent of less than $1.25 a day.

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 2.7 children. Two factors help account for larger families in India. Most poor couples believe they need several children to work and care for them in old age. And, as in China, the strong cultural preference for male children also 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 about one of every two couples actually use one.

India is undergoing rapid economic growth, which is expected to accelerate. As members of its growing middle class increase their resource use per person (Figure 1-7, p. 13), India's ecological footprint (**Concept 1-2**, p. 9) 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.

CONCEPT LINK

THINKING ABOUT

China, India, the United States, and Overpopulation

CORE CASE STUDY

Based on population size and resource use per person (Figure 1-7, p. 13) is the United States more overpopulated than China? Explain. Answer the same question for the United States vs. India.

6-5 What Are the Major Urban Resource and Environmental Problems?

▶ **CONCEPT 6-5 Most cities are unsustainable because of high levels of resource use, waste, pollution, and poverty.**

Half of the World's People Live in Urban Areas

The world's first cities emerged about 6,000 years ago. Since then, the world has become increasingly urbanized. Today 79% of Americans and about 50% of the world's people 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, entertainment, and freedom from religious, racial, and political conflicts. Some are also *pushed* from rural to urban areas by factors such as poverty, limited land for growing food, declining agricultural jobs, famine, and war.

Four major trends are important for understanding the problems and challenges of urban growth. First, *the proportion of the global population living in urban areas is increasing.* Between 1850 and 2009, the percentage of people living in urban areas increased from 2% to 50% and could reach 60% by 2030 (See Figure 10, p. S11, in Supplement 3). About 88% of this growth will occur in already overcrowded and stressed cities in developing countries.

Second, *the number and sizes of large urban areas is mushrooming.* Each week, 1 million people are added to the world's urban areas. More than 400 urban areas each have 1 million or more people. And there are 18 *megacities* or *megalopolises*—cities with 10 million or more people each—15 of them are in developing countries (Figure 6-11, p. 108). Such megacities will soon be eclipsed by *hypercities* with more than 20 million people each. So far, Greater Tokyo, Japan, with 35 million people (more than the entire population of Canada), is the only city in this category. But according to U.N. projections, Mumbai in India, Lagos in Nigeria, Dakar in Bangladesh, and São Paulo in Brazil will become hypercities by 2015.

Third, *urban growth is much slower in developed countries than in developing countries.* Still, developed countries, now with 75% urbanization, are projected to reach 81% urbanization by 2030.

Fourth, *poverty is becoming increasingly urbanized, mostly in developing countries.* The United Nations estimates that at least 1 billion people in developing countries (more than three times the current U.S. population) live in

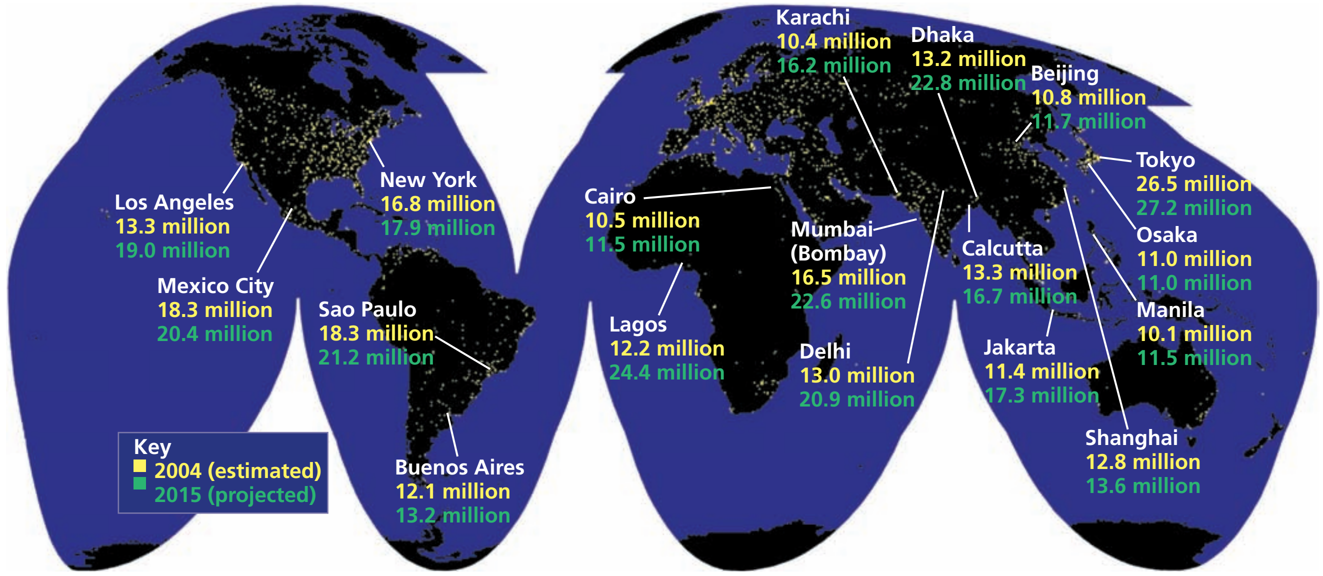


Figure 6-11 *Global outlook:* major urban areas throughout the world revealed in satellite images of the earth at night, showing city lights. Currently, the roughly 50% of the world's people living in urban areas occupy about 2% of the earth's land area. Note that most of the urban areas are found along the coasts of continents, 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 2009 and their projected populations in 2015. All but three are located in developing countries. **Question**: In order, what were the world's five most populous cities in 2009 and what will be the five most populous cities in 2015? (Data from National Geophysics Data Center, National Oceanic and Atmospheric Administration, and United Nations)

crowded and unsanitary slums and shantytowns within most cities or on their outskirts; within 30 years this number may double.

THINKING ABOUT
Urban Trends

If you could reverse one of the four urban trends discussed here, which one would it be? Explain.

CASE STUDY
Urbanization in the United States

Between 1800 and 2009, 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 of at least 50,000 people each, and nearly half live in urban areas with 1 million or more residents each (Figure 6-12).

Second, *many people migrated from large central cities to suburbs and smaller cities*. Currently, about half of urban Americans live in the suburbs, 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, Florida, and Texas, although increased drought and heat waves due to climate change may alter this trend.

Fourth, since the 1970s, and especially since 1990, *some people have fled both cities and suburbs and migrated to developed rural areas*. The result is rapid growth of *exurbs*—housing developments scattered over vast areas that lie beyond suburbs and have no socio-economic centers.

Since 1920, many of the worst urban environmental problems in the United States have been reduced significantly. Most people have better working and housing conditions, and air and water quality have improved. Better sanitation, public water supplies, and medical care have slashed death rates and incidences of sickness from malnutrition and infectious diseases (Figure 6-5). Concentrating most of the population in urban areas also has helped protect the country's biodiversity by reducing the destruction and degradation of wildlife habitat.

GOOD NEWS

However, a number of U.S. cities—especially older ones—have deteriorating services and aging *infrastructures* (streets, bridges, schools, housing, water supply pipes, and sewers). At the same time, many U.S. cities face budget crunches and decreasing public services, as businesses and people move to the suburbs and exurbs and city revenues from property taxes decline. And there is rising poverty in the centers of many older cities, where unemployment rates are typically 50% or higher.

Figure 6-12 Major urban areas in the United States revealed in satellite images of the earth at night, showing city lights (top). Almost eight of every ten Americans live in urban areas, which occupy a small but growing fraction of the country's land area. Areas with names in white are the fastest-growing metropolitan areas. Nearly half (48%) of all Americans live in cities of 1 million or more people, which are projected to merge into huge urban areas shown as shaded areas in the bottom map. **Questions**: Why are most of the largest urban areas located near water? What effect might climate change due to global warming have on these cities? (Data from National Geophysical Data Center/National Oceanic and Atmospheric Administration, U.S. Census Bureau)

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 6-13, p. 110). It results in a far-flung hodgepodge of housing developments, shopping malls, parking lots, and office complexes that are loosely connected by multilane highways and freeways.

Urban sprawl is the product of affordable land, automobiles, relatively cheap gasoline, and poor urban planning. It 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, emitting greenhouse gases and other forms of air pollution in the process. Sprawl has decreased energy efficiency, increased traffic congestion, and destroyed prime cropland, forests, and wetlands. It has also led to the economic deaths of many central cities as people and businesses move out of these areas. Figure 6-14, p. 110 summarizes some of the undesirable consequences of urban sprawl.

On the other hand, 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. Also, they often have newer public schools and lower crime rates.

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 in the long run? How might this affect your lifestyle?

CENGAGENOW™ Examine how the San Francisco Bay area in the U.S. state of California grew in population between 1900 and 1990 at CengageNOW.

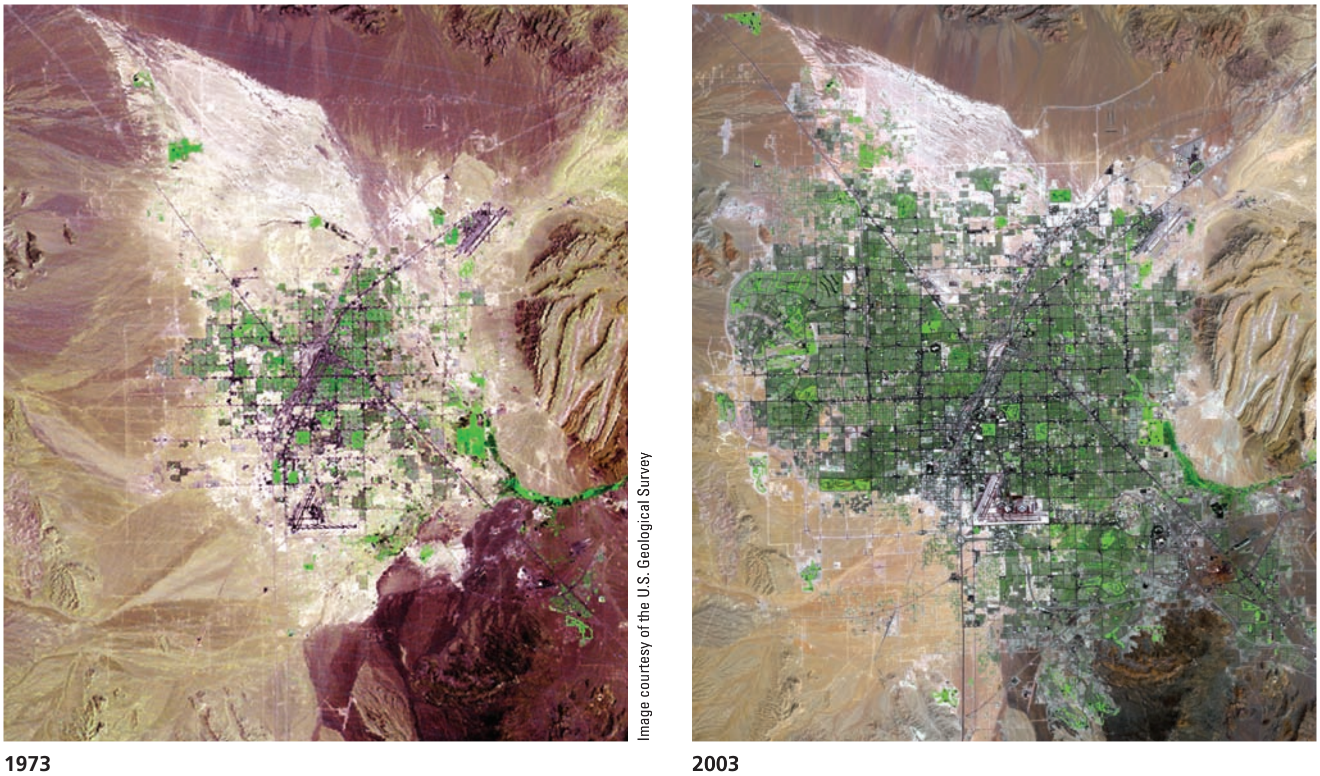


Image courtesy of the U.S. Geological Survey

Image courtesy of the U.S. Geological Survey

Figure 6-13 *Urban sprawl* in and around the U.S. city of Las Vegas, Nevada, between 1973 and 2003—a process that has continued. Between 1970 and 2008, the population of water-short Clark Country, which includes Las Vegas, increased more than sevenfold from 277,000 to more than 2 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?

Natural Capital Degradation

Urban Sprawl

Land and Biodiversity	Water	Energy, Air, and Climate	Economic Effects
Loss of cropland	Increased use of surface water and groundwater	Increased energy use and waste	Decline of downtown business districts
Loss of forests and grasslands	Increased runoff and flooding	Increased air pollution	Increased unemployment in central city
Loss of wetlands	Increased surface water and groundwater pollution	Increased greenhouse gas emissions	Loss of tax base in central city
Loss and fragmentation of wildlife habitats	Decreased natural sewage treatment	Can enhance climate change	

Figure 6-14 Some undesirable impacts of urban sprawl, a form of urban development that is dependent on cars. **Question**: Which five of these effects do you think are the most harmful?

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.

Urban residents in many parts of the world tend to live longer than do rural residents and to have lower infant mortality rates 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. And central cities can save energy if residents rely more on energy-efficient mass transportation, walking, and bicycling.

Urbanization Has Disadvantages

Most Urban Areas are Unsustainable Systems. 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 carbon dioxide emissions from human activities, according to the Worldwatch Institute. Because of this high resource input of food, water, and materials and the resulting high waste output (Figure 6-15), *most of the world's cities have huge ecological footprints and are not self-sustaining systems* (**Concept 6-5**). And their ecological footprints extend far beyond their boundaries (**Concept 1-2**, p. 9). 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.)

CONCEPT LINK

CONNECTIONS

Urban Living and Biodiversity Protection

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 of these people tend to be uninformed about the importance of protecting the earth's increasingly threatened biodiversity and other forms of natural capital that support their lives and the cities where they live.

Cities Lack Vegetation. In urban areas, most trees, shrubs, or other plants are destroyed to make way for

Figure 6-15 Natural capital degradation: urban areas rarely are sustainable systems. The typical city depends on large nonurban areas for huge inputs of matter and energy resources and for large outputs of waste matter and heat. According to an analysis by Mathis Wackernagel and William Rees, an area 58 times as large as that of London, England, is needed to supply its residents with resources. They estimate that if all 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?

buildings, roads, parking lots, and housing developments. So most cities do not benefit from vegetation that would absorb air pollutants, give off oxygen, help cool the air through transpiration, provide shade, reduce soil erosion, muffle noise, supply food, provide wildlife habitats, and give aesthetic pleasure. As one observer remarked, "Most cities are places where they cut down most of the trees and then name the streets after them."

Cities Have Water Problems. As cities grow and their water demands increase, expensive reservoirs 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 coastal areas subject to natural flooding. And covering land with buildings, asphalt, and concrete causes precipitation to run off quickly and overload storm drains. In addition, urban development has often destroyed or degraded large areas of wetlands that have served as natural sponges to help absorb excess water. Many of the world's largest cities located in coastal areas (Figure 6-11) face a new threat of flooding some time in this century as sea levels rise because of projected global warming.

Global warming will likely create another problem for cities in arid areas that depend on water withdrawn from rivers and from reservoirs behind dams. Those cities may face severe water shortages as global warming reduces the mountaintop glaciers that melt each year to feed the rivers that fill the reservoirs they use for their water supplies.

They 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. 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. *Noise pollution* (Figure 6-16) is another problem.

They Affect Local Climates and Cause Light Pollution. On average, cities tend to be warmer, rainier, foggier, and cloudier than suburbs and nearby rural areas. The enormous amount of heat generated by cars, factories, furnaces, lights, air conditioners, and heat-absorbing dark roofs and streets in cities creates an *urban heat island* that is surrounded by cooler suburban and rural areas. As cities grow and merge, their heat islands merge, which can reduce the natural dilution and cleansing of polluted air.

Also, the artificial light created by cities affects some plant and animal species. For example, endangered sea turtles (see the front cover of this book) typically lay their eggs on beaches at night and require darkness to do so. And each year, large numbers of migrating birds, lured off course by the lights of high-rise buildings, fatally collide with the buildings.

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.

Life Is a Desperate Struggle for the Urban Poor in Developing Countries

Poverty is a way of life for many urban dwellers in developing countries. At least 1 billion people live under crowded and unsanitary conditions in cities in developing countries (Figure 6-17), and according to a 2006 U.N. study, that number could reach 1.4 billion by 2020.

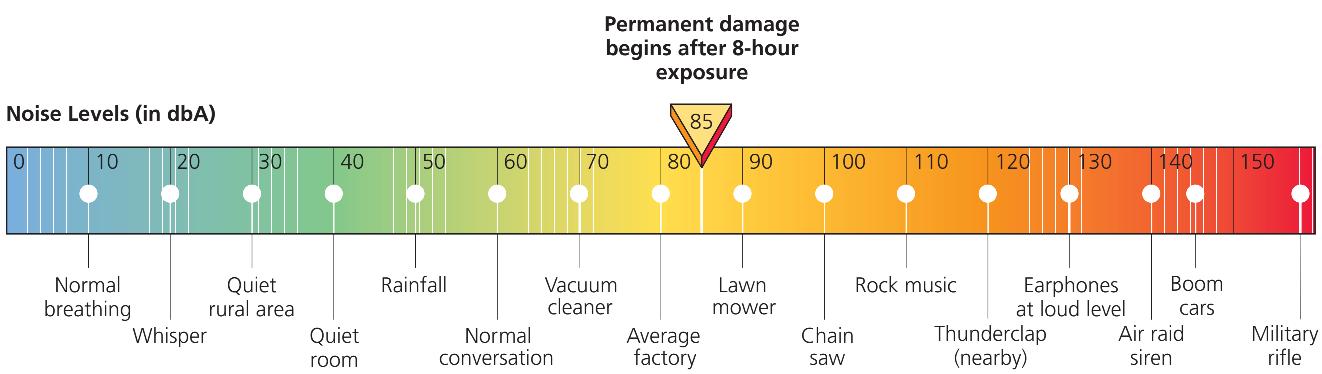
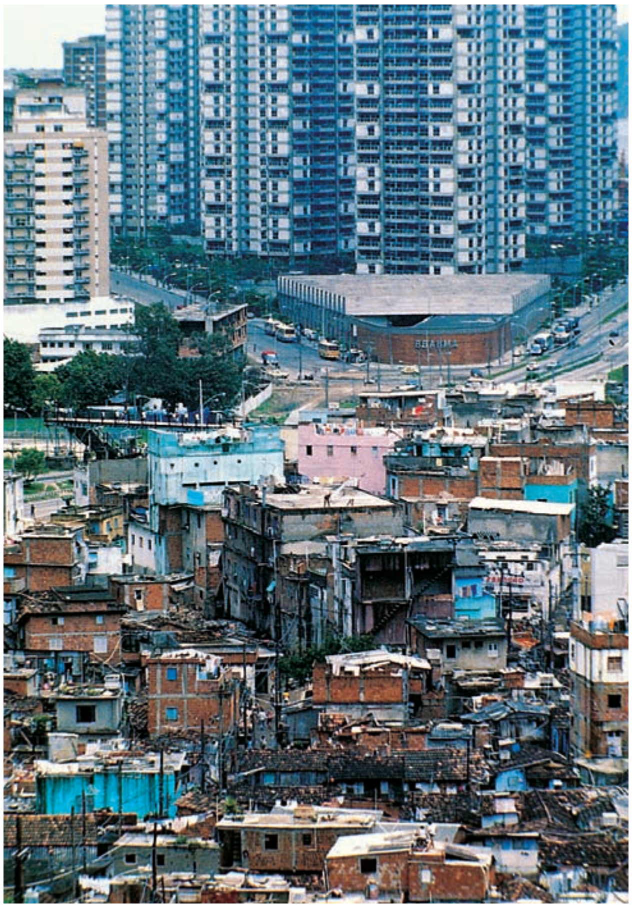


Figure 6-16 *Noise levels* (in decibel-A [dbA] sound pressure units) of some common sounds. You are being exposed to a sound level high enough to cause permanent hearing damage if you need to raise your voice to be heard above the racket, if a noise causes your ears to ring, or if nearby speech seems muffled. Prolonged exposure to lower noise levels and occasional loud sounds may not damage your hearing, but they can greatly increase internal stress. **Question**: How many times per day are your ears subjected to noise levels of 85 or more dbA?



United Nations

Figure 6-17 *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, where adequate water supplies, sewage disposal, and other services do not exist.

Some of these people live in *slums*—areas dominated by tenements and rooming houses where several people might live in a single room. Others live in *squatter settlements* and s*hantytowns* on the outskirts of these 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. Still others live or sleep on the streets.

Poor people living in shantytowns and squatter settlements usually lack clean water supplies, sewers, electricity, and roads, and are subject to severe air and water pollution and 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 or develop 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 encouraging investment in small towns. Governments can also designate land for squatter settlements, grant legal titles to the land (as is done in parts of Brazil and Peru), supply them with clean water, and provide regular bus service that enables workers living in such settlements to travel to and from their workplaces. However, extensive government corruption in many of the poorest countries hinders implementation of such policies.

HOW WOULD YOU VOTE?

Should squatters living in or near cities in developing countries be given title to land they live on? Cast your vote online at **www.cengage.com/biology/miller**.

CASE STUDY

Mexico City

Mexico City—the world's second most populous city—is an urban area in crisis. About 20 million people—a number roughly equal to the entire population of Australia or of the U.S. state of New York—live there. 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 have no sewer facilities. As a result, huge amounts of human waste are deposited in gutters, vacant lots, and open sewers 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 because of a combination of factors: too many cars, polluting factories, a 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."

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, required air pollution controls on all cars made after 1991, phased out use of leaded gasoline, and replaced old buses, taxis, and delivery vehicles with cleaner ones. The city also bought land for use as green space and planted more than 25 million trees to help absorb pollutants.

6-6 How Does Transportation Affect Urban Environmental Impacts?

▶ **CONCEPT 6-6 In some countries, most people live in dispersed urban areas and depend mostly on motor vehicles for their transportation.**

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. New high-rise apartment buildings in these Asian cities contain everything from grocery stores to fitness centers. People living in the apartments hardly have to leave the buildings to meet their needs.

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 6-6**). Such car-centered cities are found in the United States, Canada, Australia, and other countries where ample land often is available for outward expansion. The resulting urban sprawl (Figure 6-13) can have a number of undesirable effects (Figure 6-14).

The United States is a prime example of a car-centered nation. With 4.5% 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 about 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. They also are symbols of power, sex appeal, social status, and success for many people. And much of the world's economy is 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 the environment. Globally, automobile accidents kill approximately 1.2 million people a year—an average of 3,300 premature 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 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 carbon dioxide emissions. In addition, they account for two-thirds of the oil used in the form of gasoline in the United States and one-third of the world's oil consumption.

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.

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. Traffic congestion in some cities in developing countries is much worse. Building more roads may not be the answer. Many analysts agree with economist Robert Samuelson that "cars expand 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 environmental and health costs of 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 on gasoline to cover the estimated 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 (as discussed further in Chapter 13). Gradually phasing in such a tax would spur the use of more energy-efficient motor vehicles and mass transit, decrease dependence on imported oil, and thus increase economic and military 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/biology/miller**

Proponents of this approach urge governments to use gasoline tax revenues to help finance mass transit systems, bike lanes, and sidewalks as alternatives to cars and to reduce taxes on income, wages, and wealth to offset the increased taxes on gasoline. Such a *tax shift* would make higher gasoline taxes more politically acceptable.

Taxing gasoline heavily would be difficult in the United States, for four reasons. *First*, it faces strong opposition from the public, which is largely unaware of the huge hidden costs they are paying for gasoline, and from powerful transportation-related industries such as oil and tire companies, road builders, carmakers, and many real estate developers. *Second*, fast, efficient, reliable, and affordable mass transit options and bike lanes and sidewalks are not widely available in the United States. *Third*, the dispersed nature of most U.S. urban areas makes people dependent on cars. And *fourth*, most people who can afford cars are virtually addicted to them. 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 car owners must pay a high tax to use any of the roads leading into the city center. Several European cities have also imposed stiff fees for motor vehicles entering their central cities.

In Germany, Austria, Italy, Switzerland, and the Netherlands, more than 300 cities have *car-sharing* networks. 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 carbon dioxide emissions by 40–50%. Car-share companies have sprouted up in the United States since 2000 in cities such as Madison, Wisconsin, Portland, Oregon, New York City, and Los Angeles, California, among others.

Some Cities Are Promoting Alternatives to Relying on Cars

There are several alternatives to motor vehicles, each with its own advantages and disadvantages. They include *bicycles* (Figure 6-18), *mass transit rail systems in*

Figure 6-18 Advantages and disadvantages of bicycles. The key to increased bicycle use is the creation of bicycle-friendly systems, including bike lanes. Bicycling and walking account for about a third of all urban trips in the Netherlands and in Copenhagen, Denmark, compared to only 1% in the United States. Paris, France, has almost 21,000 bikes available for rental at 1,450 rental stations throughout the city at a cost of just over $1 a day. **Question**: Which single advantage and which single disadvantage do you think are the most important?

urban areas (Figure 6-19), *bus systems in urban areas* (Figure 6-20), and *high-speed (bullet train) rail systems between urban areas* (Figure 6-21).

THINKING ABOUT
Bicycles

Do you, or would you, use a conventional or an electric bicycle to go to and from work or school? Explain.

HOW WOULD YOU VOTE?

Should half the U.S. gasoline tax be used to develop mass transit, bike lanes, and sidewalks, as alternatives to the car? Cast your vote online at **www.cengage.com/biology/miller**.

Trade-Offs

Mass Transit Rail

Advantages	Disadvantages
Uses less energy and produces less air pollution than cars do	Is expensive to build and maintain
Reduced need for more roads and parking areas	Is cost-effective only in densely populated areas
Causes fewer injuries and deaths than cars do	Commits riders to transportation schedules
Reduces car congestion in cities	Can cause noise and vibration for nearby residents

Figure 6-19 Advantages and disadvantages of mass transit rail systems in urban areas. **Question**: Which single advantage and which single disadvantage do you think are the most important?

Trade-Offs

Buses

Advantages	Disadvantages
Can greatly 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
Cost less to develop and maintain than heavy-rail system	Commit riders to transportation schedules

Figure 6-20 Advantages and disadvantages of bus rapid transit (where several buses running in express lanes can be hooked together) and conventional bus systems in urban areas. **Question**: Which single advantage and which single disadvantage do you think are the most important?

Trade-Offs

Rapid Rail

Advantages	Disadvantages
Is much more energy efficient per rider than cars and planes are	Is costly to run and maintain
Produces less pollution than do cars and planes	Causes noise and vibration for nearby residents
Can reduce need for more air travel, cars, roads, and parking areas	Has some risk of collision at car crossings

Figure 6-21 Advantages and disadvantages of rapid-rail systems between urban areas. 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?

6-7 How Can Cities Become More Sustainable and Livable?

CONCEPT 6-7 An *ecocity* allows people to choose walking, biking, or mass transit for most transportation needs; recycle or reuse most of their wastes; grow much of their food; and protect biodiversity by preserving surrounding land.

We Can Make Urban Areas More Environmentally Sustainable and Enjoyable Places to Live

Many environmental scientists and urban planners call for us to make new and existing urban areas more 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.)

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. It recognizes that urban growth will occur. At the same time, it uses zoning laws and other tools to channel 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 to live. Figure 6-22 lists popular smart growth tools that are used to control urban growth and sprawl. GOOD NEWS

A more environmentally sustainable city, called an *ecocity* or *green city*, emphasizes the following goals, some of which directly apply 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 nature
- Build and redesign cities for people not cars
- Use energy and matter resources efficiently
- Prevent pollution and reduce waste
- Recycle, reuse, and compost at least 60% of all municipal solid waste
- Protect and encourage biodiversity by preserving surrounding land and protecting and restoring natural systems and wetlands
- Promote urban gardens and farmers markets
- Use zoning and other tools to keep the human population 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. Its buildings, vehicles, and appliances meet high energy-efficiency standards. 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.

In an ecocity, abandoned lots, industrial sites, and polluted creeks and rivers are cleaned up and restored. Nearby forests, grasslands, wetlands, and farms are

Figure 6-22 *Smart growth* or *new urbanism tools* that are used to control urban growth and sprawl. **Questions**: Which five of these tools do you think are the most important ways to prevent or control urban sprawl? Which, if any, of these tools are used in your community?

preserved. Much of an ecocity's food comes from nearby organic farms, solar greenhouses, community gardens, and small gardens on rooftops, in yards, and in window boxes. Parks are easily available to everyone. People designing and living in ecocities take seriously the advice that U.S. urban planner Lewis Mumford gave more than 3 decades ago: "Forget the damned motor car and build cities for lovers and friends."

The ecocity is not a futuristic dream, but a reality in many cities that are striving to become more environmentally sustainable and livable, including Curitiba, Brazil (see following Case Study); Bogotá, Colombia; Waitakere City, New Zealand; Stockholm, Sweden; Helsinki, Finland; Leichester, England; Neerlands, the Netherlands; and in the United States, Portland, Oregon; Davis, California; Olympia, Washington; and Chattanooga, Tennessee. In 2008, the oil-producing United Arab Emirates, with the world's largest per capita ecological footprint, announced plans to build a green town in the desert by 2015 for up to 50,000 residents. Planners there set goals for having zero-carbon emissions and zero wastes. China has plans to develop a number of ecocities.

GOOD NEWS

RESEARCH FRONTIER

Ecocity design. See **www.cengage.com/biology/miller**.

John Maier, Jr./Peter Arnold, Inc.

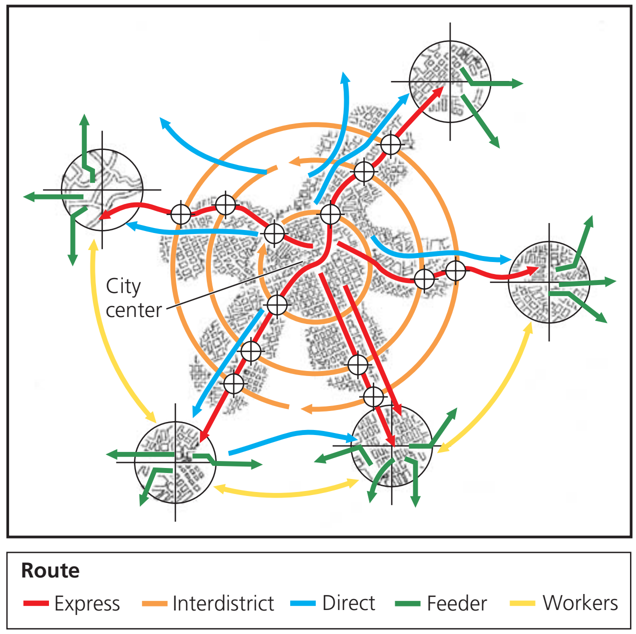


Figure 6-23 **Solutions:** bus rapid transit (BRT) system in Curitiba, Brazil. This system moves large numbers of passengers around rapidly because each of the five major spokes has two express lanes used only by buses. Double- and triple-length bus sections are hooked together as needed to carry up to 300 passengers. Boarding is speeded up by the use of extra-wide doors and boarding platforms sheltered by large glass tubes where passengers can pay before getting on the bus (top right).

CASE STUDY

The Ecocity Concept in Curitiba, Brazil

An example of an ecocity is Curitiba ("koor-i-TEE-ba"), a metropolitan area with 3.2 million people known as the "ecological capital" of Brazil.

Planners in this city decided in 1969 to focus on an inexpensive and efficient mass transit system rather than on the car. Curitiba now has the world's best rapid transit bus system, in which clean and modern buses transport about 72% of the population every day throughout the city along express lanes dedicated to buses (Figure 6-23). 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 far for shopping.

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 and less traffic congestion than do most comparable cities.

The city transformed flood-prone areas along its river banks 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. And 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. Recovered materials are sold mostly to the city's more than 500 major industries, which must meet strict pollution standards.

The poor receive free medical and dental care, child care, and job training, and 40 feeding centers are available for street children. Poor people who live in areas not served by garbage trucks, can exchange filled garbage bags for surplus food, bus tokens, and school supplies. The city uses old buses as roving classrooms to train its poor in the basic skills needed for jobs. Other retired buses have become health clinics, soup kitchens, and day care centers that are free for low-income parents.

About 95% of Curitiba's citizens can read and write and 83% of adults have at least a high school education. All school children study ecology. Polls show that 99% of the city's inhabitants would not want to live anywhere else.

Curitiba now faces new challenges, as do all cities, mostly due to a fivefold increase in its population since 1965. Curitiba's once clear streams are often overloaded with pollutants. The bus system is nearing capacity, and car ownership is on the rise. The city is considering building a light rail system to relieve some of the pressure.

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. In the face of new challenges, Lerner and other leaders in Curitiba argue that education is still a key to making cities more sustainable, and they want Curitiba to continue serving as an educational example for that great purpose.

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

- The human population is increasing rapidly and may soon bump up against environmental limits.
- We can slow human population growth by reducing poverty, encouraging family planning, and elevating the status of women.
- Most urban areas, home to half of the world's people, are unsustainable, but they can be made more sustainable and livable within your lifetime.

REVISITING Population Growth, Urbanization, and Sustainability

CORE CASE STUDY

SUSTAINABILITY

This chapter began by discussing the issue of whether the world is overpopulated (**Core Case Study**). As we have seen, some experts say this is the wrong question to be asking. Instead, they believe we ought to ask, "What is the optimal level of human population that the planet can support *sustainably now and in the future*?"

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). In this chapter, we hope you have gained a sense of the need for humans to apply these sustainability principles to their lifestyles and economies, particularly with regard to slowing human population growth and making urban areas more sustainable and desirable places to live.

There are places where such progress is being made. Curitiba, Brazil, located in a developing country (Case Study, p. 118), is one city that has made great strides toward becoming environmentally sustainable and livable. It is a source of hope based on good ecological design.

In the next three chapters, you will learn how various principles of ecology and the three **principles of sustainability** can be applied to help understand and preserve the earth's biodiversity.

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. 95.
2. List three factors that account for the rapid increase in the world's human population over the past 200 years. How many of us are likely to be here in 2050? Describe eight ways in which we have used technology to alter nature to meet our growing needs and wants. What is the **cultural carrying capacity** for a population?
3. List four variables that affect the **population change** of an area and write an equation showing how they are related. Distinguish between **birth rate** (**crude birth rate**) and **death rate** (**crude death rate**). What three countries had the largest numbers of people in 2009? What is **total fertility rate** (**TFR**)?
4. Describe population growth in the United States and explain why it is high compared to growth rates in most other developed countries and in China.
5. List seven factors that affect the birth rate and fertility rate and four factors that affect the death rate of a country. Distinguish between **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 a higher infant mortality rate than a number of other countries? What is **migration**?

Describe immigration into the United States and the issues it raises.

6. What is the **age structure** of a population? Explain how it affects population growth and economic growth. What are some problems related to rapid population decline from an aging population? Explain how a high incidence of AIDS among adults can affect the age structure of a population.

7. What is the **demographic transition** and what are its four stages? What factors could hinder some developing countries from making this transition? What is **family planning**? Describe the roles of family planning and elevating the status of women in slowing population growth. Describe China's and India's efforts to control their population growth.

8. List four trends in global urban growth. Describe four phases of urban growth in the United States. What is **urban sprawl**? List five undesirable effects of urban sprawl. What are four advantages of urbanization? What are six disadvantages of urbanization? Explain why most cities and urban areas are not sustainable. Describe some of the problems faced by the poor who live in urban areas. Describe the urban problems of Mexico City, Mexico.

9. What are the major advantages and disadvantages of motor vehicles? List three ways to reduce dependence on motor vehicles. Describe the major advantages and disadvantages of relying more on **(a)** bicycles, **(b)** mass transit rail systems, and **(c)** bus rapid transit systems within urban areas, and **(d)** rapid-rail systems between urban areas.

10. What is **smart growth**? List five tools used to promote smart growth. List eight goals of ecocity design. Describe efforts to make Curitiba, Brazil, a sustainable ecocity. What are this chapter's *three big ideas*? Describe the relationships between human population growth, urban growth and design, and the three **principles of sustainability**.

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

CRITICAL THINKING

1. Which of the three major environmental worldviews summarized on pp. 18–19 do you believe underlie each of the two major positions on whether the world is overpopulated (**Core Case Study**)? 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?

2. Identify a major local, national, or global environmental problem, and describe the role of population growth in this problem.

3. Do you believe that the population is too high in **(a)** the world (**Core Case Study**), **(b)** your own country, and **(c)** the area where you live? Explain.

4. Some people have proposed that the earth could solve its population problem by moving people to space colonies, each containing about 10,000 people. Assuming we could build such large-scale, self-sustaining space stations (a big assumption), how many people would we have to ship off each day to provide living spaces for the 82 million people added to the earth's population this year? Current space shuttles can handle about 6 to 8 passengers. If this capacity could be increased to 100 passengers per shuttle, how many shuttles would have to be launched per day to offset the 82 million people added this year? According to your calculations, determine whether this proposal is a logical solution to the earth's population problem.

5. Some people believe our most important goal should be to sharply reduce the rate of population growth in developing countries, where 97% of the world's population growth is expected to take place. Others argue that the most serious environmental problems stem from high levels of resource consumption per person in developed countries, which use 88% of the world's resources and have much larger ecological footprints per person (Figure 1-5 p. 11) than do developing countries. What is your view on this issue? Explain.

6. Experts have identified population growth as one of the major causes of the environmental problems we face (Figure 1-9, p. 15). The population of United States is growing faster than that of China and of any of the world's other developed countries. But this problem is rarely mentioned, and the U.S. government has no official policy to slow its population growth. Why do think this is so? Do you agree with this hands-off approach? If not, list three things you would do to slow U.S. population growth.

7. List 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.

8. If you own a car or hope to own one, what conditions, if any, would encourage you to rely less on the automobile and to travel to school or work by bicycle, on foot, by mass transit, or by carpool?

9. Congratulations! You are in charge of the world. List the three most important features of your policy for dealing with **(a)** global population growth and **(b)** urban growth and development.

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.

	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

Source: Data from Population Reference Bureau 2008. *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 developed or developing 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 6-11). 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

STUDENT COMPANION SITE Visit this book's website at **www.cengage.com/biology/miller** and choose Chapter 6 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, web links, information on Green Careers, and InfoTrac® College Edition articles.

CENGAGENOW™ For students with access, log on at **www.cengage.com/login** for the animations, active figures, activities, and readings indicated within the text by the CengageNOW logo. If your textbook did not come with access, visit **www.iChapters.com** to purchase.

7 Climate and Biodiversity

CORE CASE STUDY Different Climates Support Different Life Forms

Why is one area of the earth's land surface a desert, another a grassland, and another a forest? Why do rivers flow in some areas but not in others? The answers lie largely in differences in *climate,* the general pattern of atmospheric conditions in a given region over periods ranging from 30 years to thousands of years. The ecological service we call *climate* plays a major role in determining what kinds of life can live where.

Paul W. Johnson/Biological Photo Service

Differences in climate result mostly from long-term differences in average annual precipitation and temperature. For example, areas of the earth lying between the equatorial region and the earth's two poles have a *temperate climate*. In forests of these regions, plants and animals are adapted to moderately long and warm summers, fairly long and cold winters (Figure 7-1), and plenty of precipitation. However, when we look at areas with *tropical* (nearer the Equator) or *polar* climates we find different types of vegetation and animals, adapted to different conditions.

Similarly, grasslands exist in all three major regions of the earth—the tropical, temperate, and polar regions. In tropical grasslands called *savanna*, plants and animals are adapted to warm temperatures year-round and dry seasons alternating with rainy seasons. Temperate grasslands, called *prairies*, host plants and animals that can survive extremely cold seasons with deep snows and very hot seasons with uneven rains. Polar grasslands, or *arctic tundra*, are bitterly cold and windy and covered with ice and snow most of the year. Only certain plants and animals can survive these conditions.

Deserts, too, exist in all three major regions of the earth, each characterized by certain conditions. Each hosts a unique combination of plants and animals that have survived for thousands of years.

In each of these major types of ecosystems, life forms have evolved to fit the environmental conditions through the extremely long process of natural selection, according to the theory of evolution (**Concepts 4-2A** and **4-2B**, p. 63). In this chapter, we explore these regions, their conditions, and their life forms.

CONCEPT LINKS

The world's major types of terrestrial ecosystems—forests, grasslands, and deserts—largely determined by their climates, are called *biomes,* and they cover all of the earth's land surface except for ice-covered areas. But the water-covered areas of the earth where life is found, called *aquatic life zones,* cover more than 73% of the earth's surface. Much of the life in these aquatic zones also varies with their climates.

In this chapter, we examine the key role that climate plays in the formation and location of the biomes and aquatic life zones that make up one of the four components of the earth's biodiversity (Figure 4-2, p. 61).

Figure 7-1 The trees and shrubs in this temperate deciduous forest in the U.S. state of Rhode Island survive in winter by dropping most of their leaves. The middle photo in Figure 7-15 in this chapter (p. 135) shows this same forest in the fall when its leaves change color prior to dropping.

Key Questions and Concepts

7-1 What factors influence climate?

CONCEPT 7-1 Key factors determining 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.

7-4 What are the major types of aquatic systems?

CONCEPT 7-4 Saltwater and freshwater aquatic life zones cover almost three-fourths of the earth's surface, and oceans dominate the planet.

7-5 Why are the world's oceans important and how have we affected them?

CONCEPT 7-5 Saltwater ecosystems provide major ecological and economic services that are being threatened by human activities.

7-6 What are the major types of freshwater systems and how have we affected them?

CONCEPT 7-6 Freshwater lakes, rivers, and wetlands provide important ecological and economic services that are being disrupted by human activities.

Note: Supplements 2 (p. S3), 4 (p. S14), and 8 (p. S33) 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?

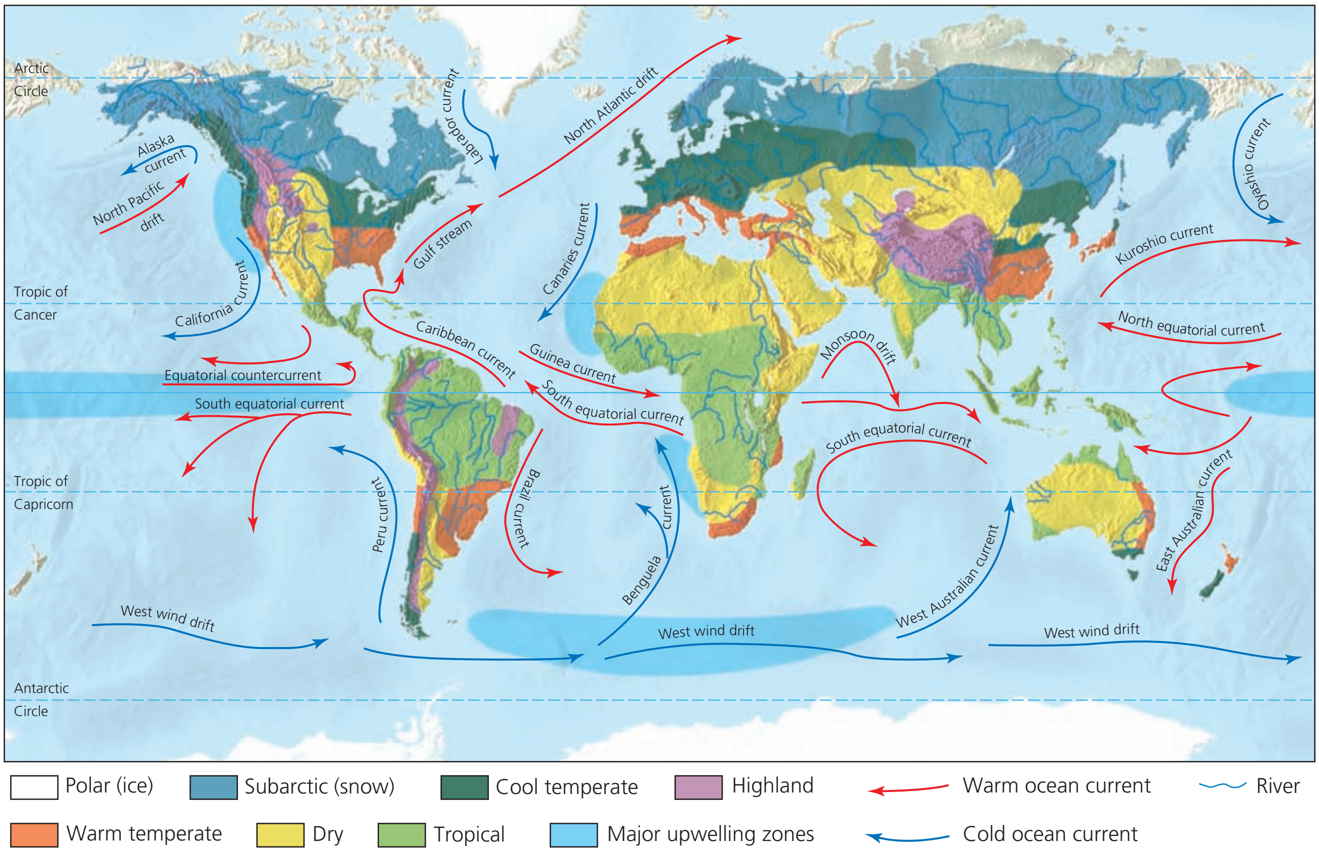
CONCEPT 7-1 **Key factors determining an area's climate are incoming solar energy, the earth's rotation, global patterns of air and water movement, gases in the atmosphere, and the earth's surface features.**

The Earth Has Many Different Climates

The first step in understanding issues related to climate such as how climate affects 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 8, p. S33, introduces you to weather basics.) Weather differs from **climate**, which is an area's general pattern of atmospheric conditions over periods ranging from at least 3 decades to thousands of years. In other words, climate is weather averaged over a long time. Figure 7-2 (p. 124) depicts the earth's current major climate zones and ocean currents, which are key components of the earth's natural capital (Figure 1-2, p. 7).

Climate varies in different parts of the earth mostly because patterns of global air circulation and ocean currents distribute heat and precipitation unevenly from the tropics to other parts of the world (Figure 7-3, p. 124). Three major factors determine how air circulates in the lower atmosphere:

- *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 a slanted 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 while polar regions are cold and temperate regions in between generally have intermediate average



CENGAGENOW™ **Active Figure 7-2** **Natural capital:** generalized map of the earth's current climate zones, showing 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?

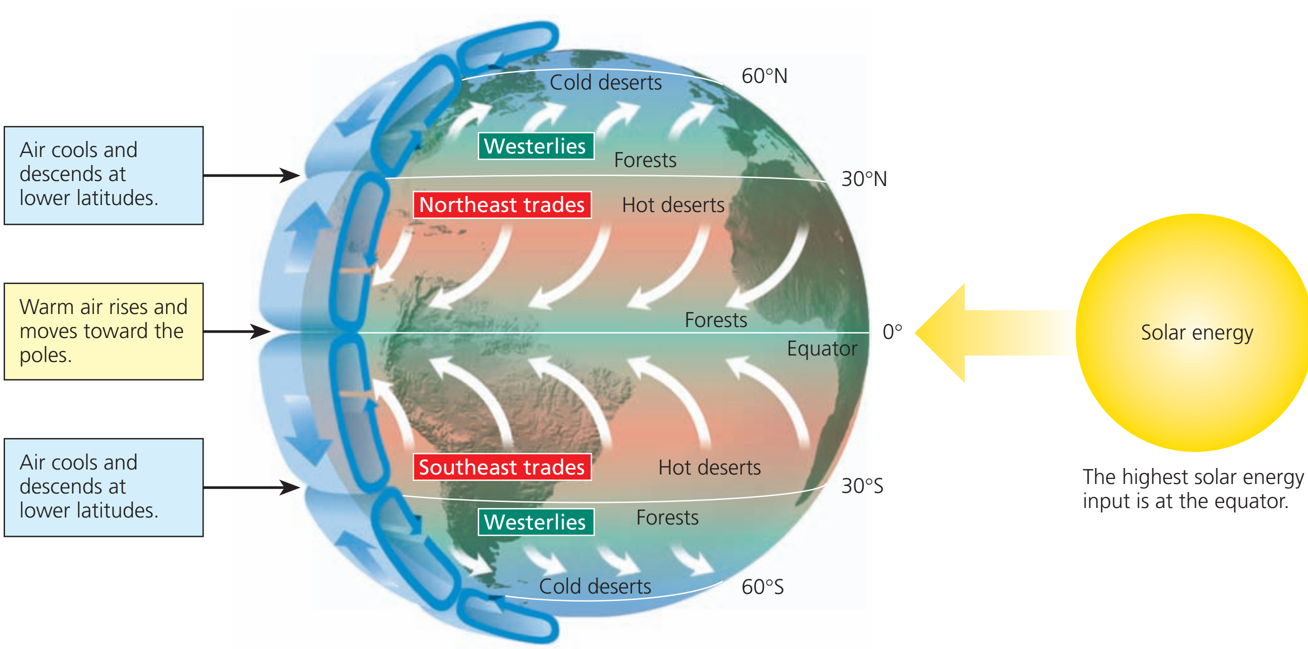


Figure 7-3 *Global air circulation.* The largest input of solar energy occurs at the equator. As this air is heated it rises and moves toward the poles. However, the earth's rotation deflects the movement of the air over different parts of the earth. This creates global patterns of prevailing winds that help to distribute heat and moisture in the atmosphere.

temperatures (Figure 7-3, left). The intense input of solar radiation in tropical regions leads to greatly increased evaporation of water from forests, grasslands, and bodies of water. As a result, tropical regions normally receive more precipitation than other areas of the earth get.

- *Rotation of the earth on its axis*. As the earth rotates around its axis, the equator spins faster than regions north and south of the equator. 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). The atmosphere over these different areas is divided into huge regions called *cells*, distinguished by direction of air movement. The differing directions of air movement are called *prevailing winds*—major surface winds that blow almost continuously and help to distribute heat and moisture over the earth's surface and to drive ocean currents.
- *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.

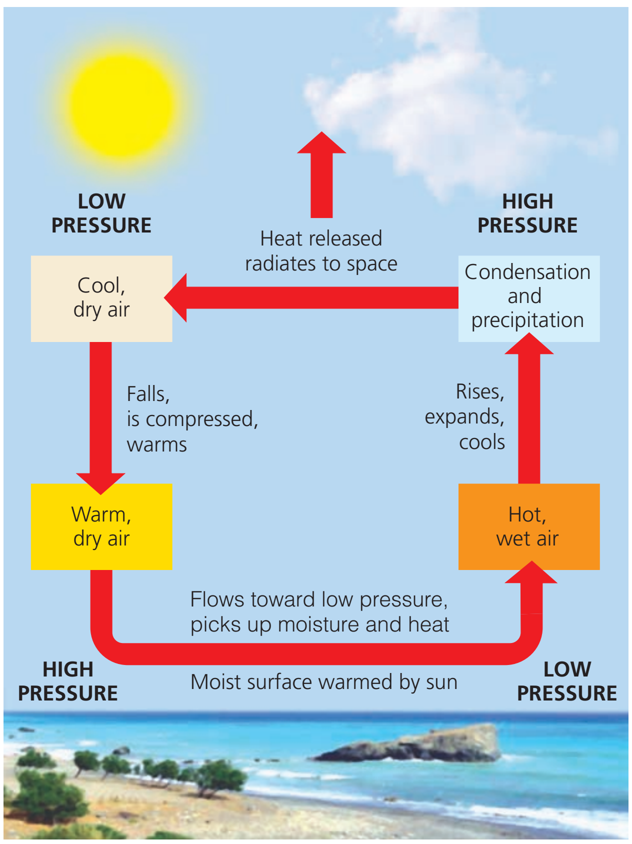


Figure 7-4 Energy transfer by convection in the atmosphere. *Convection* occurs when warm, wet air rises, cools, and releases heat and moisture as precipitation (right side). Then the cooler, denser, and drier air sinks, warms up, and absorbs moisture as it flows across the earth's surface to begin the cycle again.

Prevailing winds (Figure 7-3) 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) 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. These vertical currents become connected in a loop (Figure 7-5), which helps to transport heat to and from the deep ocean and between the poles and the tropics.

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 (Figure 7-4). One example of the interactions between the ocean and the atmosphere is the *El Niño–Southern Oscillation*, or *ENSO*. (See Figure 4, p. S34, in Supplement 8 and *The Habitable Planet*, Video 3, at **www.learner.org/resources/series209.html**.) This large-scale weather phenomenon occurs every few years when prevailing winds in the tropical Pacific Ocean weaken and change direction. The resulting above-average warming of Pacific waters can affect populations of marine species by changing the distribution of plant nutrients. It also alters the weather

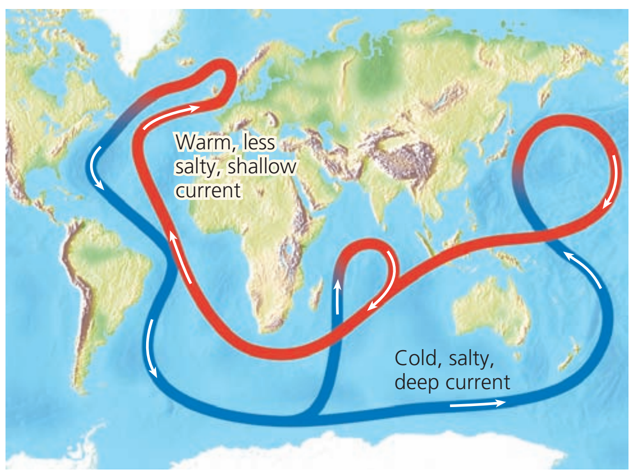


Figure 7-5 *Connected deep and shallow ocean currents.* A connected loop of shallow and deep ocean currents transports warm and cool water to various parts of the earth. This loop, which rises in some areas and falls in others, results when ocean water in the North Atlantic near Iceland is dense enough (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 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?

of at least two-thirds of the earth for 1 or 2 years (see Figure 5, p. S35, in Supplement 8).

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 7-4), three of them south of the equator and three north of the equator. These cells lead to an irregular distribution of climates and deserts, grasslands, and forests, as shown in Figure 7-6 (**Concept 7-1**).

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 3-3 (p. 41) 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 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 flows 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 3-3, p. 41, and *The Habitable Planet*, Video 2, at **www.learner.org/resources/series209.html**). Without this natural heating effect, the earth would be a cold and mostly lifeless planet.

Human activities such as burning fossil fuels, clearing forests, and growing crops release carbon dioxide, methane, and nitrous oxide into the atmosphere. A large and growing body of scientific evidence, along with climate model projections, indicate that there is more than a 90% chance that the large inputs of greenhouse gases into the atmosphere from human activities are enhancing the earth's natural greenhouse effect (Science Focus, p. 27). 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 (Figure 3-13, p. 51).

If the earth's natural greenhouse effect is enhanced at least partially by human activities as projected during this century, climate scientists expect the warmer atmosphere to cause climate changes in various places on the earth that could last for centuries to thousands of years. As this warming intensifies during this century, climate scientists expect it 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 15.

CENGAGENOW™ Witness the natural greenhouse effect and see how human activity has affected it at CengageNOW.

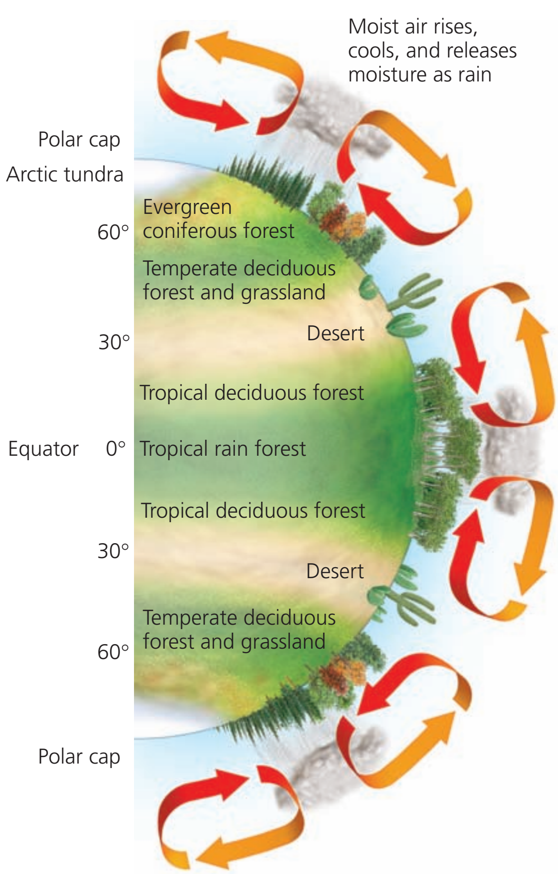


Figure 7-6 *Global air circulation, ocean currents, and biomes.* Six giant convection cells (like the one in Figure 7-4) at different latitudes distribute different amounts of heat and moisture to various parts of the world. The resulting different climates support the formation of forests, grasslands, and deserts that make up the earth's terrestrial biomes (**Core Case Study**, Figure 7-1).

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 create local and regional climatic conditions that differ from the general climate of a region. 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

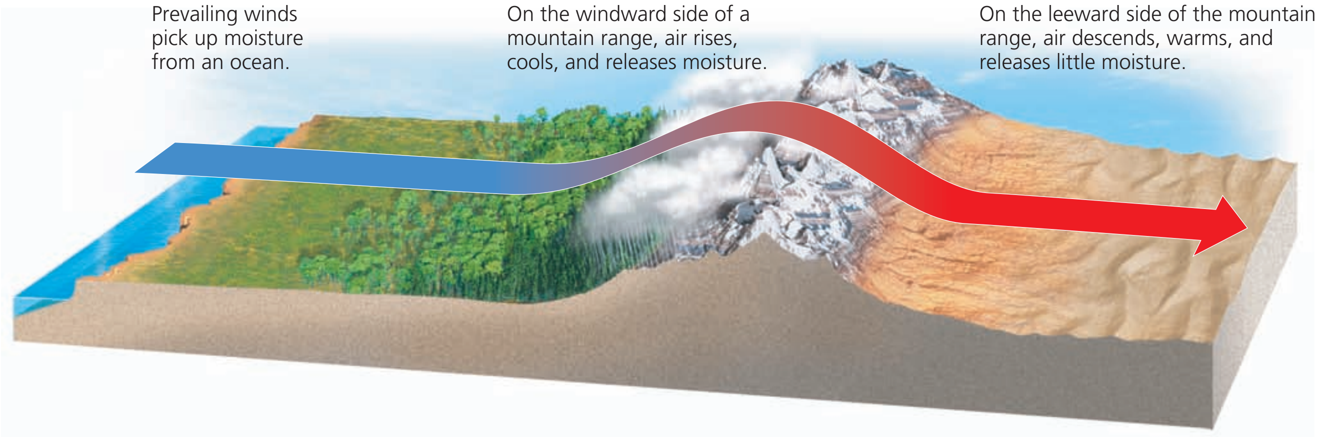


Figure 7-7 The *rain shadow effect* is a reduction of rainfall and loss of moisture from the landscape on the side of mountains facing away from prevailing surface winds. Warm, moist air in onshore winds loses most of its moisture as rain and snow on the windward slopes of a mountain range. This leads 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.

then loses most of its moisture as rain and snow on the windward slope of the mountain (the side from which the wind is blowing).

As the drier air mass passes over the mountaintops it flows down the leeward (away from the wind) slopes, warms up (which increases its ability to hold moisture), and sucks up moisture from the plants and soil below. The loss of moisture from the landscape and the resulting semiarid or arid conditions on the leeward side of high mountains create the **rain shadow effect** (Figure 7-7). Sometimes this leads to the formation of deserts such as Death Valley in the United States, which is 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 climate control systems of buildings release large quantities of heat and pollutants. As a result, cities tend to have more haze and smog, higher temperatures, and lower wind speeds than the surrounding countryside.

RESEARCH FRONTIER

Modeling and other research to learn more about how human activities affect climate. See **www.cengage.com/biology/miller**.

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.

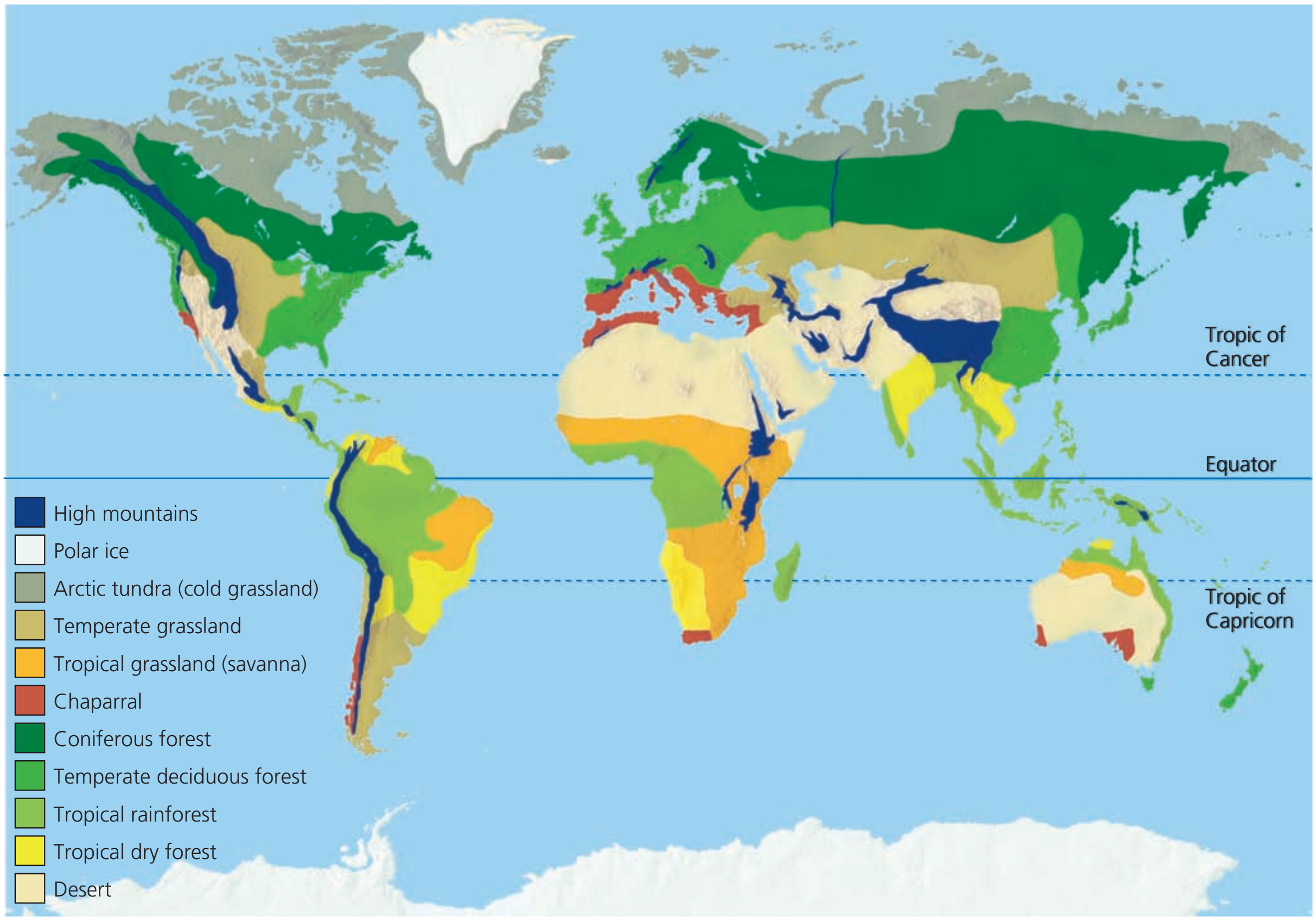
Climate Helps to Determine Where Organisms Can Live

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 and why global air circulation (Figure 7-3) accounts for different types of deserts, grasslands, and forests (**Core Case Study**). CORE CASE STUDY

Figure 7-8 (p. 128) shows how scientists have divided the world's land into several major **biomes**—large terrestrial regions, each characterized by certain types of climate and dominant plant life (**Concept 7-2**).

By comparing Figure 7-8 with Figure 7-2, you can see how the world's major biomes vary with climate. Figure 4-4 (p. 63) 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 7-8, biomes are shown with sharp boundaries, each being covered with one general type of vegetation. In reality, *biomes are not uniform*. They consist of a *mosaic of patches*, each



CENGAGENOW™ **Active Figure 7-8** **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. Human activities have removed or altered much of the natural vegetation in some areas for farming, livestock grazing, lumber and fuelwood, mining, and construction of towns and cities. (See Figure 3, p. S18, in Supplement 4.) *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?

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 7-9 shows how climate and vegetation vary with *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 one of the earth's polar regions. For example, if you hike up a tall Andes mountain in Ecuador, your trek can begin in tropical rain forest and end up on a glacier at the summit.

THINKING ABOUT
Biomes, Climate, and Human Activities

Use Figure 7-2 to determine the general type of climate where you live and Figure 7-8 to determine the general type of biome that should exist where you live. Then use Figure 3, p. S18, in Supplement 4 to determine how human ecological footprints have affected the general type of biome where you live.

Differences in climate, mostly from 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 7-10, and **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, 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.

A combination of low rainfall and different average temperatures creates tropical, temperate, and cold deserts (Figures 7-10 and 7-11, p. 130, **Concept 7-2**, and **Core Case Study**).

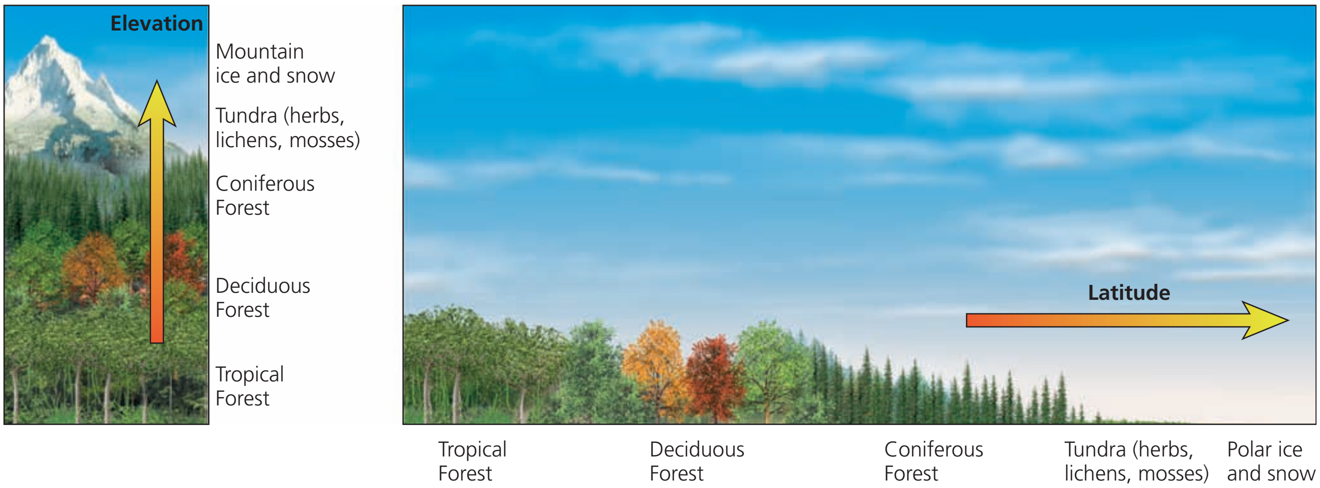


Figure 7-9 Generalized effects of elevation (left) and latitude (right) on climate and biomes. Parallel changes in vegetation type occur when we travel from the equator to the poles or from lowlands to mountaintops. **Question**: How might the components of the left diagram change as the earth warms during this century? Explain.

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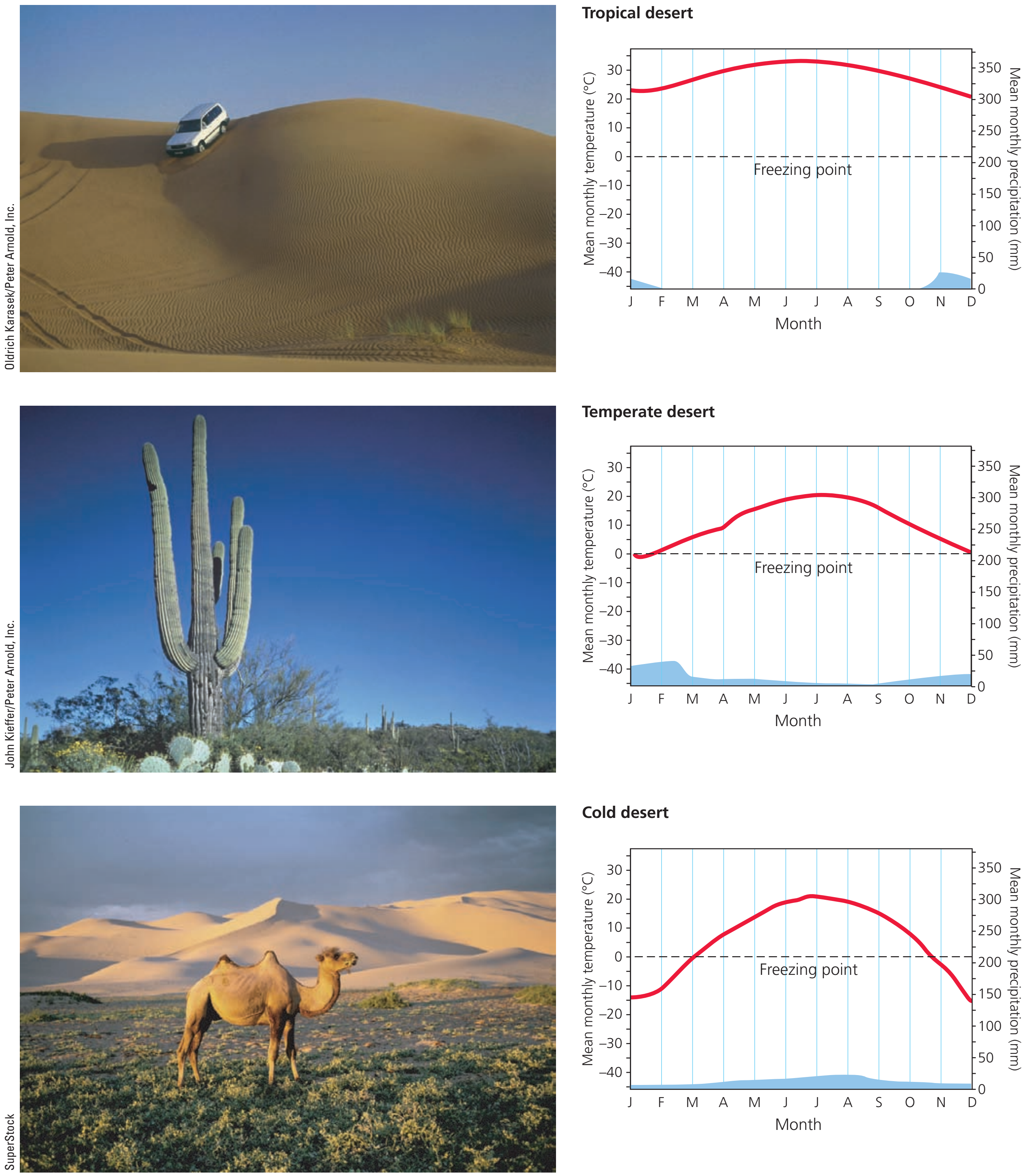

Figure 7-11 Climate graphs showing typical variations in annual temperature (red) and precipitation (blue) in tropical, temperate, and cold deserts. Top photo: *tropical desert* in the United Arab Emirates, in which a sport utility vehicle (SUV) participates in a popular (but ecologically destructive) SUV rodeo. Center photo: *temperate desert* in the U.S. state of Arizona, with saguaro cactus, a prominent species in this ecosystem. Bottom photo: Mongolia's Gobi Desert, a *cold 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 7-11, 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 to take up carbon dioxide (CO_2) only at night. 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 tissue.

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 wildflowers that last for a few weeks.

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. The camel is also covered with dense hair and does not sweat, which reduces heat gain and 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 and Gila monsters 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 things you would do to survive in the open desert?

Tropical deserts (Figure 7-11, top photo) such as the Sahara and Namib of Africa are hot and dry most of the year (Figure 7-11, 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 7-11, center photo) such as the Mojave Desert in the southern part of the U.S. state of California, daytime temperatures are high in summer and low in winter and there is more precipitation than in tropical deserts (Figure 7-11, 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.

In *cold deserts* such as the Gobi Desert in Mongolia, vegetation is sparse (Figure 7-11, bottom photo). Winters are cold, summers are warm or hot, and precipitation is low (Figure 7-11, bottom graph). Desert plants and animals have adaptations that help them stay cool and get enough water to survive (Science Focus, above).

Desert ecosystems are fragile. Their soils take decades to hundreds of years to recover from disturbances such as off-road vehicle traffic (Figure 7-11, 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.

There Are Three Major Types of Grasslands

Grasslands occur mostly in the interiors of continents in areas too moist for deserts and too dry for forests (Figure 7-8). Grasslands persist because of a combination of seasonal drought, grazing by large herbivores, and occasional fires—all of which keep large numbers of shrubs and trees from growing.

The three main types of grassland—tropical, temperate, and cold (arctic tundra)—result from combinations of low average precipitation with various average temperatures (Figure 7-10, Figure 7-12, p. 132, **Concept 7-2**, and **Core Case Study**).

CORE CASE STUDY

One type of tropical grassland, called a *savanna,* contains widely scattered clumps of trees such as acacia (Figure 7-12, 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 7-12, top graph).

Tropical savannas in East Africa are home to *grazing* (grass- and herb-eating) and *browsing* (twig- and leaf-nibbling) hoofed animals, including wildebeests (Figure 7-12, top photo), gazelles, zebras, giraffes, and antelopes and their predators such as lions, hyenas, and humans. Herds of these animals migrate to find water and food in response to seasonal and year-to-year variations in rainfall (Figure 7-12, 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

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. 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.

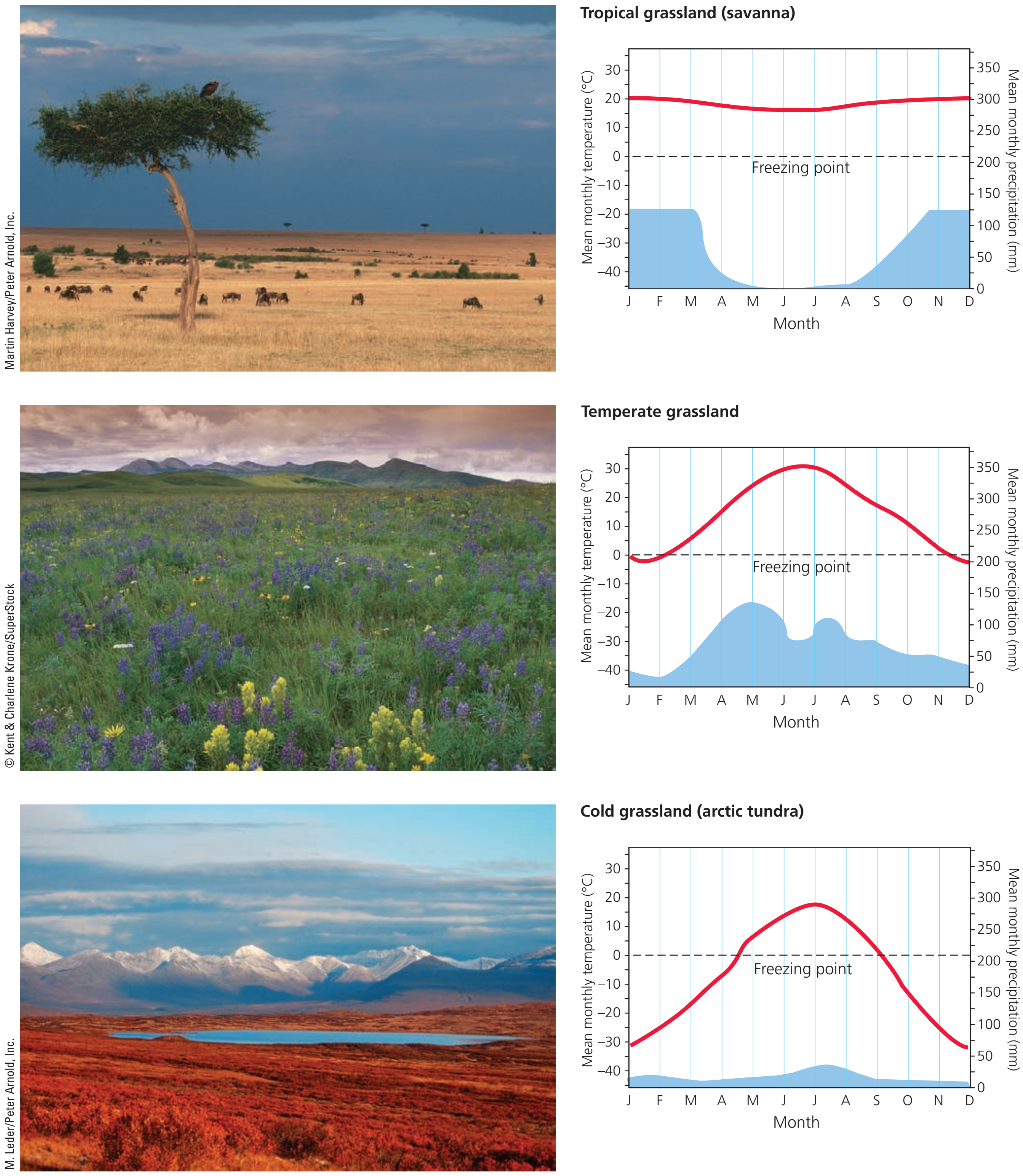

Figure 7-12 Climate graphs showing typical variations in annual temperature (red) and precipitation (blue) in tropical, temperate, and cold (arctic tundra) grassland. Top photo: *savanna* (*tropical grassland*) in Maasai Mara National Park in Kenya, Africa, with wildebeests grazing. Center photo: *prairie* (*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 near the Alaska Range, Alaska (USA). **Question**: What month of the year has the highest temperature and the lowest rainfall for each of the three types of grassland?

In a *temperate grassland*, winters can be bitterly cold, summers are hot and dry, and annual precipitation is fairly sparse and falls unevenly through the year (Figure 7-12, center graph). Because the aboveground parts of most of the grasses die and decompose each year, organic matter accumulates to produce a deep, fertile soil. This soil is held in place by a thick network of intertwined roots of drought-tolerant grasses (unless the topsoil is plowed up, which exposes it to be 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 7-12, center photo) and *tall-grass prairies* (which get more rain) of the midwestern and western United States and Canada. Many of the world's natural temperate grasslands have been converted to farmland, because their fertile soils are useful for growing crops (Figure 7-13) and grazing cattle.

Cold grasslands, or *arctic tundra* (Russian for "marshy plain"), lie south of the arctic polar ice cap (Figure 7-8). During most of the year, these treeless plains are bitterly cold (Figure 7-12, bottom graph), swept by frigid winds, and covered with ice and snow. Winters are long and dark, and scant precipitation falls mostly as snow.

Under the snow, this biome is carpeted with a thick, spongy mat of low-growing plants, primarily grasses, mosses, lichens, and dwarf shrubs (Figure 7-12, 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. Figure 7-14 (p. 134) shows some components and food-web interactions in an arctic tundra ecosystem.

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Figure 7-13 **Natural capital degradation:** 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.

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 soaking 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. 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.

An increase in the average temperature over the Arctic is causing some of the permafrost in parts of Canada, Alaska, China, Russia, and Mongolia to melt. This disrupts these ecosystems and releases methane (CH_4) and carbon dioxide (CO_2) from the soil into the atmosphere. These two greenhouse gases can warm the atmosphere more and cause more permafrost to melt, which could lead to further warming and climate change, a destructive cycle that could be repeated again and again. The melting permafrost also causes the soil to sink (subside), which can damage buildings, roads, power lines, and other human structures.

Tundra is a fragile biome. Most tundra soils formed about 17,000 years ago when glaciers began retreating after the last Ice Age (Figure 4-7, p. 67). 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 7-9, 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.

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 and boreal)—result from combinations of

Figure 7-14 Some components and interactions in an *arctic tundra (cold grassland) ecosystem*. When these organisms die, decomposers break down their organic matter into minerals that plants 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**: What species might increase and what species might decrease in population size if the arctic fox were eliminated from this ecosystem?

varying precipitation levels and average temperatures (Figures 7-10 and 7-15, **Concept 7-2**, and **Core Case Study**).

Tropical rain forests (Figure 7-15, top photo) are found near the equator (Figure 7-8), where hot, moisture-laden air rises and dumps its moisture (Figure 7-6). These lush forests have year-round, uniformly warm temperatures, high humidity, and heavy rainfall almost daily (Figure 7-15, top graph). This fairly constant warm and wet climate is ideal for a wide variety of plants and animals.

Figure 7-16 (p. 136) 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 7-15, top photo), which blocks most light from reaching the forest floor, illuminating it with a dim greenish light. 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 in 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 lianas can pull down other trees.

Tropical rain forests have a very high net primary productivity (Figure 3-11, p. 48). They are teeming with life and boast 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.

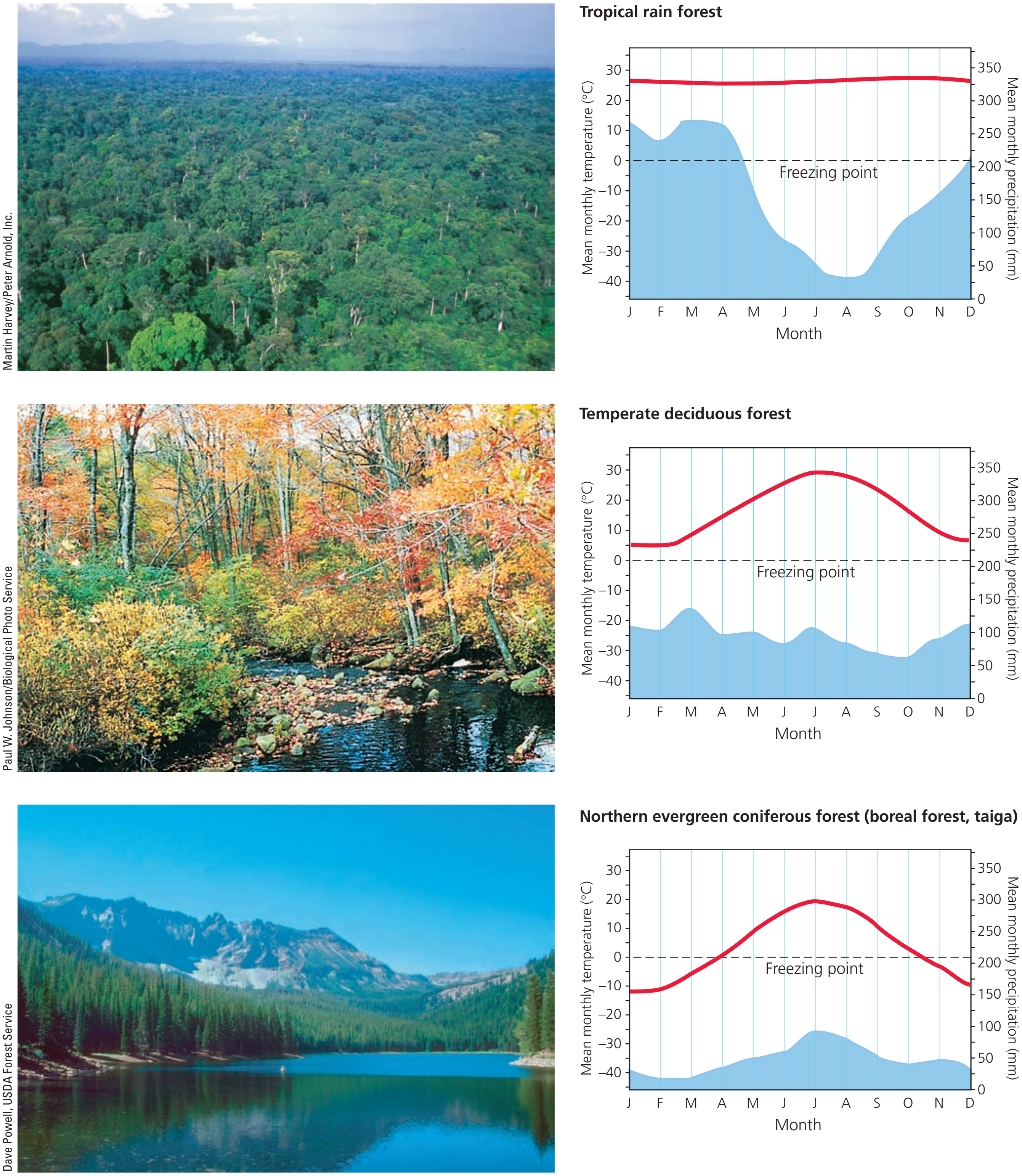


Figure 7-15 Climate graphs showing typical variations in annual temperature (red) and precipitation (blue) in tropical, temperate, and cold (northern coniferous and boreal) forests. Top photo: the closed canopy of a *tropical rain forest* in the western Congo Basin of Gabon, Africa. Middle photo: a *temperate deciduous forest* in the U.S. state of Rhode Island during the fall. (Figure 7-1 in the **Core Case Study** shows this same area of forest during winter.) Bottom photo: a *northern coniferous forest* in the Malheur National Forest and Strawberry Mountain Wilderness in the U.S. state of Oregon. **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 7-16** Some 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. **Question**: What species might increase in numbers and what species might decrease if all tree frog species were eliminated from this ecosystem?

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 helps to enable the great biodiversity (high species richness). For example, vegetation layers are structured mostly according to the plants' needs for sunlight, as shown in Figure 7-17. 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, use tall construction cranes, 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 soil 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. This 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 and the pace

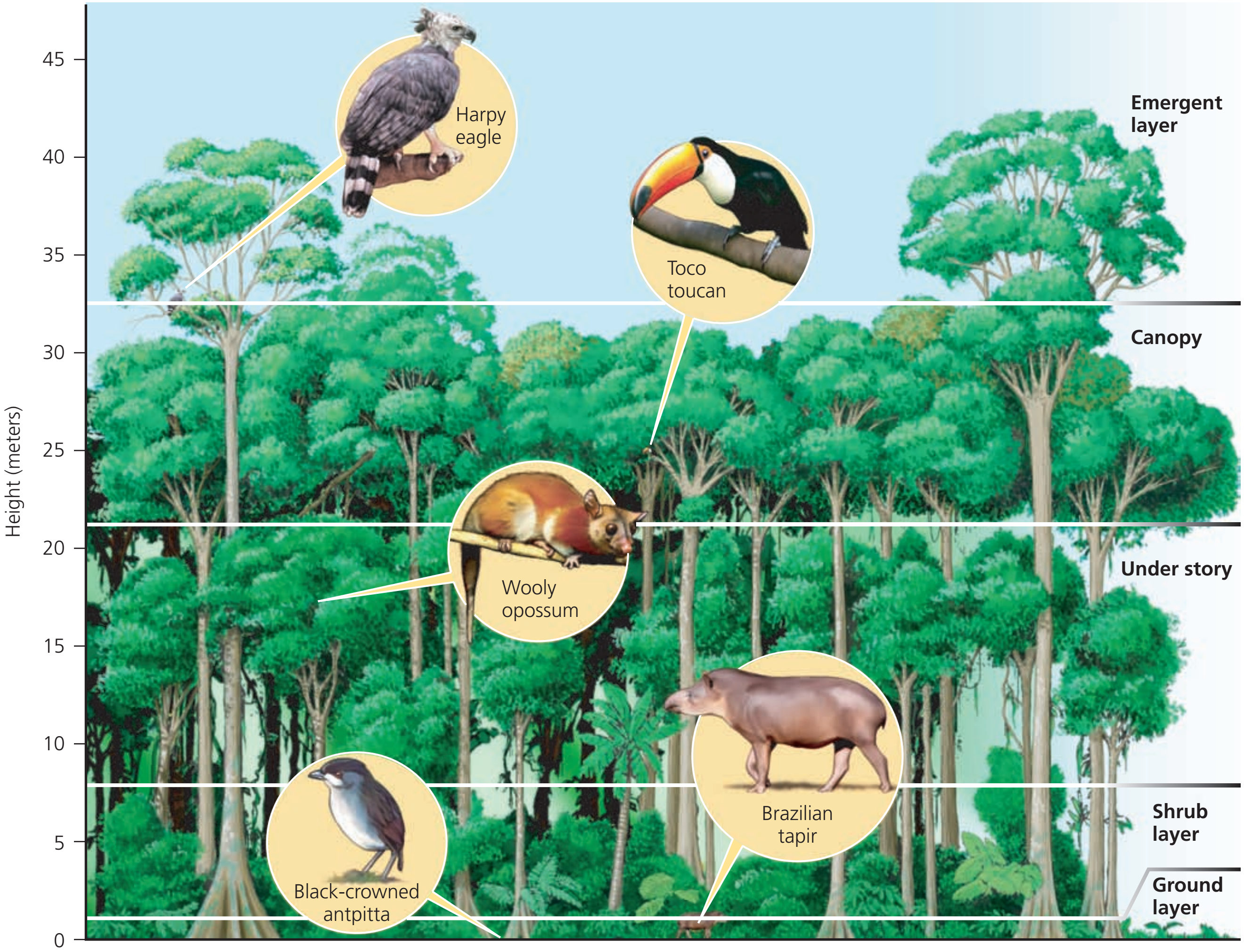


Figure 7-17 Stratification of specialized plant and animal niches in a *tropical rain forest*. Filling such specialized niches enables species to avoid or minimize competition for resources and results in the coexistence of a great variety of species.

of this destruction and degradation is increasing (see Chapter 3 Core Case Study, p. 39). Ecologists warn that without strong protective measures, most of these forests, along with their rich biodiversity and other invaluable ecological services, will probably be gone within your lifetime. (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 life and lifestyle? What are two things you could do to help reduce this loss?

Temperate deciduous forests such as the one shown in Figure 7-1 (**Core Case Study**) and Figure 7-15, center photo, grow in areas with moderate average temperatures that change significantly with the season. These areas have long, warm summers, cold but not too severe winters, and abundant precipitation, often spread fairly evenly throughout the year (Figure 7-15, center graph).

CORE CASE STUDY

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 throughout the winter, as shown in Figure 7-1 (**Core Case Study**). Each spring they grow new leaves whose colors change in the fall into an array of reds and golds (Figure 7-15, center photo) before the leaves drop.

CORE CASE STUDY

Because of a slow rate of decomposition, these forests 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. Can you explain why?

Evergreen coniferous forests (Figure 7-15, 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 7-8) 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 7-15, 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 narrow-pointed leaves (needles) year-round (Figure 7-15, bottom photo). The small, needle-shaped, waxy-coated leaves of these trees 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 soil acidic and prevent most other plants (except certain shrubs) from growing on the forest floor.

These biomes contain 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 7-12, bottom). During the brief summer, warblers and other insect-eating birds feed on hordes of flies, mosquitoes, and caterpillars.

Mountains Play Important Ecological Roles

Some of the world's most spectacular environments are high on *mountains* (Figure 7-18), steep or high lands which cover about one-fourth of the earth's land surface (Figure 7-8). Mountains are places where dramatic changes in altitude, slope, climate, soil, and vegetation take place over a very short distance (Figure 7-9, left).

About 1.2 billion people (18% of the world's population) live in mountain ranges or their foothills, and 4 billion people (59% 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 human activities such as timber cutting and agriculture. Many freestanding mountains are *islands of biodiversity* surrounded by a sea of lower-elevation landscapes transformed by human activities.

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.

GOOD NEWS

Figure 7-18 Mountains such as these in Mount Rainier National Park in the U.S. state of Washington play important ecological roles.

CONNECTIONS

Mountains and Climate

Mountains help to regulate the earth's climate. Mountaintops covered with ice and snow reflect some solar radiation back into space, which helps to cool the earth and offset global warming. However, many of the world's mountain glaciers are melting, mostly because of global warming. While glaciers reflect solar energy, the darker rocks exposed by melting glaciers absorb that energy. This helps to warm the atmosphere, which melts more glaciers—in an escalating cycle of change.

Finally, mountains play a critical role in the hydrologic cycle by serving as major storehouses of water. In the warmer weather of spring and summer, much of their snow and ice melts and is released to streams for use by wildlife and by humans for drinking and irrigating crops. As the earth warms, mountaintop snow packs and glaciers melt earlier in the spring each year. This can lower food production in certain areas, because water needed during the summer to irrigate crops has already been released.

Some scientists are projecting the disappearance of most of the world's mountaintop glaciers during this century as a result of projected climate change. 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 3, p. S18, in Supplement 4, and **Concept 1-2**, p. 9.) Figure 7-19 summarizes some of the human impacts on the world's deserts, grasslands, forests, and mountains (**Concept 7-3**).

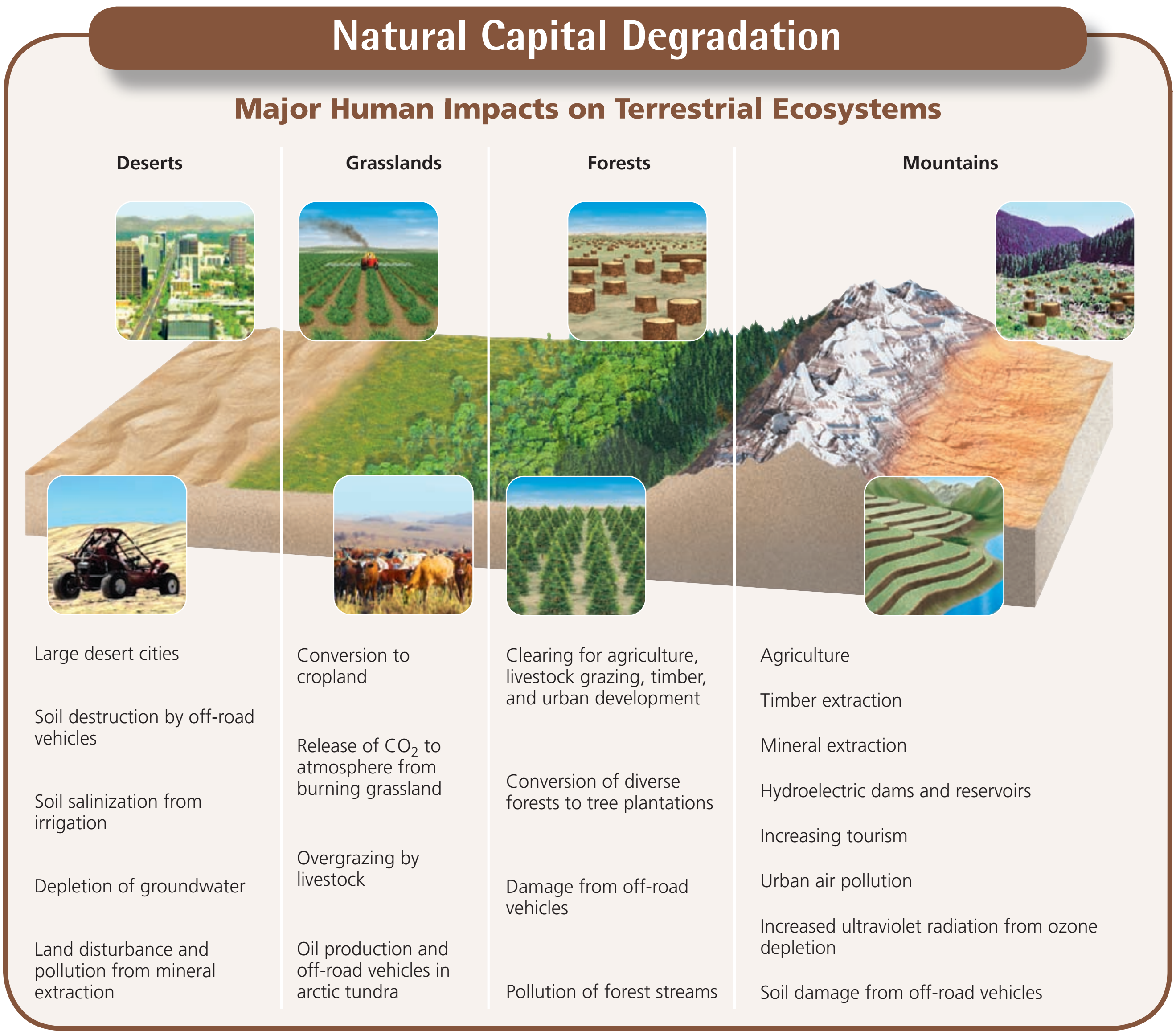


Figure 7-19 Major human impacts on the world's deserts, grasslands, forests, and mountains (**Concept 7-3**). **Question**: For each of these biomes, which two of the impacts listed do you think are the most harmful?

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.

This will require protecting the world's remaining wild areas from development. In addition, many of the land areas we have degraded need to be restored. 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 9.

RESEARCH FRONTIER

Better understanding of the effects of human activities on terrestrial biomes and how we can reduce these impacts. See **www.cengage.com/biology/miller**.

7-4 What Are the Major Types of Aquatic Systems?

▶ **CONCEPT 7-4 Saltwater and freshwater aquatic life zones cover almost three-fourths of the earth's surface, and oceans dominate the planet.**

Most of the Earth Is Covered with Water

As shown in Figure 7-20, about 71% of the earth's surface is covered with salty ocean 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.

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: *saltwater*, or *marine* (oceans and their accompanying estuaries, coastal wetlands, shorelines, coral reefs, and mangrove forests), and *freshwater* (lakes, rivers, streams, and inland wetlands).

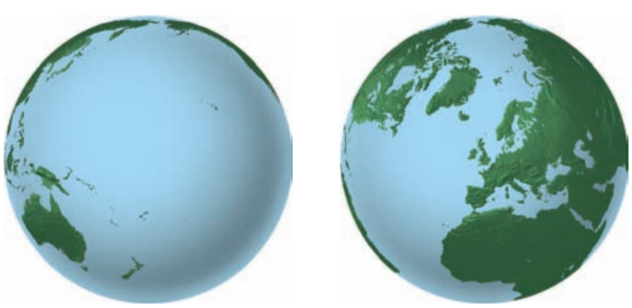


Figure 7-20 *The ocean planet.* The salty oceans cover 71% of the earth's surface and contain 97% of the earth's water. Almost all of the earth's water is in the interconnected oceans, which cover 90% of the planet's mostly ocean hemisphere (left) and half of its land–ocean hemisphere (right). Freshwater systems cover less than 2.2% of the earth's surface (**Concept 7-4**).

Bodies of Water Contain Great Biodiversity

Saltwater and freshwater life zones contain several major types of organisms. One major type consists of weakly swimming, free-floating *plankton*, which can be divided into three groups. The first group is *phytoplankton* ("FY-toe-plank-ton," see bottom of Figure 3-9, p. 46), which includes many types of algae. They and various rooted plants near shorelines are primary producers that support most aquatic food webs.

The second plankton group is *zooplankton* ("ZOH-uh-plank-ton," see bottom of Figure 3-9, p. 46). They consist of primary consumers (herbivores) that feed on phytoplankton and secondary consumers that feed on other zooplankton. A third group consists of huge populations of much smaller plankton called *ultraplankton*—extremely small photosynthetic bacteria that may be responsible for 70% of the primary productivity near the ocean surface.

A second major type of aquatic organisms is *nekton*, strongly swimming consumers such as fish, turtles, and whales. A third type, *benthos*, consists of bottom dwellers such as oysters, which anchor themselves to one spot; clams and worms, which burrow into the bottom; 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 can be used by aquatic primary producers.

Most forms of aquatic life are found in the *surface*, *middle*, and *bottom* layers of saltwater and freshwater systems. 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*.

In deep aquatic systems, photosynthesis is largely confined to the upper layer—the *euphotic* or *photic* zone, through which sunlight can penetrate. 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, nutrients are often in short supply, and this limits net primary productivity (Figure 3-11, p. 48).

7-5 Why Are the World's Oceans Important and How Have We Affected Them?

CONCEPT 7-5 Saltwater ecosystems provide major ecological and economic services that are being threatened by human activities.

Oceans Provide Important Ecological and Economic Resources

The world's salty marine systems provide many valuable ecological and economic services (Figure 7-21). GOOD NEWS

Marine aquatic systems are huge reservoirs of biodiversity. Marine life is found in three major *life zones*: the coastal zone, open sea, and ocean bottom (Figure 7-22, p. 142).

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 wetlands, mangrove forests, and coral reefs have a high net primary productivity (NPP) per unit of area (Figure 3-11, p. 48). 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.

Estuaries and Coastal Wetlands Are Highly Productive

Estuaries are where rivers meet the sea (Figure 7-23, p. 142). They are partially enclosed bodies of water where seawater mixes with freshwater as well as nutrients and pollutants from streams and runoff from the land.

Estuaries and their associated **coastal wetlands**—coastal land areas covered with water all or part of the year—include river mouths, inlets, bays, and salt marshes in temperate zones (Figure 7-24, p. 143), and **mangrove forests** in tropical zones (Figure 7-25, p. 143). 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 hitting the shallow waters.

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. 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. Despite their importance, we are degrading and destroying some of the important ecological services provided by these coastal aquatic systems.

Figure 7-21 Major ecological and economic services provided by marine systems (**Concept 7-5**). **Question**: Which two ecological services and which two economic services do you think are the most important? Why?

Figure 7-22 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 curve. **Question**: How is an ocean like a tropical rain forest? (*Hint:* see Figure 7-17.)

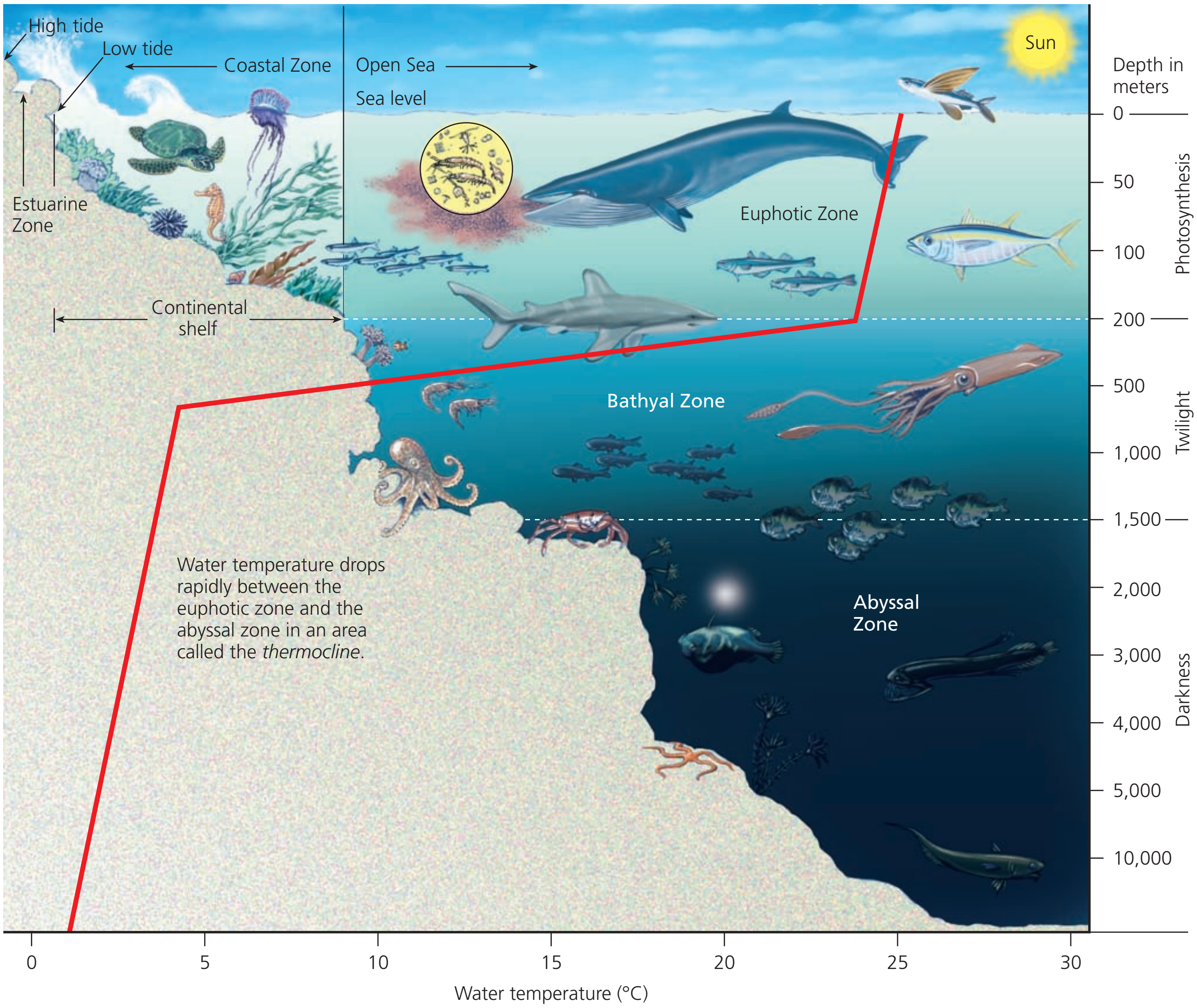


Figure 7-23 View of an *estuary* taken from space. The photo shows the sediment plume (turbidity caused by runoff) at the mouth of Madagascar's Betsiboka River as it flows through the estuary and into the Mozambique Channel. Because of its topography, heavy rainfall, and the clearing of forests for agriculture, Madagascar is the world's most eroded country.

Figure 7-24 A salt marsh in Peru.

Figure 7-25 Mangrove forest in Daintree National Park in Queensland, Australia. The mangrove trees in these coastal forests have extensive root systems that often extend above the water. This allows them to absorb oxygen and support the trees during periods of changing water levels.

■ **CASE STUDY**

Coral Reefs

Another important coastal ecosystem is a **coral reef**, which forms in clear, warm coastal waters of the tropics and subtropics (Figure 7-26). These highly productive ecosystems are dazzling centers of biodiversity.

Reefs form when massive colonies of tiny animals called *polyps*, which are close relatives of jellyfish, secrete a protective crust of limestone (calcium carbonate) around their soft bodies. When the polyps die, their empty crusts remain behind as part of a platform for more reef growth. The resulting elaborate network of crevices, ledges, and holes serves as "condominiums" for a variety of marine animals.

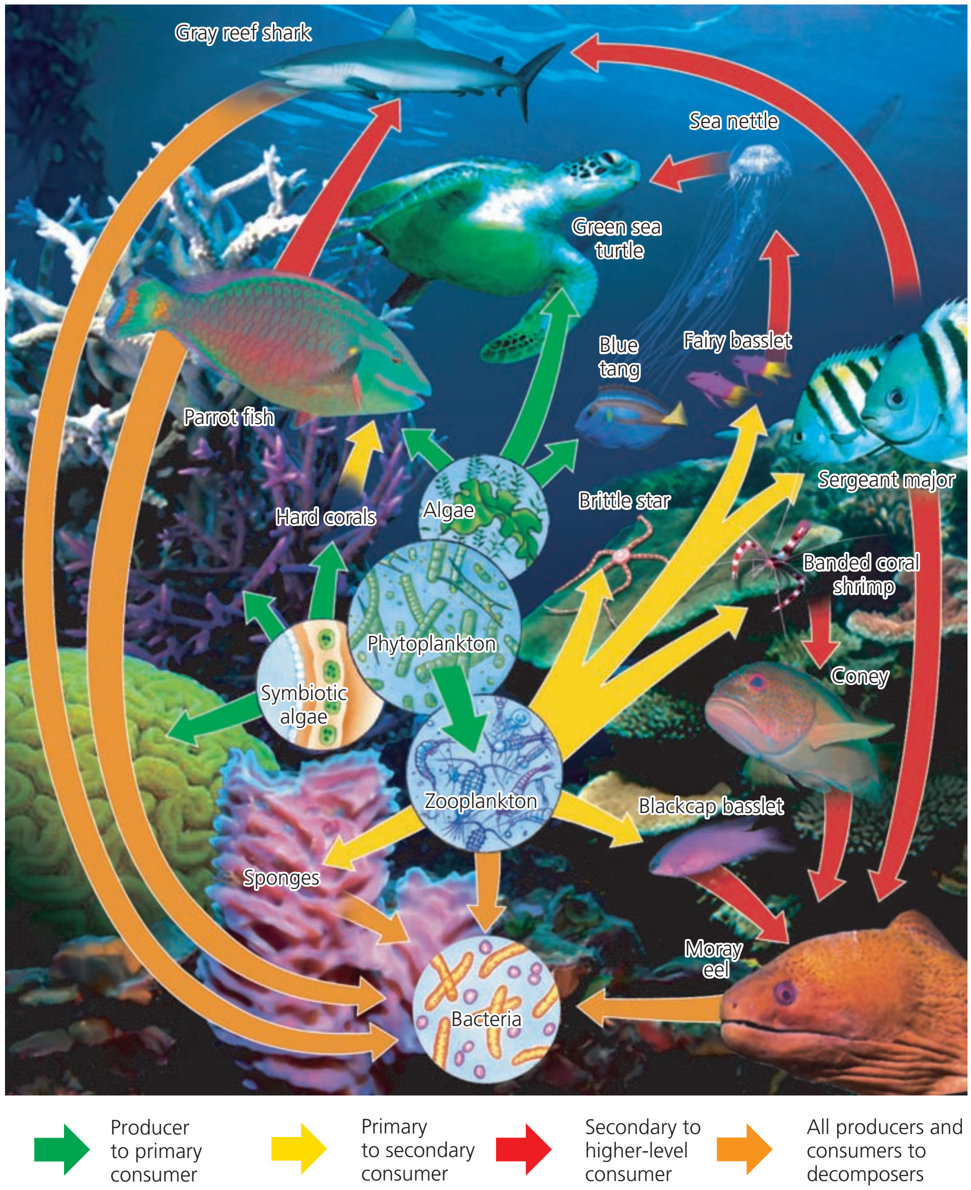
Coral reefs are the result of a mutually beneficial relationship between the polyps and tiny, single-celled algae called *zooxanthellae* ("zoh-ZAN-thel-ee") that live in the tissues of the polyps. The algae provide the polyps with food and oxygen through photosynthesis and also give the reefs their stunning coloration. The polyps, in turn, provide the algae with a home and some of their nutrients. Figure 7-27 (p. 144) shows some components and interactions in a coral reef ecosystem.

Although coral reefs occupy only about 0.2% of the ocean floor, they provide important ecological and economic services. They help moderate atmospheric temperatures by removing CO_2 from the atmosphere, and they act as natural barriers that help to protect 15% of the world's coastlines from erosion caused by battering waves and storms. And they provide habitats for one-quarter of all marine organisms. GOOD NEWS

Economically, coral reefs produce about one-tenth of the global fish catch—one-fourth of the catch in developing countries—and they provide jobs and building materials for some of the world's poorest countries. Coral reefs also support important fishing and tourism industries. Each year, more than 1 million scuba divers

Figure 7-26 Coral reef in the Red Sea.

Figure 7-27 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. **Question**: How would the species in this ecosystem be affected if phytoplankton populations suffered a sharp drop?



and snorkelers visit coral reefs to experience these wonders of aquatic biodiversity.

Coral reefs are vulnerable to damage because they grow slowly and are disrupted easily. They also thrive only in clear and fairly shallow water of constant high salinity. This water must have a temperature of 18–30 °C (64–86 °F). If the atmosphere warms as projected during this century, this could raise the water temperature in some areas above this limit and threaten many reefs. Also, increasing levels of CO_2 in the atmosphere and ocean are raising the acidity of ocean water, which makes it harder for polyps to create calcium carbonate, the material from which reefs are built.

According to a 2005 report by the World Conservation Union, 15% of the world's coral reefs have been destroyed and another 20% have been damaged by coastal development, pollution, overfishing, warmer ocean temperatures, increasing ocean acidity, and other stresses. And another 25–33% of these centers of aquatic biodiversity could be lost within 20–40 years.

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 on the basis of the penetration of sunlight, this deep blue sea is divided into three *vertical zones* (see Figure 7-22). But temperatures also change with depth and can be used to define zones that help to determine species diversity in these layers (Figure 7-22, red curve).

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**). Large, fast-swimming predatory fishes such as swordfish, sharks, and bluefin tuna populate this zone.

The *bathyal zone* is the middle zone, which gets little sunlight and therefore does not contain photosynthesizing producers. Zooplankton and smaller fishes, many of which move to the surface at night to feed, live here.

The lowest zone, called the *abyssal zone*, is dark and very cold; it 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, even though there is no sunlight to support photosynthesis. 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.

Average primary productivity and NPP per unit of area are quite low in the open sea except at an occasional equatorial upwelling, where currents bring up nutrients from the ocean bottom (Figure 7-2). However, because the open sea covers so much of the earth's surface, it makes the largest contribution to the earth's overall net primary productivity.

RESEARCH FRONTIER

Discovering, cataloging, and studying the huge number of unknown aquatic species and their interactions. See **www.cengage.com/biology/miller**.

CENGAGE**NOW**™ Learn about ocean provinces where all ocean life exists at CengageNOW.

Human Activities Are Disrupting and Degrading Marine Ecosystems

In their desire to live near a coast, people are destroying or degrading the aquatic biodiversity and the ecological and economic services (Figure 7-21) that make coastal areas so enjoyable and valuable (**Concept 7-5**). In 2009, 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 source pollution such as fertilizers, pesticides, and livestock wastes (see *The Habitable Planet*, Videos 7 and 8).
- Point source pollution such as sewage from passenger cruise ships and spills from oil tankers
- Overfishing, which depletes populations of commercial fish species
- Use of trawler fishing boats, which drag weighted nets across the ocean bottom and destroy habitats
- Invasive species, introduced by humans, that can deplete populations of native aquatic species and cause economic damage
- Increased emissions of carbon dioxide into the atmosphere, which are increasing the average temperature of the atmosphere along with the temperature and acidity of the oceans. If these effects increase as projected, this could cause a rise in sea levels that could destroy coral reefs and flood coastal marshes and coastal cities (see *The Habitable Planet,* Videos 7 and 8).

Figure 7-28 shows some of the effects of such human impacts on marine systems (left) and coral reefs (right) which we discuss further in Chapter 9.

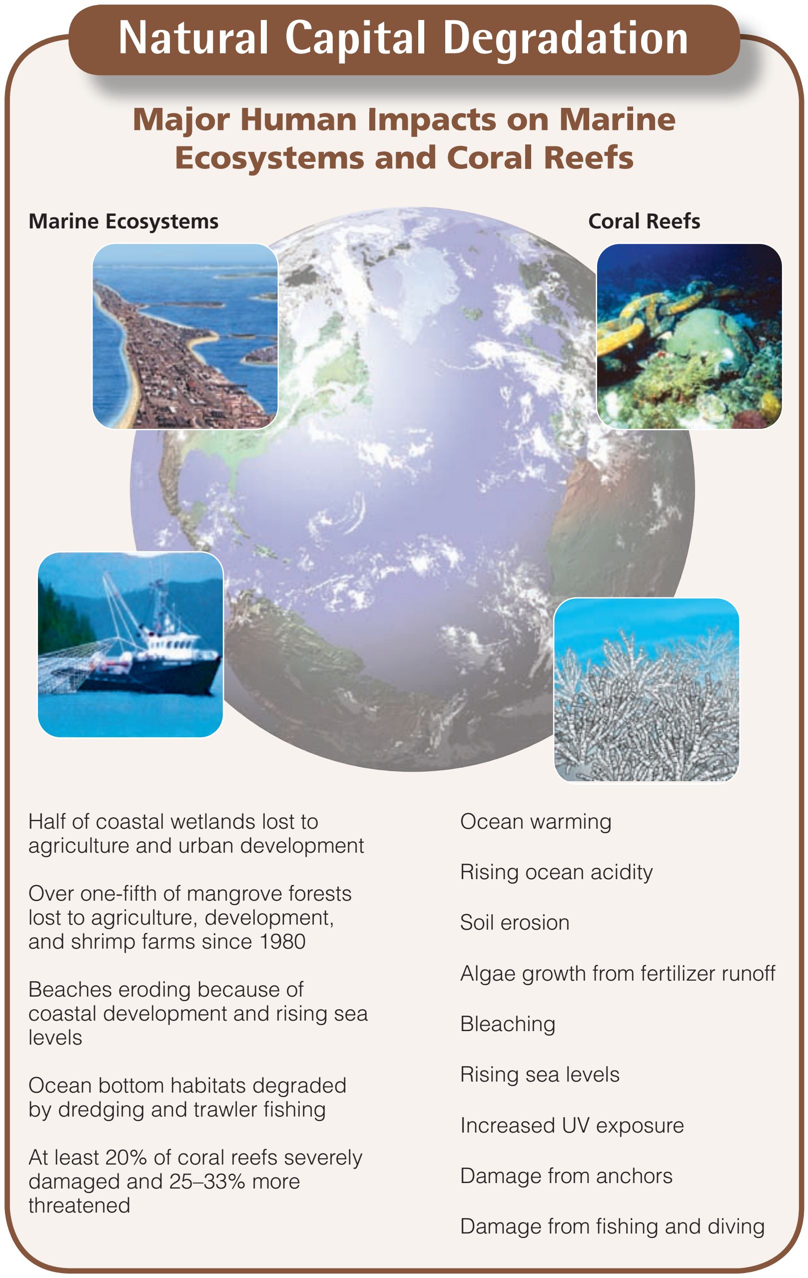


Figure 7-28 Major threats to marine ecosystems (left) and particularly coral reefs (right) resulting primarily or at least partially from human activities (**Concept 7-5**). **Questions**: Which two of the threats to marine ecosystems do you think are the most serious? Why? Which two of the threats to 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? 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/biology/miller**.

7-6 What Are the Major Types of Freshwater Systems and How Have We Affected Them?

▶ **CONCEPT 7-6 Freshwater lakes, rivers, and wetlands provide important ecological and economic services that are being disrupted by human activities.**

Water Stands in Some Freshwater Systems and Flows in Others

Freshwater life zones include *standing* bodies of freshwater such as lakes, ponds, and inland wetlands, and *flowing* systems such as streams 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 7-29).

Natural Capital

Freshwater Systems

Ecological Services	**Economic Services**
Climate moderation	Food
Nutrient cycling	Drinking water
Waste treatment	Irrigation water
Flood control	Hydroelectricity
Groundwater recharge	Transportation corridors
Habitats for many species	Recreation
Genetic resources and biodiversity	Employment
Scientific information	

Figure 7-29 Major ecological and economic services provided by freshwater systems (**Concept 7-6**). **Question**: Which two ecological services and which two economic services do you think are the most important? Why?

Lakes are large natural bodies of standing freshwater formed when precipitation, runoff, streams and rivers, and groundwater seepage fill depressions in the earth's surface. 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).

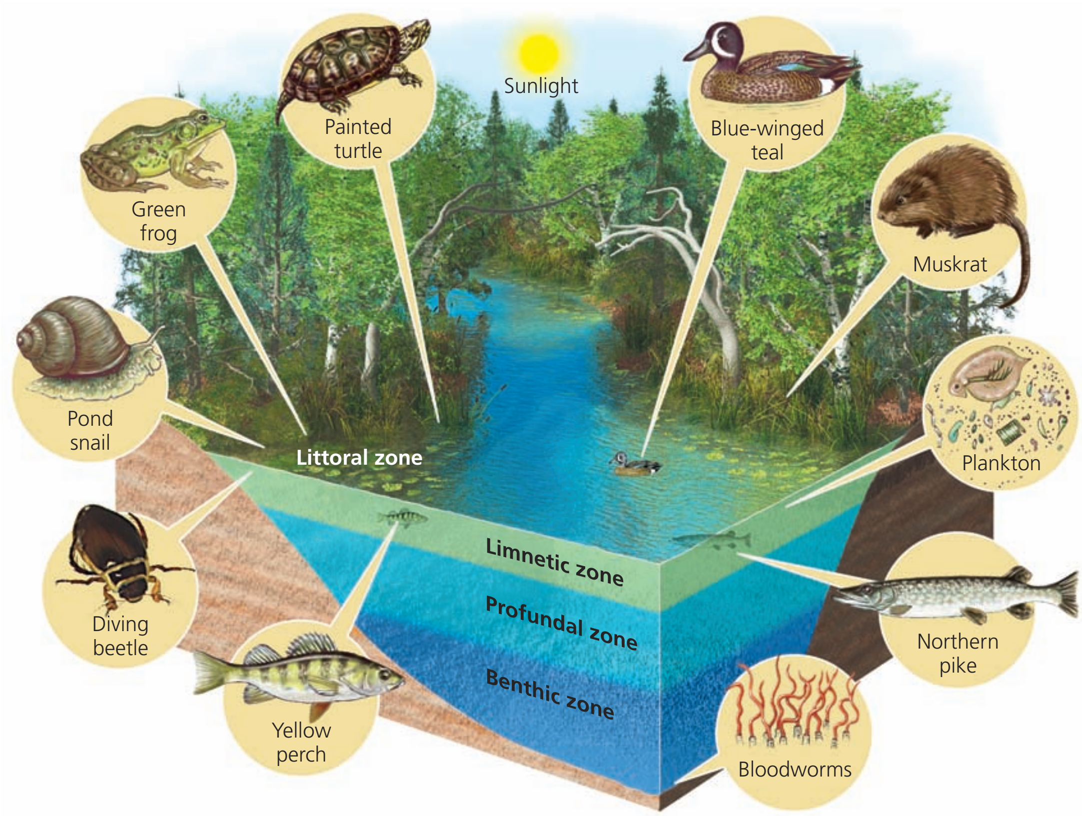
Freshwater lakes vary in size, depth, and nutrient content. Deep lakes normally consist of four distinct zones that are defined by their depth and distance from shore (Figure 7-30).

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 7-31, 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 fishes (such as smallmouth 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 7-31, 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 **cultural eutrophication**. Many lakes fall somewhere between the two extremes of nutrient enrichment. They are called **mesotrophic lakes**.

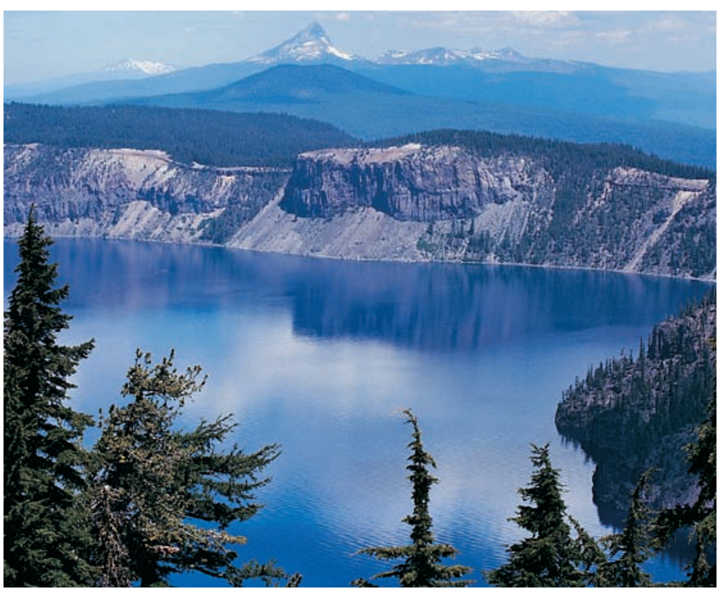


CENGAGENOW™ **Active Figure 7-30** Distinct zones of life in a fairly deep temperate zone lake. *See an animation based on this figure at* CengageNOW. **Question**: How are deep lakes like tropical rain forests? (*Hint:* See Figure 7-17)

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 join to form rivers, and rivers flow downhill to the ocean (Figure 7-32, p. 148).

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


Jack Carey


Bill Banaszewski/Visuals Unlimited

Figure 7-31 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 and cyanobacteria.

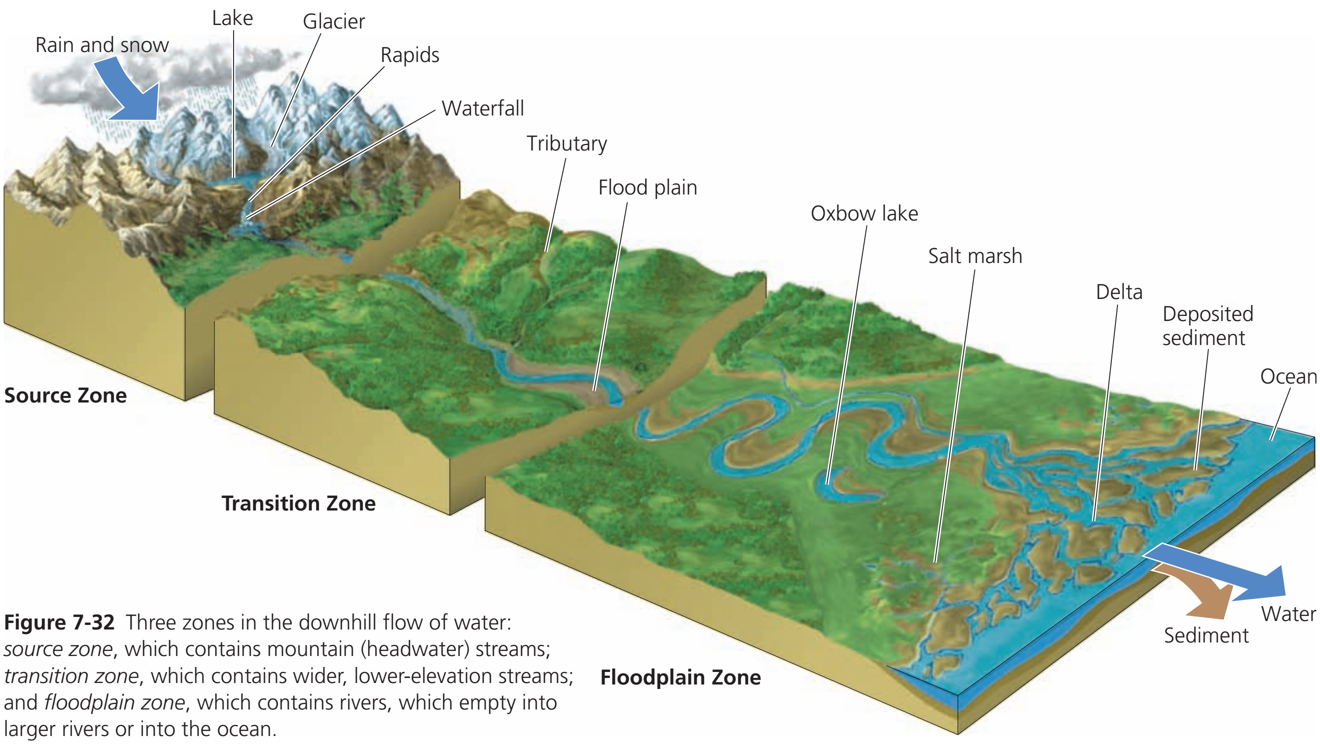


Figure 7-32 Three zones in the downhill flow of water: *source zone*, which contains mountain (headwater) streams; *transition zone*, which contains wider, lower-elevation streams; and *floodplain zone*, which contains rivers, which empty into larger rivers or into the ocean.

typically takes place in three aquatic life zones characterized by different environmental conditions: the *source zone*, the *transition zone*, and the *floodplain zone* (Figure 7-32). Rivers and streams can differ somewhat from this generalized model.

As streams flow downhill, they shape the land through which they pass. Over millions of years, the friction of moving water may level mountains and cut deep canyons, and rock and soil removed by the water are deposited as sediment in low-lying areas.

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.

Freshwater Inland Wetlands Are Vital Sponges

Inland wetlands are lands covered with freshwater all or part of the time (excluding lakes, reservoirs, and streams) and located away from coastal areas. They include *marshes* (dominated by grasses and reeds with few trees), *swamps* (dominated by trees and shrubs), and *prairie potholes* (depressions carved out by ancient glaciers). Other examples are *floodplains*, which receive excess water during heavy rains and floods, and the wet *arctic tundra* in summer. Some wetlands are huge; others are 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 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.

Inland wetlands provide a number of free ecological and economic services, which include:

GOOD NEWS

- 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 fish 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.

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 7-6**) in four major ways. *First*, dams and canals fragment about 40% of the world's 237 large rivers. They alter and destroy terrestrial and aquatic wildlife habitats along rivers and in coastal deltas and estuaries by reducing water flow and increasing damage from coastal storms. *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.

Third, cities and farmlands add pollutants and excess plant nutrients to nearby streams, rivers, and lakes. These nutrients often cause explosions in the populations of algae and cyanobacteria (Figure 7-31, right), which deplete the lake's dissolved oxygen. 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, forestry, oil and gas extraction, highways, 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 and drought damage in the United States—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/biology/miller**.

When we look further into human impacts on aquatic systems in Chapter 9, we also explore possible solutions to environmental problems that result from these impacts, as well as ways to sustain aquatic biodiversity.

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.
- Saltwater and freshwater aquatic systems cover almost three-fourths of the earth's surface, and oceans dominate the planet.
- The earth's terrestrial and aquatic systems provide important ecological and economic services, which are being degraded and disrupted by human activities.

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 terrestrial and the aquatic biodiversity found in the earth's biomes, oceans, lakes, rivers, and wetlands. 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 and aquatic 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 and aquatic life zones, 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.

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. 123. Describe how differences in climate lead to formation of tropical, temperate, and polar deserts, grasslands, and forests. Explain why a better name for Earth would be Water or Ocean.
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. Define **greenhouse gases** and the **natural greenhouse effect**. Why are they important to the earth's life and climate? What is the **rain shadow effect** and how does it lead to the formation of inland deserts? Why do cities tend to have more haze and smog, higher temperatures, and lower wind speeds than the surrounding countryside?
3. 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.
4. Describe how the three major types of deserts differ in their climate and vegetation. How do desert plants and animals survive? Describe how the three major types of grasslands differ in their climate and vegetation. What is **permafrost**? Describe how the three major types of forests differ in their climate and vegetation. What important ecological roles do mountains play?
5. Describe how human activities have affected the world's deserts, grasslands, forests, and mountains.
6. What percentage of the earth's surface is covered with water? What major ecological and economic services are provided by marine systems? Describe the major types of organisms found in aquatic life zones.
7. 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 have high net primary productivities. What is a **mangrove forest** and what major ecological services does it provide? What is a **coral reef**? How do they form and what major ecological and economic services do they provide? Why does the open sea have a low net primary productivity?
8. What human activities pose major threats to marine systems and to coral reefs?
9. What major ecological and economic services do freshwater systems provide? What is a **lake**? What four zones are found in most lakes? Distinguish among **oligotrophic**, **eutrophic**, and **mesotrophic lakes**. What is **cultural eutrophication**? Define **surface water**, **runoff**, and **watershed** (**drainage basin**). Describe the three zones that rivers pass through as they flow from mountains to the sea. Give three examples of **inland wetlands** and explain their ecological importance. What are four ways in which human activities are disrupting and degrading freshwater systems?
10. What are this chapter's *three big ideas*? Describe the connections between the climates, terrestrial and aquatic systems, and the three **principles of sustainability** (see back cover).

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

CRITICAL THINKING

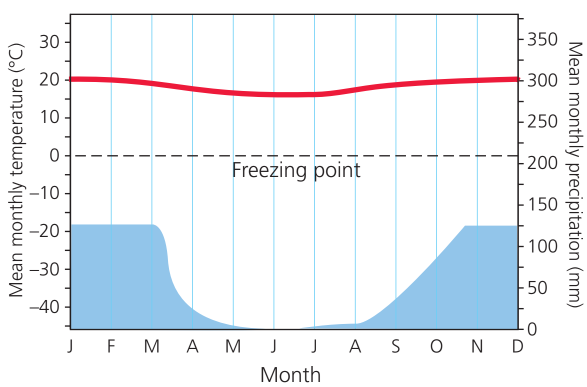
1. What would happen to the earth's terrestrial and aquatic species **(a)** if most of the world's oceans disappeared and **(b)** if most of the world's land disappeared?
2. Describe the roles of temperature and precipitation in determining what parts of the earth's land are covered with: **(a)** a desert, **(b)** arctic tundra, **(c)** temperate grassland, **(d)** a tropical rain forest, and **(e)** a temperate deciduous forest (**Core Case Study**).
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. Why do most species living at high latitudes and high altitudes tend to have generalist ecological niches while those living in the tropics tend to have specialist niches?
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 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 degradation of this biome?

7. You are a defense attorney arguing in court for sparing a tropical rain forest from being cut. Give your three most important arguments for the defense of this ecosystem.
8. You are a defense attorney arguing in court for protecting a coral reef from harmful human activities. Give your three most important 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 **(a)** terrestrial biodiversity and ecosystems services and **(b)** aquatic biodiversity and ecosystem services?
10. List two questions that you would like to have answered as a result of reading this chapter.

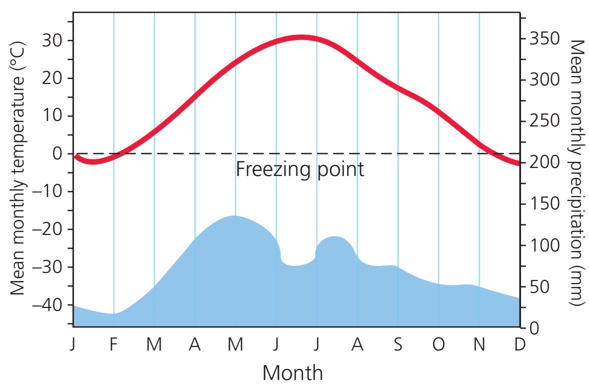
DATA ANALYSIS

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 midwestern United States.

Tropical grassland (savanna)



Temperate grassland



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.cengage.com/biology/miller** and choose Chapter 7 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, web links, information on Green Careers, and InfoTrac® College Edition articles.

CENGAGENOW™ For students with access, log on at **www.cengage.com/login** for the animations, active figures, activities, and readings indicated within the text by the CengageNOW logo. If your textbook did not come with access, visit **www.iChapters.com** to purchase.

8 Sustaining Biodiversity: The Species Approach

CORE CASE STUDY Polar Bears and Projected Climate Change

The world's 20,000–25,000 polar bears are found in 19 populations distributed across the frozen Arctic. About 60% of them are in Canada, and the rest are found in arctic areas in Denmark, Norway, Russia, and the U.S. state of Alaska.

Throughout the winter, the bears hunt for seals on floating sea ice (Figure 8-1) that expands southward each winter and contracts as the temperature rises each summer. Normally the bears swim from one patch of sea ice to another to hunt and eat seals during winter as their body fat accumulates. In the summer and fall, the animals fast and live off their body fat for several months until hunting resumes when the ice expands again each winter.

Evidence shows that the Arctic is warming twice as fast as the rest of the world is. As a result, the average annual area of floating sea ice in the Arctic is declining. And the winter ice is breaking up earlier each year, shortening the bears' hunting season.

The shrinkage of sea ice means that polar bears have less time to feed and store the fat they need to survive their summer and fall months of fasting. 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. And as bears grow hungrier, they are more likely to go to human settlements looking for food. The resulting increase in bear sightings has given people the false impression that their populations are growing.

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 prey is nearly impossible to find. According to a 2006 study by the IUCN–World Conservation Union, the world's total polar bear population is likely to decline by 30–35% by 2050, and by the end of this century, the bears might be found only in zoos.

Eventually all species become extinct or evolve into new species. The archeological record reveals at least three and perhaps five *mass extinctions* since life began—each leading to a dramatic impoverishment of life on the earth. These mass extinctions were caused by natural phenomena such as major climate change or large asteroids hitting the earth, which drastically altered the earth's environmental conditions. There is considerable evidence that we humans are causing a new mass extinction as our population grows and as we consume more resources and disturb more land and aquatic systems. Projected climate change enhanced by human activities could make such a mass extinction more likely.

Scientists project that during this century human activities, especially those that cause habitat loss and contribute to projected climate change, will lead to the premature extinction of one-fourth to one-half of the world's plant and animal species—at an incredibly rapid rate of extinction. Biologists warn that if we keep impoverishing the earth's biodiversity, eventually our species will also become impoverished.

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Figure 8-1 In recent years, the average atmospheric temperature above the Arctic has increased. This has melted some of the floating sea ice, which polar bears use to hunt seals. If this continues, polar bears could become extinct by the end of this century.

Key Questions and Concepts

8-1 **What role do humans play in the premature extinction of species?**

CONCEPT 8-1 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.

8-2 **Why should we care about preventing species extinction?**

CONCEPT 8-2 We should prevent the premature extinction of wild species because of the economic and ecological services they provide and because they have a right to exist regardless of their usefulness to us.

8-3 **How do humans accelerate species extinction?**

CONCEPT 8-3 The greatest threats to any species are (in order) loss or degradation of its habitat, harmful invasive species, human population growth, pollution, climate change, and overexploitation.

8-4 **How can we protect wild species from premature extinction?**

CONCEPT 8-4 We can reduce 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), 4 (p. S14), and 7 (p. S32), 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

8-1 What Role Do Humans Play in the Premature Extinction of Species?

CONCEPT 8-1 **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.**

Some Human Activities Cause Premature Extinctions at an Increasing Pace

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 species, especially those that play keystone and foundation roles (p. 74), can weaken or break some of the connections in the ecosystem where it once existed and thus can threaten or lessen ecosystem services. This can lead to extinctions of other species with strong connections to species that go extinct.

Although extinction is a natural biological process (p. 69), it has accelerated as human populations have spread over the globe, consuming large quantities of resources and creating large ecological footprints (Figure 1-5, p. 11, and Figure 3, p. S18, in Supplement 4). According to biodiversity expert Edward O. Wilson, "The natural world is everywhere disappearing before our eyes—cut to pieces, mowed down, plowed under, gobbled up, replaced by human artifacts." In 2008, the Worldwide Fund for Nature estimated that the world's species biodiversity declined by almost one-third since 1975 due mainly to habitat loss and the legal and illegal global trade in wildlife.

Figure 8-2 (p. 154) shows a few of the many species that have become prematurely extinct mostly because of human activities.

In the 2005 Millennium Ecosystem Assessment, scientists from around the world estimated that the current annual rate of species extinction is at least 100 to

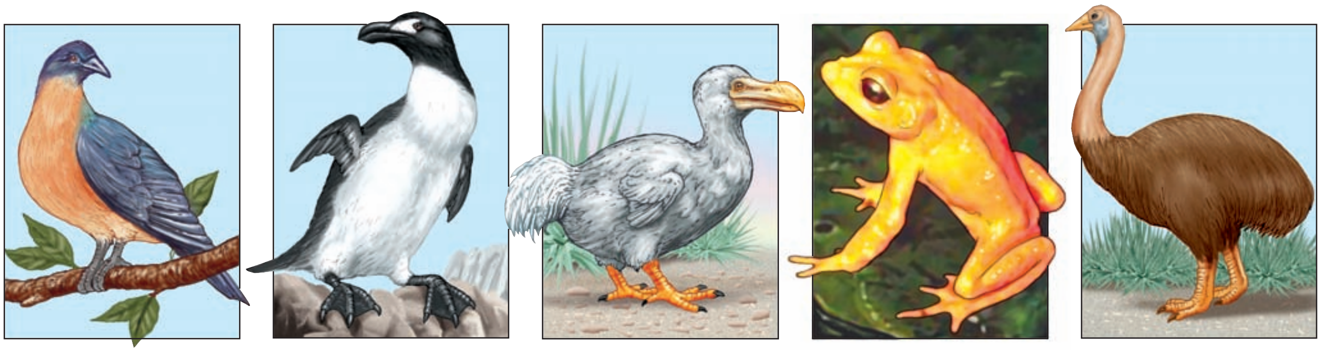

Figure 8-2 **Lost natural capital:** some animal species that have become prematurely extinct largely because of human activities, mostly habitat destruction and overhunting. **Question**: Why do you think birds top the list of extinct species?

1,000 times the *background rate* of about 0.0001%, which existed before modern humans appeared some 150,000 years ago. Biodiversity researchers project that during this century, the extinction rate caused by habitat loss, projected climate change, and other harmful effects of human activities will rise to 10,000 times the background rate (**Concept 8-1**). This will amount to an annual extinction rate of 1% per year. Scientists use a variety of methods to arrive at these projections (Science Focus, below).

According to researchers Edward O. Wilson and Stuart Pimm, at a 1% extinction rate, at least one-fourth of the world's current animal and plant species could be gone by 2050 and half 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 for at least 200,000 human generations or twenty times longer than the period since humans emerged as a species."

THINKING ABOUT
Extinction

How might your lifestyle and that of any child you might have change if human activities can contribute to the premature extinction of up to half of the world's species in your lifetime? List two aspects of your lifestyle that might contribute to this threat to the earth's natural capital.

SCIENCE FOCUS

Estimating Extinction Rates

Those scientists trying to catalog extinctions, estimate past extinction rates, and project future rates face three problems. *First,* because the extinction of a species typically takes a very long time, it is not easy to document. *Second,* we have identified only about 2 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 arrived and compare this with fossil records of extinctions prior to the arrival of humans. Determining the rates at which minor DNA copying mistakes occur can also help scientists to track how long various species typically last before becoming extinct. Such evidence indicates that under normal circumstances, species survive for 1 million to 10 million years before becoming extinct.

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 causes the extinction of 50% of the species living in that habitat.

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 inadequate data and sampling and on incomplete models. And they are continually striving to get better data and to improve the models used 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 be used as excuses for inaction. They agree with the advice of wildlife conservationist Aldo Leopold on his thoughts about preventing premature extinction: "To keep every cog and wheel is the first precaution of intelligent tinkering."

Critical Thinking

How would you improve the estimation of extinction rates?

Most extinction experts consider a projected extinction rate of 1% a year to be conservative, for several reasons. *First*, both the rate of species loss and the extent of biodiversity losses are likely to increase during the next 50–100 years because of the projected growth of the human population and of resource use per person, and because of the human impact on projected climate change (Science Focus, p. 27).

Second, current and projected extinction rates are much higher than the global average in parts of the world that are highly endangered centers of biodiversity. Biodiversity researchers urge us to focus our efforts on slowing the much higher rates of extinction in such *biodiversity hotspots* as the best and quickest way to protect much of the earth's biodiversity from being lost prematurely. (We discuss this further in Chapter 9.)

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 (**Concept 4-4**, p. 68). 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 creating a *speciation crisis*. (See the Guest Essay by Norman Myers on this topic at CengageNOW™.)

CONCEPT LINK

However, Philip Levin, Donald Levin, and other biologists argue that the increasing fragmentation and disturbance of habitats throughout the world may increase the speciation rate for rapidly reproducing opportunist species such as weeds, rodents, and cockroaches and other insects.

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 over all or most of its *natural range* (the area in which it is normally found). A **threatened species** (also known as a *vulnerable species*) is still abundant in its natural range, but because of declining numbers, is likely to become endangered in the near future.

An example of a threatened species is the polar bear (**Core Case Study**). Figure 8-3 (p. 156) shows a few of the 1,318 species officially listed in 2009 as endangered or threatened and protected under the U.S. Endangered Species Act. According to the World Wildlife Fund (WWF), the five most endangered animals in the wild are the Javan rhino (70 left), whooping crane (250 left), California condor (336 left), mountain gorilla (600 left), and the Siberian tiger (700 left).

CORE CASE STUDY

Some species have characteristics that make them especially vulnerable to ecological and biological extinction (Figure 8-4, p. 157). 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 (Case Study, below, and Figure 8-3, p. 156) and the Carolina parakeet, both extinct, nested in large flocks that made them easy to kill. Key deer, which live only in the U.S. Florida Keys, are "nicotine addicts." Many of them are killed by cars as they forage for cigarette butts along highways. Some types of species are more threatened with premature extinction from human activities than others are (Figure 8-5, p. 157).

RESEARCH FRONTIER

Identifying and cataloguing the millions of unknown species and improving models for estimating extinction rates. See **www.cengage.com/biology/miller**.

CASE STUDY

The Passenger Pigeon: Gone Forever

In 1813, bird expert John James Audubon saw a single huge flock of passenger pigeons that took 3 days to fly over him and was so dense that it darkened the skies.

By 1900, North America's passenger pigeon (Figure 8-3, p. 156), once one of the most abundant bird species on earth, had disappeared from the wild because of a combination of uncontrolled commercial hunting and habitat loss as forests were cleared to make room for farms and cities. These birds were good to eat, their feathers made good pillows, and their bones were widely used for fertilizer. They were easy to kill because they flew in gigantic flocks and nested in long, narrow, densely packed colonies.

Commercial hunters would capture one pigeon alive, sew its eyes shut, and tie it to a perch, called a stool. Soon a curious flock would land beside this "stool pigeon"—a term we now use to describe someone who turns in another person for breaking the law. Then the birds would be shot or ensnared by nets that could trap more than 1,000 of them at once.

Beginning in 1858, passenger pigeon hunting became a big business. Shotguns, traps, artillery, and even dynamite were used. People burned grass or sulfur below their roosts to suffocate the birds. Shooting galleries used live birds as targets. In 1878, one 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 because the females laid only one egg per nest each year. On March 24, 1900, a young boy in the U.S. state of Ohio shot the last known wild passenger pigeon.

Figure 8-3 **Endangered natural capital:** some species that are endangered or threatened with premature extinction, largely because of human activities. Almost 30,000 of the world's species and 1,318 of those in the United States were officially listed in 2009 as endangered or threatened species. According to most biologists, the actual number of species at risk is much larger.

Figure 8-4 Characteristics of species that are prone to ecological and biological extinction. **Question**: Which of these characteristics might possibly contribute to the premature extinction of the polar bear (**Core Case Study**) during this century?

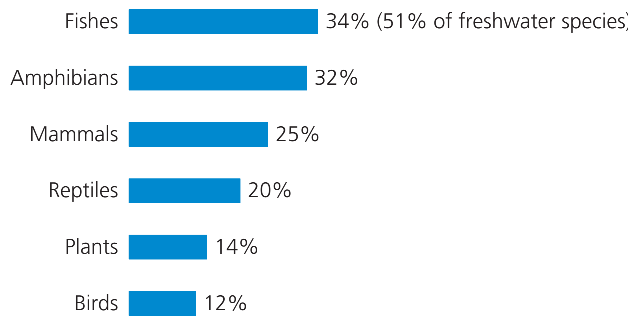

Figure 8-5 **Endangered natural capital:** percentage of various types of species threatened with premature extinction because of human activities (**Concept 8-1**). **Question**: Why do you think fishes top this list? (Data from World Conservation Union, Conservation International, Worldwide Fund for Nature, 2005 Millennium Ecosystem Assessment, and the Intergovernmental Panel on Climate Change)

8-2 Why Should We Care about Preventing Species Extinction?

CONCEPT 8-2 We should prevent the premature extinction of wild species because of the economic and ecological services they provide and because they have a right to exist regardless of their usefulness to us.

Species Are a Vital Part of the Earth's Natural Capital

So what is all the fuss about? If all species eventually become extinct, why should we worry about premature extinctions? Does it matter that the passenger pigeon became prematurely extinct because of human activities, or that the remaining polar bears (**Core Case Study**), orangutans (Figure 8-6, p. 158), or some unknown plant or insect in a tropical forest might suffer the same fate?

New species eventually evolve to take the places of those lost through mass extinctions. So why should we care if we speed up the extinction rate over the next 50–100 years? The answer: because analysis of past mass extinctions indicates that it will take 5–10 million years for natural speciation to rebuild the biodiversity that we are likely to destroy during your lifetime. So while some analysts worry about biodiversity loss, others are also concerned about a potential speciation crisis.

Biodiversity researchers say we should act now to prevent premature extinction of many species partly because of their **instrumental value**—their usefulness to us because of the many ecological and economic services they help to provide as part of the earth's natural capital (Figure 1-2, p. 7, and **Concept 8-2**). For example,

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Figure 8-6 **Natural capital degradation:** endangered orangutans in a tropical forest. In 1900, there were over 315,000 wild orangutans, which are found only in Indonesia and Malaysia. According to the WWF, today there are only 50,000–60,000 left in the wild (90% of them in Indonesia). And they are disappearing at a rate of more than 1,000–2,000 per year because of illegal smuggling and clearing of their forest habitat in Indonesia and Malaysia to make way for oil palm plantations. An illegally smuggled orangutan typically sells for a street price of $10,000. According to a 2007 study by the WWF, projected climate change will further devastate remaining orangutan populations in Indonesia and Malaysia. Without urgent protective action, the endangered orangutan may become the first great ape species to become extinct, primarily because of human activities. **Question**: What difference does it make if human activities are the key cause of the premature extinction of the orangutan?

some plant species provide economic value in the form of food crops, fuelwood and lumber, paper, and medicine (Figure 8-7). *Bioprospectors* search tropical forests and other ecosystems and test plants and animals to find chemicals that can be converted into useful medicinal drugs. According to a 2005 U. N. University report, 62% of all cancer drugs were derived from the discoveries of bioprospectors. **GREEN CAREER:** Bioprospecting

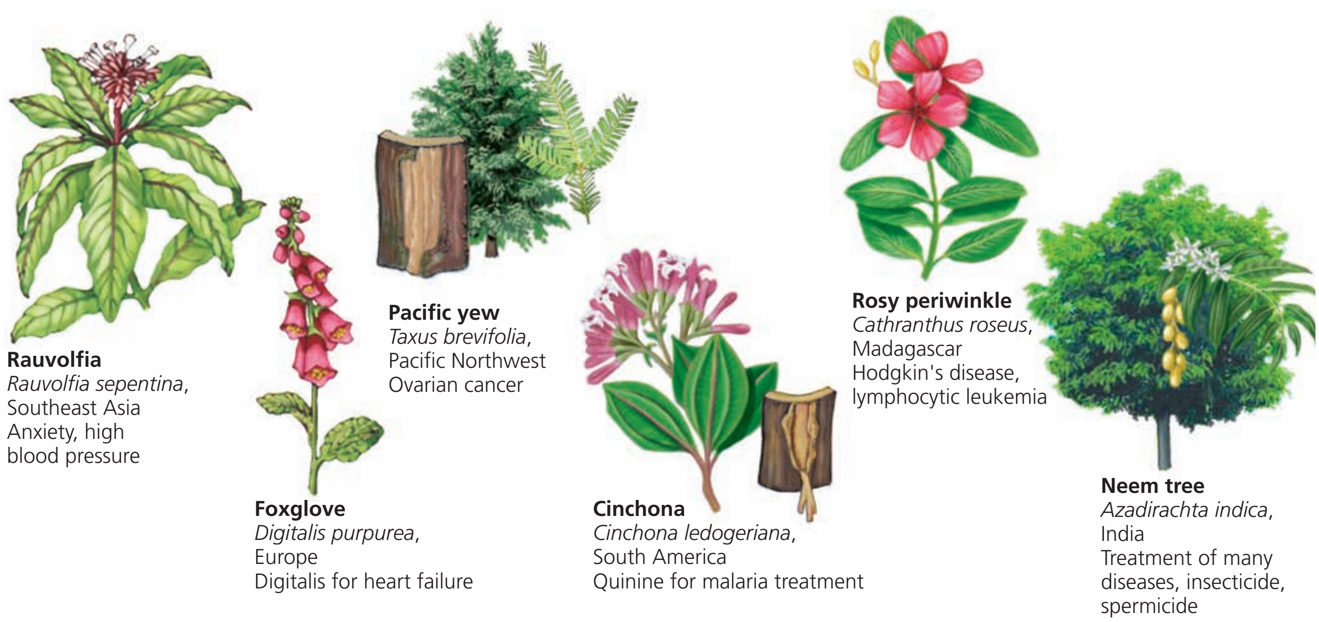


Figure 8-7 **Natural capital:** *nature's pharmacy.* Parts of these and a number of other plant and animal species (many of them found in tropical forests) are used to treat a variety of human ailments and diseases. Nine of the ten leading prescription drugs originally came from wild organisms. About 2,100 of the 3,000 plants identified by the National Cancer Institute as sources of cancer-fighting chemicals come from tropical forests. Despite their economic and health care potential, fewer than 1% of the estimated 125,000 flowering plant species in tropical forests (and a mere 1,100 of the world's 260,000 known plant species) have been examined for their medicinal properties. Once the active ingredients in the plants have been identified, they can usually be produced synthetically. Many of these tropical plant species are likely to become extinct before we can study them. **Question**: Which of these species, if any, might have helped you or people you know to deal with health problems?

Species diversity also provides economic benefits from wildlife tourism, or *ecotourism*, which generates more than $1 million per minute in tourist expenditures worldwide. GOOD NEWS Conservation biologist Michael Soulé estimates that one male lion living to age 7 generates $515,000 in tourist dollars in Kenya, but only $1,000 if killed for its skin and much less if it is killed for preying upon livestock in villages near its habitat. Similarly, over a lifetime of 60 years, a Kenyan elephant is worth about $1 million in ecotourist revenue—many times more than its tusks are worth when they are sold illegally for their ivory. The website for this chapter lists some guidelines for evaluating eco-tours. **GREEN CAREER:** Ecotourism specialist

One of the tragedies of the current extinction crisis is that we do not know what we are losing because no one has ever seen or studied many of the species that are becoming extinct. Carelessly eliminating such species that make up part of the world's vast genetic library is like burning books that we have never read.

Finally, and perhaps most important, each species holds *ecological value*, because it plays a role in the key ecosystem functions of energy flow and nutrient cycling, in keeping with the three **principles of sustainability** (see back cover). SUSTAINABILITY Thus, by protecting species from premature extinction 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.

Are We Ethically Obligated to Prevent Premature Extinction?

Some scientists and philosophers believe that each wild species has **intrinsic**, or **existence**, **value** based on its inherent right to exist, regardless of its usefulness to us (**Concept 8-2**). According to this stewardship view, we have an ethical responsibility to protect species from becoming prematurely extinct as a result of human activities and to prevent the degradation of the world's ecosystems and its overall biodiversity.

Some people distinguish between the survival rights of plants and those of animals, mostly for practical reasons. Poet Alan Watts once said he was a vegetarian "because cows scream louder than carrots."

Other people distinguish among various types of species. For example, they might think little about getting rid of the world's mosquitoes, cockroaches, rats, or disease-causing bacteria, but feel protective of polar bears (**Core Case Study**), elephants, and whales. CORE CASE STUDY

8-3 How Do Humans Accelerate Species Extinction?

CONCEPT 8-3 The greatest threats to any species are (in order) loss or degradation of its 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 8-8 (p. 160) shows the direct and underlying causes of the endangerment and premature extinction of wild species. Biodiversity researchers summarize the most important causes of premature extinction using the acronym **HIPPCO**: **H**abitat destruction, degradation, and fragmentation; **I**nvasive (nonnative) species; **P**opulation and resource use growth (too many people consuming too many resources); **P**ollution; **C**limate change; and **O**verexploitation (**Concept 8-3**).

According to biodiversity researchers, the greatest threat to wild species is habitat loss (Figure 8-9, p. 161), degradation, and fragmentation. Deforestation in tropical areas (Figure 3-1, p. 39) is the greatest eliminator of species, followed by the destruction and degradation of coral reefs (Figure 7-26, p. 143, and Figure 7-27, p. 144) destruction of wetlands, plowing of grasslands, and pollution of streams, lakes, and oceans. Globally, temperate biomes have been affected more by habitat loss and degradation than have tropical biomes because of widespread economic development in temperate countries during the past 200 years. Such development is now shifting to many tropical biomes.

Island species—many of them *endemic species* found nowhere else on earth—are especially vulnerable to extinction when their habitats are destroyed, degraded, or fragmented. This is why the collection of islands that make up the U.S. state of Hawaii are America's "extinction capital"—with 63% of its species at risk.

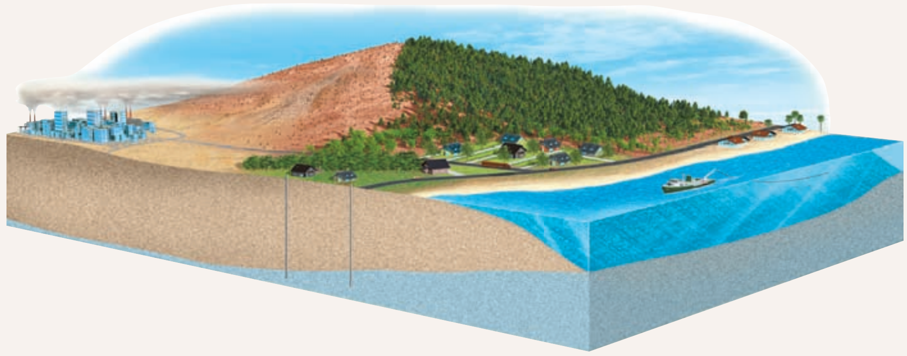
Any habitat surrounded by a different one can be viewed as a *habitat island* for most of the species that live there. Most national parks and other nature reserves are habitat islands, many of them encircled by potentially damaging logging, mining, coal-burning power plants, and industrial activities. Freshwater lakes are also habitat islands that are especially vulnerable to the introduction of nonnative species and pollution from the atmosphere and surrounding land.

Natural Capital Degradation

Causes of Depletion and Premature 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 8-8 Underlying and direct causes of depletion and premature extinction of wild species (**Concept 8-3**). The major direct cause of wildlife depletion and premature extinction 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 closely related to each of the underlying causes?

Habitat fragmentation—by roads, logging, agriculture, and urban development—occurs when a large, intact area of habitat is reduced in area and divided into smaller, more scattered, and isolated patches, or "habitat islands." This process can decrease tree species in forests (see *The Habitable Planet,* Video 9, at **www.learner.org/resources/series209.html**), and block migration routes. And it can divide populations of a species into smaller and more isolated groups that are more vulnerable to predators, competitor species, disease, and catastrophic events such as storms and fires. It can also create barriers that limit the abilities of some species to disperse and colonize new areas, to get enough to eat, and to find mates. Migrating species also face dangers from fences, farms, paved areas, skyscrapers, and cell phone towers.

CENGAGENOW™ See how serious the habitat fragmentation problem is for elephants, tigers, and rhinos at CengageNOW.

■ **CASE STUDY**

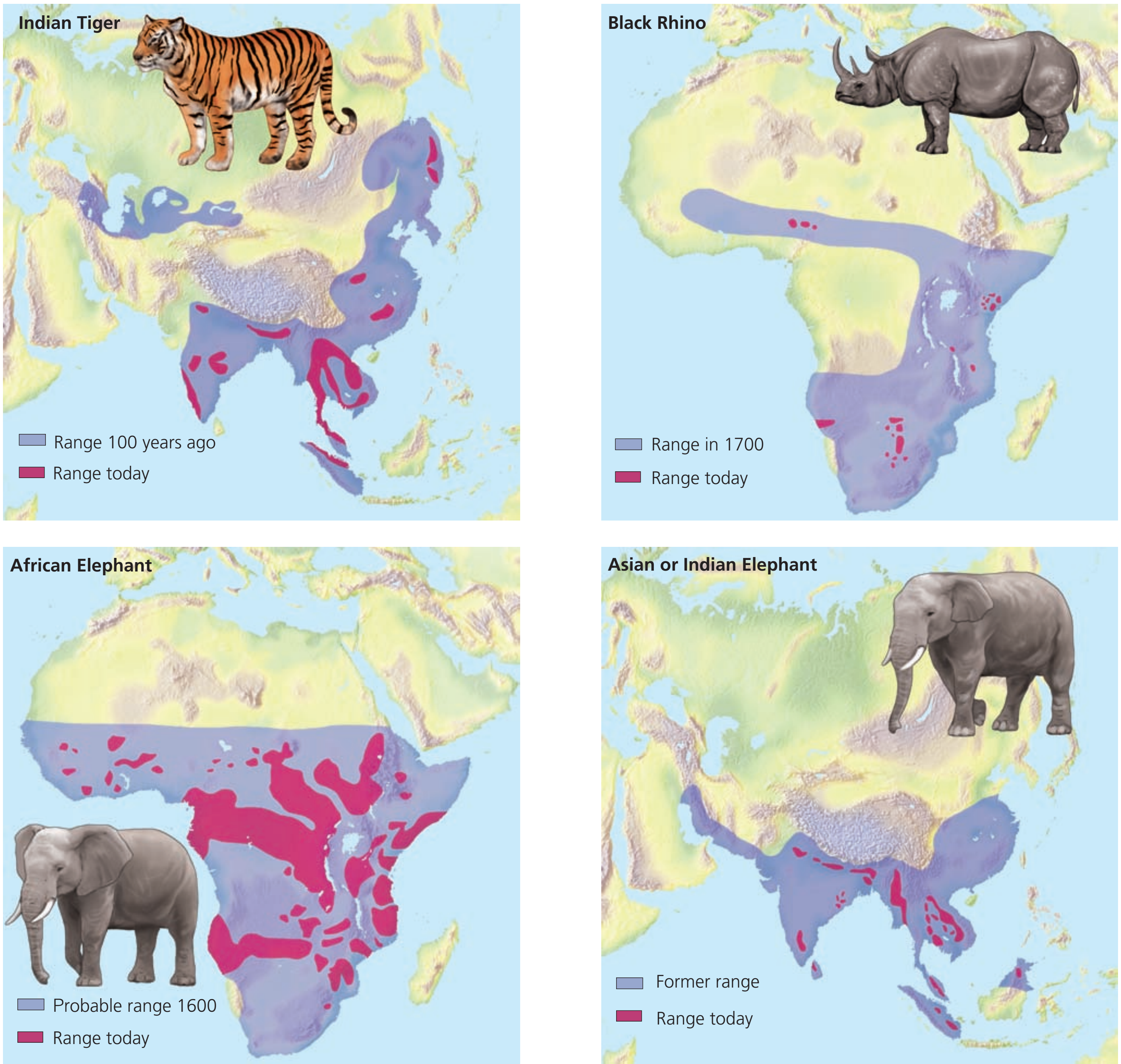
A Disturbing Message from the Birds

Approximately 70% of the world's nearly 10,000 known bird species are declining in numbers. And roughly one of every eight (12%) of these bird species is threatened with extinction, mostly because of habitat loss, degradation, and fragmentation, according to the 2008 Red List of endangered species published by the International Union for Conservation of Nature (IUCN). The report noted that about 82% of albatrosses and 60% of cranes are threatened. 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 in Asia and Latin America.

The numbers and distribution of North American bird species such as robins, blackbirds, and starlings that can prosper around humans have increased over the last 35 years. But populations of many forest songbirds have declined sharply. The greatest declines have occurred among long-distance migrant species such as tanagers, orioles, thrushes, vireos, and warblers that nest deep in North American woods in the summer and spend their winters in Central or South America or the Caribbean Islands.

The primary culprits for these declines appear to be habitat loss and fragmentation of the birds' breeding habitats. In North America, woodlands are being cleared and broken up by roads and developments. In Central and South America, tropical forest habitats, mangroves, and wetland forests are suffering the same fate.

Populations of 40% of the world's water birds are in decline because of the global loss of wetlands. And huge numbers of migrating birds are killed each year when they collide with electrical transmission and communications towers and skyscrapers that have been erected in the middle of their migration routes. According to Defenders of Wildlife, such collisions kill more than 1 billion birds a year in the United States. Other threats to birds are oil spills, exposure to pesticides, use of her-



CENGAGENOW™ **Active Figure 8-9 Natural capital degradation:** reductions in the ranges of four wildlife species, mostly as the result of habitat loss and hunting. What will happen to these and millions of other species when the world's human population doubles and per capita resource consumption rises sharply in the next few decades? *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)

bicides that destroy their habitats, and ingestion of toxic lead shotgun pellets that fall into wetlands and lead sinkers left by anglers.

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 bird populations in every part of the globe. And this is expected to increase sharply during this century.

Biodiversity scientists view this decline of bird species with alarm. One reason for concern 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 a number of important economic and ecological services in ecosystems throughout the world. They help to control populations of rodents and insects (which decimate many tree species), remove dead animal carcasses (a food source for some birds), and spread plants throughout their habitats by helping with pollination and by consuming and excreting plant seeds.

Extinctions of birds that play specialized roles in pollination and seed dispersal, especially in tropical areas, may lead to extinctions of plants dependent on these ecological services. Then some specialized animals that feed on these plants may also become extinct.

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.

CONNECTIONS

Vultures, Wild Dogs, and Rabies

Protecting birds and their habitats is important for human health. In India and South Asia, between 1992 and 2007, the populations of three species of carcass-eating vultures fell by more than 97%. Scientists discovered that the vultures were being poisoned by *diclofenac*, a drug that caused kidney failure in the vultures when they fed on the carcasses of cows that had been given the drug to increase their milk production. As the vultures died off, wild dogs and rats consumed huge numbers of cow carcasses that had been a source of food for the vultures. As wild dog populations exploded due to their greatly increased food supply, the number of stray dogs with rabies increased, and the dogs bit more people. In 1997 alone, rabies killed more than 30,000 people in India—more than half the world's total number of rabies deaths that year—and all because a large number of birds had been poisoned.

THINKING ABOUT

Bird Extinctions

How does your lifestyle directly or indirectly contribute to the premature extinction of some bird species? What are two things that you think should be done to reduce the premature 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/biology/miller**.

Some Deliberately Introduced Species Can Disrupt Ecosystems

After habitat loss and degradation, the biggest cause of premature animal and plant extinctions is the deliberate or accidental introduction of harmful invasive species into ecosystems (**Concept 8-3**).

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, and 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 also helped to control pests. GOOD NEWS

The problem is that some introduced species have no natural predators, competitors, parasites, or pathogens to help control their numbers in their new 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.

Figure 8-10 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 biologist Thomas Lovejoy, harmful invader species cost the U.S. public an average of $261,000 per minute! Ecologist David Pimentel estimates that, globally, damage to watersheds, soils, and wildlife caused by bioinvaders may cost us as much as $44,400 per second. And the damages are rising rapidly. According to the U.S. Fish and Wildlife Service, about 40% of the species listed in the United States as endangered or threatened are on the list because of threats from invasive species.

Some deliberately introduced species are plants such as kudzu (Case Study, below). Deliberately introduced animal species have also caused ecological and economic damage. Consider the estimated 1 million *European wild* (*feral*) *boars* (Figure 8-10) found in parts of Florida and other U.S. states. These deliberately introduced species compete for food with endangered animals, root up farm fields, and cause traffic accidents. Game and wildlife officials have failed to control their numbers through hunting and trapping, and they 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 so prolific and difficult to kill that it engulfs hillsides, gardens, trees, abandoned houses and cars, stream banks, patches of forest, and anything else in its path (Figure 8-11, p. 164).

This plant, which is sometimes called "the vine that ate the South," has spread throughout much of the southeastern United States. It could spread as far north as the Great Lakes by 2040 if climate change caused by global warming occurs as projected.

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 help to save trees from loggers. Researchers

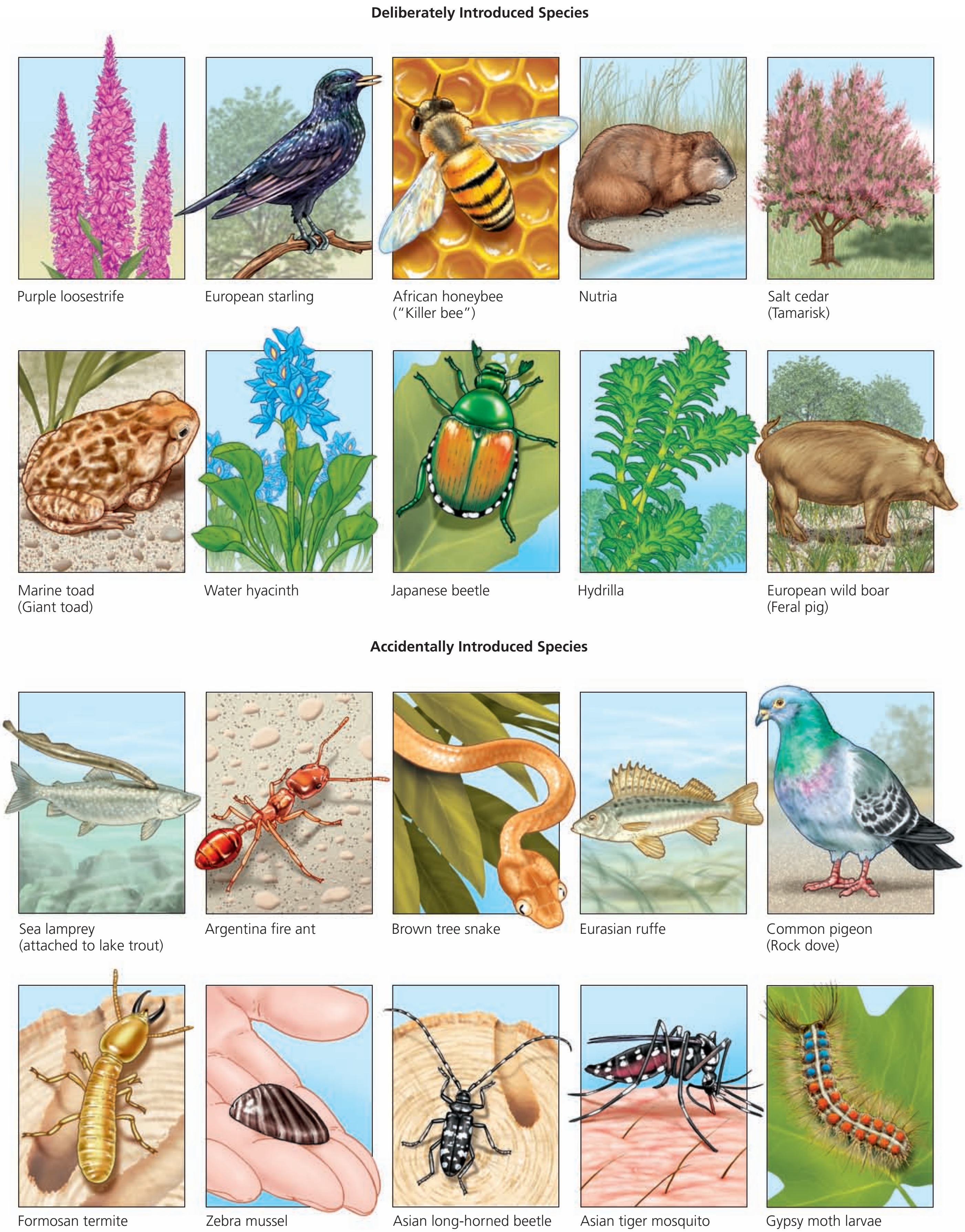


Figure 8-10 Some of the more than 7,100 harmful invasive (nonnative) species that have been deliberately or accidentally introduced into the United States.

at the Georgia Institute of Technology indicate that it could be used in place of trees as a source of fiber for making paper. Also, ingesting small amounts of the powder can lessen one's desire for alcohol. Thus, a preliminary 2005 study indicated that kudzu powder 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. These plants might also harbor insects that can escape, multiply rapidly, and threaten crops.

In the 1930s, the extremely aggressive Argentina fire ant (Figure 8-10) was introduced accidentally 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 float) over much of the southern United States. They are also found in Puerto Rico, New Mexico, and California. Now it 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. In the United States, they also do an estimated $68,000 of economic damage per hour to crops and phone and power lines.

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 (**Concept 4-2B**, p. 63). In other words, we helped wipe out many of their competitors and made the fire ants more genetically resistant to pesticides.

CONCEPT LINK

In the Everglades in the U.S. state of Florida, the population of the huge *Burmese python* snake is growing. This native of Southeast Asia was imported as a pet and ended up being dumped in the Everglades by people who learned that, when they get larger, pythons do not make good pets. They can live 25 years, reach 6 meters (20 feet) in length, weigh more than 90 kilograms (200 pounds), and have the girth of a telephone pole. They have razor-sharp teeth and can catch, squeeze to death, and swallow whole practically anything that moves and is warm-blooded, including a variety of birds and full-grown deer. They are slowly spreading to other areas and, by 2100, could be found in most of the southern half of the continental United States.

Bioinvaders also affect aquatic systems and are blamed for about two-thirds of fish extinctions in the United States between 1900 and 2000. Many of these invaders arrive in the ballast water stored in tanks in large cargo ships to keep them stable. These ships take in ballast water—along with whatever microorganisms and tiny aquatic organisms it contains—from one harbor and dump it into another. This is an environmentally harmful effect of globalized trade.

In the United States, the Great Lakes have been invaded by more than 185 alien species. At least 13 of these invading species threaten some native species and cause billions of dollars in damages. One such invader is the fish-killing sea lamprey (Figure 5-5a, p. 84). Another is a thumbnail-sized mollusk called the *zebra mussel* (Figure 8-10), which reproduces rapidly and has no known natural enemies in the Great Lakes. It has displaced other mussel species and depleted the food supply for some native Great Lakes species. The mussels have also clogged irrigation pipes, shut down water intake pipes for power plants and city water supplies, jammed ship rudders, and grown in huge masses on boat hulls, piers, rocks, and almost any exposed aquatic surface (Figure 8-12).

NOAA

Figure 8-12 *Zebra mussels* 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.

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 and dispersed into the atmosphere. 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 allow species to become successful invaders and the types of ecosystems that are vulnerable to invaders (Figure 8-13).
- Greatly increase ground surveys and satellite observations to detect and monitor species invasions and to develop better models for predicting how they will spread and what harmful effects they might have.
- Step up inspection of imported goods and goods carried by travelers that are likely to contain invader species.
- Identify major harmful invader species and establish international treaties banning their transfer from one country to another, as is now done for endangered species.
- Require cargo ship handlers 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 kill most invader organisms.
- Increase research to find and introduce natural predators, parasites, bacteria, and viruses to control populations of established invaders.

Characteristics of Successful Invader Species	Characteristics of Ecosystems Vulnerable to Invader Species
High reproductive rate, short generation time	Climate similar to habitat of invader
Pioneer species	Absence of predators on invading species
Long lived	Early successional systems
High dispersal rate	Low diversity of native species
Generalists	Absence of fire
High genetic variability	Disturbed by human activities

Figure 8-13 Some general characteristics of successful invader species and ecosystems vulnerable to invading species. **Question**: Which, if any, of the characteristics on the right-hand side could humans influence?

RESEARCH FRONTIER

Learning more about harmful invasive species, why they thrive, and how to control them. See **www.cengage.com/biology/miller**.

Figure 8-14 shows some of the things you can do to help prevent or slow the spread of harmful invader species.

Population Growth, Overconsumption, Pollution, and Climate Change Can Cause Species Extinctions

Past and projected human population growth (Figure 6-2, p. 96) and excessive and wasteful consumption of resources have greatly expanded the human ecological footprint (Figure 1-5, p. 11, and Figure 3, p. S18, in Supplement 4), which has eliminated vast areas of wildlife habitat (Figure 8-9). Acting together, these two factors have caused premature extinction of many species (**Concept 8-3**). (See *The Habitable Planet,* Video 13, at **www.learner.org/resources/series209.html**.)

Population growth can also reduce aquatic biodiversity. About 45% of the world's people live along or near the world's coasts, mostly in large coastal cities (Figure 6-11, p. 108). According to the U.N. Environment Programme (UNEP) this percentage is likely to reach 80% in the near future. This will add to the already intense pressure on the world's marine ecosystems and species and coral reefs (Figure 7-28, p. 145), primarily by destroying more aquatic habitat and increasing pollution. In 2004, the UNEP estimated that 80% of all ocean pollution comes from land-based coastal activities.

This and other forms of pollution threaten some species with extinction (**Concept 8-3**), 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 (Case Study, right). 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.

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 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 any waterways.
- After dogs visit woods or the water, brush them before taking them home.
- After each use, clean your mountain bike, canoe, boat, hiking boots, and other gear before heading for home.

Figure 8-14 **Individuals matter:** 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?

During the 1950s and 1960s, populations of fish-eating birds such as ospreys, brown pelicans (See Photo 3 in the Detailed Contents), and bald eagles plummeted. A chemical derived from the pesticide DDT, when biologically magnified in food webs (Figure 8-15), 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.

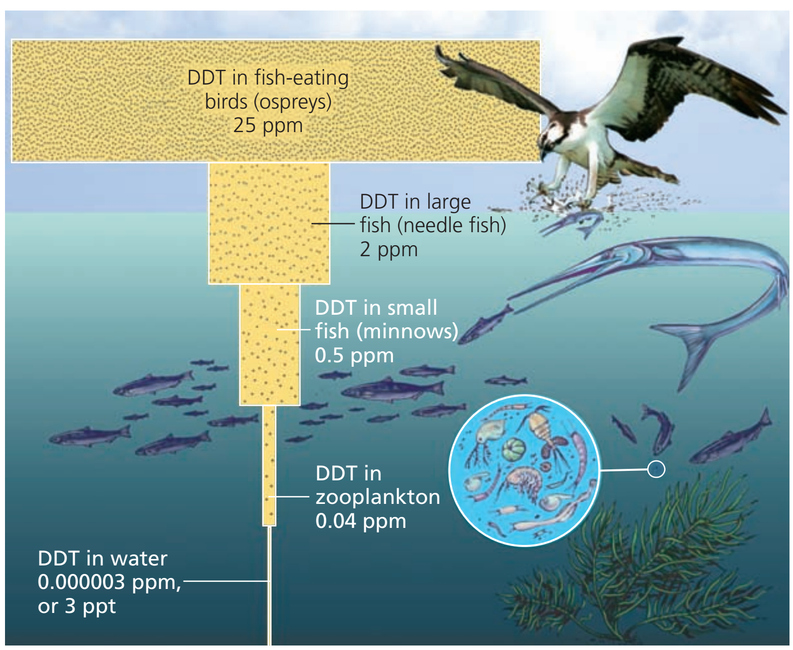


Figure 8-15 *Bioaccumulation* and *biomagnification*. DDT is a fat-soluble chemical that can accumulate in the fatty tissues of animals. In a food chain or web, the accumulated DDT is biologically magnified in the bodies of animals at each higher trophic level. (Dots in this figure represent DDT.) The 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 from the water 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?

According to a 2004 study by Conservation International, projected climate change (Science Focus, p. 27) could 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 premature extinction.

Projected climate change will also threaten aquatic species, habitats, and ecosystem services if it causes sea levels to rise as projected during this century. This would destroy some coral reefs, swamp some low-lying islands, drown many highly productive coastal wetlands, and cause some Pacific island nations to lose more than half of their protective coastal mangrove forests by 2100, according to a 2006 study by the UNEP.

■ **CASE STUDY**

Where Have All the Honeybees Gone?

Globally, about one-third of the human diet comes from insect-pollinated plants, and honeybees are responsible for 80% of that pollination, according to the U.S. Department of Agriculture (USDA). In 2006, the U.S. National Academy of Sciences reported a 30% drop in U.S. honeybee populations since the 1980s. Causes include pesticide exposure (the wax in beehives absorbs these and other airborne toxins), attacks by parasitic mites that can wipe out a colony in hours, and invasion by Africanized honeybees (killer bees, p. 73).

In 2008, a record 36% of the honeybee colonies (each with 30,000 to 100,000 individual bees) in 27 U.S. states were lost. Almost one-third of the deaths were due to *colony collapse disorder,* a mysterious disease that causes adult bees to disappear from their hives without a trace. Suspected causes include parasites, a fungus, viruses, bacteria, pesticides, and poor nutrition and stress caused when bee colonies are fed an artificial diet while being trucked around the country and rented out for pollination.

A combination of these or other causes may be involved. But a growing number of beekeepers believe that a significant cause may be relatively new nicotine-based pesticides, known to affect the immune and nervous systems of insects and to reduce their ability to fight off infections. So far, there is no smoking gun to explain the die offs.

So what can we do to reduce threats to honeybees, which pollinate abut one-third of the crops we eat? 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. And we can make our yards and gardens a buffet for bees by planting native plants such as bee balm, foxglove, red clover, and Joe-Pye weed. These species provide food for bees and can be grown without the use of pesticides.

> **THINKING ABOUT**
> **Honeybees**
>
> What difference would it make to you if most of the honeybees disappeared? What are two ways 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 $1.1 million 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 live mountain gorilla is worth $150,000, a giant panda pelt $100,000, a chimpanzee $50,000, an Imperial Amazon macaw $30,000, and a Komodo dragon reptile from Indonesia $30,000. A poached rhinoceros horn (Figure 8-16, p. 168) can be worth as much as $55,000 per kilogram ($25,000 per pound). It is used to make dagger handles in the Middle East and as a fever reducer and alleged aphrodisiac in China and other parts of Asia.

In 1900, an estimated 100,000 tigers roamed free in the world. Despite international protection, only about 3,500 tigers remain in the wild, on a rapidly shrinking range (Figure 8-9, top left), according to a 2006 study by the World Conservation Union. Today, all six tiger subspecies are endangered in the wild and roam across only about 7% of their natural range. The Bengal or Indian tiger 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 $25,000—and because few of the poachers are caught or punished—it is not surprising that illegal hunting has skyrocketed. According to a 2006 study by tiger experts, without emergency action to curtail poaching and preserve their habitat, few if any tigers will be left in the wild within 20 years.

> **THINKING ABOUT**
> **Tigers**
>
> What difference would it make if all the world's wild tigers disappeared? What two steps would you take to help protect the world's remaining wild tigers from premature extinction?

Martin Harvey/Peter Arnold, Inc

Figure 8-16 White rhinoceros killed by a poacher for its horn in South Africa. **Question**: What would you say if you could talk to the poacher of this animal?

The global 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, an estimated 50 others are killed or die in transit. About 25 million U.S. households have exotic birds as pets, 85% of them imported. More than 60 bird species, mostly parrots, are endangered or threatened because of this wild bird trade. Most people are also unaware that some imported exotic animals can carry dangerous infectious diseases.

CONNECTIONS

Exotic Pets and Human Health

Keeping birds as pets can be dangerous. A 1992 study suggested that keeping a pet bird indoors for more than 10 years doubles a person's chances of getting lung cancer from inhaling tiny particles of bird dander. Other exotic animals sometimes carry diseases that can spread from pets to humans, including hantavirus, Ebola virus, Asian bird flu, herpes B virus (carried by most adult macaques), and salmonella (from pets such as hamsters, turtles, and iguanas).

Other wild species whose populations are depleted because of the pet trade include amphibians, reptiles, 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 polyps that create the reef.

Some exotic plants, especially orchids and cacti, are endangered when they are gathered (often illegally) and sold to collectors to decorate houses, offices, and landscapes. A collector may pay $5,000 for a single rare orchid. A mature crested saguaro cactus can earn cactus rustlers as much as $15,000.

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.

INDIVIDUALS MATTER

GOOD NEWS

A Scientist Who Confronted Poachers

In Thailand, biologist Pilai Poonswad (Figure 8-A) decided to do something about poachers taking Rhinoceros hornbills from a rain forest. This black or brown and white bird has a large beak that starts out white but becomes bright orange and red over the bird's lifetime. The bird's peculiar squawking is amplified by its great beak. This species is one of the largest hornbills, with a length of 110–127 centimeters (43–50 inches).

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, they now help to protect the birds from poachers.

The Rhinoceros hornbill's population was in steady decline. 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 8-A Professor Pilai Poonswad, a biologist at Mahidol University, Thailand, decided to confront poachers who were a threat to the rare Rhinoceros hornbill.

Rising Demand for Bush Meat Threatens Some African Species

Indigenous people in much of West and Central Africa have sustainably hunted wildlife for *bush meat,* a source of food, for centuries. 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 8-17). 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.

CONNECTIONS

Bush Meat Hunting and Overfishing

A 2004 study showed that people living in coastal areas of West Africa have increased bush meat hunting because local fish harvests have declined, due to overfishing by heavily subsidized European Union fishing fleets.

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 Africa and has driven one species—Miss Waldron's red colobus monkey—to complete extinction. It is also a factor in reducing gorilla, orangutan (Figure 8-6), chimpanzee, elephant, and hippopotamus populations. According to the International Union for Conservation of Nature, almost half (48%) of the world's primates (such as orangutans, chimpanzees, and lemurs) were in danger of extinction in 2008 (compared to 39% in 2003), mostly as a result of habitat loss and hunting for meat. 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 to humans. The U.S. Agency for International Development is trying to reduce unsustainable hunting for bush meat in some areas by introducing alternative sources of food such as fish farms. They are also showing villagers how to breed large rodents such as cane rats as a source of food.

Jacques Fretey/Peter Arnold, Inc.

Figure 8-17 *Bush meat* such as this severed head of a lowland gorilla in the Congo is consumed as a source of protein by local people in parts of West Africa and sold in the national and international marketplace. You can find bush meat on the menu in Cameroon and the Congo in West Africa as well as in Paris, London, Toronto, New York, and Washington, D.C. It is often supplied by poaching. 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?

8-4 How Can We Protect Wild Species from Premature Extinction?

▶ **CONCEPT 8-4 We can reduce 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 8-4**). One of the most far reaching is the 1975 *Convention on International Trade in Endangered Species (CITES).* This treaty, now signed by 174 countries, bans hunting, capturing, and selling of threatened or endangered species. It lists some 900 species that cannot be commercially traded as live specimens or wildlife products because they are in danger of extinction. It also restricts international trade of roughly 5,000 species of animals and 28,000 plants species that are at risk of becoming threatened.

CITES has helped to reduce 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 190 countries (but as of 2009, not by the United States), legally commits participating governments to reversing the global decline of biodiversity 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 8-4**). 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 Services (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, economic factors can be used 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 an 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 2009, the number of U.S. species on the official endangered and threatened species lists increased from 92 to 1,318. According to a 2000 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 1,318 species on the endangered and threatened species lists. (For a clickable map listing endangered U.S. species by state, see **http://www.endangeredspecie.com/map.htm**.) 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, 86% of the protected species were covered by active recovery plans. Examples of successful recovery plans include those for the American alligator (Science Focus, p. 75), the gray wolf, the peregrine falcon, and the bald eagle. The ESA also protects another 574 species from other countries.

GOOD NEWS

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 such animals are also brought in illegally, but few illegal shipments of endangered or threatened animals or plants are confiscated. Even when they are caught, many violators are not prosecuted, and convicted violators often pay only a small fine.

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.

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 beer companies spend on two 30-second TV commercials during the annual U.S. football Super Bowl.

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, right).

SCIENCE FOCUS

Accomplishments of the Endangered Species Act

Critics of the ESA call it an expensive failure because only 37 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. This is like setting up a poorly funded hospital emergency room that takes only the most desperate cases, often with little hope for recovery, and saying it 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 of 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 its patients and keeping 99% of them alive would be considered an astounding success.

GOOD NEWS

Fourth, the 2007 ESA budget amounted to an average expenditure of about 44¢ per year 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, biologists call for it to be strengthened and modified to help protect ecosystems and the nation's overall biodiversity.

A study by the U.S. National Academy of Sciences recommended three major changes to make the ESA more scientifically sound and effective:

- Greatly increase the meager funding for implementing the act.
- 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.
- When a species is first listed, establish a core of its survival habitat as critical, as a temporary emergency measure that could support the species for 25–50 years.

Most biologists and wildlife conservationists believe that the United States 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 9.)

Critical Thinking

Should the U.S. Endangered Species Act be modified to protect and sustain the nation's overall biodiversity more effectively? Explain.

Laws and Treaties Also Help to Protect Marine Species

The U.S. Endangered Species Act and international agreements have been used to identify and protect endangered and threatened marine species such as seals, sea lions, sea turtles, and whales (Case Study, p. 172).

Six of the world's major sea turtle species are critically endangered or endangered. One is the endangered green sea turtle shown on the front cover of this book. Another is the leatherback sea turtle (Figure 8-18).

Two major threats to sea turtles are loss or degradation of beach habitat (where the leatherback and other species come ashore to lay their eggs) and the legal and illegal taking of their eggs. Other threats include unintentional capture and drowning by commercial fishing boats (especially shrimp trawlers) and increased use of the turtles as sources of food, medicinal ingredients, tortoiseshell (for jewelry), and leather from their flippers. Pollution is another threat. Sea turtles can mistake discarded plastic bags for jellyfish and choke to death on them. And if the oceans continue to warm as projected, this will raise sea levels, which will flood nesting and feeding habitats and change ocean currents, which could disrupt the turtles' migration routes.

There are numerous efforts to protect sea turtles. On some beaches, nesting areas are roped off. Since 1991,

The National Oceanographic and Atmospheric Association

Figure 8-18 An endangered *leatherback sea turtle* is entangled in a fishing net and lines and could have starved to death had it not been rescued. These turtles are hunted for meat and leather, and their eggs are taken for food. Almost 95% of these turtles in the Pacific have disappeared in the past 25 years.

the U.S. government has required offshore shrimp trawlers to use turtle excluder devices (TEDs) that help keep sea turtles from being caught in their nets or that allow caught turtles to escape. TEDs have been adopted in 15 countries that export shrimp to the United States and have led to significant declines in the number of sea turtles killed by becoming trapped in fishing nets. And, in 2004, the United States banned long-line swordfish fishing off the Pacific coast to help save dwindling sea turtle populations.

GOOD NEWS

Despite some successes, two major problems hinder efforts to protect marine biodiversity by protecting endangered species. One is our limited knowledge about marine species. The other is the difficulty of monitoring and enforcing treaties to protect marine species, especially in the vast open ocean.

CASE STUDY

Protecting Whales: A Success Story . . . So Far

Whales are fairly easy to kill because of their large size and their need to come to the surface to breathe. Whale hunters became 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 (p. 9), 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 and drove the blue whale, the world's largest animal, to the brink of biological extinction. Fully grown, the blue whale is longer than three railroad boxcars and weighs more than 25 adult elephants. The adult has a heart the size of a compact car, and some of its arteries are big enough for a child to swim through.

Before commercial whaling began, an estimated 250,000 blue whales roamed the Antarctic Ocean. Today, there are 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 species to recover.

In 1946, the International Convention for the Regulation of Whaling established the International Whaling Commission (IWC). Its mission was to regulate the whaling industry by setting annual quotas to prevent overharvesting and commercial extinction. But IWC quotas often were based on inadequate data or were ignored by whaling countries. Without powers of enforcement, 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, the U.S. government, and governments of many nonwhaling countries, the IWC imposed a moratorium on commercial whaling starting in 1986. It worked. The estimated number of whales killed commercially worldwide dropped from 42,480 in 1970 to about 1,300 in 2008. However, despite the ban, more than 27,000 whales were hunted and killed between 1986 and 2008.

GOOD NEWS

Japan hunts and kills at least 1,000 minke and fin whales each year for what it calls "scientific purposes." Critics see this annual whale hunt as poorly disguised commercial whaling, because the whale meat is sold to restaurants. Each whale is worth up to $30,000 wholesale. Norway (Figure 8-19) and Iceland openly defy the international ban on commercial whaling and export much of their catch to Japan.

Tony Martin/WWI Peter Arnold, Inc.

Figure 8-19 Norwegian whalers harpooning a sperm whale. Norway and Japan kill up to 2,000 whales a year. They believe that increased but sustainable commercial whaling should be allowed for sperm, minke, and pilot whales whose stocks have built back to large numbers.

Japan, Norway, Iceland, Russia, and a growing number of small tropical island countries—which Japan brought into the IWC to support its position—hope to overthrow the IWC ban on commercial whaling and reverse the international ban on buying and selling whale products. They contend that the ban is emotionally motivated and not supported by current scientific estimates of populations of sperm, pilot, and minke whales, which have increased since the moratorium.

Most conservationists disagree. Some argue that whales are peaceful, intelligent, sensitive, and highly social mammals that should be protected for ethical reasons. Others question IWC estimates of the allegedly recovered whale species, noting the inaccuracy of such estimates in the past and the inability of the IWC to enforce quotas. And many conservationists fear that opening the door to any commercial whaling may weaken international disapproval and legal sanctions against it and eventually lead to widespread harvests of most whale species.

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/biology/miller**.

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, to help protect birds such as the brown pelican (See Photo 3 in the Detailed Contents) from extinction. 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. 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 8-4**). These areas have helped Florida's key deer, the brown pelican, and the trumpeter swan to recover. According to a General Accounting Office study, however, 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. And a 2008 study prepared for Congress, found that, for years, the country's wildlife refuges have been so underfunded that a third of them have no staff and boardwalks and buildings are in disrepair.

Biodiversity scientists call for setting aside more refuges for endangered plants and significantly increasing the long-neglected budget for the refuge system. They also urge Congress and 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.

Some species cannot be preserved in gene banks. The banks are also 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 and will not be vulnerable to power losses, fires, storms, or war.

The world's 1,600 *botanical gardens* and *arboreta* contain living plants, representing 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 on *farms* for commercial sale. Farms in Florida raise alligators for their meat and hides. Butterfly farms flourish in Papua New Guinea, where many butterfly species are threatened by development activities.

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 captured 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 (Case Study, p. 174).

The ultimate goal of captive breeding programs is to build up populations to a level where they can be reintroduced into the wild. But most reintroductions fail because of lack of suitable habitat, inability of individuals bred in captivity to survive in the wild, renewed overhunting, or poaching of some of the returned individuals.

Limited space and money restricts efforts to maintain breeding populations of endangered animal species in zoos and research centers. The captive population of each species must number 100–500 individuals

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 8-20 **Individuals matter:** you can help prevent premature extinction of species. **Question**: Which two of these actions do you believe are the most important? Why?

for them 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 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.

Thus, zoos, aquariums, and botanical gardens by themselves are not biologically or economically feasible solutions for the growing problem of premature extinction of species. Figure 8-20 lists some things you can do to help deal with this problem.

CASE STUDY

Trying to Save the California Condor

At one time the California condor (Figure 8-3), North America's largest bird, was nearly extinct with only 22 condors remaining in the wild. One approach to saving the species was to capture the remaining birds and breed them in captivity at zoos.

All 22 birds were captured and isolated from human contact as much as possible. To reduce genetic defects, closely related individuals were prevented from breeding. As they gradually recovered, they were released a few at a time. As of 2009, 167 condors were flying free in the wild, with more than 80 of them located in California.

These birds are greatly threatened by lead poisoning, which they get when they ingest lead pellets from ammunition in animal carcasses or gut piles left behind by hunters. 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 have lobbied state game commissions and legislatures to ban the use of lead in ammunition and to require use of less harmful substitutes. They also urge people who hunt in condor ranges to remove all killed animals or to hide carcasses and gut piles by burying them, covering them with brush or rocks, or putting them in inaccessible areas.

THINKING ABOUT
The California Condor's Comeback

What are some differences between the stories of the condor and the passenger pigeon (Case Study, p. 155) that might give the condor a better chance of avoiding premature extinction than the passenger pigeon had?

The Precautionary Principle

Biodiversity scientists call for us to take precautionary action to help *prevent* premature extinctions and 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 established scientifically. It is based on the commonsense idea behind many adages such as "Better safe than sorry," and "Look before you leap."

Scientists use the precautionary principle to argue for preservation of species, and also for preserving entire ecosystems, which is the focus of the next chapter. It 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:

- How do we allocate limited resources between protecting species and protecting their habitats?
- How do we decide which species should get the most attention in our efforts to protect species? For example, should we focus on protecting the most threatened species or on protecting keystone and foundation species? Protecting *charismatic species* such as orangutans (Figure 8-6) and tigers can increase public awareness of the need for wildlife conservation. But some argue that we should instead protect more ecologically important endangered species.
- How do we determine which areas of land and water are the most critical to protect?

This chapter's *three big ideas* are:

- We are greatly increasing the premature extinction of wild species by destroying and degrading their habitats, introducing harmful invasive species, and increasing human population growth, pollution, contributions to projected climate change, and overexploitation.
- We should prevent the premature extinction of wild species because of the economic and ecological services they provide and because they have a right to exist regardless of their usefulness to us.
- We can work to prevent the premature 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 premature extinction resulting 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—which supports all life and economies.

Yet, despite these efforts, there is overwhelming evidence that we are in the midst of wiping out as many as half of the world's wild species within your lifetime, including the polar bear (**Core Case Study**). Ecological ignorance accounts for some of the failure to deal with this problem. But many argue that the real cause 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 premature extinction of species helps to preserve the earth's biodiversity, energy flow, and matter cycling in ecosystems. Thus it is not only for the species that we ought to act, but also for the overall long-term health of the biosphere, on which we all depend, and 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 climate change, which will affect the polar bear (**Core Case Study**) and many other species and their habitats. And it will require reducing the size and impact of our ecological footprints (Figure 1-5, p. 11).

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 QUESTIONS

1. Review the Key Questions and Concepts for this chapter on p. 153. Describe how human activities threaten polar bears in the Arctic.
2. Distinguish between background extinction and mass extinction. How can the extinction of a species affect other species and ecosystem services? Describe how scientists estimate extinction rates. Give four reasons why many extinction experts believe that human activities are now causing a sixth mass extinction. Distinguish between **endangered species** and **threatened species** and give an example of each. List some characteristics that make some species especially vulnerable to extinction. Describe the extinction of the passenger pigeon in North America.
3. What are two reasons for trying to prevent the premature extinction of wild species? Distinguish between the **instrumental value** and the **intrinsic** (**existence**) **value** of a species.
4. What are the four underlying causes of premature species extinction? What is **HIPPCO**? In order, what are the six largest direct causes of premature extinction of species resulting from human activities? Describe the major effects of habitat loss and fragmentation.
5. Describe the threats to bird species in the world and in the United States. List three reasons why many experts are alarmed by the decline of many bird species.

6. Give two examples of the benefits of introducing some nonnative species and two examples of the harmful effects of nonnative species that have been introduced **(a)** deliberately and **(b)** accidentally. List ways to limit the harmful impacts of nonnative species. Describe the roles of population growth, overconsumption, pollution, and climate change in the premature extinction of wild species. Describe what is happening to many of the honeybees in the United States, and list possible causes of the drop in honeybee populations. What economic and ecological roles do honeybees play? Explain how pesticides such as DDT can be biomagnified in food chains and webs. How is global warming threatening polar bears and many of the world's penguin species?

7. Describe the poaching of wild species and give three examples of species that are threatened by this illegal activity. Why are tigers likely to disappear by the end of this century? Describe the threat to some forms of wildlife from increased hunting for bush meat.

8. Describe two international treaties that are used to help protect species. Describe the U.S. Endangered Species Act, how successful it has been, and the controversy over this act. Describe efforts to protect sea turtles and whales from premature extinction by human activities.

9. Describe the roles and limitations of wildlife refuges, gene banks, botanical gardens, wildlife farms, zoos, and aquariums in protecting some species. What is the **precautionary principle** and how can it be used to help protect wild species and overall biodiversity?

10. What are this chapter's *three big ideas*? Describe how the three **principles of sustainability** are related to protecting wild species from premature extinction and to protecting 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 premature extinction 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, and that the polar bear (**Core Case Study**) and 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, "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?

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 their 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? Can you come up with a compromise?

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 premature extinction, caused by human activities, 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 ANALYSIS

Examine these data on threatened bird species in various countries 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.cengage.com/biology/miller** and choose Chapter 8 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, web links, information on Green Careers, and InfoTrac® College Edition articles.

CENGAGENOW™ For students with access, log on at **www.cengage.com/login** for the animations, active figures, activities, and readings indicated within the text by the CengageNOW logo. If your textbook did not come with access, visit **www.iChapters.com** to purchase.

9 Sustaining Biodiversity: The Ecosystem Approach

CORE CASE STUDY Wangari Maathai and the Green Belt Movement

In the mid-1970s, Wangari Maathai (Figure 9-1) 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.

United Nations Environment Programme

Figure 9-1 Wangari Maathai was the first Kenyan woman to earn a Ph.D. 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, she has received many honors, including 13 honorary doctorate degrees, the Goldman Environmental Prize, the U.N. Africa Prize for Leadership, induction into the International Womens' 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 and still serves in this position.

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 has established 6,000 village nurseries and planted and protected more than 30 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. And the trees improve the environment by reducing soil erosion, providing shade and beauty, and helping to slow projected climate change by removing CO_2 from the atmosphere.

GOOD NEWS

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 9-1), 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. Wangari 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* (Figure 4-2, p. 61) has emerged as one of the most important integrative principles 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 the services they provide that sustain biodiversity. This chapter is devoted to helping us understand the threats to the earth's forests, grasslands, coral reefs, oceans, and other storehouses of terrestrial and aquatic biodiversity, and to seeking ways to help sustain these vital ecosystems.

SUSTAINABILITY

Key Questions and Concepts

9-1 What are the major threats to forest ecosystems?

CONCEPT 9-1 Ecologically valuable forest ecosystems are being cut and burned at unsustainable rates in many parts of the world.

9-2 How should we manage and sustain forests?

CONCEPT 9-2 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.

9-3 How should we manage and sustain grasslands?

CONCEPT 9-3 We can sustain the productivity of grasslands by controlling the number and distribution of grazing livestock and by restoring degraded grasslands.

9-4 How should we manage and sustain parks and nature reserves?

CONCEPT 9-4 We need to put more resources into sustaining existing parks and nature reserves and into protecting much more of the earth's remaining undisturbed land area.

9-5 How can we help to sustain terrestrial biodiversity?

CONCEPT 9-5 We can help to sustain terrestrial biodiversity by identifying and protecting severely threatened areas (biodiversity hotspots), rehabilitating damaged ecosystems (using restoration ecology), and sharing with other species much of the land we dominate (using reconciliation ecology).

9-6 How can we help to sustain aquatic biodiversity?

CONCEPT 9-6 We can help to sustain aquatic biodiversity by establishing protected sanctuaries, managing coastal development, reducing water pollution, and preventing overfishing.

Note: Supplements 2 (p. S3), 4 (p. S14), 5 (p. S21), and 9 (p. S38) can be used with this chapter.

Forests precede civilizations; deserts follow them.

FRANCOIS-AUGUSTE-RENÉ DE CHATEAUBRIAND

9-1 What Are the Major Threats to Forest Ecosystems?

▶ **CONCEPT 9-1 Ecologically valuable forest ecosystems are being cut and burned at unsustainable rates in many parts of the world.**

Forests Vary in Their Age, Make-Up, and Origins

Natural and planted forests occupy about 30% of the earth's land surface (excluding Greenland and Antarctica). Figure 7-8 (p. 128) shows the distribution of the world's boreal, temperate, and tropical forests.

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** is an uncut or regenerated primary forest that has not been seriously disturbed by human activities or natural disasters for several hundred years or more (Figure 9-2, p. 180). Old-growth forests are reservoirs of biodiversity because they provide ecological niches for a multitude of wildlife species (Figure 7-16, p. 136, and Figure 7-17, p. 137).

A **second-growth forest** is a stand of trees resulting from secondary ecological succession (Figure 5-11, p. 90, and Figure 7-15, center photo, p. 135). These forests develop after the trees in an area have been removed by human activities such as clear-cutting for 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 9-3, p. 180) is a managed tract with uniformly aged trees of one or two genetically uniform species that usually are 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

Kevin Schafer/Peter Arnold, Inc.

Figure 9-2 **Natural capital:** an old-growth forest in the U.S. state of Washington's Olympic National Forest.

their owners' profits. Some analysts project that eventually tree plantations may supply most of the world's demand for industrial wood and thus 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**. And repeated cycles of cutting and replanting eventually deplete the soil of nutrients and lead to an irreversible ecological tipping point that hinders the regrowth of any type of forest in such areas.

Forests Provide Important Economic and Ecological Services

Forests provide highly valuable ecological and economic services (Figure 9-4 and **Concept 9-1**). For example, through photosynthesis, forests remove CO_2 from the atmosphere and store it in organic compounds (biomass). By performing this ecological service, forests help to stabilize the earth's temperature and slow projected climate change as a part of the global carbon cycle (Figure 3-13, p. 51, and **Core Case Study**). 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, right).

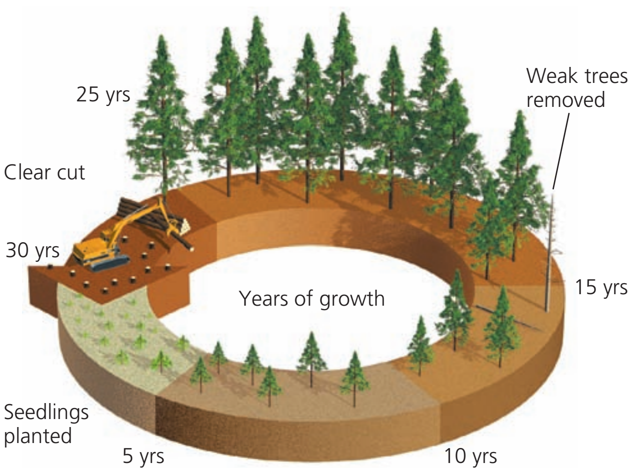
CORE CASE STUDY

RESEARCH FRONTIER

Refining estimates of the economic values of the ecological services provided by forests and other major ecosystems. See **www.cengage.com/biology/miller**.

There Are Several Ways to Harvest Trees

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 (Fig-



SuperStock

Figure 9-3 Short (25- to 30-year) rotation cycle of cutting and regrowth of a monoculture tree plantation in modern industrial forestry. In tropical countries, where trees can grow more rapidly year-round, the rotation cycle can be 6–10 years. Old-growth or second-growth forests are clear-cut to provide land for growing most tree plantations (see photo, right). **Question**: What are two ways in which this process can degrade an ecosystem?

ure 9-5, p. 182)—namely, increased erosion and sediment runoff into waterways, habitat fragmentation, and loss of biodiversity. 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 vehicle users.

Once loggers reach a forest area, they use a variety of methods to harvest the trees (Figure 9-6, p. 182). With *selective cutting,* intermediate-aged or mature trees in an uneven-aged forest are cut singly or in small groups (Figure 9-6a). But often, loggers remove all the trees from an area in what is called a *clear-cut* (Figures 9-6b and 9-7, p. 182).

CONNECTIONS

Clear-Cutting and Loss of Biodiversity

Scientists found that removing all the tree cover from a watershed greatly increases water runoff and loss of soil nutrients (Chapter 2 Core Case Study, p. 23, and Figure 2-3, p. 30). This increases soil 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.

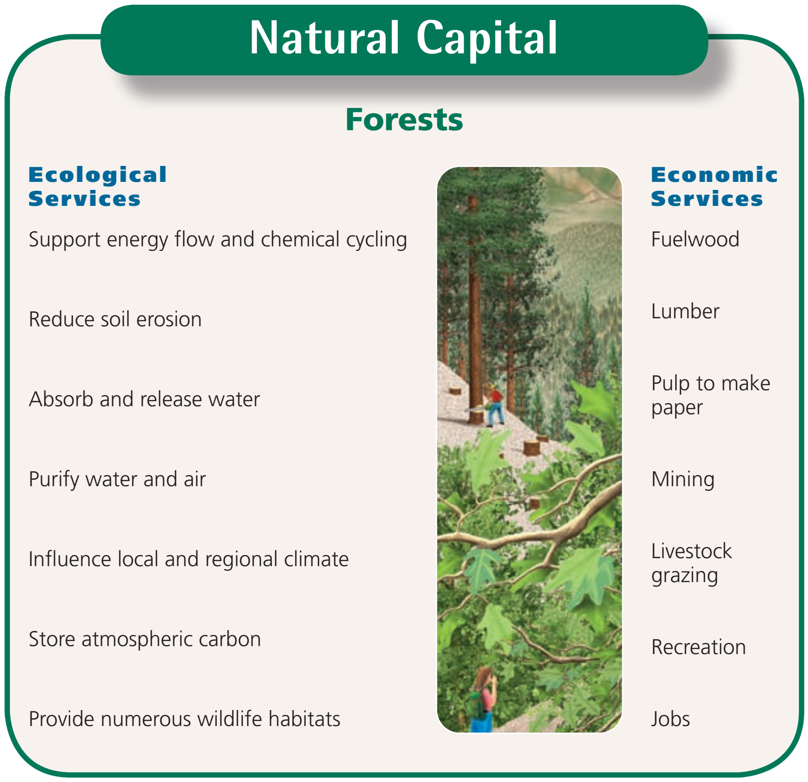


Figure 9-4 Major ecological and economic services provided by forests (**Concept 9-1**). **Question**: Which two ecological services and which two economic services do you think are the most important?

SCIENCE FOCUS

Putting a Price Tag on Nature's Ecological Services

Currently, forests and other ecosystems are valued mostly for their economic services (Figure 9-4, right). But suppose we took into account the monetary value of the ecological services provided by forests (Figure 9-4, 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 and the biological income they provide. They estimated the latter 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 amount of money required to provide such interest income—and thus the estimated value of the world's natural capital—would have to be at least \$500 trillion—an average of about \$73,500 for each person on earth!

According to this 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. And these are very conservative estimates.

Some of Costanza team's estimates for forests are shown in Figure 9-A. Note that the collective estimated value of these ecosystem services is much greater than the value of timber and other raw materials extracted from forests.

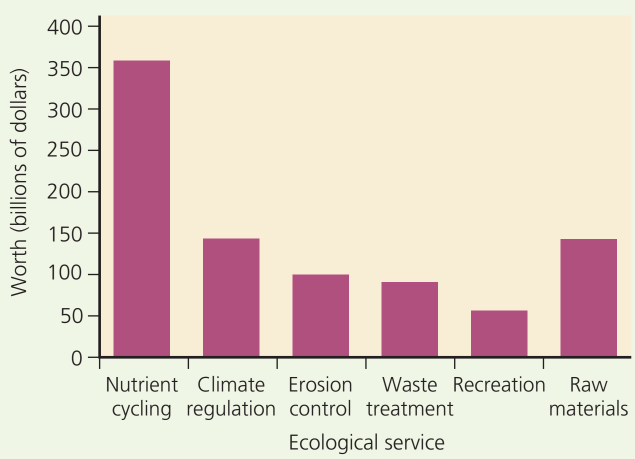


Figure 9-A Estimated annual global economic values of some ecological services provided by forests compared to the raw materials they produce (in billions of dollars).

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; their economic value is huge; and they are an ongoing source of ecological income, as long as they are used sustainably.

However, unless estimated values of these ecological services are included in the market prices of goods and services, through market tools such as regulations, taxes, and subsidies that encourage protection of biodiversity, the world's forests and other ecosystems will continue to be degraded.

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?

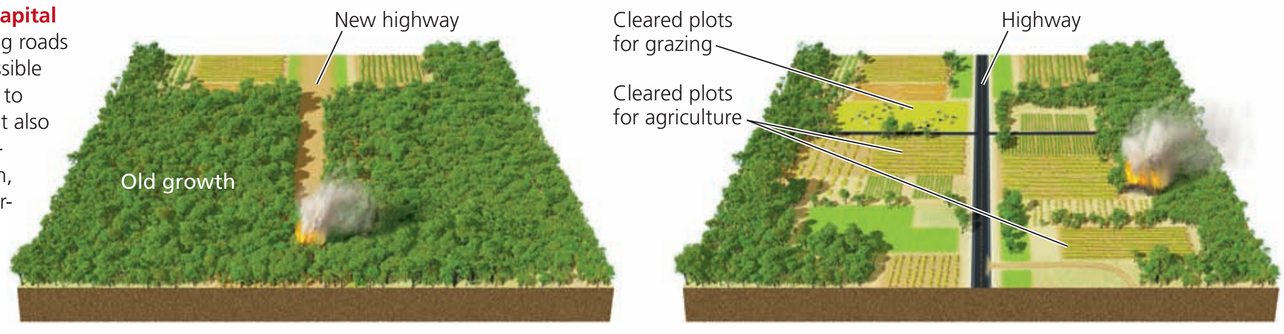


Figure 9-5 **Natural capital degradation:** Building roads into previously inaccessible forests is the first step to providing timber, but it also paves the way to fragmentation, destruction, and degradation of forest ecosystems.

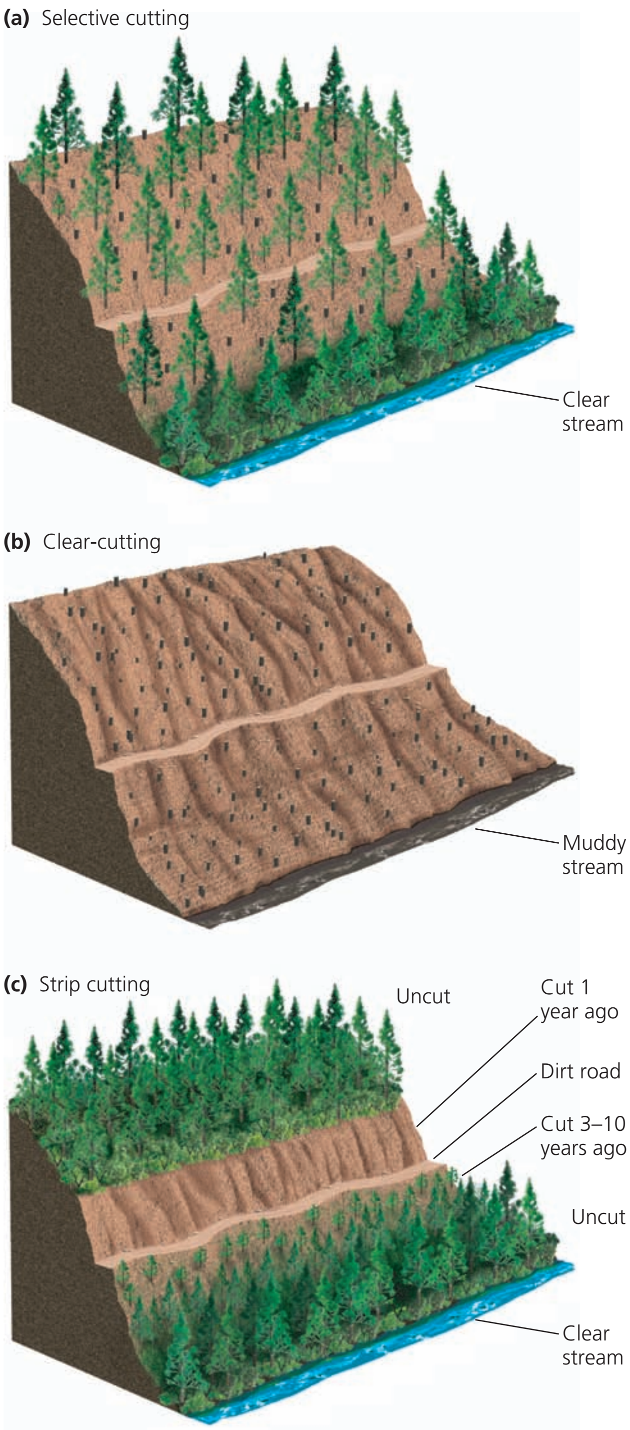


Figure 9-6 Major tree harvesting methods. **Question**: If you were cutting trees in a forest you owned, which method would you choose and why?

Daniel Dancer/Peter Arnold, Inc.

Figure 9-7 Clear-cut logging in the U.S. state of Washington.

CENGAGENOW™ Learn more about how deforestation can affect the drainage of a watershed and disturb its ecosystem at CengageNOW.

A variation of clear-cutting that allows a more sustainable timber yield without widespread destruction is *strip cutting* (Figure 9-6c). It involves clear-cutting a strip of trees along the contour of the land within a corridor narrow enough to allow natural regeneration within a few years. After regeneration, loggers cut another strip next to the first, and so on.

Fire Can Threaten and Benefit Forest Ecosystems

Two types of fires can affect forest ecosystems. *Surface fires* (Figure 9-8, 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 and help to prevent more destructive fires. They also free valuable mineral nutrients tied up in slowly decomposing litter and undergrowth; release seeds from the cones of lodgepole pines; stimulate the germination of certain tree seeds such as those of the giant sequoia and jack pine; and help to control tree diseases and insects. Wildlife species such as deer, moose, muskrat, and quail depend on occasional surface fires to maintain their habitats and provide food in the form of vegetation that sprouts after fires.

Another type of fire, called a *crown fire* (Figure 9-8, 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.

CONNECTIONS

Climate Change and Forest Fires

Rising temperatures and increased drought from projected climate change 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, which would further increase atmospheric temperatures and cause even more forest fires in a spiraling cycle of increasingly harmful changes.

We Have Cut Down Almost Half of the World's Forests

Deforestation is the temporary or permanent removal of large expanses of forest for agriculture, settlements, or other uses (Figure 9-9, p. 184). Surveys by the World

David J. Moorhead/The University of Georgia

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Figure 9-8 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 set deliberately to prevent buildup of flammable ground material in forests. They 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?

S. Chamnanrith-UNEP/Peter Arnold, Inc.

Figure 9-9 Natural capital degradation: extreme tropical deforestation in Chiang Mai, Thailand. Such clearing of trees, which absorb carbon dioxide as they grow, contributes to projected climate change. It also dehydrates the soil 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 be reestablished in the area.

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.

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 9-4, left), but it also has a number of harmful environmental effects (Figure 9-4, right and Figure 9-10).

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 9-10 Harmful environmental effects of deforestation, which can reduce biodiversity and the ecological services provided by forests (Figure 9-4, left). **Question**: What are three products you have used recently that might have come from old-growth forests?

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/biology/miller**.

In some countries, there is encouraging news about forest use. In 2007, the U.N. Food and Agriculture Organization (FAO) reported that the net total forest cover in several countries, including the United States (see the following Case Study), changed very little or increased between 2000 and 2007. Some of the increases resulted from natural reforestation by secondary ecological succession on cleared forest areas and abandoned croplands. Other increases in forest cover are 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 Study**) and her Green Belt Movement is very encouraging to many scientists. Some scientists, however, are concerned about the growing amount of land occupied by commercial forests, because replacement of old-growth forests by these 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 that cover about 30% of the U.S. land area provide habitats for more than 80% of the country's wildlife species and supply about two-thirds of the nation's surface water. 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 (Figure 5-11, p. 90).

GOOD NEWS

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 9-2) 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**. And harvesting tree plantations too frequently depletes forest soils of key nutrients. Many biodiversity researchers favor establishing tree plantations only on land that has already been degraded instead of cutting existing old-growth and second-growth forests and replacing them with tree plantations.

Tropical Forests Are Disappearing Rapidly

Tropical forests (Figure 7-15, top photo, p. 135) cover about 6% of the earth's land area—roughly the area of the lower 48 U.S. 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 tropical forest has taken place since 1950 (Chapter 3 Core Case Study, p. 39).

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 9-9), and South America (Figure 3-1, p. 39). Studies indicate that at least half of the world's known species of terrestrial plants and animals live in tropical forests. Because of their specialized niches (Figure 7-17, p. 137, and **Concept 4-6**, p. 71) these species are highly vulnerable to extinction when their forest habitats are destroyed or degraded.

CORE CASE STUDY

CONCEPT LINK

Brazil, for example, has more than 30% of the world's remaining tropical rain forest 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 had been deforested or degraded increased from 1% in 1970 to about 20% by 2008, mostly to make way for cattle ranching and large plantations of crops such as soybeans used for cattle feed.

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 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.

Many forest experts acknowledge this regrowth. However, they point out that these second-growth tropical forests do not have the biological diversity—especially the diversity of animals—or the important uninterrupted expanses of old-growth tropical forests. These scientists applaud the return of second-growth forests and the planting of tree farms on degraded forestland. But they warn that this should not be used as an excuse for scaling back efforts to strictly protect the world's remaining old-growth forests. They note that these forests, especially in tropical areas, harbor biodiversity that could not be regenerated in second-growth or commercial forests, simply because it took many millions of years to evolve along with the old-growth tropical forests.

Because of difficulties in estimating tropical forest loss, yearly estimates of global tropical deforestation vary widely from 50,000 square kilometers (19,300 square miles)—roughly the size of Costa Rica or the U.S. state of West Virginia—to 170,000 square kilometers (65,600 square miles)—about the size of the South American country of Uruguay or the U.S. state of Florida. At such rates, half of the world's remaining tropical old-growth forests will be gone or severely degraded in 35–117 years, resulting in a dramatic loss of biodiversity and degradation of ecosystem services.

RESEARCH FRONTIER

Improving estimates of rates of tropical deforestation and forest regrowth. See **www.cengage.com/biology/miller**.

Causes of Tropical Deforestation Are Varied and Complex

Tropical deforestation results from a number of interconnected basic and secondary causes (Figure 9-11, p. 186). Pressures of population growth and poverty

Natural Capital Degradation

Major Causes of the Destruction and Degradation of Tropical Forests

Basic Causes

- Not valuing ecological services
- Crop and timber exports
- Government policies
- Poverty
- Population growth

Secondary Causes

- Roads
- Fires
- Settler farming
- Cash crops
- Cattle ranching
- Logging
- Tree plantations

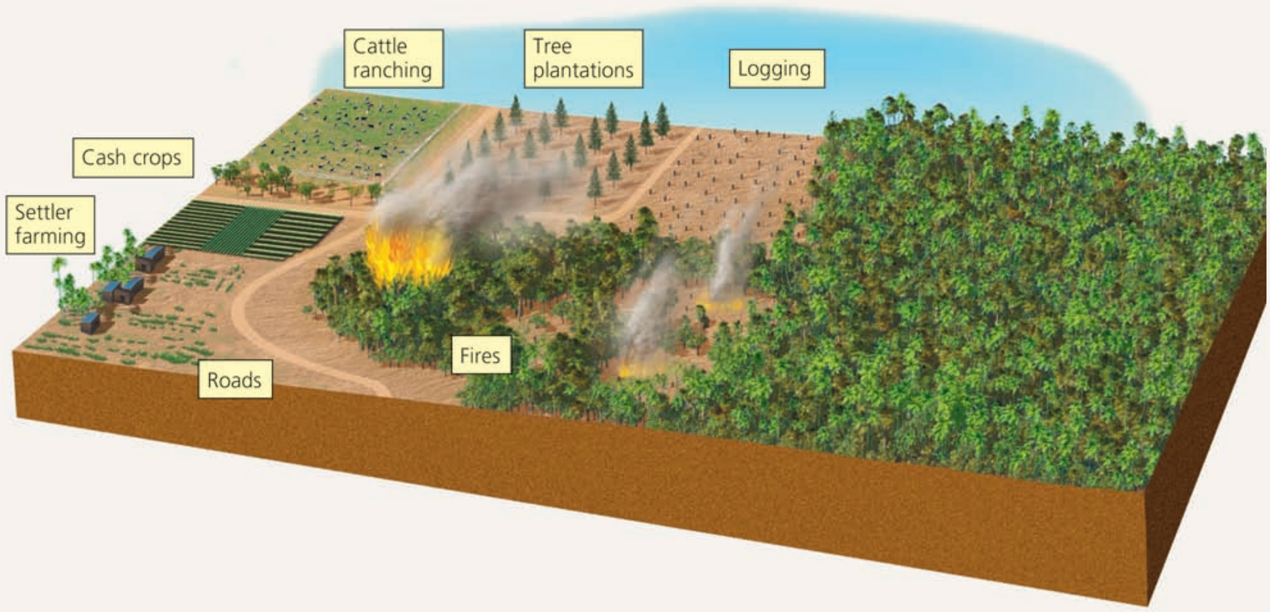


Figure 9-11 *Major interconnected causes* of the destruction and degradation of tropical forests. The importance of specific secondary causes varies in different parts of the world. **Question**: If we could eliminate the basic causes, which if any of the secondary causes might automatically be eliminated?

push subsistence farmers and the landless poor into tropical forests, where they try to grow enough food to survive. Government subsidies can accelerate deforestation by reducing the costs of timber harvesting, cattle grazing, and establishing vast plantations of crops such as soybeans and oil palms.

The degradation of a tropical forest usually begins when a road is cut deep into the forest interior for logging and settlement (Figure 9-5). Loggers then use selective cutting (Figure 9-6a) 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 caused by using a match or a chainsaw to burn or clear-cut areas of such forests to make way for cattle ranches or crop plantations.

The secondary causes of deforestation (Figure 9-11) vary in different tropical areas. Tropical forests in the Amazon and other South American countries are cleared or burned mostly for cattle grazing and large soybean plantations. In Indonesia, Malaysia, and other areas of Southeast Asia, tropical forests are being replaced with vast plantations of oil palm, whose oil is used in cooking, cosmetics, and biodiesel fuel for motor vehicles (especially in Europe). In Africa, people struggle to survive by clearing plots for small-scale farming and by harvesting wood for fuel, which is causing deforestation on that continent. However, women in the Green Belt Movement (**Core Case Study**) have helped to reestablish forest areas in several African countries.

CORE CASE STUDY

A 2005 study by forest scientists found that widespread fires in the Amazon basin (Figure 9-12) are changing weather patterns by raising temperatures and

Herbert Giradet/Peter Arnold, Inc.

Figure 9-12 **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, 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?

reducing rainfall. This is converting large deforested areas of tropical forests to tropical grassland (savanna)—another example of 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, which is projected to warm the atmosphere and change the global climate at an increasing rate during this century. Scientists estimate that, globally, these fires account for at least 20% 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 (Figure 9-12) accounts for three-fourths of Brazil's greenhouse gas emissions, making Brazil the world's fourth largest emitter of such gases. And with these forests gone, even if they are replaced by savannah or second-growth forests, far less CO_2 will be absorbed for photosynthesis, which will accelerate climate change.

Foreign corporations operating under government concession contracts do much of the logging in tropical countries. After the best timber has been removed, the companies typically move on to another country, and they or the local government often sell the land to ranchers who burn it 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 crops such as soybeans or to settlers who have migrated to tropical forests hoping to grow enough food to survive. After a few years of crop growing and erosion from rain, the already nutrient-poor soil is depleted of nutrients. Then the farmers and settlers move on to newly cleared land to repeat this environmentally destructive process.

The Philippines and the African country of Nigeria are two nations that have lost most of their once-abundant tropical hardwood forests in this way. Both countries are now net importers of forest products. Several other tropical countries are following this ecologically and economically unsustainable path.

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 you might have?

9-2 How Should We Manage and Sustain Forests?

▶ **CONCEPT 9-2 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 9-13 lists ways to achieve this goal (**Concept 9-2**). Certification of sustainably grown timber and of sustainably produced forest products can help consumers to play their part in reaching the goal (Science Focus, below). Removing government subsidies and tax breaks that encourage deforestation would also help. (See the Guest Essay by Norman Myers on such *perverse subsidies* at CengageNOW™.) And massive tree planting programs such as those run by the Green Belt Movement (**Core Case Study**) and the United Nations help to restore degraded forests. **GREEN CAREER:** Sustainable forestry (See website career information on Forester.)

CORE CASE STUDY

Solutions

Sustainable Forestry

- Identify and protect forest areas high in biodiversity
- Rely more on selective cutting and strip cutting
- No clear-cutting on steep slopes
- No logging of old-growth forests
- Sharply reduce road building into uncut forest areas
- Leave most standing dead trees and fallen timber for wildlife habitat and nutrient recycling
- Plant tree plantations primarily on deforested and degraded land
- Certify timber grown by sustainable methods
- Include ecological services of forests in estimating their economic value

Figure 9-13 Ways to grow and harvest trees more sustainably (**Concept 9-2**). **Questions**: Which three of these solutions do you think are the most important? Why?

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 (Figure 9-8, right) by allowing accumulation of highly flammable underbrush and smaller trees in some forests.

SCIENCE FOCUS

Certifying Sustainably Grown Timber

Collins Pine 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) has evaluated the company's timber production. SCS, which is part of the nonprofit Forest Stewardship Council (FSC), was formed to develop a list of environmentally sound practices for use in certifying timber and products made from such timber.

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; soils are not 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.

According to the FSC, by 2008 about 8% of the world's forest area had been certified by international standards. The countries with the largest areas of FSC-certified forests are, in order, Canada, Russia, Sweden, the United States, Poland, and Brazil. The paper used in this book was produced by sustainably grown timber, as certified by the FSC, and contains recycled paper.

Critical Thinking

Should governments provide tax breaks for sustainably grown timber to encourage this practice? Explain.

Ecologists and forest fire experts have proposed several strategies for reducing fire-related harm to forests and people. One approach is to set small, contained surface fires to remove flammable small trees and underbrush in the highest-risk forest areas. Such *prescribed fires* require careful planning and monitoring to keep them from getting out of control.

A second strategy is to allow many 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 flammable materials such as wooden roofs.

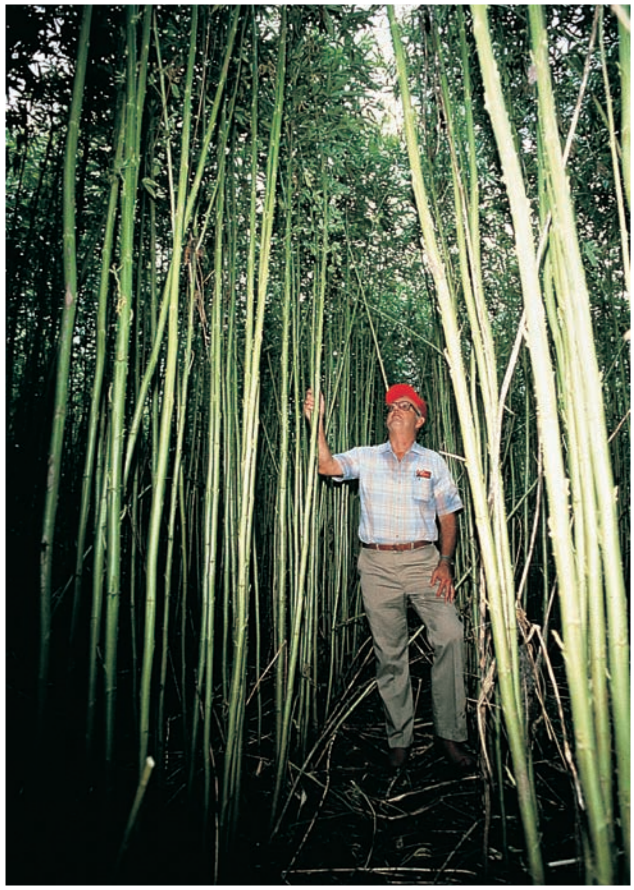
A fourth approach is to thin forest areas vulnerable to fire by clearing away small fire-prone trees and underbrush under careful environmental controls. Many forest fire scientists warn that such thinning should not involve removing economically valuable medium-size and large trees for two reasons. *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*, or brush and deadwood left over after thinning. Many of the worst fires in U.S. history—including some of those during the 1990s—burned through cleared forest areas containing 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.

Proponents of these strategies argue that healthier forests could be maintained at a relatively low cost to taxpayers by giving grants to communities in fire-prone areas to help them implement the strategies.

We Can Reduce the Demand for Harvested Trees

One way to reduce the pressure on forest ecosystems is to sharply reduce wood waste. According to the Worldwatch Institute and 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 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 9-14). Kenaf and other nontree fibers such as hemp yield more paper pulp per hectare than tree farms do and require fewer pesticides and herbicides.



U.S. Department of Agriculture.

Figure 9-14 **Solutions:** 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.

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 alternative sources.

GOOD NEWS

Ways to Reduce Tropical Deforestation

Analysts have suggested various ways to protect tropical forests and use them more sustainably (Figure 9-15, p. 190).

One approach is a *debt-for-nature swap*, which 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. Another similar approach is to allow corporations and countries that emit large amounts of greenhouse gases such as CO_2, to help offset such emissions by protecting CO_2-absorbing old-growth forests in tropical and other areas.

Another way to use tropical forests more sustainably is to use strip cutting (Figure 9-6c) to harvest tropical trees for lumber. Loggers can also be more careful when cutting individual trees. For example, cutting canopy vines (lianas) before felling a tree and using the least obstructed paths to remove the logs can sharply reduce damage to neighboring trees.

GOOD NEWS

Individuals can plant trees—a powerful example of the idea that all sustainability is local. In 2007, efforts by Wangari Maathai (**Core Case Study**) and the U.N. Environment Programme (UNEP) led to the planting of 2 billion trees in 155 countries, with Ethiopia, Turkey, Mexico, and Kenya planting more than 70% of these trees. In 2008, the UNEP set a goal of planting an additional 5 billion trees. As of mid-2009, more than 3.1 billion had been planted (see **www.unep.org**).

CORE CASE STUDY

Finally, each of us can use substitutes for wood such as bamboo and building materials made from recycled plastic or recycled waste lumber (marketed by companies such as TerraMai and EcoTimber). We can also buy only lumber and wood products that are certified as sustainably produced (Science Focus, p. 188).

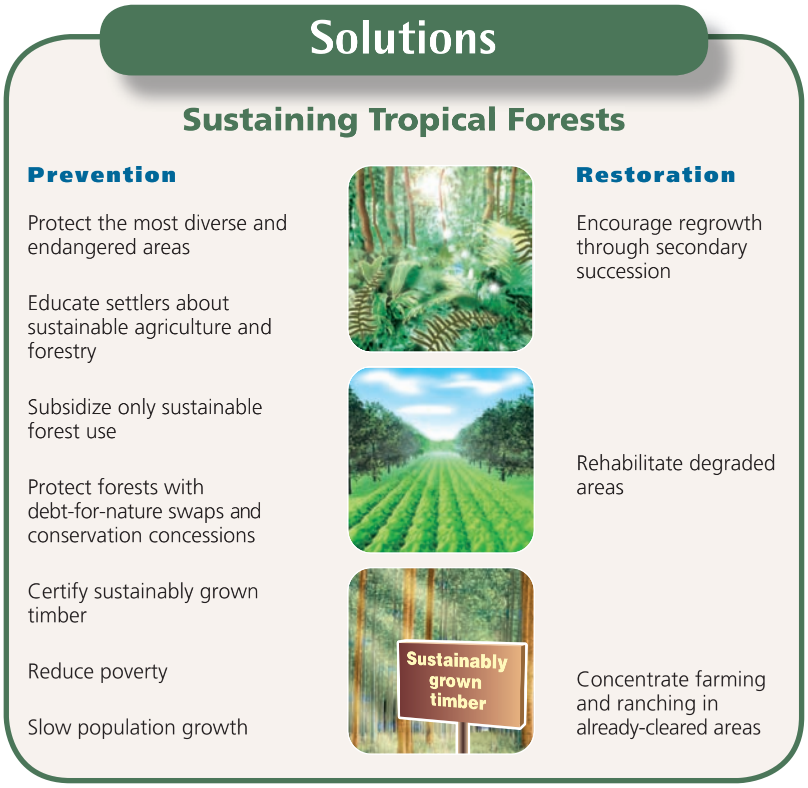


Figure 9-15 Ways to protect tropical forests and use them more sustainably (**Concept 9-2**). **Questions**: Which three of these solutions do you think are the most important? Why?

9-3 How Should We Manage and Sustain Grasslands?

▶ **CONCEPT 9-3 We can sustain the productivity of grasslands by controlling the number 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, nutrient cycling, storage of atmospheric carbon dioxide in biomass, and maintenance of biodiversity.

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 enclosed meadows usually planted with domesticated grasses or other forage.

Blades of rangeland grass grow from the base, not at the tip. So 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. However, **overgrazing** occurs when too many animals graze for too long and exceed the carrying capacity of a rangeland area (Figure 9-16, left). It 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 enhances invasion 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 a loss in productivity in as much as a fifth of the world's rangeland.

We Can Manage Rangelands More Sustainably

The most widely used method for more sustainable management of rangeland 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 9-3**). One way of doing this is *rota-*

Figure 9-16 **Natural capital degradation:** overgrazed (left) and lightly grazed (right) rangeland.

tional 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.

Livestock 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 9-17, left). Protecting overgrazed land from further grazing by moving livestock around and by fencing off these areas eventually leads to its natural ecological restoration by ecological succession (Figure 9-17, right). Ranchers can also move cattle around by providing supplemental feed at selected sites and by strategically locating water holes and tanks and salt blocks.

GOOD NEWS

A more expensive and less widely used method of rangeland management is to suppress the growth of unwanted invader plants by 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 livestock.

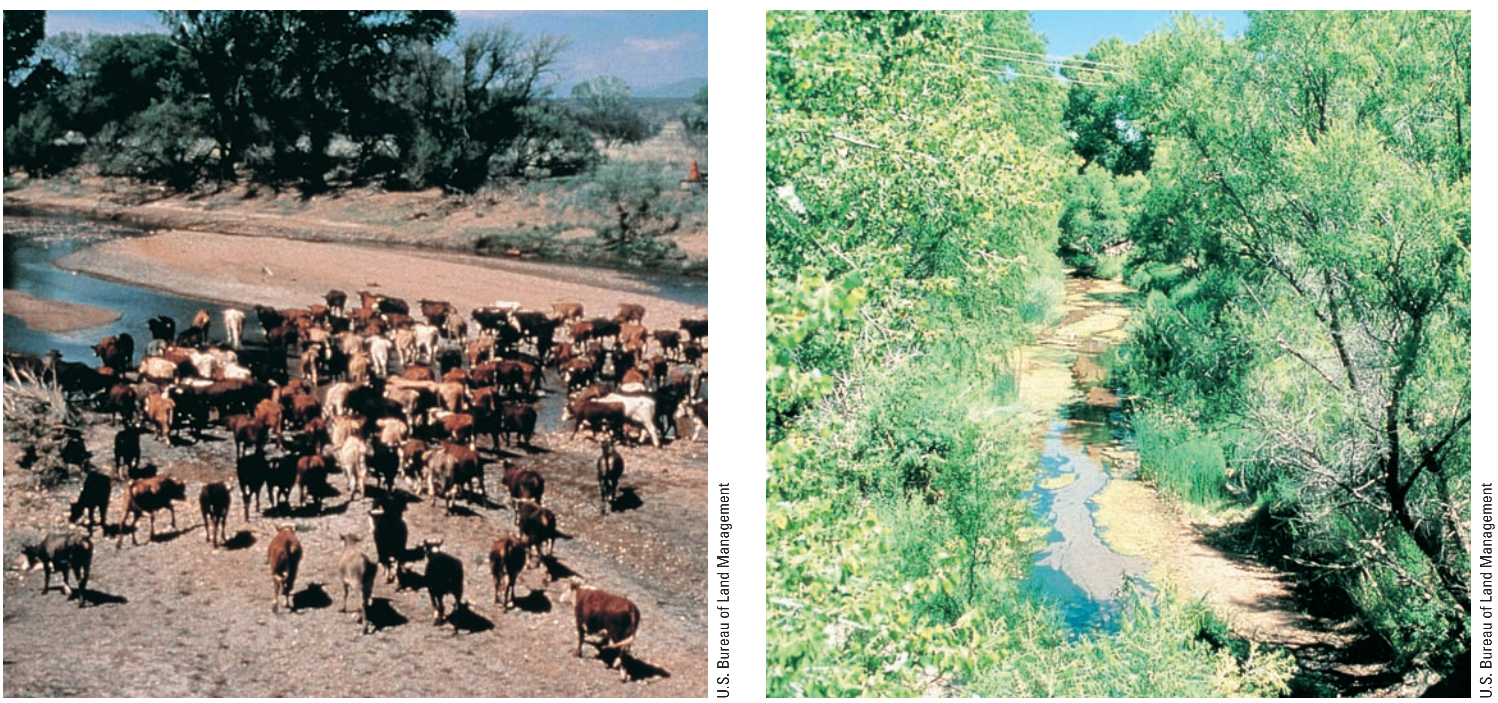


Figure 9-17 **Natural capital restoration:** in the mid-1980s, cattle had degraded the vegetation and soil on this stream bank along the San Pedro River in the U.S. state of Arizona (left). Within 10 years, the area was restored through natural regeneration (right) after grazing and off-road vehicle use were banned (**Concept 9-3**).

9-4 How Should We Manage and Sustain Parks and Nature Reserves?

▶ **CONCEPT 9-4 We need to put more resources into sustaining existing parks and nature reserves and into protecting 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 7-12, top, p. 132, and Figure 7-18, p. 138). 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 developing countries have the greatest biodiversity of all parks, 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 developing countries have too little money and too few employees 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. States, counties, and cities also operate public parks.

Popularity is one of the biggest problems for many parks. In some parks and other public lands, noisy 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. Many visitors also expect parks to have grocery stores, laundries, bars, and other such conveniences.

Many parks also suffer damage from the migration or deliberate introduction of nonnative species. European wild boars (imported to 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 native vegetation and accelerate soil erosion.

At the same time, native species—some of them threatened or endangered—are killed or removed illegally in 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, right).

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-burning in power plants, water diversion, and urban development. According to the National Park Service, air pollution, mostly from coal-fired power plants and dense vehicle traffic, degrades scenic views in many U.S. national parks more than 90% of the time.

Another problem, reported by the U.S. General Accounting Office, is that the national parks need at least $6 billion for long overdue repairs of trails, buildings, and other infrastructure. 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%. Conservation scientists say these percentages could reasonably be increased to around 20%.

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, only 12% of the earth's land area is protected strictly or partially in nature reserves, parks, wildlife refuges, wilderness, and other areas. This 12% 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*, and most of the remaining 5% consists of ice, tundra, or desert—places where most people do not want to live (See the map in Figure 3, p. S18–19, in Supplement 4).

SCIENCE FOCUS

Reintroducing the Gray Wolf to Yellowstone National Park

Around 1800, at least 350,000 gray wolves (Figure 9-B) roamed over about three-quarters of the lower 48 states, especially in the West. They survived mostly by preying on abundant bison, elk, caribou, and mule deer. But between 1850 and 1900, most of them were shot, trapped, and 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, and mule deer, and kept down coyote populations. They also provided uneaten 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 (Figure 4-9, right, p. 70) often found growing near streams and rivers. This increased soil erosion and threatened habitats of other wildlife species and the food supplies of beaver, which eat willow and aspen. This in turn affected species that depend on wetlands created by the beavers.

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 prevent further environmental degradation in 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 in Yellowstone National Park. Scientists estimate that the long-term carrying capacity of the park is 110 to 150 gray wolves. In 2008, the park had 124 gray wolves according to biologists' estimates.

Tom Kitchin/Tom Stack & Associates

Figure 9-B **Natural capital restoration:** the *gray wolf*. 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 the Yellowstone National Park in 1995 and 1996. In 2008, there were about 124 gray wolves 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 the Yellowstone National Park (see *The Habitable Planet,* Video 4, at **www.learner.org/resources/series209.html**). This research has suggested that the return of the gray wolf, a keystone predator species, has sent ecological ripples through the park's ecosystem. With wolves around, elk populations have declined. Remains 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 those areas. This in turn helped to stabilize and shade stream banks, which lowered the water temperature and made better habitat for trout. Beavers seeking willow and aspen have returned. And the dams they build establish 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 in surrounding ranches and has increased populations of smaller animals such as ground squirrels and mice, hunted by coyotes. 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. Also, projected changes in climate during this century will alter some of the species composition of the Yellowstone ecosystem in ways that are hard to predict.

Critical Thinking

Do you approve or disapprove of the reintroduction of the gray wolf into the Yellowstone National Park system? Explain.

Conservation scientists 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 9-4**). But powerful economic and political interests oppose this idea.

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 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/biology/miller**.

Whenever possible, conservation biologists call for using the *buffer zone concept* to design and manage nature reserves. This means 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. The United Nations has used this principle in creating its global network of 531 biosphere reserves in 105 countries. But most biosphere reserves fall short of these ideals and receive too little funding for their protection and management.

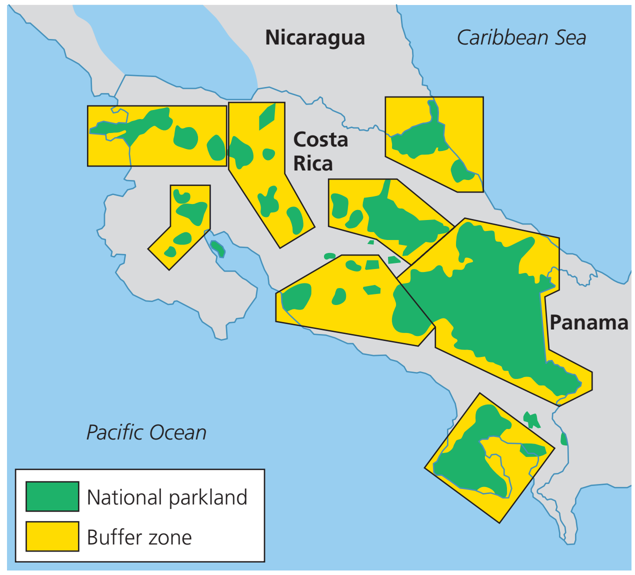


Figure 9-18 **Solutions:** Costa Rica has consolidated its parks and reserves into eight zoned *megareserves* designed to sustain about 80% of the country's rich biodiversity. Green areas are protected reserves and yellow areas are nearby buffer zones, which can be used for sustainable forms of forestry, agriculture, hydropower, hunting, and other human activities.

CASE STUDY (GOOD NEWS)

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 are consolidated into eight zoned *megareserves* (Figure 9-18). 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 helps to preserve the country's biodiversity. This follows the example set by Wangari Maathai (**Core Case Study**). As they grow, the trees also 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 1986 and 2007, the country's forest cover grew from 26% to 51%. What is the country where you live doing to protect its forests and biodiversity?

Protecting Wilderness Is an Important Way to Preserve Biodiversity

One way to protect undeveloped lands from human exploitation is by legally setting them aside as large areas of undeveloped land called **wilderness** (**Concept 9-4**). 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 following Case Study). 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 here today. But to most biologists, there are two important reasons for protecting wilderness and other areas from exploitation and degradation, both involving long-term needs. One is to *preserve biodiversity* as a vital part of the earth's natural capital. The other reason is to *protect wilderness areas as centers for evolution.* This allows them to respond to mostly unpredictable changes in environmental conditions. In other words, wilderness serves as a biodiversity bank and an eco-insurance policy.

■ **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. (See Figure 3, p. S22, in Supplement 5 for more details.) It allowed the government to protect undeveloped tracts of public land from development as part of the National Wilderness Preservation System.

The area of protected wilderness in the United States increased tenfold between 1970 and 2008. Even so, only about 4.6% of U.S. land is protected as wilderness—almost three-fourths of it in Alaska. Only 1.8% of the land area of the lower 48 states is protected, most of it in the West.

In other words, *Americans have reserved 98% of the continental United States to be used as they see fit and they have protected only 2% as wilderness*. This explains why the United States ranks 42nd among nations in terms of total terrestrial area protected as wilderness.

9-5 How Can We Help to Sustain Terrestrial Biodiversity?

▶ **CONCEPT 9-5 We can help to sustain terrestrial biodiversity by identifying and protecting severely threatened areas (biodiversity hotspots), rehabilitating damaged ecosystems (using restoration ecology), and sharing with other species much of the land we dominate (using reconciliation ecology).**

We Can Use Three Principles to Protect Ecosystems

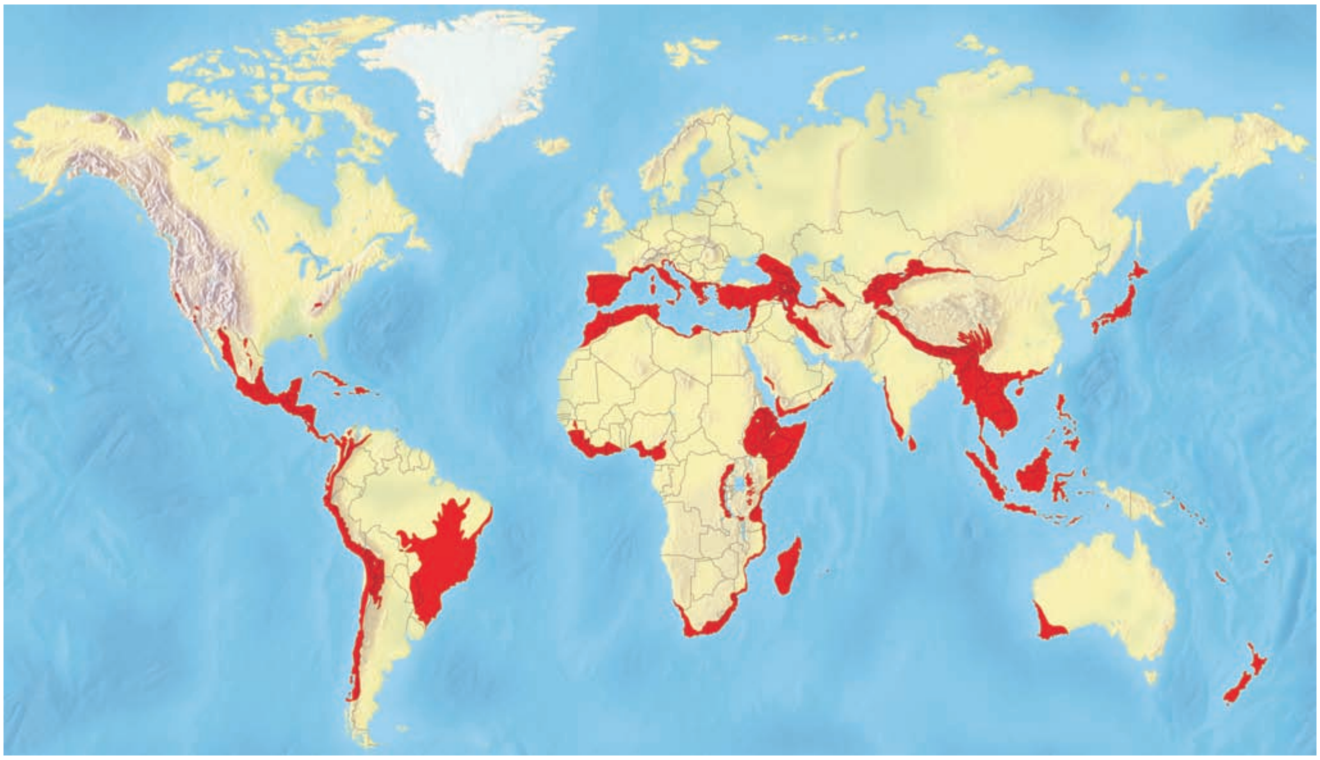
Most conservation scientists believe that the best way to prevent premature extinction of species is to protect threatened habitats and ecosystem services. This *ecosystems approach* generally follows three principles:

- Map the world's terrestrial and aquatic ecosystems and create an inventory of the species contained in each of them and the ecosystem services they provide.
- Locate and protect the most endangered ecosystems and species, with emphasis on protecting plant biodiversity and ecosystem services.
- Seek to restore as many degraded ecosystems as possible.

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 (see the map in Figure 2, p. S16–17, in Supplement 4).

To protect as much of the earth's remaining biodiversity as possible, some biodiversity scientists urge adoption of an *emergency action* strategy to identify and quickly protect **biodiversity hotspots** (**Concept 9-5**)—an idea first proposed in 1988 by environmental scientist Norman Myers. (See his Guest Essay on this topic at CengageNOW.) These "ecological arks" are areas especially rich in plant species that are found nowhere else and are in great danger of extinction. These areas suffer



CENGAGENOW™ **Active Figure 9-19 Endangered natural capital:** 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 9-5**). Compare these areas with those on the map of the human ecological footprint in the world, as shown in Figure 3, p. S18, in Supplement 4. 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).

serious ecological disruption, mostly because of rapid human population growth and the resulting pressure on natural resources.

Figure 9-19 shows 34 global terrestrial biodiversity hotspots identified by biologists. 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. 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."

CENGAGENOW™ Learn more about biodiversity hotspots around the world, what is at stake there, and how they are threatened at CengageNOW.

RESEARCH FRONTIER

Identifying and taking emergency action to preserve all of the world's terrestrial and aquatic biodiversity hotspots. See **www.cengage.com/biology/miller**.

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 9-17, right), reintroducing native species (Science Focus, p. 193), removing invasive species, and freeing river flows by removing dams.

CORE CASE STUDY

By studying how natural ecosystems recover, scientists are learning how to speed up repair operations using a variety of approaches, including the following four:

- *Restoration:* returning a particular degraded habitat or ecosystem to a condition as similar as possible to its natural state.

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 (Figure 9-18), a small tropical dry forest was burned, degraded, and fragmented by large-scale conversion to cattle ranches and farms. Now it is being restored and relinked to the cloud 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, galvanized 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.

Jansen 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 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*.

GOOD NEWS

By actively participating in the project, local residents reap educational, economic, and environmental benefits. Local farmers make money by sowing large areas with tree seeds and planting 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 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.

- *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.
- *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.
- *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:

- Identify the causes of the degradation (such as pollution, farming, overgrazing, mining, or invasive species).
- 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, above).
- If necessary, reintroduce species—especially pioneer, keystone, and foundation species—to help restore natural ecological processes, as was done with wolves in the Yellowstone ecosystem (Science Focus, p. 193).
- Protect the area from further degradation and allow secondary ecological succession to occur (Figure 9-17, right).

RESEARCH FRONTIER

Exploring ways to improve ecological restoration efforts. See **www.cengage.com/biology/miller**.

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/biology/miller**.

We Can Share Areas We Dominate with Other Species

Ecologist Michael L. 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.

GOOD NEWS

For example, people can learn how 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, 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 visiting biological researchers.

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.

People have also worked together to protect bluebirds within human-dominated habitats where most of the bluebirds' nesting trees have been cut down and bluebird populations have declined. Special boxes were designed to accommodate nesting bluebirds, and the North American Bluebird Society has encouraged Canadians and Americans to use these boxes on their properties and to keep house cats away from nesting bluebirds. Now bluebird numbers are growing again.

In Berlin, Germany, people have planted gardens on many large rooftops. These gardens support a variety of wild species by having varying depths and types of soil and exposures to sun. Such roofs also save energy by providing insulation; they absorb less heat than conventional rooftops do, thereby helping to keep cities cooler. They also conserve water by reducing evapotranspiration. Some reconciliation ecology proponents call for a global campaign to use the roofs of the world to help sustain biodiversity. **GREEN CAREER:** Rooftop garden designer

In the U.S. state of California, San Francisco's Golden Gate Park is a large oasis of gardens and trees in the midst of a major city. It is a good example of reconciliation ecology, because it was designed and planted by people who transformed it from a system of sand dunes. **GREEN CAREER:** Reconciliation ecology specialist

RESEARCH FRONTIER

Determining where and how reconciliation ecology can work best. See **www.cengage.com/biology/miller**.

Figure 9-20 lists some ways in which you can help to sustain the earth's terrestrial biodiversity.

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 natural to the area

Figure 9-20 **Individuals matter:** you can help 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?

9-6 How Can We Help to Sustain Aquatic Biodiversity?

▶ **CONCEPT 9-6 We can help to sustain aquatic biodiversity by establishing protected sanctuaries, managing coastal development, reducing water pollution, and preventing overfishing.**

Human Activities Are Destroying and Degrading Aquatic Biodiversity

Human activities have destroyed or degraded a large portion of the world's coastal wetlands, coral reefs, mangroves, and ocean bottom, and disrupted many of the world's freshwater ecosystems (**Concept 7-6**). CONCEPT LINK Scientists reported in 2006 that these coastal habitats are disappearing at rates 2–10 times higher than the rate of tropical forest loss. During this century, rising sea levels, mostly caused by projected climate change, are likely to destroy many coral reefs (Figure 7-26, p. 143) and swamp some low-lying islands along with their protective coastal mangrove forests (Figure 7-25, p. 143).

Another major threat is loss and degradation of many sea-bottom habitats caused by dredging operations and trawler fishing boats. Like 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 9-21). Each year, thousands of trawlers scrape and disturb an area of ocean floor about 150 times larger than the area of forests clear-cut annually. In 2004, some 1,134 sci-

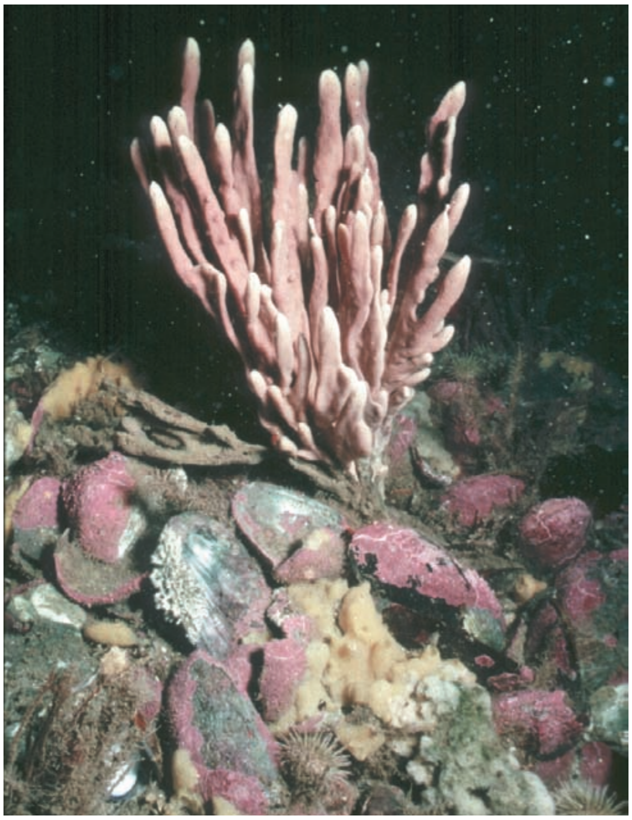


Figure 9-21 **Natural capital degradation:** area of ocean bottom before (left) and after (right) a trawler net scraped it like a gigantic plow. These ocean floor communities could take decades or centuries to recover. According to marine scientist Elliot Norse, "Bottom trawling is probably the largest 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?

entists signed a statement urging the United Nations to declare a moratorium on bottom trawling on the high seas. However, in 2006, fishing nations led by Iceland, Russia, China, and South Korea blocked U.N. negotiations on implementing such a ban.

Habitat disruption is also a problem in freshwater aquatic zones. Dams and excessive water withdrawal from rivers for irrigation and urban areas destroy aquatic habitats, degrade water flows, and disrupt freshwater biodiversity.

According to the International Union for the Conservation of Nature and Natural Resources (IUCN), 34% of the world's known marine fish species and 71% of the world's freshwater fish species face premature extinction within your lifetime. Indeed, *marine and freshwater fishes are threatened with extinction by human activities more than any other group of species* (Figure 8-5, p. 157).

Overfishing: Gone Fishing; Fish Gone

A **fishery** is a concentration of a particular aquatic species (usually fish or shellfish) suitable for commercial harvesting in a given ocean area or inland body of water. The world's highly efficient industrial fishing fleets made up of millions of fishing boats (see Case Study, p. 200) have sought to meet the rapidly growing global demand for seafood.

But just to keep consuming seafood at our current rate, we will need 2.5 times the area of the earth's oceans, according to the *Fishprint of Nations 2006*, a study based on the concept of the human ecological footprint (**Concept 1-2**, p. 9, and Figure 1-5, p. 11). The **fishprint** is defined as the area of ocean needed to sustain the consumption of an average person, a nation, or the world. The study found that all nations together are overfishing the world's global oceans by an unsustainable 157%. The resulting vacuuming of the seas has led to the collapse of some of the world's major fisheries (Figure 9-22, p. 200).

CONCEPT LINK

CONNECTIONS

Domino Effect from the Collapse of the North Atlantic Cod Fishery

After the cod were fished out in the North Atlantic, fishers began harvesting sharks, which provide important ecosystem services and help to control the populations of other species (Case Study, p. 75). Since then, overfishing of big sharks has cut Atlantic stocks of those species by 99%. With the large sharks essentially gone from the northwest Atlantic, populations of rays and skates, which the sharks once fed on, have exploded and have wiped out most of the region's bay scallops, which in turn had served as a food source for other species, including humans.

These practices, along with simply catching more fish than the fisheries can sustain, have had serious effects on fish populations. 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 have disappeared since

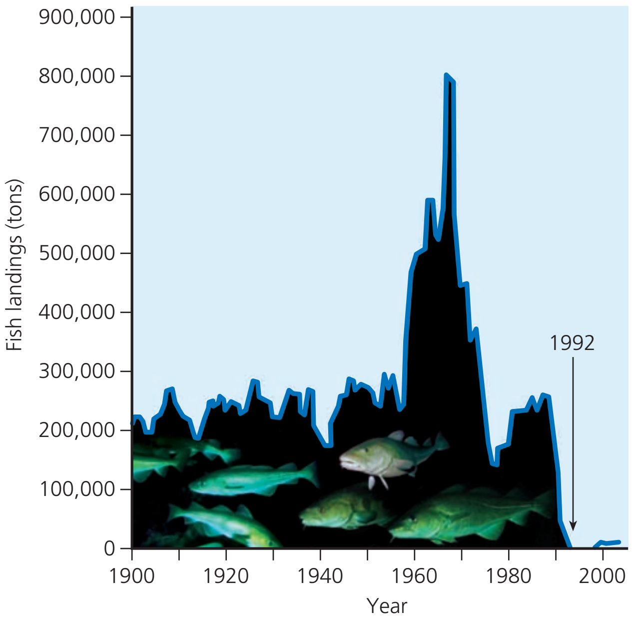


Figure 9-22 **Natural capital degradation:** this graph illustrates the collapse of Canada's 500-year-old Atlantic cod fishery off the coast of Newfoundland in the northwest Atlantic. Beginning in the late 1950s, fishers used bottom trawlers to capture more of the stock, reflected in the sharp rise in this graph. This resulted in extreme overexploitation of the fishery, which began a steady fall throughout the 1970s, followed by a slight recovery in the 1980s and total collapse by 1992, when the site was closed to fishing. Despite a total ban on fishing, the cod population has not recovered. This has put at least 20,000 fishers and fish processors out of work and severely damaged Newfoundland's economy. (Data from Millennium Ecosystem Assessment)

1950 (See *The Habitable Planet*, Video 9, at **www.learner.org/resources/series209.html**).

As large species are overfished, the fishing industry has begun working its way down marine food webs by shifting to smaller species. This reduces the breeding stock needed for recovery of depleted species, which unravels marine food webs and disrupts marine ecosystems and their ecosystem services.

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 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. Today, 77% of the world's commercial fisheries are being fished at or beyond their estimated sustainable yields, according to the FAO.

Figure 9-23 shows the major methods used for the commercial harvesting of various marine fishes and shellfish.

Let us look at a few of these methods. *Trawler fishing* is used to catch fish and shellfish—especially shrimp, cod, flounder, 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 process scrapes up almost everything that lies on the ocean floor and often destroys bottom habitats—somewhat like clear-cutting the ocean floor (Figure 9-21). Newer trawling nets are large enough to swallow 12 jumbo jet planes and even larger ones are on the way.

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 used to capture yellow fin 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 *longlining*, which involves putting out lines up to 130 kilometers (80 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 bottom fishes such as halibut and cod. Longlines also hook and kill large numbers of endangered sea turtles (see the front cover of this book), dolphins, and seabirds each year. 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, marine mammals, sea turtles, and seabirds.

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 monitoring fishing fleets over vast ocean areas is difficult. Also, the decrease in drift net use has led to increased use of longlines, which often have similar harmful effects on marine wildlife.

We Can Protect and Sustain Marine Biodiversity

Protecting marine biodiversity is difficult for several reasons. *First*, the human ecological footprint (Figure 1-5, p. 11) and fishprint are expanding so rapidly into aquatic areas that it is difficult to monitor the 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. And *fourth*, most of the world's ocean area lies outside the

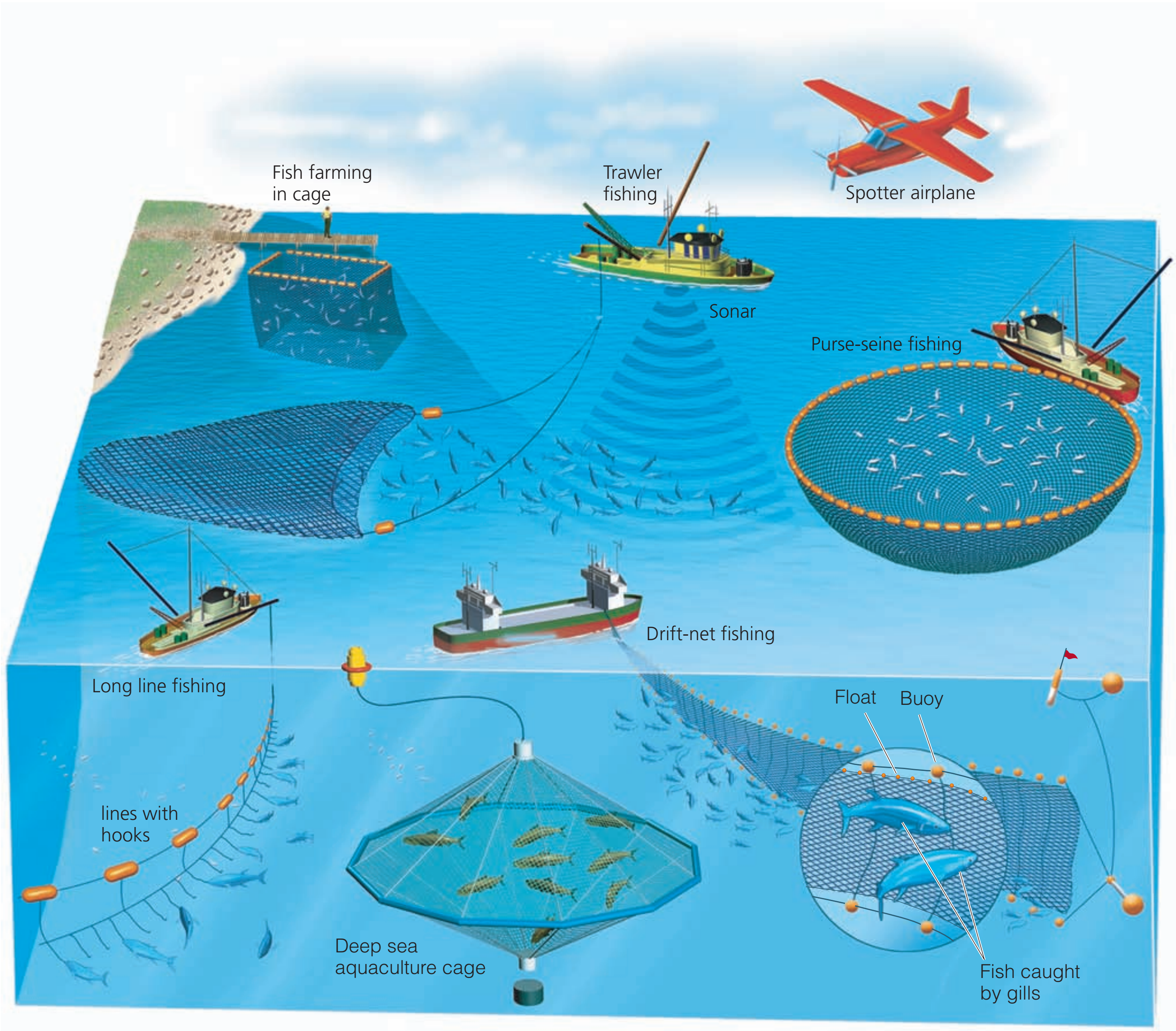


Figure 9-23 Major commercial fishing methods used to harvest various marine species. These methods have become so effective that many fish species have become commercially extinct.

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 (p. 9).

Nevertheless, there are several ways to protect and sustain marine biodiversity (**Concept 9-6**). For example, we can *protect endangered and threatened aquatic species*, as discussed in Chapter 8. And some individuals find economic rewards in restoring and sustaining streams, wetlands, and aquatic systems.

We can also *establish protected 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, 200 of them in U.S. waters. However, nearly all MPAs allow dredging, trawler fishing, and other ecologically harmful resource extraction activities.

GOOD NEWS

Many scientists and policymakers call for protecting and sustaining whole marine ecosystems in a global network of fully protected *marine reserves*. These areas are put off-limits to destructive human activities such as commercial fishing, dredging, mining, and waste disposal in order to enable their ecosystems to recover and flourish.

In 2008, the Pacific Island nation of Kiribati created the world's largest protected marine reserve. This California-sized area is found about halfway between the Pacific islands of Fiji and Hawaii. In 2006, the United States created the world's second largest protected reserve northwest of the state of Hawaii. The area is about the size of the state of Montana and supports more than 7,000 marine species, including the endangered Hawaiian monk seal and the endangered green sea turtle (see front cover of this book).

Marine reserves work and they work quickly. Scientific studies show that within fully protected marine reserves, fish populations double, fish size grows by almost a third, fish reproduction triples, and species diversity increases by almost one-fourth. Furthermore, this improvement happens within 2–4 years after strict protection begins.

Despite their importance, less than 1% of the world's oceans are closed to fishing and other harmful human activities in marine reserves and only 0.1% are fully protected—compared to 5% of the world's land. Thus, *humans have reserved essentially 99.9% of the world's oceans to use as they see fit*. Many marine scientists argue that in order to sustain marine biodiversity, we must protect at least 30% of the world's oceans as marine reserves.

RESEARCH FRONTIER

Determining characteristics and locations of fully protected marine reserves that will maximize their effectiveness. See **www.cengage.com/biology/miller**.

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?

Coastal communities can also establish *integrated coastal management* in which fishers, scientists, conservationists, citizens, business interests, developers, and politicians collaborate to develop and use coastal areas and resources more sustainably. Currently, more than 100 integrated coastal management programs are being developed throughout the world, including the Chesapeake Bay in the United States and Australia's huge Great Barrier Reef Marine Park.

Another important strategy is to protect existing coastal and inland wetlands from being destroyed or degraded. We can also regulate and prevent aquatic pollution, as discussed in Chapter 11.

Figure 9-24 lists some ways to manage global fisheries more sustainably and to protect marine biodiversity (**Concept 9-6**). Most of these approaches rely on some sort of government regulation to help avoid the tragedy of the commons.

There is considerable evidence that the current harmful human impacts on the earth's terrestrial and aquatic biodiversity and on the ecosystem services they provide could be reversed over the next 2 decades. Doing this will require implementing an ecosystem approach to sustaining and managing terrestrial and aquatic ecosystems. According to biodiversity expert E. O. Wilson, 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.

Such a strategy for protecting the earth's precious biodiversity will not be implemented without bottom-up political pressure on elected officials from individual citizens and groups. It will also be important for individuals to "vote with their wallets" by buying only products and services that do not have harmful impacts on terrestrial and aquatic biodiversity.

Here are the *three big ideas* in this chapter:

- The economic values of the important ecological services provided by the world's ecosystems need to be included in the prices of goods and services.
- We can sustain *terrestrial biodiversity* by protecting severely threatened areas, restoring damaged ecosystems, and sharing with other species much of the land we dominate.
- We can sustain *aquatic biodiversity* by establishing protected sanctuaries, managing coastal development, reducing water pollution, and preventing overfishing.

Solutions

Managing Fisheries

Fishery Regulations

Set catch limits well below the maximum sustainable yield

Improve monitoring and enforcement of regulations

Economic Approaches

Sharply reduce or eliminate fishing subsidies

Charge fees for harvesting fish and shellfish from publicly owned offshore waters

Certify sustainable fisheries

Protect Areas

Establish no-fishing areas

Establish more marine protected areas

Rely more on integrated coastal management

Consumer Information

Label sustainably harvested fish

Publicize overfished and threatened species

Bycatch

Use wide-meshed nets to allow escape of smaller fish

Use net escape devices for seabirds and sea turtles

Ban throwing edible and marketable fish back into the sea

Aquaculture

Restrict coastal locations for fish farms

Control pollution more strictly

Depend more on herbivorous fish species

Nonnative Invasions

Kill organisms in ship ballast water

Filter organisms from ship ballast water

Dump ballast water far at sea and replace with deep-sea water

Figure 9-24 Ways to manage fisheries more sustainably and protect marine biodiversity. **Questions:** Which four of these solutions do you think are the most important? Why?

REVISITING Wangari Maathai and Sustainability

In this chapter, we looked at how terrestrial and aquatic biodiversity are being destroyed or degraded in a variety of ecosystems. We also saw how we can reduce this destruction and degradation by using terrestrial resources and aquatic systems of all kinds 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, wilderness areas, and fully protected marine reserves.

We also learned about the importance of preserving what remains of richly biodiverse and highly endangered ecosystems (biodiversity hotspots). We examined the key strategy of restoring or rehabilitating some of the ecosystems we have degraded (restoration ecology). And 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 and aquatic biodiversity involves applying the three **principles of sustainability** (see back cover). First, it means respecting biodiversity by trying to sustain it. If we are successful, we will also be restoring and preserving the flows of energy from the sun through food webs and the cycling of nutrients in ecosystems. These measures help to support many important aspects of biodiversity, including the species interactions in food webs that help to prevent excessive population growth of any species, including our own.

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. 179. Describe the Green Belt Movement founded by Wangari Maathai.
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 services 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 two types of forest fires? What are some ecological benefits of occasional surface fires? What effects might projected climate change have on forests?
4. 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. What are the major basic and secondary causes of tropical deforestation?
5. Describe four ways to manage forests more sustainably. What is certified timber? What are four ways to reduce the harmful effects that forest fires have on forests and people? What are three ways to reduce the need to harvest trees? 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? What are three ways to reduce overgrazing and use rangelands more sustainably?
7. What major environmental threats affect national parks? 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? What is a *biosphere reserve?* 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.
8. What are three principles of the ecosystems approach to protecting ecosystems? What is a **biodiversity hotspot** and why is it important to protect such areas? 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**.

9. Describe major human threats to aquatic diversity. What is a **fishery**? What is a **fishprint**? Describe the collapse of the cod fishery in the northwest Atlantic Ocean and some of its side effects. Describe the harmful ecological effects of trawler fishing, purse-seine fishing, longlining, and drift-net fishing.

10. 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 are fully protected from harmful human activities in marine reserves? What is *integrated coastal management*? List five ways to manage fisheries more sustainably and to protect marine biodiversity. What are this chapter's *three big ideas?* Describe the relationship between Wangari Maathai's Green Belt Movement (**Core Case Study**) and the three **principles of sustainability**.

CORE CASE STUDY

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**). Are there any areas near where you live that could benefit from such intensive planting of trees? If so, describe how it would benefit the areas.

CORE CASE STUDY

2. 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 in 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.

3. 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, are opposed to this idea. 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.

4. In 2007, 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 this money, at an average annual cost of $25 per American. Would you support doing this? Explain.

5. Should developed countries provide most of the money needed to help preserve the remaining tropical forests in developing countries? Explain.

6. 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?

7. What do you think are the three greatest threats to aquatic biodiversity and aquatic ecosystem services? Why? Why is it more difficult to identify and protect endangered marine species and ecosystems than to protect endangered species and ecosystems on land?

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 coral reef 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)** the world's aquatic biodiversity and 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.

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.cengage.com/biology/miller** and choose Chapter 9 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, web links, information on Green Careers, and InfoTrac® College Edition articles.

CENGAGENOW™ For students with access, log on at **www.cengage.com/login** for the animations, active figures, activities, and readings indicated within the text by the CengageNOW logo. If your textbook did not come with access, visit **www.iChapters.com** to purchase.

10 Food, Soil, and Pest Management

CORE CASE STUDY Is Organic Agriculture the Answer?

We face the critical challenges of increasing food production without causing serious environmental harm. Each day, there are about 225,000 more mouths to feed and by 2050 there will probably be 2.5 billion more people to feed. This increase alone is more than twice China's current population and 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 and animals are grown with little or no use of synthetic pesticides, synthetic fertilizers, genetically engineered seeds, synthetic growth regulators, or feed additives. Organic agriculture is compared with conventional agriculture in Figure 10-1.

Although certified organic farming has grown rapidly since 1990, it is used on less than 1% of the world's cropland and only 0.1% of U.S. cropland. But in many European countries, 6–18% of the cropland is devoted to organic farming. Since 1969, when their oil supply from the Soviet Union was cut off, Cubans have grown most of their food using organic agriculture. The government has established centers where organisms used for biological pest control are produced, and it encourages people to grow organic food in urban gardens. About 30% of the vegetables in Havana, Cuba, are grown organically on land in the city.

Research conducted over 2 decades indicates that organic farming has a number of environmental advantages over conventional farming. On the other hand, organic farming requires more human labor. Another drawback is that most organically grown food costs 10–75% more than conventionally produced food (depending on the items), primarily because organic farming is more labor intensive. But if we included the costs of the harmful environmental impacts of food production in food prices, organic food would 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.

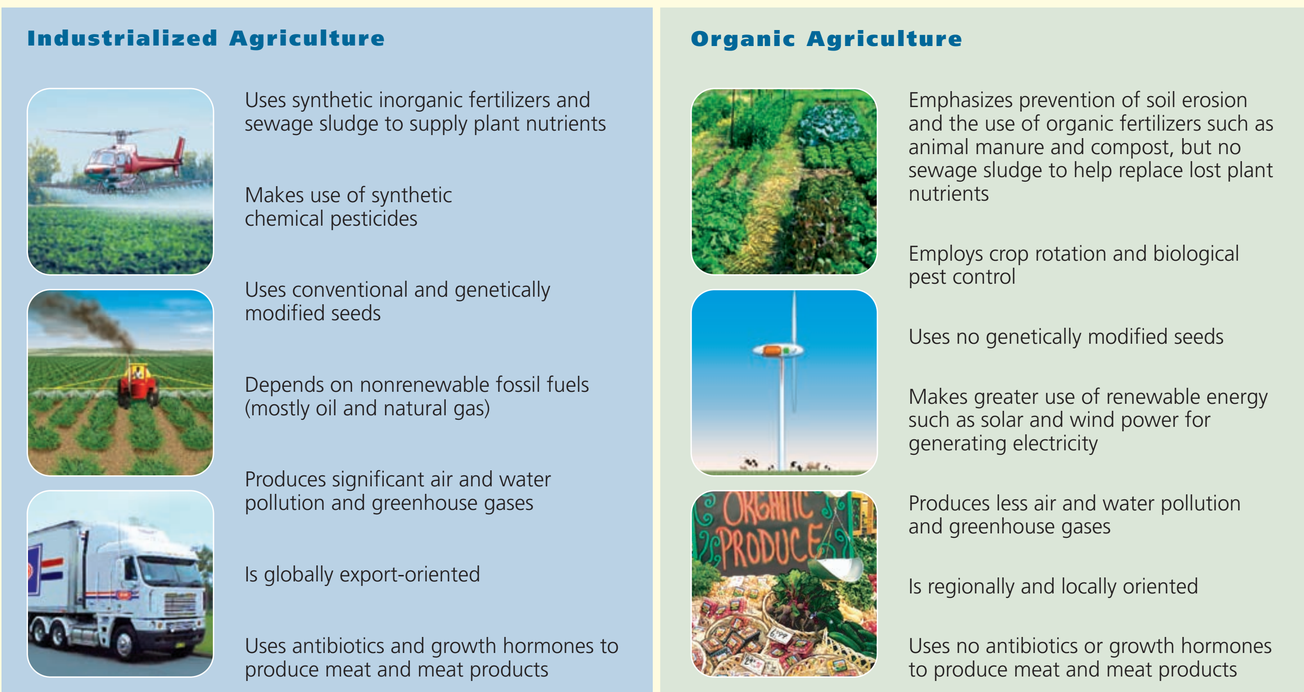


Figure 10-1 Comparison of conventional industrialized agriculture and organic agriculture. In the United States, a label of *100 percent organic* means that a product is raised only by organic methods and contains all organic ingredients. Products labeled *organic* must contain at least 95% organic ingredients. And products labeled *made with organic ingredients* must contain at least 70% organic ingredients but cannot display the USDA Organic seal on their packages.

Key Questions and Concepts

10-1 What is food security and why is it difficult to attain?

CONCEPT 10-1A Many of the poor have health problems from not getting enough food, while many people in affluent countries suffer health problems from eating too much.

CONCEPT 10-1B The greatest obstacles to providing enough food for everyone are poverty, political upheaval, corruption, war, and the harmful environmental effects of food production.

10-2 How is food produced?

CONCEPT 10-2 We have used high-input industrialized agriculture and lower-input traditional methods to greatly increase supplies of food.

10-3 What environmental problems arise from food production?

CONCEPT 10-3 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.

10-4 How can we protect crops from pests more sustainably?

CONCEPT 10-4 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).

10-5 How can we improve food security?

CONCEPT 10-5 We can improve food security by creating programs to reduce poverty and chronic malnutrition, relying more on locally grown food, and cutting food waste.

10-6 How can we produce food more sustainably?

CONCEPT 10-6 More sustainable food production involves decreasing topsoil erosion, reducing overgrazing and overfishing, irrigating more efficiently, using integrated pest management, promoting agrobiodiversity, and providing government subsidies only for more sustainable agriculture, fishing, and aquaculture.

Note: Supplements 2 (p. S3), 3 (p. S6), 4 (p. S14), 6 (p. S26), and 7 (p. S32) 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

10-1 What Is Food Security and Why Is It Difficult to Attain?

▶ **CONCEPT 10-1A Many of the poor have health problems from not getting enough food, while many people in affluent countries suffer health problems from eating too much.**

▶ **CONCEPT 10-1B The greatest obstacles to providing enough food for everyone are poverty, political upheaval, corruption, war, and the harmful environmental effects of food production.**

Many People Have Health Problems from Not Getting Enough to Eat

Today, we produce more than enough food to meet the basic nutritional needs of every person on the earth, and thus to provide them with **food security**. But even with this food surplus, one of every six people in developing countries is not getting enough to eat. These people face **food insecurity**—living with chronic hunger and poor nutrition, which threatens their ability to lead healthy and productive lives (**Concept 10-1A**).

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 environmental degradation, political upheaval, war (Figure 10-2, p. 208), and corruption (**Concept 10-1B**). In addition, according to a 2009 study by climate scientist David Battisti and food scientist

Figure 10-2 *War and hunger:* starving children collecting ants to eat in famine-stricken Sudan, Africa, where a civil war has been going on since 1983.

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 a rapidly warming climate.

To maintain good health and resist disease, individuals need fairly large amounts of *macronutrients* (such as carbohydrates, proteins, and fats, see Figures 8, 9, and 12, pp. S29–S30, in Supplement 6), and smaller amounts of *micronutrients*—vitamins (such as A, C, and E) and minerals (such as iron, iodine, and calcium).

People who cannot grow or buy enough food to meet their basic energy needs suffer from **chronic undernutrition**, or **hunger** (**Concept 10-1A**). (See Figure 11, p. S12, in Supplement 3 for a global map of chronic hunger and malnutrition.) Most of the world's chronically undernourished children live in low-income developing countries. Many suffer from mental retardation or stunted growth or die prematurely from infectious diseases such as measles and diarrhea, which rarely kill children in developed countries.

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.

According to the U.N. Food and Agriculture Organization (FAO), there were an estimated 925 million chronically undernourished or malnourished people (Figure 1-13, p. 17) in 2007—more than 3 times the entire U.S. population.

CONNECTIONS

Corn, Ethanol, and Hunger

Since 2007, prices for corn, rice, wheat, and other basic foodstuffs have risen sharply. This was caused by a number of factors, including the diversion of large quantities of corn, primarily in the United States, to make ethanol fuel for cars. Much of this corn would have been used as food for livestock and people. The resulting rise in food prices has led to food riots and social unrest in 30 countries, including Thailand, Pakistan, Egypt, Haiti, and Mexico. In a 2007 study, University of Minnesota economists Ford Runge and Benjamin Senauer estimated that rising food prices and a sharp drop in international food aid could lead to an increase in the number of hungry and malnourished people from 925 million to 1.2 billion, which is roughly equal to the current population of China.

In 2005, the FAO estimated that each year, nearly 6 million children die prematurely from chronic undernutrition and malnutrition and increased susceptibility to normally nonfatal infectious diseases (such as measles and diarrhea) because of their weakened condition (**Concept 10-1A**). This means that each day, an average of 16,400 children die prematurely from these mostly poverty-related causes. How many children died from such causes during your lunch hour?

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*. Most of these people live in developing 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*—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 tropical developing 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. Iodine is found in seafood and in crops grown in iodine-rich soils. Chronic lack of iodine can cause stunted growth, mental retardation, and goiter—a swollen thyroid gland that can lead to deafness (Figure 10-3). 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)—most of them in rural areas of south and southeast Asia—suffer from goiter. And 26 million children suffer irreversible brain damage with an IQ loss of

John Paul Kay/Peter Arnold, Inc.

Figure 10-3 Woman with goiter in Bangladesh. A diet insufficient in iodine can cause this enlargement of the thyroid gland. Adding traces of iodine to salt has largely eliminated this problem in developed countries but iodine deficiency is a serious problem in many developing countries.

10–15 points 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.

Correcting dietary deficiencies of key vitamins and minerals is not a glamorous problem that attracts widespread publicity or donors. But according to the World Bank, "Probably no other technology offers as large an opportunity to improve lives . . . at such low cost and in such a short time."

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 those 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 10-1A**).

We live in a world where 925 million people have health problems because they do not get enough to eat and about 1.6 billion people face health problems from eating too much. In other words, for every four of the world's hungry people, there are nearly seven people who are overweight.

In 2007, the Centers for Disease Control and Prevention (CDC) found that about 66% of American adults are overweight and 34% are obese (up from 15% in 1980)—the highest overnutrition rate of all developed countries. 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. 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.

10-2 How Is Food Produced?

▶ **CONCEPT 10-2 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, with which they grew edible plants in nutrient-rich topsoil and raised animals for food and labor. Today three systems supply most of our food. *Croplands* produce mostly grains. *Rangelands, pastures*, and *feedlots* produce meat. And *fisheries* and *aquaculture* (fish farming) provide us with seafood.

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 47% of the calories that people consume. A small number of animals also provide most of the world's meat and seafood.

Since 1960, there has been a staggering increase in global food production from all three of the major food production systems (**Concept 10-2**). GOOD NEWS

This occurred because of technological advances such as increased use of tractors and farm machinery and high-tech fishing equipment. Other technological developments include inorganic chemical fertilizers, high-volume irrigation, pesticides, high-yield grain varieties, and raising large numbers of livestock, poultry, fish, and shellfish in factory-like conditions.

Industrialized Crop Production Relies on High-Input Monocultures

Agriculture used to grow crops can be divided roughly into two types: industrialized agriculture and subsistence agriculture. **Industrialized agriculture**, or **high-input agriculture**, uses heavy equipment and large amounts of financial capital, fossil fuel, water, commercial inorganic fertilizers, and pesticides to produce single crops, or *monocultures*, (Figure 7-14, p. 134). 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 on about one-fourth of the world's cropland, mostly in developed countries, produces about 80% of the world's food (**Concept 10-2**).

Industrialized agriculture involves several important shifts:

- From relying on energy from sunlight, human muscle power, and draft animals to supplementing such energy with cheap energy from fossil fuels (primarily oil and natural gas).
- From producing a diversity of crops and farm animals (polycultures) to producing a few types of crops and animals (monocultures).
- From producing food mostly for local and regional consumption to producing food for global consumption.
- From relying on supply and demand in the marketplace to using government subsidies and policies to help manipulate supply and demand and keep food prices artificially low.

Plantation agriculture is a form of industrialized agriculture used primarily in tropical developing countries. It involves growing *cash crops* such as bananas, soybeans (mostly to feed livestock), sugarcane (to produce sugar and ethanol fuel), coffee, palm oil (used as a cooking oil and to produce biodiesel fuel), and vegetables. Crops are grown on large monoculture plantations, mostly for export to developed countries. Producing such monoculture crops in the tropics increases yields but decreases biodiversity when tropical forests are cleared or burned (Figure 9-12, p. 187) to make way for crop plantations.

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** by relying more on fossil fuels than on sunlight, reducing natural and crop biodiversity, and neglecting the conservation and recycling of nutrients in topsoil (Science Focus, right). What makes industrialized agriculture even more unsustainable is that our economic systems do not include the harmful environmental costs of food production in the market prices of food. This makes food prices much lower than the real costs of producing food, which we eventually pay in other ways.

Traditional Agriculture Often Relies on Low-Input Polycultures

Some 2.7 billion people (40% of the world's people) in developing 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 (for photosynthesis) 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 have some left to sell 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** (see back cover)—reduces the chance of losing most or all of the year's food supply to pests, bad weather, and other misfortunes.

In parts of South America and Africa, some traditional farmers grow as many as 20 different crops together on small cleared plots in tropical forests. The crops rely on sunshine for their growth rather than on petroleum-based fertilizers. They mature at different times, provide food throughout the year, reduce the input of human labor, and keep the soil covered to reduce erosion from wind and water. Polyculture lessens needs for fertilizer and water, because root systems at different depths in the soil capture nutrients and moisture efficiently. 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 of crop plants.

Recent research shows that, on average, such low-input polyculture produces higher yields than does high-input monoculture. For example, a 2001 study by 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.

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 10-A shows profiles of different-aged soils.

Soil, the base of life on land, is a key component of the earth's natural capital. It supplies most of the nutrients needed for plant growth (Figure 3-5, p. 43), purifies and stores water, and helps to control the earth's climate by removing carbon dioxide from the atmosphere and storing it as carbon compounds.

Most soils that have developed over a long period of time, called *mature soils*, contain horizontal layers, or *horizons*, (Figure 10-A), each with a distinct texture and composition. The numbers and types of horizons vary with different types of soils, but most mature soils have at least three of the 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 a 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. The result is 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 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 10-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. 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 releasing it in a nourishing trickle.

Some 15–20 centimeters (6–8 inches) of *topsoil* is all that stands between much of the world and mass starvation. 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 people plow grassland or clear a forest and leave its topsoil unprotected.

There are no technological substitutes for fertile and uncontaminated topsoil. Without topsoil, there would be no food and no life on the land. Thus, reducing and preventing soil erosion should be the most fundamental components of more sustainable agriculture.

Yet, for a long time, human activities have accelerated natural soil erosion and contaminated soils with excess salts, pesticides, and other chemicals that can reduce food production and biodiversity and threaten human health. We discuss the erosion and degradation of soil and solutions to these problems later in this chapter.

Critical Thinking

How does soil contribute to each of the four components of biodiversity described in Figure 4-2, p. 61?

Image not available due to copyright restrictions

One very important advantage of polyculture is that it is less likely to degrade topsoil than industrialized agriculture is. The same can be said for organic agriculture (**Core Case Study**). All types of crop production depend on having fertile topsoil (Science Focus, p. 211).

CORE CASE STUDY

RESEARCH FRONTIER

Investigating the design and benefits of polyculture. See **www.cengage.com/biology/miller**.

CENGAGENOW™ Compare soil profiles from grassland, desert, and three types of forests at CengageNOW™.

A Closer Look at Industrialized Crop Production

Farmers can produce more food by farming more land or by 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 10-1, left) to increase 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 inorganic fertilizers, pesticides, and water. *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 developed countries, especially the United States (Case Study, at right) 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 India and China and several developing countries in Latin America such as Brazil (Case Study, p. 213). 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 be used for farming.

Between 1950 and 1996, mostly because of the two green revolutions, world grain production tripled (Figure 10-4, left). Per capita food production increased by 31% between 1961 and 1985, but since then it has generally declined (Figure 10-4, right).

CASE STUDY

Industrialized Food Production in the United States

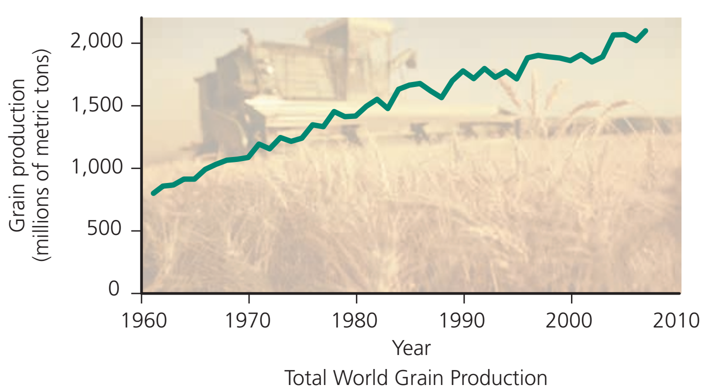
In the United States, industrialized farming has evolved into *agribusiness*, as a small number of giant multinational corporations increasingly control the growing, processing, distribution, and sale of food in U.S. and global markets.

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) employs more people than any other industry. Still, U.S. farms use industrialized agriculture to produce about 17% of the world's grain with only 3 of every 1,000 of the world's farm workers.

Since 1950, U.S. industrialized agriculture 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.

GOOD NEWS

As a result of this system, Americans spend an average of less than 10% of their household income on food. But this is misleading because the huge government (taxpayer) agricultural subsidies and the high and harmful environmental costs of industrialized agricul-



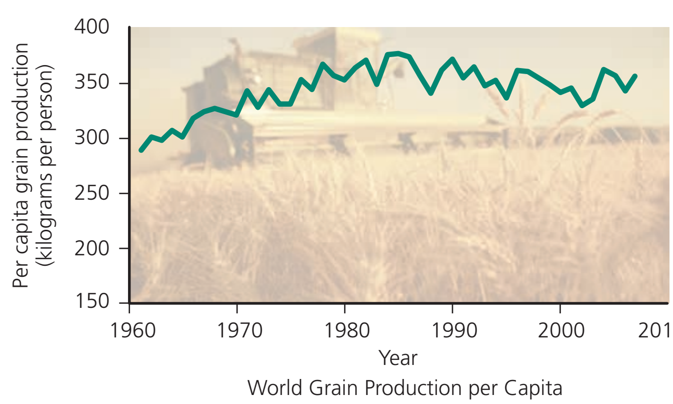


Figure 10-4 *Global outlook:* total worldwide grain production of wheat, corn, and rice (left), and per capita grain production (right), 1961–2007. In order, the world's three largest grain-producing countries are China, the United States, and India. **Question**: Why do you think grain production per capita has grown less consistently than total grain production? (Data from U.S. Department of Agriculture, Worldwatch Institute, U.N. Food and Agriculture Organization, and Earth Policy Institute)

ture are not included in the market prices of food. In other words, the prices of food in the United States are artificially low.

■ **CASE STUDY**

Brazil: The World's Emerging Food Superpower

Brazil, with ample sun and freshwater and more available arable (farmable) land than any other country, is on its way to becoming the next global breadbasket. One factor in this significant growth in food production is the Brazilian government's agricultural research corporation, EMBRAPA, which is now the world's largest agricultural research agency.

The country's agricultural scientists figured out how to modify soil and seeds to produce high crop yields on its humid, sun-drenched *cerrado*, a tropical savanna region that makes up about one-fifth of Brazil's huge land area. Because of favorable weather, farmers in this region routinely grow two crops a year (and three with irrigation) compared to one crop a year in the breadbasket of the midwestern United States. And they produce food without the huge government farm subsidies provided in the United States and Europe.

The main problem delaying Brazil's emergence as the world's number one food producer and exporter is a lack of roads and shipping ports. Another problem is that the Cerrado area is one of the world's biodiversity hotspots (Figure 9-19, p. 196). Thus, clearing much of it to grow crops is a severe threat to its biodiversity.

Crossbreeding and Genetic Engineering Can Produce New Crop Varieties

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.

GOOD NEWS

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 (Figure 11, p. S30, in Supplement 6) to produce desirable traits or to eliminate undesirable ones—a process that is also called *gene splicing*. It enables scientists to transfer genes between different species that would not interbreed in nature. The resulting organisms are called *genetically modified organisms (GMOs)*. Figure 10-5 (p. 214) outlines the steps involved in developing a genetically modified plant. 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*. At least three-fourths of the food products on U.S. supermarket shelves contain some form of genetically engineered food, and the proportion is increasing rapidly. Bioengineers are developing, or plan to develop, new varieties of crops that are resistant to heat, cold, herbicides, insect pests, parasites, viral diseases, drought, and salty or acidic soil. They also hope to develop crop plants that can grow faster and survive with little or no irrigation and with less fertilizer and pesticides.

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 meat products such as eggs and milk are good sources of high-quality protein. Between 1950 and 2008, world meat production increased more than fivefold. It is likely to more than double again by 2050 as affluence rises and middle-income people begin consuming more meat in rapidly developing countries such as China, which now leads the world in both meat production and consumption.

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 energy-intensive industrialized system in which animals are raised mostly in densely packed *feedlots* and *confined animal feeding operations* where they are fed grain or meal produced from fish. For example, large numbers of cattle are brought to feedlots where they are fattened up for about 4 months before slaughter. Most pigs and chickens in developed countries spend their lives in pens and cages, often in huge buildings where they eat mostly grain grown on cropland.

Fish and Shellfish Production Have Increased Dramatically

The world's third major food-producing system consists of fisheries and aquaculture. Industrial fishing fleets take most of the world's marine fish catch (Case

Study, p. 200). In 2006, 43% of the fish and shellfish consumed were produced through **aquaculture**—raising marine and freshwater fish in ponds and underwater cages instead of hunting and gathering them. This percentage is expected to grow steadily.

Figure 10-6 shows the effects of the global efforts to boost the seafood harvest through fishing and aquaculture (**Concept 10-2**). Since 1950, the world fish catch (marine and freshwater harvests, excluding aquaculture) has increased almost sevenfold. Aquacultural production in the same period increased over 40-fold.

China raises 70% of the world's farmed fish, mostly in inland ponds and rice fields. Globally, aquaculture is devoted mostly to raising herbivorous species—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 carnivorous fish is growing rapidly, especially in developed countries. As a result, nearly one-third of global catch of wild fish is converted to fish meal and fish oil and fed to farmed carnivorous fish, cattle, and pigs.

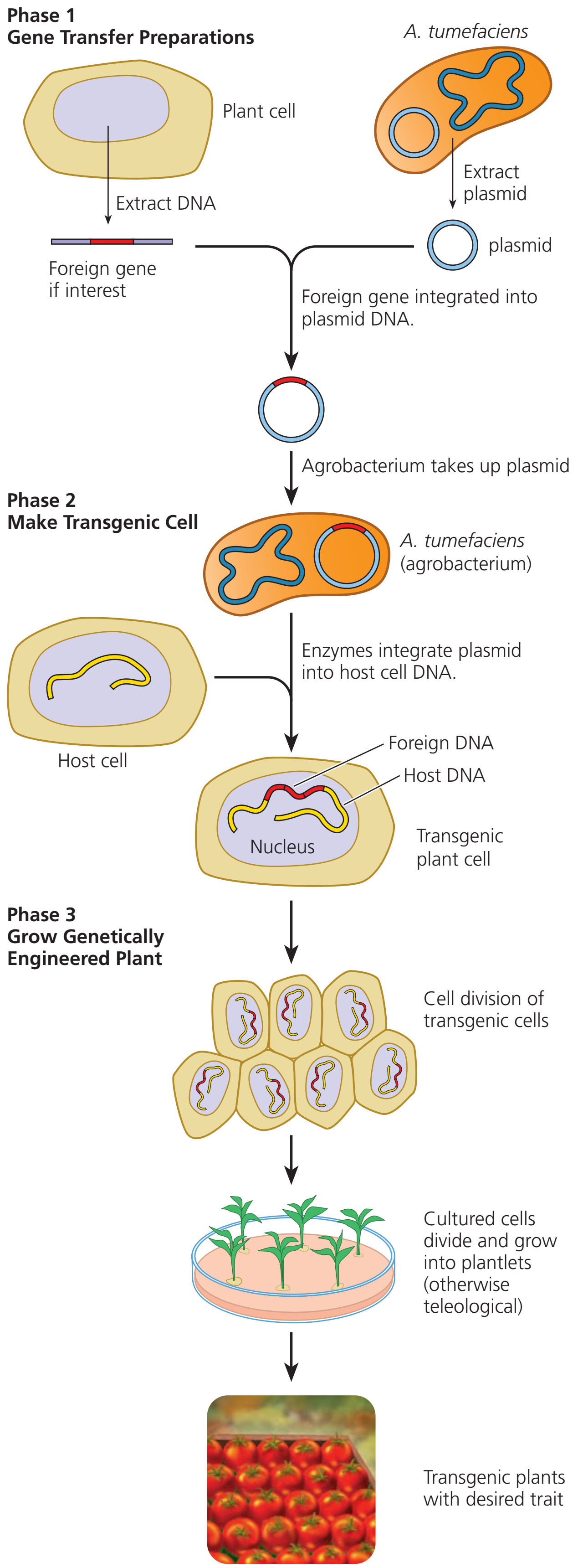


Figure 10-5 *Genetic engineering:* steps in genetically modifying a plant. **Question**: How does this process change the nature of evolution by natural selection?

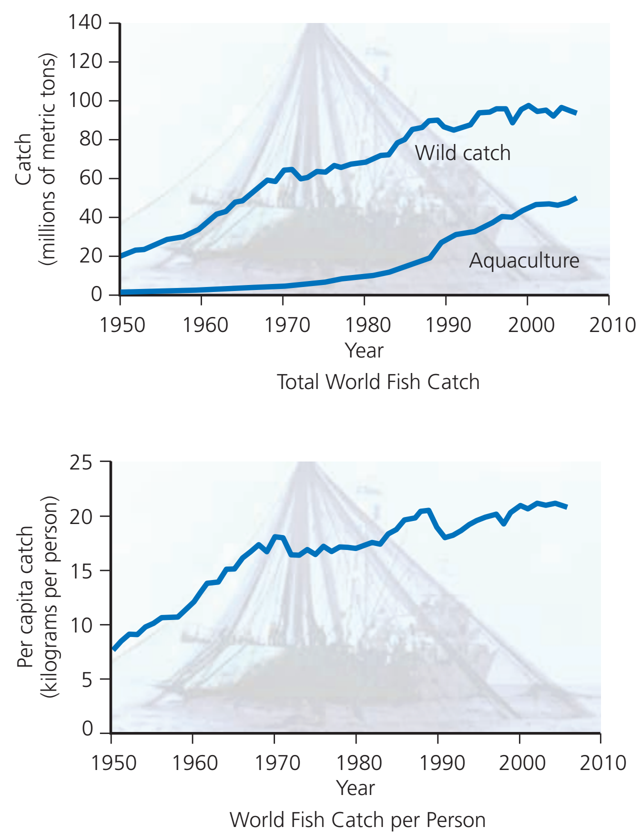


Figure 10-6 World fish catch, including both wild catch and aquaculture, 1950–2006. **Question**: What are two trends that you can see in these data? (Data from U.N. Food and Agriculture Organization, U.S. Census Bureau, and Worldwatch Institute)

10-3 What Environmental Problems Arise from Food Production?

▶ **CONCEPT 10-3 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

The good news is the spectacular increases in the world's food production since 1950. The bad news is the harmful environmental effects associated with such production increases. Figure 10-7 summarizes the harmful effects of modern agriculture on air, fertile soil, water, and biodiversity. According to many analysts, agriculture has a greater total harmful environmental impact than any human activity. Some scientists warn that these environmental effects may limit future food production and make it unsustainable (**Concept 10-3**). Here, we 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 (Science Focus, p. 211), from one place to another by the actions of wind and water. Some soil erosion is natural, and some is caused

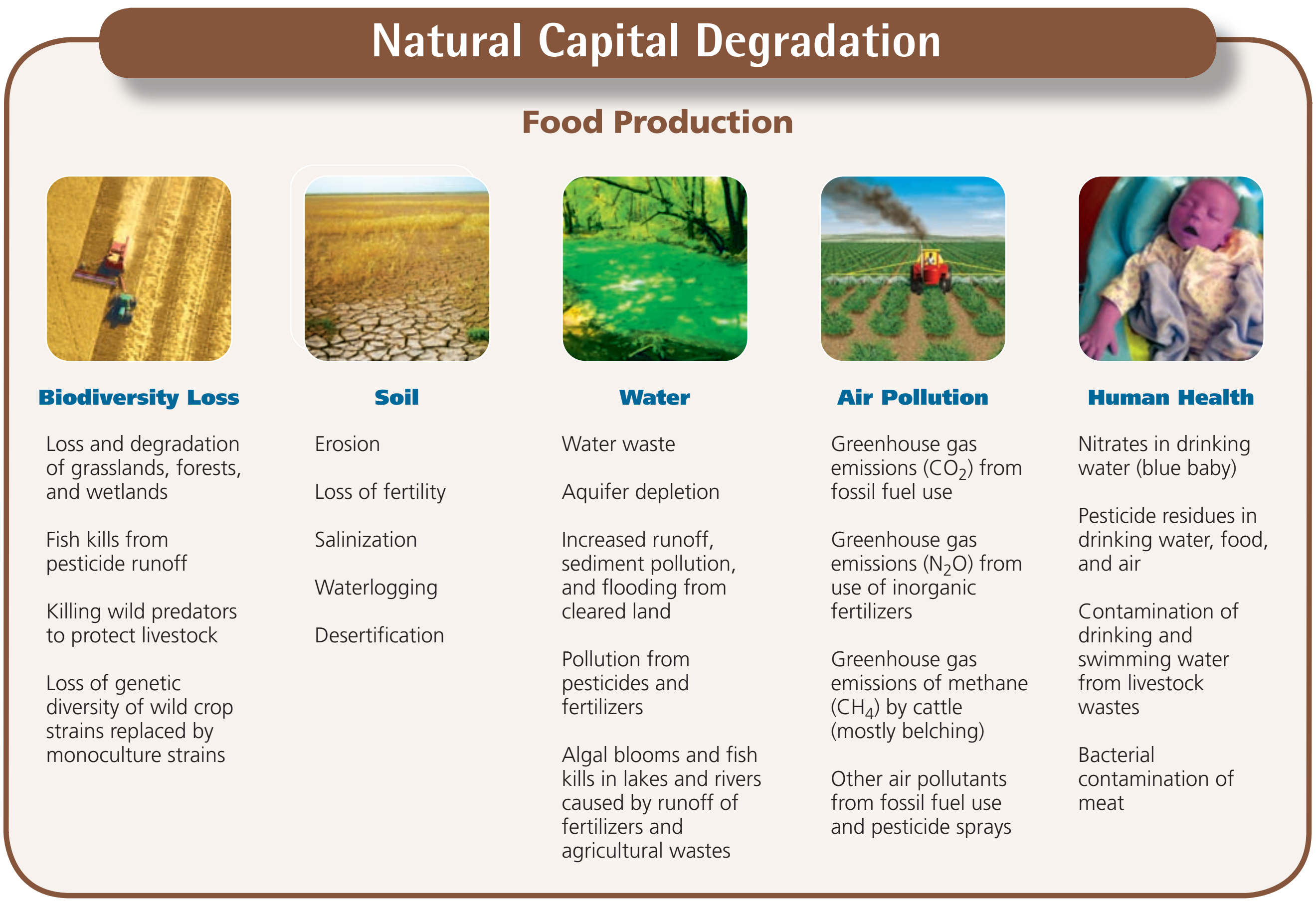


Figure 10-7 **Natural capital degradation:** major harmful environmental effects of food production (**Concept 10-3**). According to a 2008 study by the U.N. Food and Agriculture Organization (FAO), more than 20% of the world's cropland (65% in Africa) has been degraded to some degree by soil erosion, salt buildup, and chemical pollution. This threatens the food supply for about a quarter of the world's population who are trying to eke out a living on such degraded land. **Question**: Which item in each of these categories do you believe is the most harmful?

Figure 10-8 **Natural capital degradation:** severe gully erosion on cropland in Bolivia.

by human activities. In undisturbed, vegetated ecosystems, the roots of plants help to anchor the soil. The soil can then store water and release it in a nourishing trickle, and, usually, soil is not lost faster than it forms.

Flowing water, the largest cause of erosion, carries away particles of topsoil that have been loosened by rainfall. Severe erosion of this type leads to the formation of gullies (Figure 10-8). Wind loosens and blows topsoil particles away, especially in areas with a dry climate and relatively flat and exposed land. We lose natural capital in the form of fertile topsoil when we destroy soil-holding grasses through activities such as farming (Figure 7-14, p. 134), clear-cutting forests (Figure 9-9, p. 184), and overgrazing (Figure 9-16, left, p. 191).

Soil erosion 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 soil 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 residues of pesticides. In degrading soil and polluting water, we are altering the carbon, nitrogen, and phosphorus cycles by removing vital plant nutrients from the soil and adding excess plant nutrients to aquatic systems.

In 2008, the Chinese government estimated that one-third of its land suffers from serious soil erosion. And a joint survey by the U.N. 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 10-9) and has cut crop production by about 17%. (See the Guest Essay on soil erosion by David Pimentel at CengageNOW.) However, in some cases the loss in crop yields in one area can be offset by an increased yield when eroded topsoil is deposited in another area.

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 soil falls by 10% or more because of a combination of prolonged drought and human activities that reduce or degrade topsoil. The process can be *moderate* (a 10–25% drop in productivity), *severe* (a 25–50% drop), or *very severe* (a drop of more

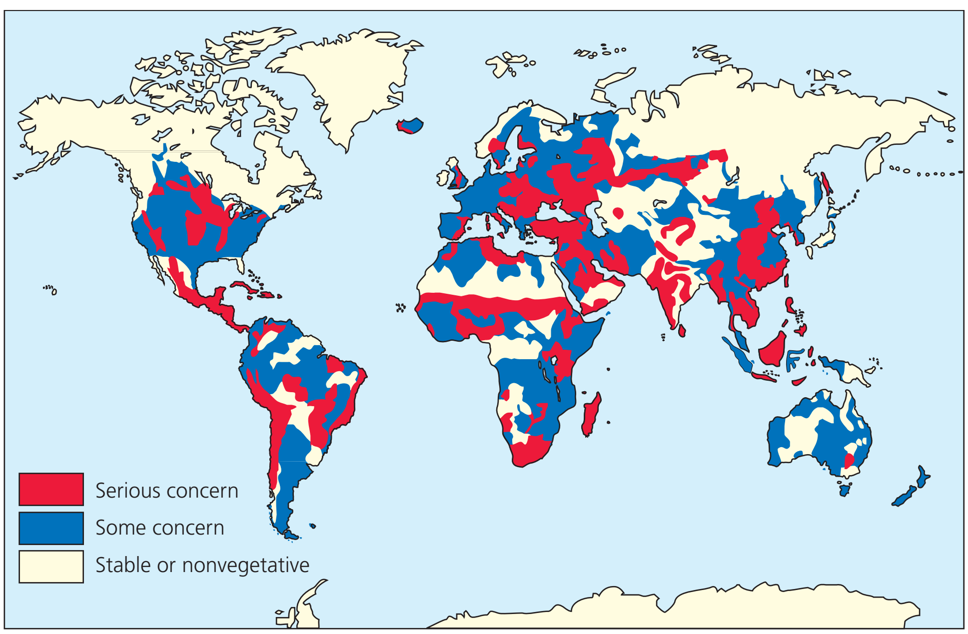


Figure 10-9 **Natural capital degradation:** global soil erosion. **Question**: Can you see any geographical pattern associated with this problem? (Data from U.N. Environment Programme and the World Resources Institute).

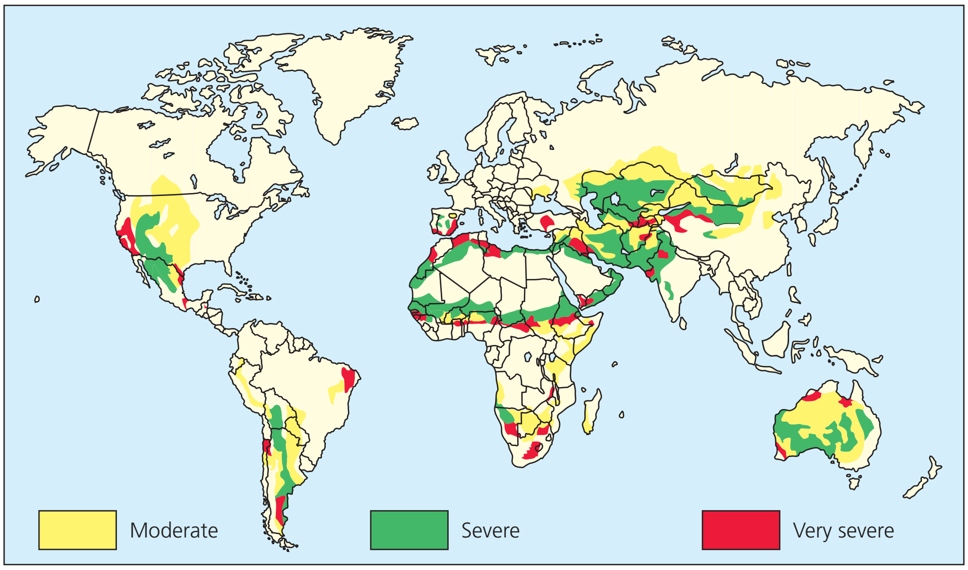


Figure 10-10 **Natural capital degradation:** desertification of arid and semiarid lands. It is caused by a combination of prolonged drought and human activities that expose soil to erosion. **Question**: Can you see any geographical pattern associated with this problem? (Data from U.N. Environment Programme and Harold E. Drengue)

than 50%, usually resulting in huge gullies and sand dunes, see Figure 10-10). Only in extreme cases does desertification lead to what we call desert. 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.

According to a 2007 study by the Intergovernmental Panel on Climate Change, projected climate change during this century (mostly the result of human activities) is expected to greatly increase severe and prolonged drought and, consequently, desertification in arid and semiarid parts of the world. This could result in sharp drops in food production (**Concept 10-3**), water shortages for 1–3 billion people, and huge numbers of environmental refugees.

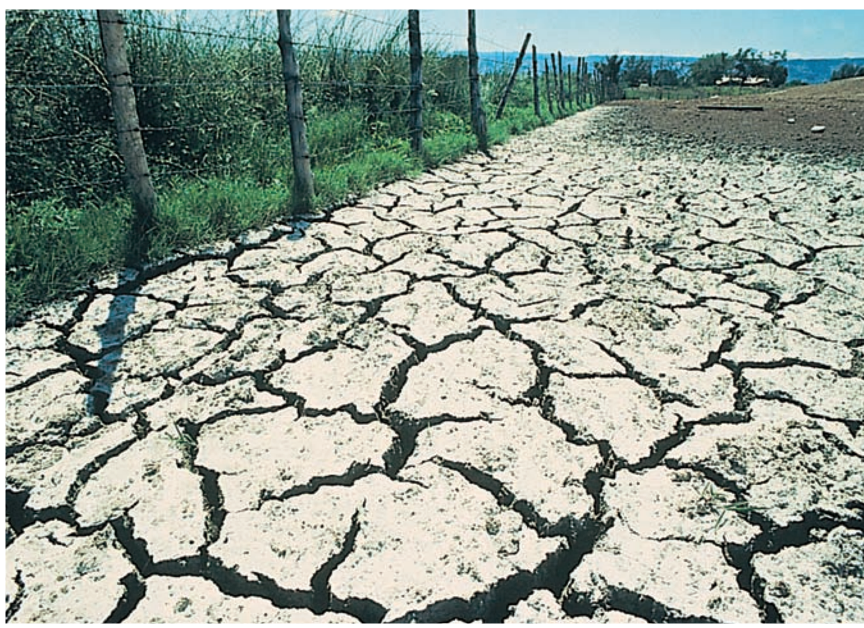
Excessive Irrigation Has Serious Consequences

Between 1950 and 2008, the world's area of irrigated cropland tripled, with most of the growth occurring from 1950 to 1978. Currently, about one-fifth of the world's cropland is irrigated. It produces about 45% of the world's food.

But irrigation has a downside. Most irrigation water is a dilute solution of various salts that are picked up as the water flows over or through soil and rocks. Irrigation water that has not been absorbed into the soil evaporates, leaving behind a thin crust of dissolved salts in the topsoil.

Repeated annual 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 (**Concept 10-3**). The United Nations estimates that severe salinization has reduced yields on at least one-tenth of the world's irrigated cropland, and the problem is getting worse. The most severe salinization occurs in Asia, especially in China, India, Egypt, Pakistan, and Iraq. Salinization affects almost one-fourth of irrigated cropland in the United States, especially in western states (Figure 10-11).

Another problem with irrigation is **waterlogging**, in which water accumulates underground and gradually raises the water table. Farmers often apply large amounts of irrigation water to leach salts deeper into the soil. Without adequate drainage, waterlogging occurs and saline water then surrounds the deep roots of plants, lowering their productivity and killing them after prolonged exposure. At least one-tenth of the world's irrigated land suffers from waterlogging, and the problem is getting worse (**Concept 10-3**).



U.S. Natural Resources Conservation Service

Figure 10-11 **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.

There May Be Limits to Expanding the Green Revolutions

Several factors have limited the success of the green revolutions to date and may limit them in the future. Without huge inputs of inorganic fertilizer, pesticides, and water, most green revolution 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 developing countries.

Can we expand the green revolutions by irrigating more cropland? In 2006, the International Water Management Institute projected that between 2005 and 2050, water use for agriculture will have to increase by 80% to help provide food for an estimated 2.5 billion more people.

However, since 1978, the amount of irrigated land per person has been declining, and it is projected to fall much more between 2008 and 2050. One reason for this is that, since 1978, the world's population has grown faster than has use of irrigation. Other factors are depletion of underground water supplies (aquifers), wasteful use of irrigation water, soil salinization, and climate change, which is melting mountain glaciers that provide irrigation water for countries such as China and India. In addition, most of the world's farmers do not have enough money to irrigate their crops.

Is cultivating more land the answer? Clearing tropical forests and irrigating arid land could more than double the area of the world's cropland. But much of this is *marginal land* with poor soil fertility, steep slopes, or both. Cultivating marginal land is usually expensive, is unlikely to be sustainable, and reduces wildlife habitats and biodiversity. In addition, during this century, fertile croplands in many coastal areas are likely to be flooded by rising sea levels resulting from climate change.

Industrialized Food Production Requires Huge Inputs of Energy

The industrialization of agriculture has been made possible by the availability of energy, mostly from nonrenewable oil. 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 cars.

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. Today, 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 are to put 1 unit of food energy on the table*. In the United States, food travels an average 2,400 kilometers (1,300 miles) from farm to plate. Some types of food take more energy to produce than others do. According to a 2002 study by the John Hopkins Bloomberg School of Public Health, it takes 35 units of energy to produce 1 unit of energy in grain-fed beef. And this does not include the additional energy used to process, transport, and cook the beef.

Using large ships to find, catch, and freeze ocean fish also requires huge amounts of energy. According to a 2005 study by ecological economist Peter Tyedmers and his colleagues, this large-scale hunting and gathering operation by the world's fishing fleets uses about 12.5 times as much energy as the fish provide for the people who eat them.

Bottom line: industrialized food production and consumption, overall, 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? How would you reduce this risk for yourself and your loved ones?

There Is Controversy over Genetically Engineered Foods

Despite its promise, controversy has arisen over the use of *genetically modified* (*GM*) *food* (Figure 10-5) 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. But some critics consider it potentially dangerous "Frankenfood." Figure 10-12 summarizes projected advantages and disadvantages of this new technology.

Critics recognize the potential benefits of GM crops. But they warn that we know too little about the long-term potential harm to human health and ecosystems from the widespread use of such crops. They point out that genetic engineering mixes genes from widely differing species, which has never occurred in nature or even in selective breeding. They warn that if GM organisms released into the environment cause some unintended harmful genetic and ecological effects, as some scientists expect, they 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 reduce the gene pool needed to crossbreed new crop varieties and to develop new genetically engineered varieties. This also threatens the production of certified organic crops (**Core Case Study**), which must be grown in the absence of GM crop genes. Critics call for more controlled field experiments, long-term testing to evaluate the risks, and stricter regulation of this rapidly growing technology.

CORE CASE STUDY

Trade-Offs

Genetically Modified Crops and Foods

Projected Advantages	Projected Disadvantages
Need less fertilizer	Irreversible and unpredictable genetic and ecological effects
Need less water	Harmful toxins in food from possible plant cell mutations
More resistant to insects, disease, frost, and drought	New allergens in food
Grow faster	Lower nutrition
Can grow in slightly salty soils	Increase in pesticide-resistant insects, herbicide-resistant weeds, and plant diseases
May need less pesticides	Can harm beneficial insects
Tolerate higher levels of herbicides	Lower genetic diversity
Higher yields	
Less spoilage	

Figure 10-12 Projected advantages and disadvantages of genetically modified crops and foods. **Questions**: Which two advantages and which two disadvantages do you think are the most important? Why?

Another issue related to GM food arises from court decisions granting seed companies patents (and thus exclusive ownership) of GM crop varieties. Companies with such patents have successfully sued some farmers who saved the seeds from their crops for use in the following year (an important component of agriculture for thousands of years) rather than buying a new batch of seeds. They have also successfully sued farmers to have them pay seed costs for crops that came up from GM seeds blown onto their land. Seed companies argue that they have spent large amounts of money developing these new varieties and that patents allow them to recoup their expenses and make profits.

Critics argue that such companies take genetic resources and traditional knowledge about crops developed over thousands of years for free, modify them slightly, and claim in court that they have invented these varieties that were based primarily on ancient varieties. Then they patent each type of seed, claim an exclusive right to it, and charge anyone for using it. Critics say that this will allow a few large seed companies to own and control the world's seed supply and thus its food supply.

THINKING ABOUT
Gene Patenting

Do you believe that companies should have the legal right to patent crop varieties and other forms of life? How could this benefit or harm you?

Food and Biofuel Production Systems Have Caused Major Losses of Biodiversity

Natural biodiversity and some ecological services are threatened when forests are cleared and grasslands are plowed up and replaced with croplands used to produce food or biofuels such as ethanol (**Concept 10-3**).

A related problem is the increasing loss of *agrobiodiversity*—the world's genetic variety of animals and plants 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 that were available to farmers in the 1940s no longer exist, except perhaps in small amounts in seed banks and in the backyards of a few gardeners.

In other words, 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 new plant and livestock varieties that can adapt to climate change. This failure to preserve agrobiodiversity is a serious violation of the biodiversity **principle of sustainability**.

Industrialized Meat Production Has Harmful Environmental Consequences

Proponents of industrialized meat production point out that producing meat by using feedlots and other confined animal production facilities increases meat production, reduces overgrazing, and yields 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 waste that sometimes pollute surface water and groundwater and saturate the air with their odors.

In 2008, the FAO reported that overgrazing, soil compaction, and erosion by livestock have degraded one-fifth of the world's grasslands and pastures. The same report estimated that rangeland grazing and industrialized livestock production cause 55% of all soil erosion and sediment pollution, use 37% of the world's pesticides, and account for half of all antibiotic use and a third of the water pollution that results from excessive inputs of nitrogen and phosphorous.

CONNECTIONS

Corn, Ethanol, and Ocean Dead Zones

Huge amounts of inorganic fertilizers are used in the midwestern United States to produce corn for animal feed and for conversion to ethanol fuel. Much of this fertilizer runs off cropland, eventually goes into the Mississippi River, and ends up over-fertilizing 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 to fuel cars with ethanol and to produce protein-rich meat decreases aquatic biodiversity and the production of protein-rich seafood in the Gulf of Mexico.

Energy (mostly from oil) is also an essential ingredient in industrialized meat production. Using this energy pollutes the air and water and contributes to projected climate change. Livestock production generates almost one-fifth of the world's greenhouse gases—more than all cars, buses, and planes emit—according to the 2006 FAO study, *Livestock's Long Shadow*.

Cattle and dairy cows also release the powerful greenhouse gas methane, mostly through belching. 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 in the United States each year is equal to the greenhouse gas emissions of 33 million automobiles. A 2003 Swedish study found that raising beef cattle on grass results in 40% lower greenhouse gas emissions and uses 85% less energy than raising the cattle on grain crops.

Finally, according to the United States Department of Agriculture (USDA), the American meat industry produces about 130 times more animal waste than is 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 **sustainability principle**. Much of the other half of this waste ends up polluting the air, water, and soil and producing foul odors.

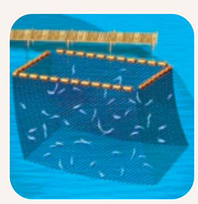
Producing Fish through Aquaculture Can Harm Aquatic Ecosystems

Figure 10-13 lists the major advantages and disadvantages of aquaculture. Some analysts project that aquaculture could provide at least half of the world's seafood by 2025. Others warn that the harmful environmental effects of aquaculture could limit future production.

Trade-Offs

Aquaculture

Advantages	Disadvantages
High efficiency	Needs large inputs of land, feed, and water
High yield in small volume of water	Large waste output
Can reduce overharvesting of fisheries	Can destroy mangrove forests and estuaries
Low fuel use	Uses grain, fish meal, and fish oil to feed some species
High profits	Dense populations vulnerable to disease



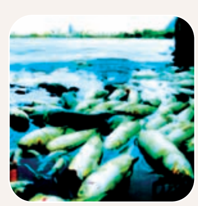


Figure 10-13 Advantages and disadvantages of *aquaculture*. **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

One problem is that using fish meal and fish oil to feed farmed carnivorous fish can deplete populations of wild fish. It is also very inefficient. 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.

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 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 11 times higher than those of wild-caught salmon. Aquaculture producers contend that the concentrations of these chemicals are not high enough to threaten human health.

Fish farms also produce large amounts of wastes. Along with pesticides and antibiotics used in aquaculture operations, these wastes pollute aquatic ecosystems. This threatens aquatic biodiversity and can make these systems undesirable for recreation and other uses.

HOW WOULD YOU VOTE?

Do the advantages of aquaculture outweigh its disadvantages? Cast your vote online at **www.cengage.com/biology/miller**.

Later in this chapter (Section 10-5), we consider some possible solutions to the 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.

10-4 How Can We Protect Crops from Pests More Sustainably?

CONCEPT 10-4 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. For example, the world's 30,000 known species of spiders, including the wolf spider (Figure 10-14), kill far more insects every year than humans do by using chemicals. GOOD NEWS

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 10-14 **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 such as insects, weeds, rats, and mice. 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 herbivores that feed on them. This battle produces a never-ending, ever-changing coevolutionary process: herbivores overcome various plant defenses through natural selection (**Concept 4-2B**, p. 63), then new plant defenses are favored by natural selection, and the process is repeated in this ongoing cycle of evolutionary punch and counterpunch.

CONCEPT LINK

Since 1950, pesticide use has increased more than 50-fold, and 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 developed countries, but their use in developing countries is soaring.

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 (Figure 8-15, p. 166). 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 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 U.S. cropland. In 1962, biologist Rachel Carson warned against relying on synthetic organic chemicals to kill insects and other species we regard as pests (see Individuals Matter, at right).

Modern Synthetic Pesticides Have Several Advantages—the Good News

Conventional chemical pesticides have advantages and disadvantages. Proponents contend that their benefits (Figure 10-15, left) outweigh their harmful effects (Figure 10-15, 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).

GOOD NEWS

- *They increase food supplies.* According to the FAO, 55% of the world's potential human food supply is lost to pests. Without pesticides, these losses would be worse and food prices would rise.
- *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 (p. 64) 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.* Pesticide industry scientists argue that when pesticides are used as directed, they pose no major risk to farm workers and consumers.

Trade-Offs

Conventional Chemical Pesticides

Advantages	Disadvantages
Save lives	Promote genetic resistance
Increase food supplies	Kill natural pest enemies
Profitable	Pollute the environment
Work fast	Can harm wildlife and people
Safe if used properly	Are expensive for farmers

Figure 10-15 Advantages and disadvantages of conventional chemical pesticides. **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

INDIVIDUALS MATTER

Rachel Carson

Rachel Carson (Figure 10-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 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 an 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

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topics she covered in her day. And her critics cannot dispute the fact that her wake-up call got the public and the scientific community focused on the potential threats from 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.

- *Newer pest control methods are safer and more effective than many older ones.* Greater use is being made of chemicals derived originally from plants. They 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—the Bad News

Opponents of widespread pesticide use believe that the harmful effects of these chemicals (Figure 10-15, right) outweigh their benefits (Figure 10-15, 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. Because of genetic resistance, farmers can find themselves having to pay more and more for a pest control program that becomes less and less effective.
- *Some insecticides kill natural predators and parasites that help control the pest populations.* Of the 300 most destructive insect pests in the United States, 100 were once minor pests that became major pests after 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, 98–99.9% of the insecticides and more than 95% of the herbicides that are applied do not reach the target pests and

end up in the air, surface water, groundwater, bottom sediments, food, and nontarget organisms, including humans and wildlife.

- *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% (Case Study, p. 167). 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 developing countries and at least 300,000 people 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. Such pesticides are a major source of accidental poisonings and deaths of young children.

According to studies by the National Academy of Sciences, exposure to legally allowed pesticide residues in food causes 4,000–20,000 cases of cancer per year in the United States. Some scientists are concerned about possible genetic mutations, birth defects, nervous system and behavioral disorders, and effects on the immune and endocrine systems from long-term exposure to low levels of various pesticides. The pesticide industry disputes these claims, arguing that the exposures are not high enough to cause serious harm. (See more on this topic in Chapter 14 and in *The Habitable Planet*, Video 7, at **www.learner.org/resources/series209.html**.)

Children are much more susceptible than adults are to low levels of pesticides and other toxic chemicals, because on an amount-per-weight basis, they eat more food, drink more water, and breathe more air. They also put their fingers in their mouths more often and spend more time playing on grass, carpeting, and soil where pesticides can accumulate.

Figure 10-16 lists some ways in which you can reduce your exposure to pesticides.

Pesticide use has not reduced U.S. crop losses to pests, mostly because of genetic resistance and reduction of natural predators. When David Pimentel, an expert on insect ecology, evaluated data from more than 300 agricultural scientists and economists, he reached three major conclusions:

- *First,* although the use of synthetic pesticides has increased 33-fold since 1942, about 37% of the U.S. food supply is lost to pests today compared to 31% in the 1940s. Since 1942, losses attributed to insects almost doubled from 7% to 13%, despite a tenfold increase in the use of synthetic insecticides.

What Can You Do?

Reducing Exposure to Pesticides

- Grow some of your food using organic methods
- Buy organic food
- Wash and scrub all fresh fruits, vegetables, and wild foods you pick
- Eat less meat or no meat
- Trim the fat from meat

Figure 10-16 **Individuals matter:** you can reduce your exposure to pesticides. **Questions**: Which three of these actions do you think are the most important? Why?

- *Second*, estimated environmental, health, and social costs of pesticide use in the United States, according to the International Food Policy Research Institute, are $5–10 in damages for every dollar spent on pesticides.
- *Third*, alternative pest management practices could cut the use of chemical pesticides by half on 40 major U.S. crops without reducing crop yields (**Concept 10-4**). The pesticide industry disputes these findings.

HOW WOULD YOU VOTE?

Do the advantages of using synthetic chemical pesticides outweigh their disadvantages? Cast your vote online at **www.cengage.com/biology/miller**.

Laws Can Help to Protect Us from the Harmful Effects of Pesticides

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 pesticides under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), first passed in 1947 and amended in 1972. 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.

There is controversy over how well U.S. citizens are protected from the harmful effects of pesticides, with some scientists calling FIFRA the weakest and most poorly enforced U.S. environmental law. After more than 37 years, less than 10% of the 600 active (pest-

SCIENCE FOCUS

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 were happy. 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, we can never do just one thing, and we need to ask, "Now what will happen?"

Critical Thinking

Do you think the beneficial effects of spraying pesticides in Sabah to kill malaria-carrying mosquitoes outweighed the resulting unexpected harmful effects? Explain.

killing) ingredients in pesticide products have been evaluated by using tests for chronic health effects. And serious evaluation of the health effects of the 1,200 inactive ingredients used in pesticide products began only recently.

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 study by the National Academy of Sciences 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 of 12 types of conventional foods that tend to have the highest pesticide residues. These foods, which EWG calls the "dirty dozen," are peaches, apples, bell peppers, celery, nectarines, cherries, strawberries, lettuce, imported grapes, spinach, pears, and potatoes. Pesticide proponents say the residue concentrations in foods treated with pesticides are too low to cause harm. But some scientists urge consumers to play it safe by using the precautionary principle and buying only organic versions of the dirty dozen foods.

There Are Alternatives to 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 10-4**). 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, adjusting planting times so that major insect pests either starve or get eaten by their natural predators, and growing crops in areas where their major pests do not exist.
- *Provide homes for pest enemies.* Farmers can increase the use of polyculture, which uses plant diversity to reduce losses to pests. Homeowners can apply the biodiversity sustainability principle by planting yards with a variety of low-maintenance natural plants adapted to local climates.
- *Implant genetic resistance.* Use genetic engineering to speed up the development of pest- and disease-resistant crop strains (Figure 10-17, p. 226). But controversy persists over whether the projected advantages of using GM plants and foods outweigh their projected disadvantages (Figure 10-13, right).
- *Bring in natural enemies.* Use *biological control* by importing natural predators (Figures 10-14 and 10-18, p. 226), parasites, and disease-causing bacteria and viruses to help regulate pest populations. This approach is nontoxic to other species, minimizes genetic resistance, and is usually less costly than applying pesticides. However, biological control agents are often slower acting and more difficult to apply than conventional pesticides are, can sometimes multiply and become pests themselves, and must be protected from pesticides sprayed in nearby fields.
- *Use insect perfumes. Sex attractants* (called *pheromones*) can lure pests into traps or attract their natural predators into crop fields. Each of these chemicals

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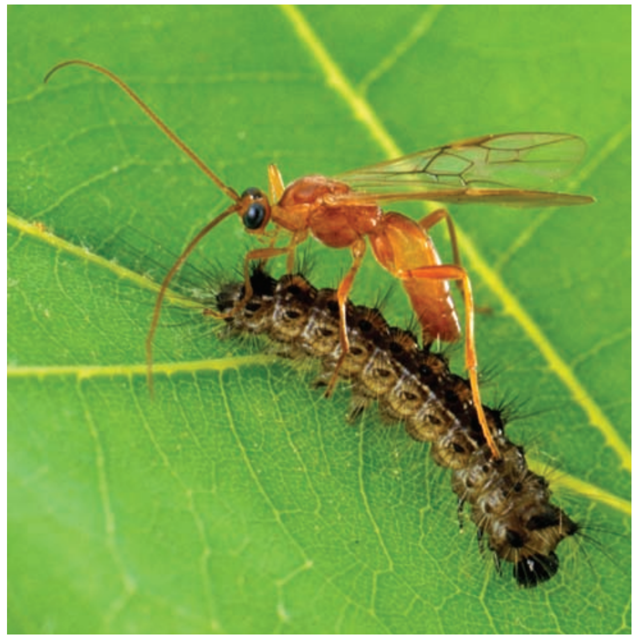


Scott Bauer/USDA Agricultural Research Service.

Figure 10-18 **Natural capital:** biological pest control. Wasp parasitizing a gypsy moth caterpillar.

attracts only one species, and they work in trace amounts, have little chance of causing genetic resistance, and are not harmful to nontarget species. However, it is costly and time-consuming to identify, isolate, and produce the specific sex attractant for each pest or predator.

- *Bring in the hormones.* Hormones are chemicals produced by animals to control 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 the same advantages as sex attractants. But they take weeks to kill an insect, often are ineffective with large infestations of insects, and sometimes break down before they can act. In addition, they must be applied at exactly the right time in the target insect's life cycle. They can sometimes affect the target's predators and other beneficial species and are difficult and costly to produce.

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 (**Concept 10-4**).

The overall aim of IPM is to reduce crop damage to an economically tolerable level. Each year, crops are moved from field to field to disrupt pest infestations, and fields are monitored carefully. When an economically damaging level of pests is reached, farmers first use biological methods (natural predators, parasites, and disease organisms) and cultivation controls (such as rotating crops, altering planting time, and using large machines to vacuum up harmful bugs). They apply small amounts of insecticides—mostly based on those naturally produced by plants—only as a last resort and in the smallest amounts possible. 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%.

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 assaulted 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**.

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 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 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

HOW WOULD YOU VOTE?

Should governments heavily subsidize a switch to integrated pest management? Cast your vote online at **www.cengage.com/biology/miller**.

Several U.N. agencies and the World Bank have joined together to establish an IPM facility. Its goal is to promote the global use of IPM by disseminating information and establishing networks among researchers, farmers, and agricultural extension agents involved in IPM.

GOOD NEWS

10-5 How Can We Improve Food Security?

CONCEPT 10-5 We can improve food security by creating programs to reduce poverty and chronic malnutrition, relying more on locally grown food, and cutting food waste.

Use Government Policies to Improve Food Production and 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:

- *Control prices.* Use price controls to keep food prices artificially low. This makes consumers happy but makes it harder for farmers to make a living.
- *Provide subsidies.* Give farmers price supports, tax breaks, and other subsidies to keep them in business and to encourage them to increase food production. According to the United Nations, subsidies and tax breaks provided by governments in developed countries average $533,000 a minute and account for about 31% of global farm income. Farmers in developing countries cannot compete in the global marketplace with the artificially low prices of subsidized crops in developed countries. Some analysts call for phasing out 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 (Case Study, p. 213) has also ended most of its farm subsidies. Other analysts call for replacing traditional subsidies for farmers with subsidies that promote more sustainable forms of agriculture.

Studies show that government subsidies to fishing fleets can promote overfishing and the subsequent reduction of aquatic biodiversity. For example, governments give the highly destructive bottom trawling industry (Figure 9-21, right, p. 199) about $150 million in subsidies a year, which is the main reason they can stay in business. Many analysts call for replacing those environmentally harmful (perverse) 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 agriculture and fishing? Cast your vote online at **www.cengage.com/biology/miller**.

To improve food security, 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 with the following measures:

- Immunizing children against childhood diseases such as measles
- Encouraging breast-feeding (except for mothers with AIDS)
- Preventing dehydration from diarrhea by giving infants a mixture of sugar and salt in a glass of water
- Preventing blindness by giving children a vitamin A capsule twice a year at a cost of about 75¢ per child. Other options are fortifying common foods with vitamin A and other micronutrients at an annual cost of about 10¢ per child.
- Providing family planning services to help mothers space births at least 2 years apart
- Increasing education for women, with emphasis on nutrition, drinking water sterilization, contraception, and childcare

10-6 How Can We Produce Food More Sustainably?

▶ **CONCEPT 10-6 More sustainable food production involves decreasing topsoil erosion, reducing overgrazing and overfishing, irrigating more efficiently, using integrated pest management, promoting agrobiodiversity, and providing government subsidies only for more sustainable agriculture, fishing, and aquaculture.**

Reduce Soil Erosion

Using land to produce food requires fertile topsoil (Science Focus, p. 211). And it takes hundreds of years for fertile topsoil to form. Thus, sharply reducing soil erosion is the single most important component of more sustainable agriculture.

Soil conservation involves using a variety of ways to reduce soil erosion and restore soil fertility, mostly by keeping the soil covered with vegetation. Figure 10-19 shows some of the methods farmers have used to reduce soil erosion (**Concept 10-6**). For example, *terracing* is a way to grow food on steep slopes without depleting 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 10-19a). This retains water for crops at each level and reduces soil erosion by controlling runoff. GOOD NEWS

On ground with a significant slope, *contour planting* (Figures 10-19b) can be used to reduce soil erosion. It involves plowing and planting crops in rows across the slope of the land rather than up and down. Each row acts as a small dam to help hold topsoil and to slow water runoff.

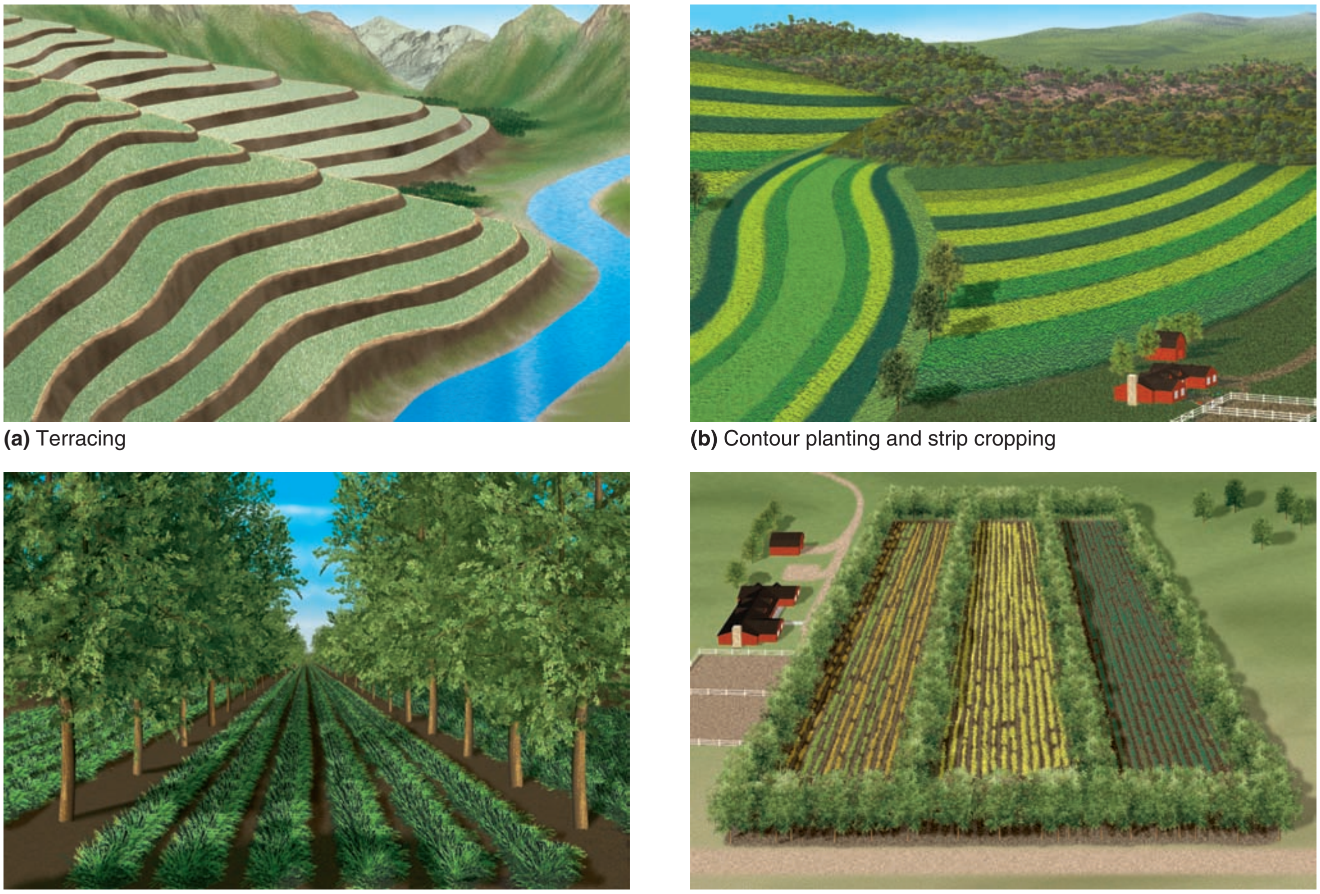
Strip cropping (Figure 10-19b) involves planting alternating strips of a row crop (such as corn or cotton) and another crop that completely covers the soil, called a *cover crop* (such as alfalfa, clover, rye, or a grass–legume mixture). The cover crop traps topsoil that erodes from the row crop and catches and reduces water runoff. When one crop is harvested the other strip is left to catch and reduce water runoff. Other ways to reduce 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 10-19c), is yet another way to slow erosion. One or more crops are planted together in strips or alleys between trees and shrubs, which provide shade. This reduces water loss by evaporation and helps retain and slowly release soil moisture—an insurance policy during prolonged drought. The trees also can provide fruit, fuelwood, and trimmings that can be used as mulch (green manure) for the crops and as feed for livestock.

Farmers can establish *windbreaks*, or *shelterbelts*, of trees around crop fields to reduce wind erosion (Figure 10-19d). 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.

Eliminating the plowing and tilling of soil greatly reduces soil erosion. Many farmers in the United States and several other countries practice *conservation-tillage farming* by using special tillers and planting machines that drill seeds directly through crop residues into the undisturbed soil. The only soil disturbance is a narrow slit and weeds are controlled with herbicides. Such *no-till* and *minimum-tillage* farming also increases crop yields; reduces the projected threat of climate change by storing more carbon in the soil; reduces water pollution from sediment and fertilizer runoff; and lowers use of water, pesticides, and tractor fuel. GOOD NEWS

In 2008, farmers used conservation tillage on about 41% of U.S. cropland. The USDA estimates that using conservation tillage on 80% of U.S. cropland would reduce soil erosion by at least half. No-till cultivation is



(a) Terracing

(b) Contour planting and strip cropping

(c) Alley cropping

(d) Windbreaks

Figure 10-19 Soil conservation methods include **(a)** terracing, **(b)** contour planting and strip cropping, **(c)** alley cropping, and **(d)** windbreaks (**Concept 10-6**). The problem is that modern industrialized farming operations make little use of these well-known and effective ways to conserve fertile topsoil.

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. But 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.

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 soil 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 soils have been renewed.

CASE STUDY

Soil Erosion in the United States

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. In 1935, prompted by the loss of soil, farms, and jobs in this "dust bowl," the United States passed the *Soil Erosion Act*, which established the Soil Conservation Service (SCS) as part of the USDA. Soil conservation districts were formed throughout the country, and farmers and ranchers were given technical assistance to set up soil conservation programs. (The SCS is now called the Natural Resources Conservation Service, or NRCS.)

Despite such efforts, 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 farming. According to the NRCS, 90% of American farmland is, on average, losing topsoil 17 times faster than new topsoil is being formed.

Of the world's major food-producing nations, only the United States is sharply reducing some of its soil losses through a combination of conservation-tillage farming and government-sponsored soil conservation programs. Under the 1985 Food Security Act (Farm Act), more than 400,000 farmers participating in the Conservation Reserve Program 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 soil losses on U.S. cropland by 40%. However, effective soil conservation is practiced today on only half of all U.S. agricultural land.

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 the highly successful soil conservation reserve program.

Restore Soil Fertility

Soil conservation is the best way to maintain soil fertility. The next best option is to restore some of the lost plant nutrients. To do this, farmers can use **organic fertilizer** from plant and animal materials or **commercial inorganic fertilizer** produced from various minerals.

There are several types of *organic fertilizers*. One is **animal manure:** the dung and urine of cattle, horses, poultry, and other farm animals. It 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 soil 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.

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 soil nutrients but also reduces erosion by keeping the topsoil covered with vegetation.

The active ingredients in *commercial inorganic fertilizers* used by many farmers (especially in developed countries) are inorganic compounds that contain *nitrogen*, *phosphorus*, and *potassium*. Other plant nutrients may be present in low or trace amounts. Inorganic fertilizer use has grown more than eleven-fold 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 where rivers empty into the sea (see Connections, p. 220). These fertilizers can help to replace depleted inorganic nutrients, but they do not replace organic matter.

Reduce Soil Salinization and Desertification

We know how to prevent and deal with soil salinization, as summarized in Figure 10-20.

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 soil erosion and thus 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 (Chapter 9 Core Case

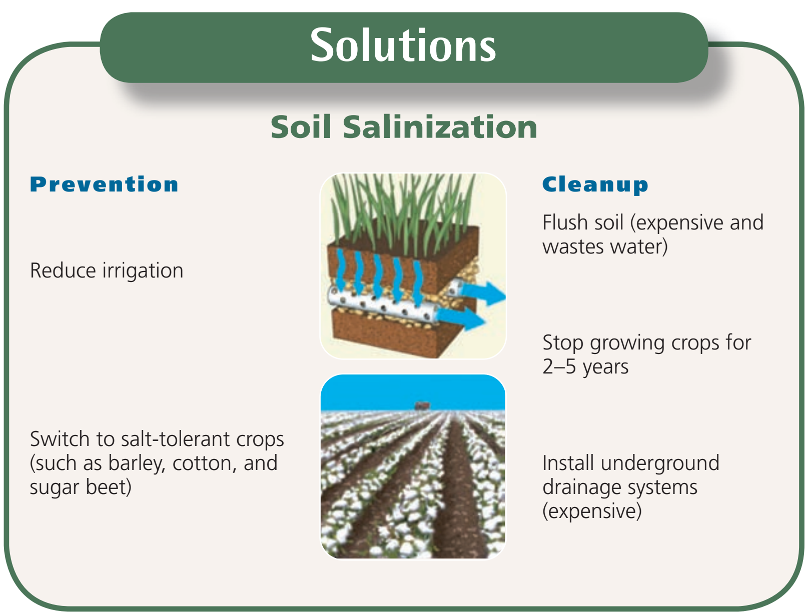


Figure 10-20 Methods for preventing and cleaning up soil salinization (**Concept 10-6**). **Questions**: Which two of these solutions do you think are the most important? Why?

Study, p. 178) and grasses that anchor topsoil and hold water. Other remedies are to establish windbreaks (Figure 10-19d) and to grow trees and crops together (Figure 10-19c).

Practice More Sustainable Aquaculture

Figure 10-21 lists some ways to make aquaculture more sustainable and to reduce its harmful environmental effects. Open-ocean aquaculture, which the United States is planning to develop, is one such alternative. It involves raising large carnivorous fish in underwater pens located up to 300 kilometers (190 miles) offshore (Figure 9-23, p. 201). The fish are fattened with fish meal supplied by automated buoys and wastes are diluted in the open ocean.

Using another approach, scientists are reducing damage to coastal areas in Florida by raising shrimp far inland in zero-discharge freshwater ponds. **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 feed on plants rather than on other fish. Raising carnivorous fishes such as salmon, trout, tuna, grouper, and cod contributes to overfishing of species used to feed these carnivores, and it will eventually be unsustainable. For example, it takes an average of 2 kilograms (4.4 pounds) of wild fish to produce 1 kilogram (2.2 pounds) of the 10 most commonly farmed fish species. Raising plant-eating fishes such as carp and tilapia (called the chicken of fish farming) does not add to this problem and is a more sustainable form of aquaculture.

Another such change would be for fish farmers to emphasize *polyaquaculture*, which has been part of aquaculture for centuries, especially in Southeast Asia. Polyaquaculture operations raise fish or shrimp along with algae, seaweeds, and shellfish in coastal lagoons, ponds, and tanks. The wastes of the 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 applies the recycling and biodiversity **principles of sustainability**.

Produce Meat More Efficiently and Eat Less Meat

Meat production and consumption account for the largest contribution to the ecological footprints of most individuals in affluent nations (**Concept 1-2**, p. 9). If everyone in the world today was on the average U.S. meat-based diet, the current annual global grain harvest could sustainably feed only about one-third of the world's current population.

A more sustainable form of meat production and consumption involves 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 herbivorous farmed fish (Figure 10-22), as many people are doing. Other people are simply eating less meat, some of them by having one or two meatless days per week. This reduces their ecological footprints, and many doctors argue that it also improves their health and increases their life expectancies. According to Dr. Rajendra Pachauri, head of the U.N. Intergovernmental Panel on Climate Change, eating less meat, especially less red meat, is the single best way to reduce one's contribution to projected climate change.

Some people are going further and eliminating most or all meat from their diet. They are replacing it with a vegetarian diet that includes a healthy combination

Solutions

More Sustainable Aquaculture

- Restrict locations of fish farms to reduce losses of mangrove forests and estuaries
- Improve management of aquaculture wastes
- Reduce escape of aquaculture species into the wild
- Raise some aquaculture species in deeply submerged cages to protect them from wave action and predators and to allow dilution of wastes into the ocean
- Certify sustainable forms of aquaculture and label products accordingly

Figure 10-21 Ways to make aquaculture more sustainable and to reduce its harmful effects. **Questions**: Which two of these solutions do you think are the most important? Why?

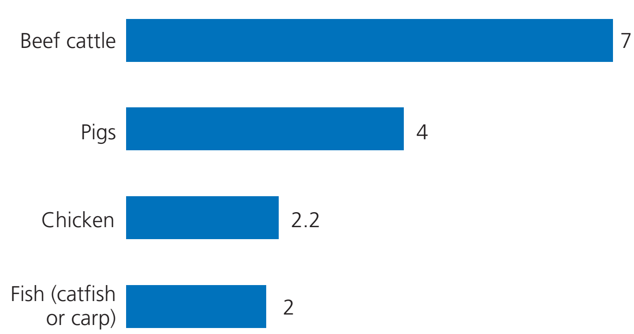


Figure 10-22 Efficiency of converting grain into animal protein. (Data in kilograms of grain per kilogram of body weight added.) **Question**: If you eat meat, what changes could you make in your meat-eating habits to reduce your environmental impact? (Data from U.S. Department of Agriculture)

of organically grown fruits and vegetables (**Core Case Study**) and protein-rich foods such as legumes. Some people like to supplement such a diet with moderate amounts of fish.

THINKING ABOUT
Meat Consumption

Would you be willing to live lower on the food chain (**Concept 3-3**, p. 45) by eating little or no meat? Explain.

Shift to More Sustainable Agriculture

Industrialized agriculture produces large amounts of food at reasonable prices. But to a growing number of analysts, this form of agriculture is unsustainable, because it violates the three **principles of sustainability**. It relies more on fossil fuels than on naturally available sunlight; reduces biodiversity and agrobiodiversity; and does not emphasize conservation and recycling of nutrients in topsoil—the irreplaceable base of all food production on land. These facts are hidden from consumers because the harmful environmental costs of food production (Figure 10-7) are not included in the market prices of food.

Figure 10-23 lists the major components of more sustainable agriculture (**Concept 10-6**). One component is *organic farming* (**Core Case Study**). 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 10-24 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 developed countries can be as much as 20% lower than yields of conventionally raised crops. But organic farmers often make up for this difference by not having to use or pay for expensive pesticides, herbicides, and synthetic fertilizers, and usually by getting higher prices for their crops. And a recent review of 286 systems employing organic agriculture in 57 developing countries found that their average yield was 70% higher than that from conventional agriculture.

Organic agriculture is an important start, but will be sustainable only if it puts primary emphasis on conserving the topsoil that supports all crop growth. Another important component of more sustainable agriculture is to rely more on *organic polyculture*—in which a diversity of organic crops are grown on the same plot—than on conventional single-crop organic agriculture. Another form of polyculture is to raise a diversity of animals on the same land.

Of particular interest to some scientists is the idea of growing *perennial crops*—crops that grow back year after year on their own—using polyculture (Science Focus, at right).

Solutions

More Sustainable Agriculture

More	Less
High-yield polyculture	Soil erosion
Organic fertilizers	Aquifer depletion
Biological pest control	Overgrazing
Integrated pest management	Overfishing
Efficient irrigation	Loss of biodiversity
Perennial crops	Food waste
Crop rotation	Subsidies for unsustainable farming and fishing
Water-efficient crops	Soil salinization
Soil conservation	Population growth
Subsidies for sustainable farming and fishing	Poverty

Figure 10-23 Major components of more sustainable, low-throughput agriculture based mostly on mimicking and working with nature (**Concept 10-6**). **Questions**: Which two solutions do you think are the most important? Why?

Well-designed polyculture helps to conserve and replenish topsoil, requires less water, and reduces the need for fertilizers and pesticides. Organic agriculture has the same advantages, plus it decreases the air and water pollution and does not create huge piles of animal wastes associated with conventional industrialized agriculture.

RESEARCH FRONTIER

Organic polyculture. See **www.cengage.com/biology/miller**.

Another key to more sustainable agriculture is to shift from using imported fossil fuel to relying more on solar energy for food production—an important application of the solar energy **principle of sustainability**. Farmers can also use wind, flowing water, and natural gas (produced from farm wastes in *biogas digesters*) to produce electricity and other forms of power needed for food production. And some farmers make money by selling any excess electricity they generate to power companies.

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 10-24 Environmental benefits of organic farming over conventional farming, based on 22 years of research comparing these two systems at the Rodale Institute in Kutztown, Pennsylvania (USA). (Data from Paul Mader, David Dubois, and David Pimentel)

Some say that making a shift to more sustainable agriculture by using strategies such as those listed in Figure 10-23 is idealistic and cannot work. Proponents disagree. They point out that we have all of the components needed for making such a shift. Some argue that over the next five decades, a combination of education and economic policies that reward more sustainable agriculture can lead to such a shift.

Some analysts contend that three factors have resulted in the current unsustainable systems: (1) our lack of knowledge about sustainability; (2) our failure to include the harmful environmental costs of food production in the market prices of food; and (3) our use of economic systems that reward unsustainable agriculture. These experts argue that if we can find the political and ethical will, we can make the shift to more sustainable ways of producing food.

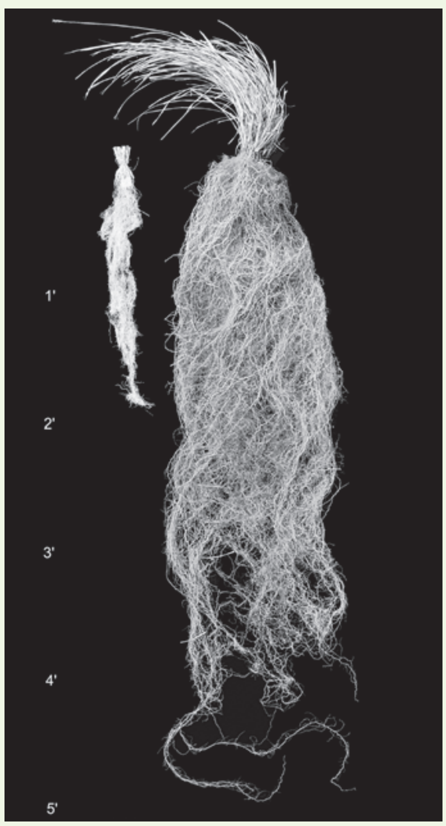
SCIENCE FOCUS

The Land Institute and Perennial Polyculture

Some scientists call for greater reliance on 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 co-founded The Land Institute in the U.S. state of Kansas. One of the institute's goals has been to use an ecological approach to agriculture. It has copied nature by growing a diverse mixture (polyculture) of edible perennial plants, especially perennial versions of annual grain crops such as wheat, sorghum, and sunflowers.

Because the plants are perennials, there is no need to till the soil and replant seeds each year. This reduces soil erosion and water pollution from eroded sediment, because the unplowed soil is not exposed to wind and rain. And it reduces the need for irrigation because the deep roots of such perennials retain more water than do the shorter roots of annuals (Figure 10-C). Also, there is little or no need for chemical fertilizers and pesticides, and thus little or no pollution from these sources.



Scott Bontz/The Land Institute

Figure 10-C Comparison of the roots of an annual wheat crop plant (left) with the roots of a tallgrass prairie perennial plant, big bluestem (right). The perennial plant is in the ground year-round and is much better at using water and nutrients and making and maintaining healthy soil. It also needs less fertilizer.

Wes Jackson calls for governments to promote this and other forms of more sustainable agriculture that would help to protect soil from erosion, sustain nitrogen nutrients in topsoil, cut the wasteful use of irrigation water, reduce dependence on fossil fuels, eliminate toxins in soil and water, and reduce dead zones in coastal areas caused by excessive runoff of plant nutrients into rivers. He reminds us that "if our agriculture is not sustainable, then our food supply is not sustainable."

Critical Thinking

Why do you think most conventional seed companies are strongly opposed to greatly increased use of perennial polyculture?

Critics say that this approach will not produce enough food and will lead to food shortages. Not so. Experience and research show that well-designed forms of more sustainable polyculture can produce much higher crop yields per unit of land than conventional monocultural agriculture can. 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 six major strategies to help farmers and consumers make the transition to more sustainable agriculture over the next 50 years (**Concept 10-6**). *First*, greatly increase research on sustainable organic farming (**Core Case Study**) and perennial polyculture (Science Focus, p. 233) and on improving human nutrition. *Second*, set up demonstration projects so that farmers can see how more sustainable agricultural systems work. *Third*, set up an international fund to give farmers in poor countries access to forms of more sustainable agriculture. *Fourth*, establish training programs in sustainable agriculture for farmers and government agricultural officials, and encourage the creation of college curricula in sustainable agriculture. *Fifth*, replace government subsidies for environmentally harmful forms of industrialized agriculture with subsidies that encourage more sustainable agriculture. *Sixth*, mount a massive program to educate consumers about the true costs of the food they buy. This would help consumers 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.

Consumers Can Buy Local, Grow Some of Their Own Food, and Cut Food Waste

Figure 10-25 lists ways in which you can promote more sustainable agriculture.

What Can You Do?

Sustainable Organic Agriculture

- Waste less food
- Eat less meat or no meat
- Use organic farming to grow some of your food
- Buy organic food
- Eat locally grown food
- Compost food wastes

Figure 10-25 **Individuals matter:** ways to promote more sustainable agriculture (**Concept 10-6**). **Questions**: Which three of these actions do you think are the most important? Why?

One important component of more sustainable agriculture, according to most experts, will be to have much more of our food grown locally, or at least regionally. Consumers can help farmers to make a transition to more sustainable farming by increasing their demand for organic foods. They can also buy more of their food from local and regional producers in farmers' markets or other outlets. A growing number of 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 and vegetables each week during the summer and fall. One commentator referred to this commitment to buying local as "becoming a locavore."

Buying locally supports local economies and farm families, and it might help to slow the rapid conversion of farmland to suburban development, with resulting problems of urban sprawl (p. 109). It can also reduce the environmental impact of most food production, because locally grown food does not have to be transported very far from producer to consumer.

People living in urban areas could grow more of their own food. According to the U.S. Department of Agriculture, around 15% of the world's food is grown in urban areas, and this percentage could easily be doubled. People plant gardens in suburban backyards. In cities, they grow food in vacant lots, on rooftops, in window boxes, and in raised beds in unused or partially used parking lots (a growing practice known as *asphalt gardening*). In London, England, and in the United States, a growing number of city dwellers are raising chickens in their backyard, with the wastes used as fertilizer for backyard gardens.

Shifting to more sustainable agriculture and supplying more food locally could result in more small farms. This means that more people would be making a living by producing food more sustainably for people living in their regions. Eco-farming could be one of this century's challenging new careers for many young people. **GREEN CAREER:** Small-scale sustainable agriculture

Finally, people can sharply cut food waste. This is an important component of improving food security (**Concept 10-5**). In 2008, environmental scientist Vaclav Smil estimated that Americans waste 35-45% of their food supply. 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 U.N. estimates. Many developed countries have similarly high rates of food waste.

We are at a fork in the road. We can keep on using our current food production system, which some experts argue is unsustainable and could collapse if the prices of oil and natural gas rise sharply, as is projected by many economists. Or we can try a new, more sustainable path.

Proponents of decentralizing and diversifying our food production systems say that this major shift will improve local and regional economies by providing large numbers of green jobs. They argue that it will also improve economic and military security for many nations by reducing their dependence on increasingly expensive imported oil and food. And this shift will sharply reduce the harmful environmental impacts of industrialized agriculture.

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

- About 925 million people have health problems because they do not get enough to eat and 1.6 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 and national security for all countries.

REVISITING Organic Agriculture and Sustainability

CORE CASE STUDY

SUSTAINABILITY

This chapter began with a look at how food can be produced by 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 10-7).

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, includes too little recycling of crop and animal wastes, accelerates soil erosion, does too little to preserve agrobiodiversity, and 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 the 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 nutrient cycling through soil conservation and 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 and integrated pest management 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, water, and other resources. We can also insist that elected officials replace environmentally harmful agricultural subsides and tax breaks with more environmentally beneficial ones and work to include the harmful environmental costs of food production in the market prices of food.

Making the transition to more sustainable forms of food production will not be easy. But it can be done if we heed the ecological lessons from nature represented by the three **principles of sustainability**.

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. 207. Compare the main components of **organic agriculture** 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. Describe the effects of diet deficiencies in vitamin A, iron, and iodine. What is **overnutrition**, and what are its harmful health effects?
3. What three systems supply most of the world's food? Distinguish among **industrialized agriculture** (**high-input agriculture**), **plantation agriculture**, **traditional subsistence agriculture**, **traditional intensive agriculture**, and **polyculture**. Define **soil** and describe its formation and the major layers in mature soils and why soil conservation is so important. What is a **green revolution**? Describe industrialized food production in the United States and in Brazil.
4. Distinguish between producing crops through *crossbreeding* and producing crops through *genetic engineering*. Describe

industrialized meat production. What is a **fishery**? What is **aquaculture**?

5. 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.

6. What factors can limit green revolutions? Describe the use of energy in industrialized agriculture. Describe the advantages and disadvantages of genetically engineered foods. Explain how most industrialized food production systems reduce biodiversity and agrobiodiversity. Describe the advantages and disadvantages of industrialized meat production. Describe the advantages and disadvantages of aquaculture.

7. What is a **pest**? Define and give two examples of a **pesticide**. Describe Rachel Carson's contribution to environmental science. Describe the advantages and disadvantages of modern pesticides. Describe the use of laws to help protect us from the harmful effects of pesticides. Describe seven alternatives to conventional pesticides. Define **integrated pest management** (**IPM**) and discuss its advantages.

8. Describe three ways in which governments influence food production. List six ways to reduce nutrition-related premature childhood deaths. What is **soil conservation**? Describe soil erosion and soil conservation in the United States. Describe seven ways to reduce soil erosion. Distinguish among the use of **organic fertilizer**, **commercial inorganic fertilizer**, **animal manure**, **green manure**, **compost**, and *crop rotation* as ways to help restore soil fertility. Describe ways to prevent and clean up *soil salinization* and *desertification*.

9. Describe ways to produce meat more efficiently and sustainably. Describe ways to make aquaculture more sustainable. What are three factors that contributed to the growth of the current industrialized food production systems? What are the major components of *more sustainable agriculture*? What are the major advantages of *organic agriculture*? Describe the advantages of relying more on polycultures of perennial crops. What can individuals do to promote more sustainable agriculture?

10. What are this chapter's *three big ideas*? Describe the relationships among organic agriculture (**Core Case Study**), more sustainable food production, and the three **principles of sustainability**.

CORE CASE STUDY

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? 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.

CORE CASE STUDY

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 food **(b)** polyculture, and **(c)** perennial polyculture.

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 increased mosquito populations 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 soil erosion.

8. According to physicist and philosopher Albert Einstein, "Nothing will benefit human health and increase chances of survival of life on Earth as much as the evolution to a vegetarian diet." Do you agree with this statement? Explain. 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)** strategy for reducing soil erosion, **(c)** strategy 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.

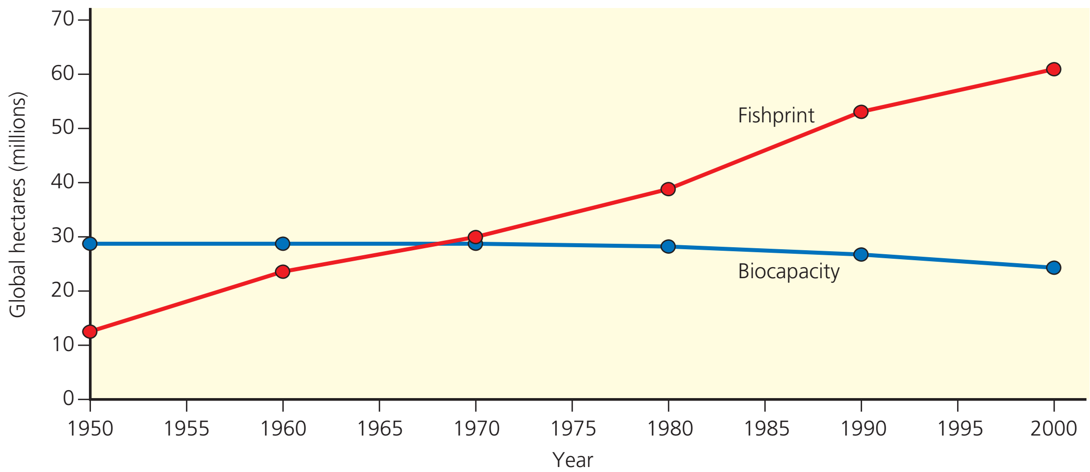
ECOLOGICAL FOOTPRINT ANALYSIS

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 *biocapacity*, its ability to provide a stable supply of fish year after year, again in terms of area, it indicates whether the country's fishing intensity is sustainable. The fishprint and biocapacity are calculated using the following formulas:

$$\text{Fishprint in (gha)} = \frac{\text{metric tons of fish harvested per year}}{\text{productivity in metric tons per hectare}} \times \text{weighting factor}$$

$$\text{Biocapacity in (gha)} = \frac{\text{sustained yield of fish in metric tons per year}}{\text{productivity in metric tons per hectare}} \times \text{weighting factor}$$

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 exceeding the biocapacity of the world's oceans?
   c. By how much did the global fishprint exceed the biocapacity 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 biocapacity?
   b. Is the county's fishing intensity sustainable?
   c. To what extent, as a percentage, is the country under- or overshooting its biocapacity?

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengage.com/biology/miller** and choose Chapter 10 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, web links, information on Green Careers, and InfoTrac® College Edition articles.

CENGAGENOW™ For students with access, log on at **www.cengage.com/login** for the animations, active figures, activities, and readings indicated within the text by the CengageNOW logo. If your textbook did not come with access, visit **www.iChapters.com** to purchase.

11 Water Resources and Water Pollution

CORE CASE STUDY The Colorado River Story

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 11-1). 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 11-2) and canals that supply water to farmers, ranchers, industries, and cities.

Figure 11-1 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.

This system provides water and electricity from hydroelectric plants at the major dams, for 30 million people in seven states—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, desert-like climate, that very little of it reaches the sea. This overtapping of the Colorado River illustrates the challenges faced by governments and people living in arid and semiarid regions with shared river systems, as population growth and economic growth 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 and water pollution problems discussed in this chapter—along with the related problems of biodiversity loss and climate change—are the most serious environmental problems the world faces during this century.

Jim Wark/Peter Arnold, Inc.

Figure 11-2 Aerial view of Glen Canyon Dam, built across the Colorado River in 1963, and its reservoir, Lake Powell, the second largest reservoir in the United States.

Key Questions and Concepts

11-1 Will we have enough usable water?

CONCEPT 11-1A We are using available freshwater unsustainably by wasting it, polluting it, and charging too little for this irreplaceable natural resource.

CONCEPT 11-1B One of every six people does not have sufficient access to clean water, and this situation will almost certainly get worse.

11-2 How can we increase water supplies?

CONCEPT 11-2A Groundwater used to supply cities and grow food is being pumped from aquifers in some areas faster than it is renewed by precipitation.

CONCEPT 11-2B Using dams, reservoirs, and water transfer projects to provide water to arid regions has increased water supplies in some areas but has disrupted ecosystems and displaced people.

CONCEPT 11-2C 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.

11-3 How can we use water more sustainably?

CONCEPT 11-3 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.

11-4 How can we reduce the threat of flooding?

CONCEPT 11-4 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.

11-5 How can we deal with water pollution?

CONCEPT 11-5A Streams can cleanse themselves of many pollutants if we do not overload them or reduce their flows.

CONCEPT 11-5B Reducing water pollution requires preventing it, working with nature in treating sewage, cutting resource use and waste, reducing poverty, and slowing population growth.

Note: Supplements 3 (p. S6), 4 (p. S14), 5 (p. S21), and 6 (p. S26) 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

11-1 Will We Have Enough Usable Water?

▶ **CONCEPT 11-1A We are using available freshwater unsustainably by wasting it, polluting it, and charging too little for this irreplaceable natural resource.**

▶ **CONCEPT 11-1B 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 (Figure 7-20, p. 140). Look in the mirror. What you see is about 60% water, most of it inside your cells.

You could survive for several weeks without food, but for only a few days without water. And it takes huge amounts of water to supply you with food, provide you with shelter, and meet your other daily needs and wants. Water, as a vital form of natural capital, also helps to sculpt the earth's surface, moderate climate, and remove and dilute wastes and pollutants.

Despite its importance, water is one of our most poorly managed resources. We 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 11-1A**).

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 a *women's and children's*

Figure 11-3 Girl carrying water from a well across dried out and cracked earth during a severe drought in India. According to the United Nations, over 1 billion people—more than three times the entire U.S. population—do not have access to clean water where they live. Girls and women in this group typically spend an average 3 hours a day collecting water from distant sources.

issue in developing countries because poor women and girls often are responsible for finding and carrying daily supplies of water (Figure 11-3). And water is a *national and global security issue* because of increasing tensions 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 dropping water tables, lower river flows (**Core Case Study**), shrinking lakes, and losses of wetlands. This and pollution of water result in declining water quality, lower fish populations, species extinctions, and degradation of aquatic ecosystem services (Figure 7-21, p. 141, and Figure 7-29, p. 146). Virtually all of these interconnected environmental indicators related to water availability and quality are worsening in some regions.

CORE CASE STUDY

Most of the Earth's Freshwater Is Not Available to Us

Only a tiny fraction of the planet's abundant 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, in frozen polar ice caps and glaciers, or in deep underground and 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 (Figure 3-12, p. 49). This irreplaceable water recycling and purification system works well, unless we overload it with slowly degradable and nondegradable wastes or withdraw water from underground and surface water supplies faster than it is replenished. The system is also hindered when we destroy wetlands and cut down forests that store and slowly release water or alter the rate and distribution patterns of water as a result of climate change. In parts of the world, we are doing all of these things (**Concept 7-5**, p. 140, and **Concept 7-6**, p. 146), mostly because we have placed little or no economic value on the natural ecological services provided by water (Science Focus, p. 181). (See *The Habitable Planet*, Video 8, at **www.learner.org/resources/series209.html**.)

CONCEPT LINKS

We Get Freshwater from Groundwater and Surface Water

Some precipitation infiltrates 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. 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 bedrock through which groundwater flows. 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 bedrock 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.

Most aquifers are replenished naturally by precipitation that percolates downward through soil and rock, a process called *natural recharge*. Others are recharged from the side by *lateral recharge* from nearby rivers and streams. Most aquifers recharge extremely slowly.

Because so much of the urban landscape has been built on or paved over, water can no longer penetrate the ground to recharge aquifers below some urban areas.

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.

One of our most important resources is **surface water**, the freshwater from precipitation and snowmelt that flows across the earth's land surface and into lakes, wetlands, streams, rivers, estuaries, and ultimately to 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**, such as the one that supplies water to the Colorado River (Figure 11-1).

CORE CASE STUDY

We Use a Large and Growing Portion of the World's Reliable Runoff

According to hydrologists (scientists who study water supplies), two-thirds of the annual surface runoff in rivers and streams is lost by seasonal floods and is not available for human use. The remaining one-third is **reliable surface runoff**, which we can generally count on as a source of freshwater from year to year.

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. Because of increased population growth alone, global withdrawal rates of surface water could reach more than 70% of the reliable runoff by 2025, and 90% if per capita withdrawal of water continues increasing at the current rate.

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 irrigation (**Core Case Study**).

CORE CASE STUDY

Worldwide, we use about 70% of the water we withdraw each year from rivers, lakes, and aquifers to irrigate cropland. 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, much of it unnecessarily wasted. According to a 2004 study by the World Water Council, it takes about 30 bathtubs full of water to produce a typical cotton T-shirt, 12 bathtubs full of water to produce a hamburger, and 18 buckets of water to produce a cup of coffee or a glass of wine.

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 11-4, top, yellow areas).

According to the U.S. Geological Survey, about 79% of the water used in the United States is used for irrigating crops (40%) and removing heat from electric power plants (39%). In the East, most water is used for power plant cooling and manufacturing. In many parts of the eastern United States, the most serious water problems are flooding, occasional urban shortages as a result of pollution, and **drought**: a prolonged period in which

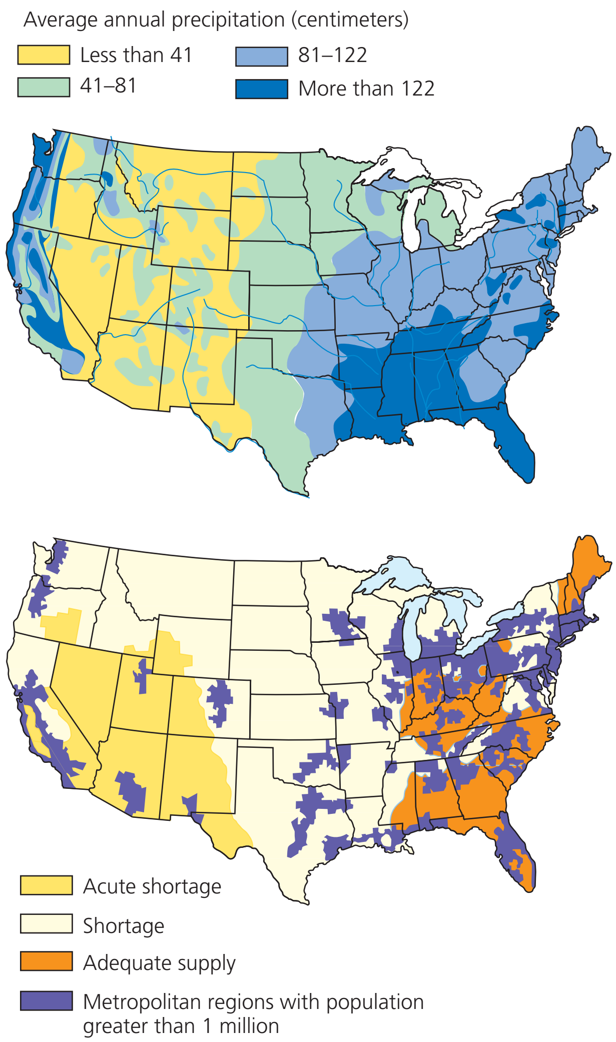


Figure 11-4 Average annual precipitation and major rivers (top) and water-deficit regions in the continental United States and their proximity to metropolitan areas having populations greater than 1 million (bottom). **Question**: Why do you think some areas with moderate precipitation still suffer from water shortages? (Data from U.S. Water Resources Council and U.S. Geological Survey)

precipitation is at least 70% lower and evaporation is higher than normal in an area that is normally not dry.

In the arid and semiarid areas of the western half of the United States (Figure 11-4, bottom), irrigation accounts for 85% of water use. Much of it is unnecessarily wasted and used to grow thirsty crops on arid and semiarid land. The major water problem is a shortage of runoff caused by low precipitation (Figure 11-4, top), high evaporation, and recurring severe drought.

Almost half the water used in the United States comes from groundwater sources, and the rest 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 11-4, bottom) deplete many aquifers faster than they can be recharged.

In 2007, the U.S. Geological Survey projected that at least 36 U.S. states are likely to face water shortages by 2013 because of a combination of drought, rising temperatures, population growth, urban sprawl, and excessive use and waste of water. In 2003, the U.S. Department of the Interior mapped out *water hotspots* in 17 western states (Figure 11-5). 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.

Such shortages are likely to increase from extreme drought projected for the rest of this century as a result of projected climate change. A 2008 report by the U.S.

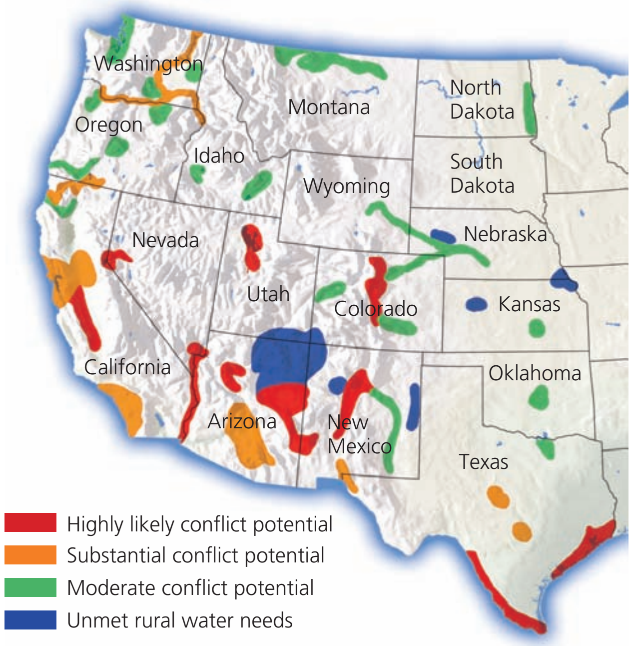


Figure 11-5 Water *hotspots* in 17 western states that, by 2025, could face intense conflicts over scarce water needed for urban growth, irrigation, recreation, and wildlife. Some analysts suggest that this is a map of places not to live in the foreseeable future. **Question**: Which, if any, of these areas are found in the Colorado River basin (Figure 11-1)? (Data from U.S. Department of the Interior)

Geological Survey warned that the southwestern United States faces "permanent drying" by 2050 as its already dry climate becomes much drier.

An excellent example is the Colorado River system (Figure 11-1), where there are five major problems associated with use of water from the 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 allocated more water for human use in the United States and Mexico than the river can supply—even in rare years when there is no drought—and the pacts allocated no water for environmental purposes. *Fourth*, since 1960, the river has rarely flowed fully to the Gulf of California because of its reduced water flow (due to many dams), increased water withdrawals, and a prolonged drought in 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.

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 11-6 shows the current degree of stress faced by 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 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.

Currently, about 30% of the earth's land area—a total area roughly five 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—about seven times the size of the United States—could experience extreme drought, mostly as a result of projected climate change (**Concept 11-1B**).

In 263 of the world's water basins, two or more countries share the available water supplies. But 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. We can find substitutes for resources such as oil, but there is no substitute for freshwater.

Here is what the United Nations said in 2008 about water shortages in the world:

- About 1 billion people—one of every seven—in the world currently lack regular access to enough clean water for drinking, cooking, and washing.

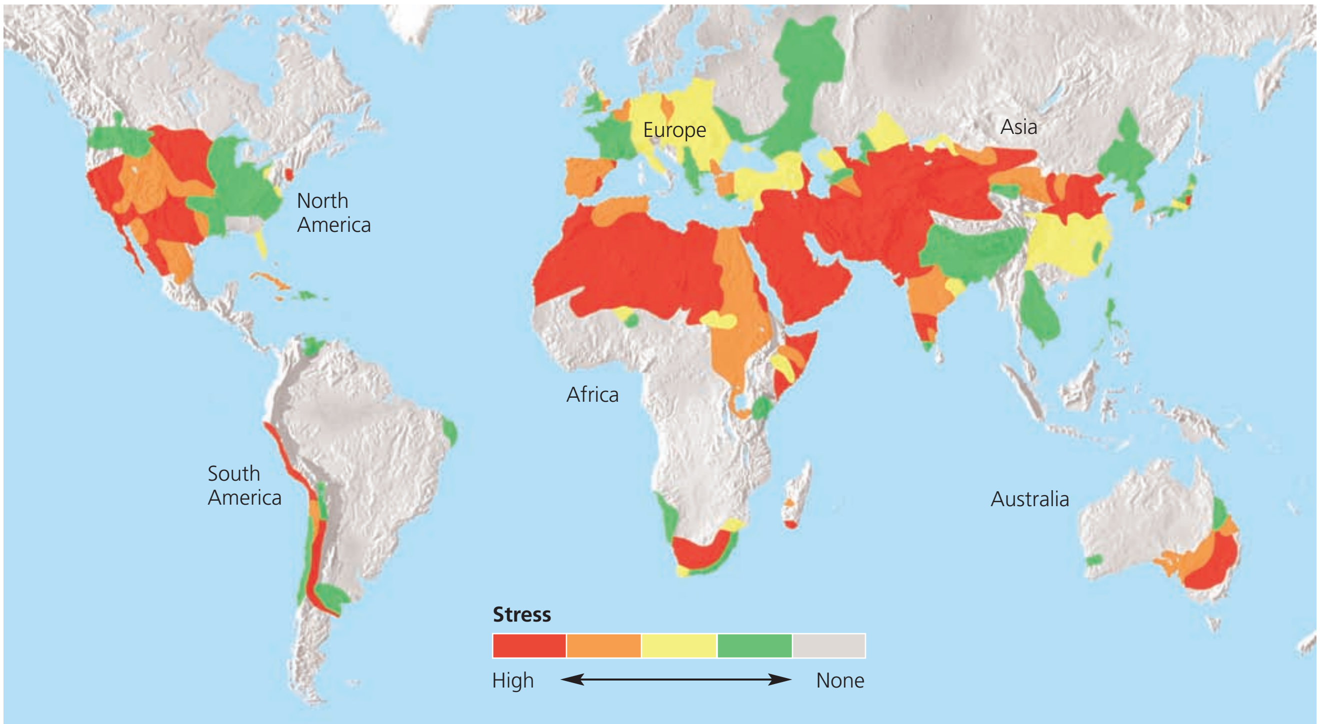


Figure 11-6 **Natural capital degradation:** stress on the world's major river basins, based on a comparison of the amount of water available with the amount used by humans (**Concept 11-1B**). **Questions**: If you live in a water-stressed area, what signs of stress have you noticed? In what ways, if any, has it affected your life? (Data from World Commission on Water Use in the 21st century)

- 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 almost three times the current population of China and nearly ten times the current population of the United States.

If the second projection is correct, there are three likely results: greatly increased sickness and deaths 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 most serious environmental problems the world faces.

11-2 How Can We Increase Water Supplies?

▶ **CONCEPT 11-2A Groundwater used to supply cities and grow food is being pumped from aquifers in some areas faster than it is renewed by precipitation.**

▶ **CONCEPT 11-2B Using dams, reservoirs, and water transfer projects to provide water to arid regions has increased water supplies in some areas but has disrupted ecosystems and displaced people.**

▶ **CONCEPT 11-2C 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.**

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. Another solution is to increase water supplies in water-short areas, mostly 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

CORE CASE STUDY

(desalination) (**Concepts 11-2A**, **11-2B**, and **11-2C**). Let us look at the advantages and disadvantages of each of these approaches.

Water Tables Fall When Groundwater Is Withdrawn Faster Than It Is Replenished

Most aquifers are renewable resources unless their water 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 11-7).

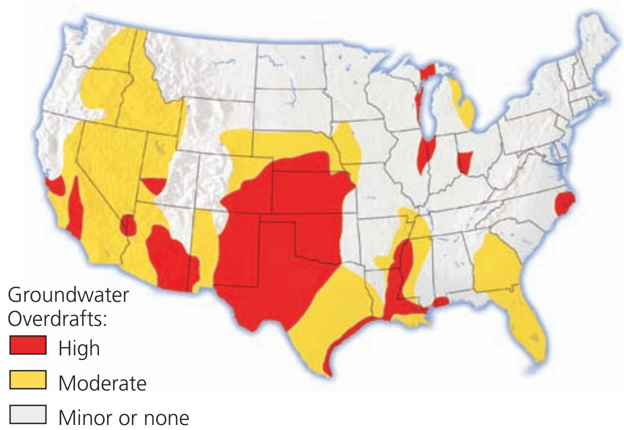
Water tables are falling in many areas of the world because the rate of pumping water from aquifers (mostly to irrigate crops) exceeds the rate of natural recharge from rainfall and snowmelt (**Concept 11-2A**). The world's three largest grain producers—India, China, and the United States—and several other countries such as Saudi Arabia, Mexico, Iran, Yemen, Israel, Mexico, and Pakistan are overpumping many of their aquifers.

Trade-Offs

Withdrawing Groundwater

Advantages	Disadvantages
Useful for drinking and irrigation	Aquifer depletion from overpumping
Available year-round	Sinking of land (subsidence) from overpumping
Exists almost everywhere	Aquifers polluted for decades or centuries
Renewable if not overpumped or contaminated	Saltwater intrusion into drinking water supplies near coastal areas
No evaporation losses	Reduced water flows into surface waters
Cheaper to extract than most surface waters	Increased cost and contamination from deeper wells

Figure 11-7 Advantages and disadvantages of withdrawing groundwater. **Questions**: Which two advantages and which two disadvantages do you think are the most important? Why?



CENGAGENOW™ **Active Figure 11-8 Natural capital degradation:** areas of greatest aquifer depletion from groundwater overdraft in the continental United States (**Concept 11-2A**). Aquifer depletion is also high in Hawaii and Puerto Rico (not shown on map). *See an animation based on this figure at* CengageNOW. **Question**: If you live in the United States, how is your lifestyle affected directly or indirectly by water withdrawn from the essentially nonrenewable Ogallala aquifer? (Data from U.S. Water Resources Council and U.S. Geological Survey)

In the United States, groundwater is being withdrawn, on average, four times faster than it is replenished, according to the U.S. Geological Survey. Figure 11-8 shows the areas of greatest depletion. One of the most serious overdrafts 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 11-8).

The gigantic Ogallala aquifer supplies about one-third of all the groundwater used in the United States and has helped turn the Great Plains into one of world's most productive irrigated agricultural regions. The problem is that the Ogallala is essentially a one-time deposit of liquid natural capital with a very slow rate of recharge.

In some areas of the Ogallala, water is being pumped out at a rate that is 10–40 times higher than the natural recharge rate, which has lowered water tables and increased pumping costs. Government subsidies designed to increase crop production and encourage farmers to grow water-thirsty crops in dry areas have encouraged depletion of the Ogallala. Serious groundwater depletion is also taking place in California's semi-arid Central Valley, which supplies half of the country's fruits and vegetables (long red area in the California portion of Figure 11-8). 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. . . . I'm hoping that the American people will wake up."

CONNECTIONS

Groundwater Overpumping and Poverty

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 the 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.

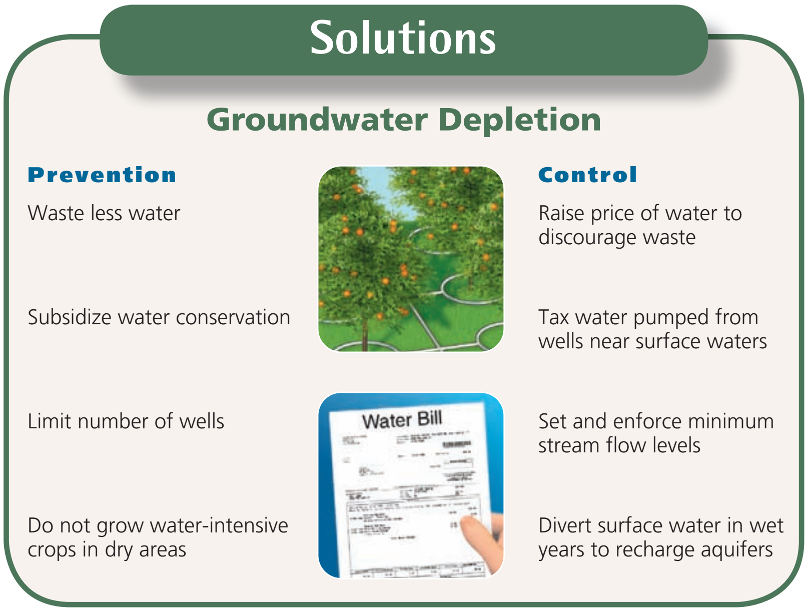


Figure 11-9 Ways to prevent or slow groundwater depletion by using water more sustainably. **Questions**: Which two of these solutions do you think are the most important? Why?

Groundwater overdrafts near coastal areas, where many of the world's largest cities and industrial areas are found, can contaminate groundwater supplies by pulling saltwater into freshwater aquifers. The resulting contaminated groundwater is undrinkable and unusable for irrigation. This problem is especially serious in coastal areas of the U.S. states of Florida, California, South Carolina, Georgia, New Jersey, and Texas, as well as in coastal areas of Turkey, Manila in the Philippines, and Bangkok in Thailand.

Figure 11-9 lists ways to prevent or slow the problem of groundwater depletion by using this largely renewable resource more sustainably. **GREEN CAREER:** Hydrogeologist

There is growing interest in using treated wastewater or storm runoff to help replenish natural aquifers. Scientists are also evaluating the use of deep aquifers as a source of freshwater (Science Focus, below).

Large Dams and Reservoirs Have Advantages and Disadvantages

Large **dams**—structures built across rivers to block some of the flow of water—and **reservoirs**—stores of water collected behind the dams—(**Core Case Study** and Figure 11-2) have benefits and drawbacks (Figure 11-10, p. 246). 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 boating.

CORE CASE STUDY

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 (Figure 7-29, left, p. 146 and **Concept 11-2B**). 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

SCIENCE FOCUS

Are Deep Aquifers the Answer?

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; they 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 several different countries, and there are no international water treaties that govern rights to such water. Without such treaties, conflicts could occur over who has the right to tap into these valuable resources. *Fourth*, the costs are unknown and could be high.

Critical Thinking

What are some other possible problems that could arise from withdrawing freshwater from deep aquifers?

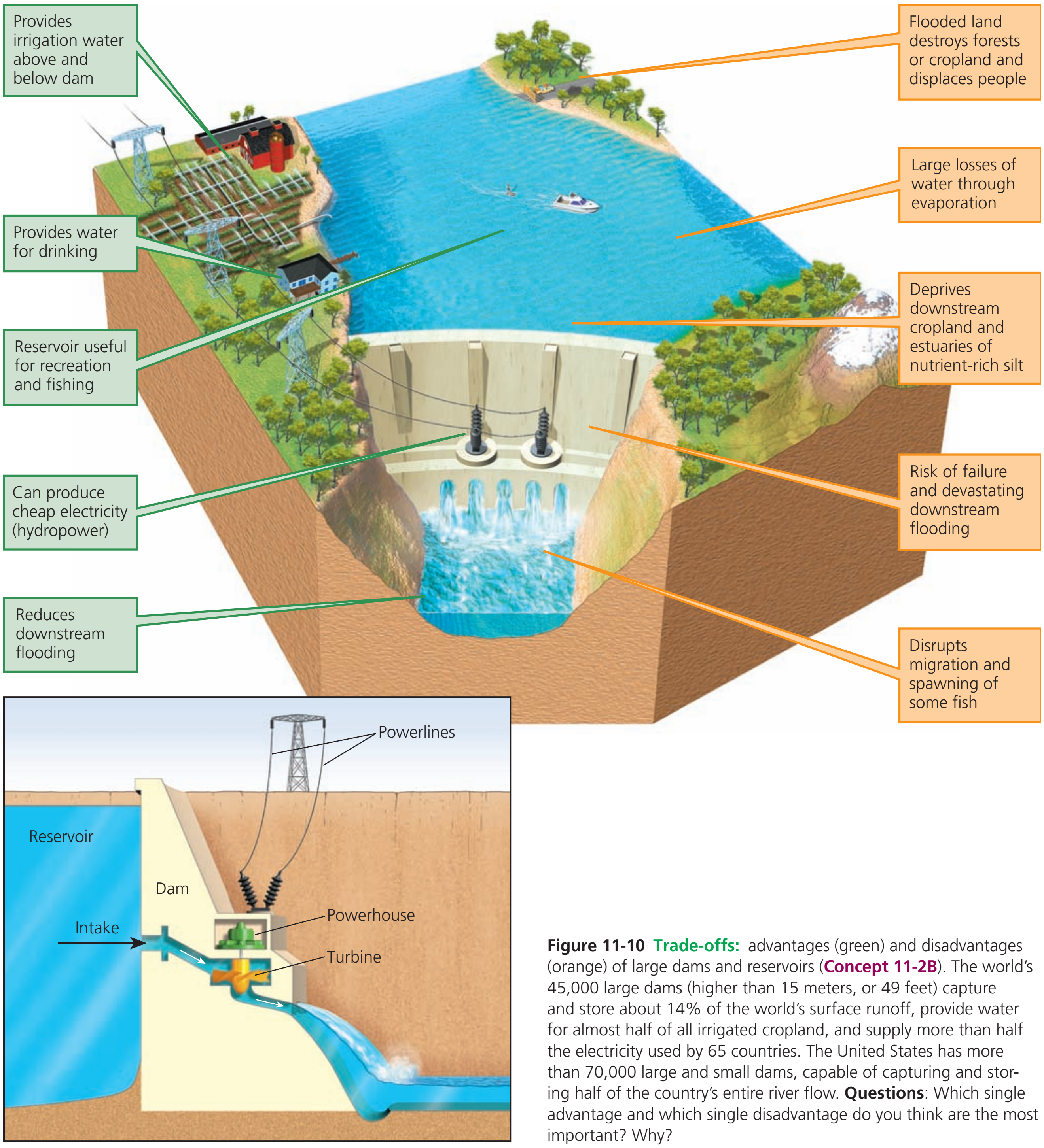


Figure 11-10 **Trade-offs:** advantages (green) and disadvantages (orange) of large dams and reservoirs (**Concept 11-2B**). The world's 45,000 large dams (higher than 15 meters, or 49 feet) capture and store about 14% of the world's surface runoff, provide water for almost half of all irrigated cropland, and supply more than half the electricity used by 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. **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

rivers, including the Colorado (Figure 11-1). CORE CASE STUDY The study also found that only 21 of the planet's 177 longest rivers run freely from their sources to the sea (Figure 7-32, p. 148) because of dams, excessive water withdrawals, and in some areas, prolonged severe drought.

HOW WOULD YOU VOTE?

Do the advantages of large dams outweigh their disadvantages? Cast your vote online at **www.cengage.com/biology/miller**.

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**) CORE CASE STUDY has dropped dramatically (Figure 11-11). In most years since 1960, the river has dwindled to a small stream by the time it reaches the Gulf of California. This threatens the survival of species that spawn in the river and that live in its estuary near the coast.

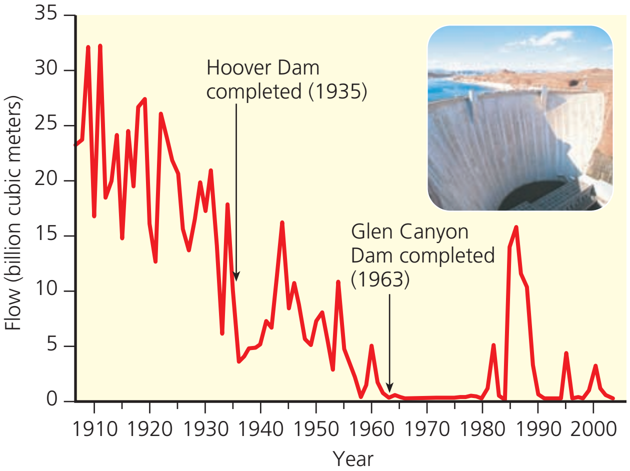


Figure 11-11 The measured flow of the Colorado River at its mouth has dropped sharply since 1905 as a result of multiple dams, water withdrawals for agriculture and urban areas, and prolonged drought (Data from U.S. Geological Survey).

At a December 2008 meeting, water scientists warned that the current withdrawal of water from the Colorado River is not sustainable. And in February 2008, water experts at the Scripps Institution of Oceanography in San Diego, California, concluded that there is a 50% chance that the Lake Mead reservoir behind Hoover Dam (Figure 11-1) could run dry by 2021.

Water experts also project that the water available from the Colorado River is likely to decrease even more because of projected climate change. They warn that as the climate continues to warm, mountain snows that feed the river will melt faster and earlier and the resulting water will evaporate in greater amounts.

CORE CASE STUDY

If some of the Southwest's largest reservoirs (Figure 11-2) empty out 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, likely would have to migrate to other areas. Withdrawing more groundwater is not a solution, because water tables under much of the area served by the Colorado River have been dropping, sometimes drastically, due to overpumping (Figure 11-8).

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. The amount of silt being deposited on the bottoms of the Lake Powell (Figure 11-2) 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 enough water for generating hydroelectric power or controlling floods.

THINKING ABOUT
The Colorado River Basin

What are three things you would you do to help deal with the problems of the Colorado River basin? How would you implement them politically? Would you live in this basin (if you do not already)?

CASE STUDY

California Transfers Massive Amounts of Water from Water-Rich Areas to Water-Poor Areas

Tunnels, aqueducts (lined channels), and underground pipes can be used to transfer stream runoff collected by dams and reservoirs from water-rich areas to water-poor areas, but such transfers also create environmental problems (**Concept 11-2B**).

One of the world's largest water transfer projects is the *California Water Project* (Figure 11-12). It uses a maze of giant dams, pumps, and aqueducts to transport water from water-rich northern California to water-poor southern California's heavily populated agricultural regions and cities. This project supplies massive amounts of water to areas that, without such water transfers, would be mostly desert.

According to a 2002 study by a group of scientists and engineers, even in the best-case scenario, projected climate change will sharply reduce water availability in California (especially southern California) and other

Figure 11-12 California Water Project and the Central Arizona Project. These projects involve large-scale water transfers from one watershed to another. Arrows show the general direction of water flow.

water-short states in the western United States (Figure 11-5). Some analysts project that sometime 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.

Pumping more groundwater is not the answer, because groundwater is already being withdrawn faster than it is replenished in much of central and southern California (Figure 11-8). And desalinating seawater with current methods is too expensive to provide large amounts of water for irrigation and major coastal urban areas. According to many analysts, it would be quicker and cheaper to reduce water waste by improving irrigation efficiency, not growing water-thirsty crops in arid areas, and raising the historically low price of water to encourage water conservation.

■ **CASE STUDY**

The Aral Sea Disaster: A Striking Example of Unintended Consequences

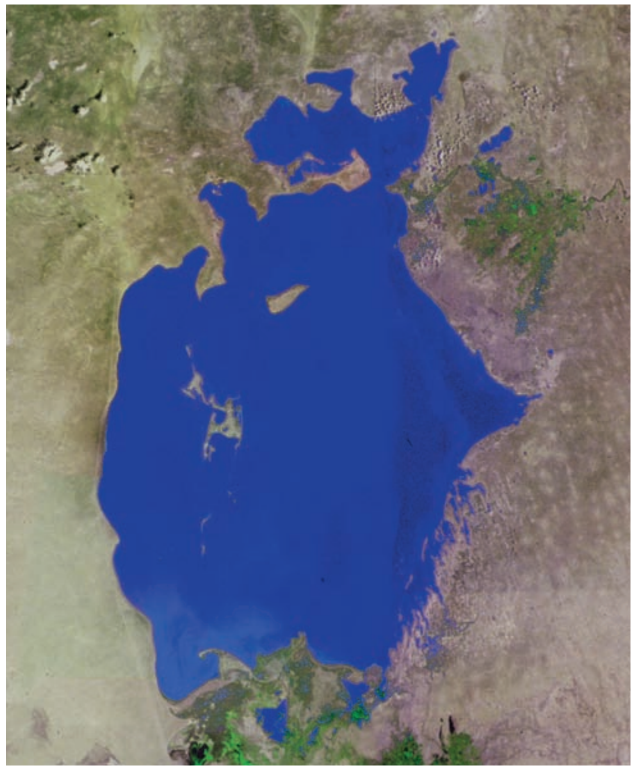
The shrinking of the Aral Sea (Figure 11-13) is the result of a large-scale water transfer project in an area of the former Soviet Union with the driest climate in central Asia. Since 1960, enormous amounts of irrigation water have been diverted from the inland Aral Sea and its two feeder rivers. The goal was to create one of the world's largest irrigated areas, mostly for raising thirsty cotton and rice crops in a very dry area. 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.

Since 1961, the sea's salinity has risen sevenfold and the average level of its water has dropped by 22 meters (72 feet)—roughly the height of a six-story building. It has lost 90% of its volume of water and has split into two major parts, separated mostly by salt-covered desert (Figure 11-13, bottom).

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 former lake bottom is now a human-made desert covered with glistening white salt. The sea's greatly increased salt concentration 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 once located on the sea's coastline now sit abandoned in a salt desert.

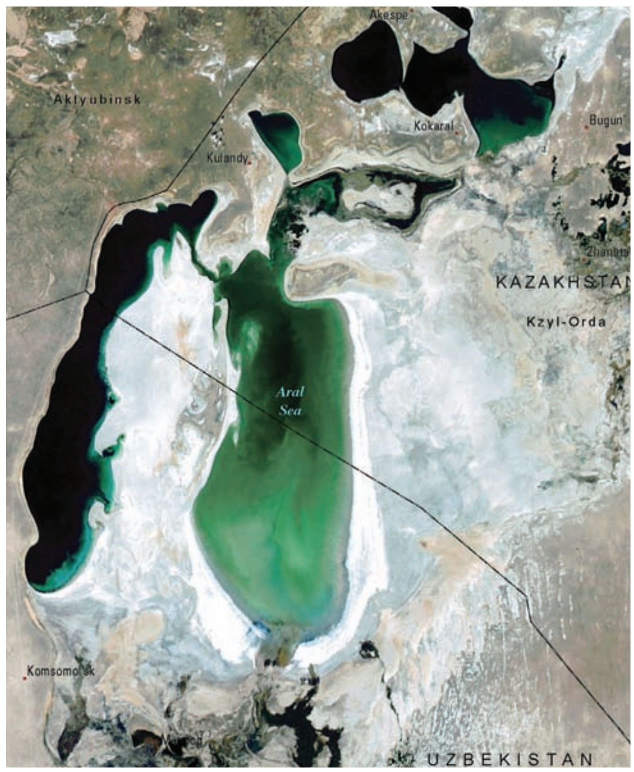
Winds pick up the sand and salty dust and blow it onto fields as far as 500 kilometers (310 miles) away. As the salt spreads, it pollutes water and kills wildlife, crops, and other vegetation. Aral Sea dust settling on glaciers in the Himalayas is causing them to melt at a faster-than-normal rate—a prime 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



UNEP/GRID-Sioux Falls

1976



NASA image courtesy of Jeff Schmaltz, MODIS Rapid Response Team, NASA-Goddard Space Flight Center.

2006

Figure 11-13 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 rivers that replenish it has been diverted to grow cotton and food crops. These satellite photos show the sea in 1976 and in 2006. As the lake shrank, it split into two lakes and left behind a salty desert, economic ruin, increasing health problems, and severe ecological disruption. **Question**: What are three things that you think could be done to help prevent further shrinkage of the Aral Sea?

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.

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. A dike completed in 2005 has raised the average level of the small Aral by 3 meters (10 feet), adding back a little less than one-seventh of what was lost and decreasing its salinity.

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 others requiring less irrigation water. As a result, the total annual volume of water in the Aral Sea basin has been stabilized. Nevertheless, experts expect the largest portion of the Aral Sea to continue shrinking.

GOOD NEWS

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 for domestic use. It is another way to increase supplies of freshwater (**Concept 11-2C**).

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 13,000 desalination plants 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.

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 desalinate water. Pumping desalinated water inland also takes lots of energy and is costly. 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 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 11-2C**).

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. Some scientists have hopes for using solar energy as the primary power source for desalination. Stay tuned as this idea is developed and evaluated.

RESEARCH FRONTIER

Developing better and more affordable desalination technologies. See **www.cengage.com/biology/miller**.

11-3 How Can We Use Water More Sustainably?

CONCEPT 11-3 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

A basic economic and environmental principle is to begin by *cutting the waste*. Cutting the waste of water is almost always quicker and easier than trying to provide new supplies of water. Cutting waste is also cheaper, unless supply systems are subsidized, which makes water prices artificially low. This reduce-first rule also applies to the waste of energy or any other resource.

Here are three amazing estimates 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 wasted.
- It is economically and technically feasible to reduce such water losses to 15%, thereby meeting most of the world's water needs for the foreseeable future. GOOD NEWS

According to water resource experts, the main cause of water waste is *its low cost to users*. Such underpricing 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. According to water resource expert Sandra Postel, "By heavily subsidizing water, governments give out the false message that it is abundant and can afford to 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 settlement and farming of arid, unproductive land; stimulate local economies; and help 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 (perverse) subsidies that encourage water waste and providing environmentally beneficial subsidies for more efficient water use would sharply reduce water waste and help 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/biology/miller**.

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 11-14, 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.

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 11-14, 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 11-14, 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 salt that irrigation water leaves in the soil.

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. GOOD NEWS

Drip irrigation is used on just over 1% of the world's irrigated crop fields and 4% of those in the United States. This percentage rises to 90% in Cyprus, 66% in Israel, and 13% in the U.S. state of California. 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/biology/miller**.

Figure 11-15 lists other ways to reduce water waste in crop irrigation. Since 1950, Israel has used many of these techniques to slash irrigation water GOOD NEWS

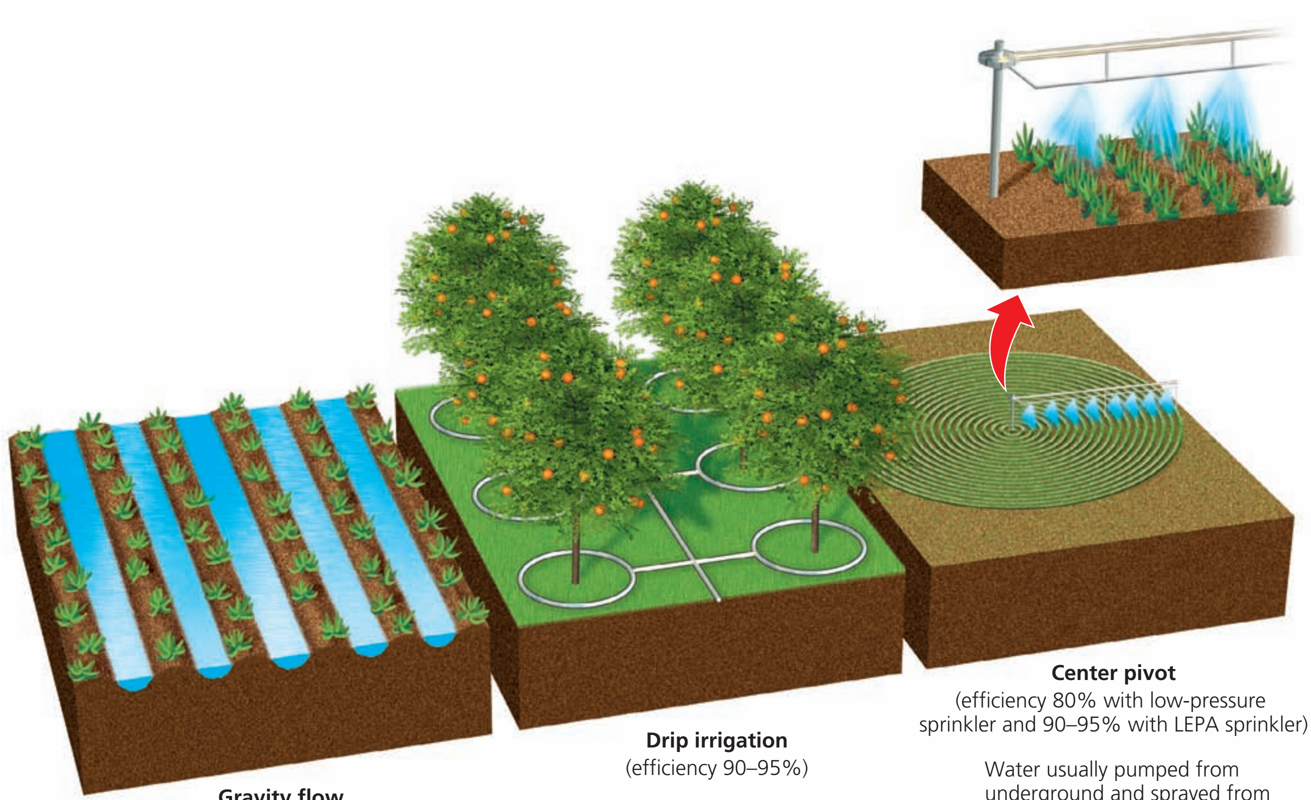


Figure 11-14 Major *irrigation systems*. Because of high initial costs, center-pivot irrigation and drip irrigation are not widely used. The development of new, low-cost, drip-irrigation systems may change this situation.

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 also gradually eliminated most water subsidies to raise Israel's price of irrigation water to one of the highest in the world.

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 cities and industries through 2025.

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 urban wastewater
- Import water-intensive crops and meat

Figure 11-15 Methods for reducing water waste in irrigation. **Questions**: Which two of these solutions do you think are the best ones? Why?

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 is recycled. Even so, most industrial processes could be redesigned to use much less water. Figure 11-16 (p. 252) lists ways to use water more efficiently in industries, homes, and businesses (**Concept 11-3**).

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

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 11-16 Methods of reducing water waste in industries, homes, and businesses (**Concept 11-3**). **Questions**: Which three of these solutions do you think are the best ones? Why?

standards have required that new toilets use no more than 6.1 liters (1.6 gallons) of water per flush. 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 save large amounts of water by cutting shower water flow 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, thereby reducing the water used to wash clothes by 98%.

According to U.N. studies, 40–60% of the water supplied in nearly all of the world's major cities in developing countries is lost mostly through leakage of water mains, pipes, pumps, and valves. Water experts say that fixing these leaks should be a high government priority that would cost less than building dams or importing water. Even in advanced industrialized countries such as the United States, these losses average 10–30%. However, leakage losses have been reduced to about 3% in Copenhagen, Denmark, and to 5% in Fukuoka, Japan. GOOD NEWS

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.

Many homeowners and businesses in water-short areas are using drip irrigation on their properties and copying nature by replacing green lawns with plants that need little water. Such water-thrifty landscaping reduces water use by 30–85% and sharply reduces needs for labor, fertilizer, and fuel. This example of reconciliation ecology (p. 197) also helps preserve biodiversity, and reduces polluted runoff, air pollution, and yard wastes. GOOD NEWS

About 50–75% of the slightly dirtied water from bathtubs, showers, sinks, dishwashers, and clothes washers in a typical house could be stored in a holding tank and then reused as *gray water* 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. And U.S. cities such as Las Vegas, Nevada, and Los Angeles, California, are beginning to recycle some of their wastewater. These efforts mimic the way nature purifies water by recycling it, and thus follows one of the **principles of sustainability**. SUSTAINABILITY

Underpricing 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 use of high-quality water. Also, many apartment dwellers have little incentive to conserve water, 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%. **GREEN CAREER:** Water conservation specialist

CONNECTIONS

Smart Cards and Water Conservation GOOD NEWS

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 water and electrical power and typically reduces household water bills by 40%.

We Can Use Less Water to Remove Wastes

Currently, we use large amounts of freshwater good enough to drink to flush away industrial, animal, and household wastes. According to the FAO, if current trends continue, 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.

For example, sewage treatment plants remove valuable plant nutrients and dump most of them into rivers, lakes, and oceans. This overloads aquatic systems with plant nutrients that could be recycled to the soil. We could mimic nature and use the nutrient cycling **principle of sustainability** and return the nutrient-rich sludge produced by conventional waste treatment plants to the soil as a fertilizer, instead of using freshwater to transport it. To make this feasible we would have to ban the discharge of industrial toxic chemicals into sewage treatment plants. Otherwise the sludge would be too toxic to apply to cropland soils.

Another way to recycle waste 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) successfully used a composting toilet for over a decade, while living and working in an experimental home and office.

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 11-17 Methods for achieving more sustainable use of the earth's water resources (**Concept 11-3**). **Questions**: Which two of these solutions do you think are the most important? Why?

We Need to Use Water More Sustainably

Figure 11-17 lists strategies that scientists have suggested for using water more sustainably (**Concept 11-3**).

Each of us can help bring about such a "blue revolution" by using and wasting less water to reduce our water footprints (Figure 11-18). As with other problems, the solution starts with thinking globally and acting locally.

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 11-18 **Individuals matter:** You can reduce your use and waste of water. See www.h2ouse.org for a number of tips that can be used anywhere for saving water, provided by the Environmental Protection Agency and the California Urban Water Conservation Council. **Questions**: Which of these steps have you taken? Which of them would you like to take?

11-4 How Can We Reduce the Threat of Flooding?

> **CONCEPT 11-4** 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

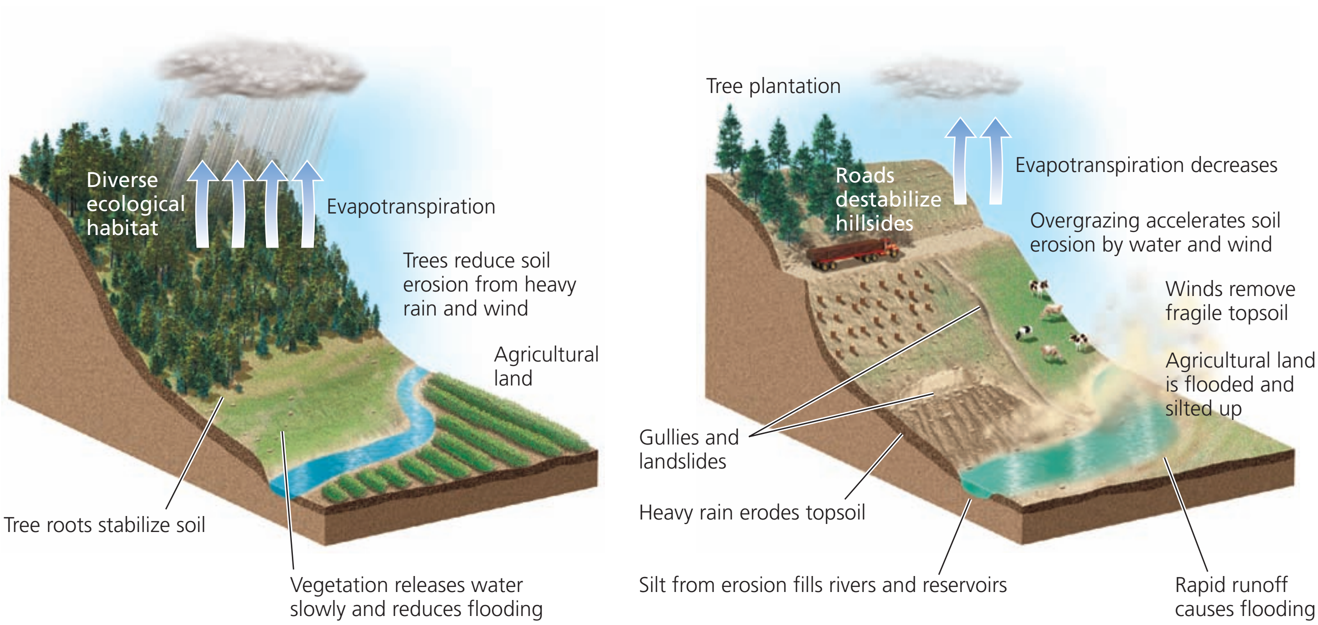
Some areas have too little water, but others sometimes have too much because of natural flooding by streams, caused mostly by heavy rain or rapidly melting snow. A flood happens when water in a stream overflows its normal channel and spills into the adjacent area, called a **floodplain**. Floodplains, 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), equipped with protective levees and walls, and dammed to create reservoirs that store and release water as needed. However, in the long run, such measures can lead to greatly increased flood damage when prolonged rains overwhelm them.

Floods actually provide several benefits. They have created 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 cause tens of billions of dollars in property damage. Floods usually are 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 *removal of water-absorbing vegetation*, especially on hillsides (Figure 11-19). People usually replace such vegetation with farm fields, pastures, pavement, or buildings that cannot absorb rainwater.



Forested Hillside **After Deforestation**

CENGAGENOW™ **Active Figure 11-19 Natural capital degradation:** 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?

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—an amount equal to about half the population of the U.S. state of California—and caused massive economic losses. Scientists identified the causes as heavy rainfall, rapid snowmelt, and deforestation 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 flood-control ecological 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 and surrounding areas, the damage was intensified because of the degradation or removal of coastal wetlands that had historically helped to buffer the land from storm surges.

Another human-related factor that will increase flooding is a rise in sea level from projected climate change (as discussed in Chapter 15). 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.

■ **CASE STUDY**

Living Dangerously on Floodplains in Bangladesh

Bangladesh is one of the world's most densely populated countries. In 2009, its 148 million people were packed into an area roughly the size of the U.S. state of Wisconsin, which has a population of 5.6 million. And the country's population is projected to increase to 215 million by 2050. Bangladesh is a very flat country, only slightly 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 country's delta basin. The annual floods 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 flooding. 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 since the 1970s, they have come roughly every 4 years. 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 11-19, right).

This increased runoff of soil, combined with heavier-than-normal monsoon rains, has led to more severe flooding along Himalayan rivers and downstream in Bangladesh. In 1998, a disastrous flood covered two-thirds of Bangladesh's land area for 9 months, drowned at least 2,000 people, and left 30 million people 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. In 1970, as many as 1 million people—roughly equal to the entire population of Dublin, Ireland, or the U.S. city of Dallas, Texas—drowned as a result of one tropical cyclone. Another cyclone in 2003 killed more than a million people and left tens of millions homeless.

Many of the country's coastal mangrove forests (Figure 7-25, p. 143) have been cleared for fuelwood, farming, and aquaculture ponds for raising shrimp. The result: more severe flooding, because these coastal wetlands had 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 rise in sea level and an increase in storm intensity, mostly because of climate change, will be a major threat in coming years to people in Bangladesh who live along its largely flat delta, bound by the Bay of Bengal. This would create millions of environmental refugees with no place to go in this already densely populated country.

THINKING ABOUT

Bangladesh

What are three measures that could be taken to help reduce the threat of flooding in Bangladesh?

We Can Reduce Flood Risks

Figure 11-20 lists some ways to reduce flooding risks (**Concept 11-4**). 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 natural vegetation in watersheds.

GOOD NEWS

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 11-20 Methods for reducing the harmful effects of flooding (**Concept 11-4**). **Questions**: Which two of these solutions do you think are the most important? Why?

Straightening and deepening streams (*channelization*) reduces 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. And channelization encourages human settlement in floodplains, which increases the risk of damages and deaths from major floods.

Levees or floodwalls along the sides of streams contain and speed up stream flow, but they increase the water's capacity for doing damage downstream. And they 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 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 11-10).

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 climate change, which will likely raise sea levels and flood many coastal areas of the world during this century.

On a personal level, we can use the precautionary principle (p. 174) 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.

11-5 How Can We Deal with Water Pollution?

▶ **CONCEPT 11-5A Streams can cleanse themselves of many pollutants if we do not overload them or reduce their flows.**

▶ **CONCEPT 11-5B Reducing water pollution requires preventing it, working with nature in treating sewage, cutting resource use and waste, reducing poverty, and slowing population growth.**

Water Pollution Comes from Point and Nonpoint Sources

Water pollution is any change in water quality that harms humans or other living organisms or makes water unsuitable for desired uses. It can come from single (point) sources or from larger and dispersed (nonpoint) sources. **Point sources** discharge pollutants at specific locations through drain pipes, ditches, or sewer lines into bodies of surface water. Examples include factories (see Photo 2, Detailed Contents), 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 developed countries have laws to control point-source discharges of harmful chemicals into aquatic systems. In most developing countries, there is little control of such discharges.

Nonpoint sources are broad, 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. We have made little progress in controlling water pollution from nonpoint sources because of the difficulty and expense of identifying and controlling discharges from such sources.

Agricultural activities are by far the leading cause of water pollution. Sediment eroded from agricultural lands is the largest source. Other major agricultural pollutants include fertilizers and pesticides, bacteria from livestock and food processing wastes, and excess salt 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. *Mining* is the third biggest source. Surface mining disturbs the land by creating major erosion of sediments and runoff of toxic chemicals. (See *The Habitable Planet*, Video 6 at **www.learner.org/resources/series209.html** for discussion of how scientists measure water pollution from toxic heavy metals from mining wastes and abandoned underground mines.)

CONNECTIONS

Climate Change and Water Pollution

Projected climate change will likely contribute to water pollution in some areas. 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 11-1 lists the major types of water pollutants along with examples of each and their harmful effects and sources.

The WHO estimates that about 1 billion people—almost one of every seven in the world—do not have access to clean drinking water. As a result, in 2007, the WHO estimated that each year more than 1.6 million people—equivalent to the entire population of the U.S. city of Phoenix, Arizona, or of Barcelona, Spain—die from largely preventable waterborne infectious diseases that they get by drinking contaminated water or by not having enough clean water for adequate hygiene. This amounts to an average of nearly 4,400 premature deaths a day, 90% of them children younger than age 5. Diarrhea alone, caused mostly by exposure to polluted water, on average, kills a young child every 18 seconds.

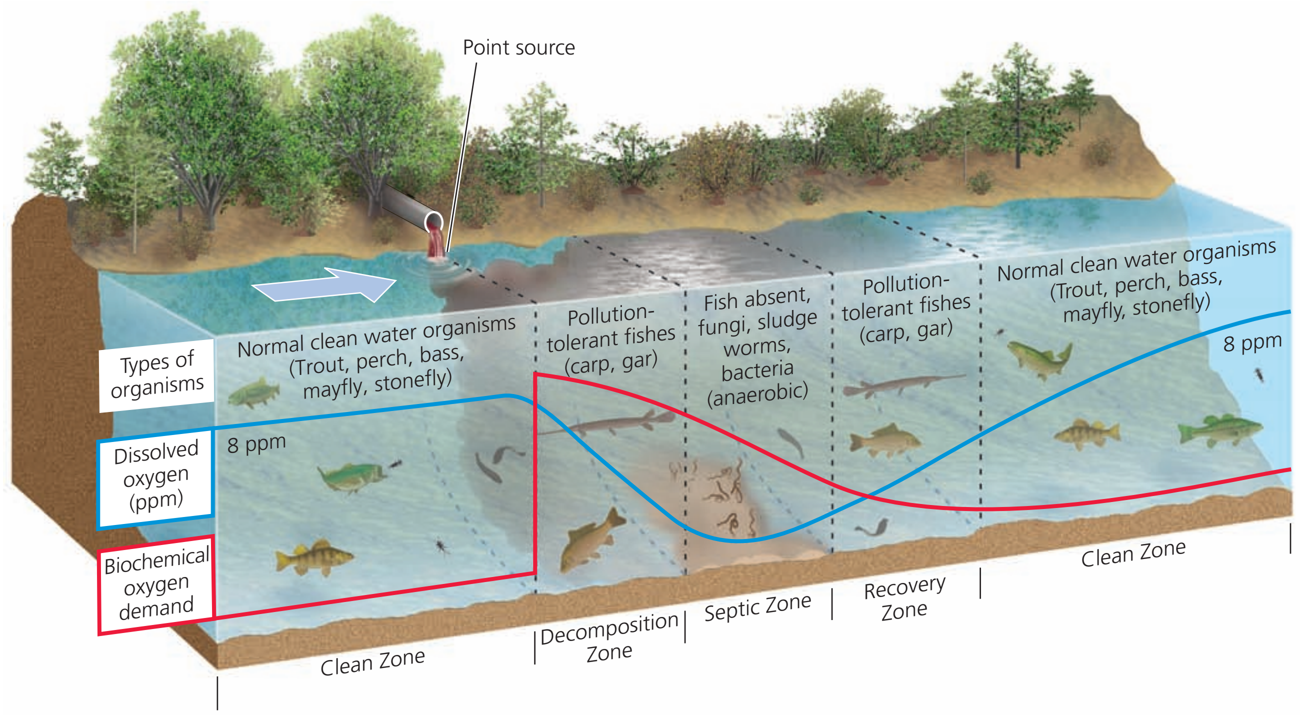
Streams Can Cleanse Themselves of Some Wastes, if We Do Not Overload Them

Flowing rivers and streams can recover rapidly from moderate levels of degradable, oxygen-demanding wastes through a combination of dilution and biodegradation of such wastes by bacteria. But this natural recovery process does not work when streams become overloaded with such pollutants or when drought, damming, or water diversion reduces their flows (**Concept 11-5A**). Also, while this process can remove

Table 11-1

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, pulp 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, cleaning solvents	Industry, farms, households
Inorganic chemicals *Add toxins to aquatic systems*	Acids, bases, salts, metal compounds	Industry, households, surface runoff
Sediments *Disrupt photosynthesis, food webs, other processes*	Soil, silt	Land erosion
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



CENGAGENOW™ **Active Figure 11-21** **Natural capital:** dilution and decay of degradable, oxygen-demanding wastes (or heated water) in a stream, showing 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 injection of oxygen-demanding wastes or heated water if they are given enough time and are not overloaded (**Concept 11-5A**). *See an animation based on this figure at* CengageNOW™. **Question**: What would be the effect of putting another discharge pipe for biodegradable wastes to the right of the one in this picture?

biodegradable wastes, it does not eliminate slowly degradable and nondegradable pollutants.

In a flowing stream, the breakdown of biodegradable wastes by bacteria depletes dissolved oxygen and creates an *oxygen sag curve* (Figure 11-21). This reduces or eliminates populations of organisms with high oxygen requirements until the stream is cleansed of oxygen-demanding wastes. Similar oxygen sag curves can be plotted when heated water from industrial and power plants is discharged into streams, because heating water decreases its levels of dissolved oxygen. Some good news is that streams can recover if given a chance (Individuals Matter, below).

CENGAGENOW™ Learn more about how pollution affects the water in a stream and the creatures living there at CengageNOW™.

INDIVIDUALS MATTER

GOOD NEWS

The Man Who 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 southwest hills of Seattle, Washington (USA), into the Duwamish River, which empties into Puget Sound. 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 companies to stop polluting the creek, and he hauled out many truckloads of trash and 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 and salmon spawning beds.

At first he worked alone and many people thought he was crazy. But word spread and other people joined him. TV 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 a death sentence—his reward was the personal satisfaction he felt about having made a difference for Hamm Creek and his community. His dedication to making the world a better place is an outstanding example of *stewardship* based on the idea that *all sustainability is local*.

Water pollution control laws enacted in the 1970s have resulted in a great increase in the number and quality of wastewater treatment plants in the United States and most other developed countries. In addition, such laws 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

In most developing 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 rivers are heavily polluted, and most of these polluted rivers run through developing countries. Most of these countries cannot afford to build waste treatment plants and do not have, or do not enforce, laws for controlling water pollution.

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 11-22).

Zhao Weiming/UNEP/Peter Arnold, Inc.

Figure 11-22 Natural capital degradation: highly polluted river in China. Water in many of central China's rivers is greenish-black from uncontrolled pollution by thousands of factories. Water in some rivers is too toxic to touch, much less drink. The cleanup of some modernizing Chinese cities such as Beijing and Shanghai is forcing polluting refineries and factories to move to rural areas where two-thirds of China's population resides. Liver and stomach cancer, 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.

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. And 300 million Chinese—an amount nearly equal to the entire U.S. population—do not have access to drinkable water. In Latin America and Africa, most streams passing through urban or industrial areas suffer from severe pollution. Garbage is purposely dumped into rivers in some places (See Photo 13, Detailed Contents).

Too Little Mixing and Low Water Flow Make Lakes Vulnerable to Water Pollution

Lakes and reservoirs are generally less effective at diluting pollutants than streams are, for two reasons. *First*, deep lakes and reservoirs often contain stratified layers (Figure 7-30, p. 147) 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, mercury, and arsenic. Many toxic chemicals and acids also enter lakes and reservoirs from the atmosphere.

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. An *oligotrophic lake* is low in nutrients and its water is clear (Figure 7-31, left, p. 147). Over time, some lakes become more eutrophic (Figure 7-31, 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**. Mostly nitrate- and phosphate-containing effluents in runoff from various sources cause this change. These sources include farmland, animal feedlots, urban areas, chemically fertilized suburban yards, mining sites, and treated and untreated municipal sewage outlets. Some nitrogen also reaches lakes by deposition from the atmosphere.

During hot weather or drought, this nutrient overload produces dense growths or "blooms" of organisms such as algae and cyanobacteria (Figure 7-31, right, p. 147) 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 phytoplankton that support fish.

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 and in the bottom layer. This kills fish and other aerobic aquatic animals. 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. And the International Water Association estimates that more than half of the lakes in China suffer from cultural eutrophication.

There are several ways to *prevent* or *reduce* cultural eutrophication. We can use advanced (but expensive) waste treatment to remove nitrates and phosphates before wastewater enters lakes. 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 and land-use control to reduce nutrient runoff.

GOOD NEWS

There are several ways to *clean up* lakes suffering from cultural eutrophication. We can mechanically remove excess weeds, control undesirable plant growth with herbicides and algicides, and pump air through lakes and reservoirs to prevent oxygen depletion, all of which are expensive and energy-intensive methods. The good news is that a lake usually can recover from cultural eutrophication if excessive inputs of plant nutrients are stopped.

Groundwater Cannot Cleanse Itself Very Well

According to many water experts, 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 11-23). People who dump or spill gasoline, oil, and paint thinners and other organic solvents onto the ground also contaminate groundwater.

When groundwater becomes contaminated, it cannot cleanse itself of *degradable wastes* as quickly as flowing surface water does. Groundwater flows so slowly

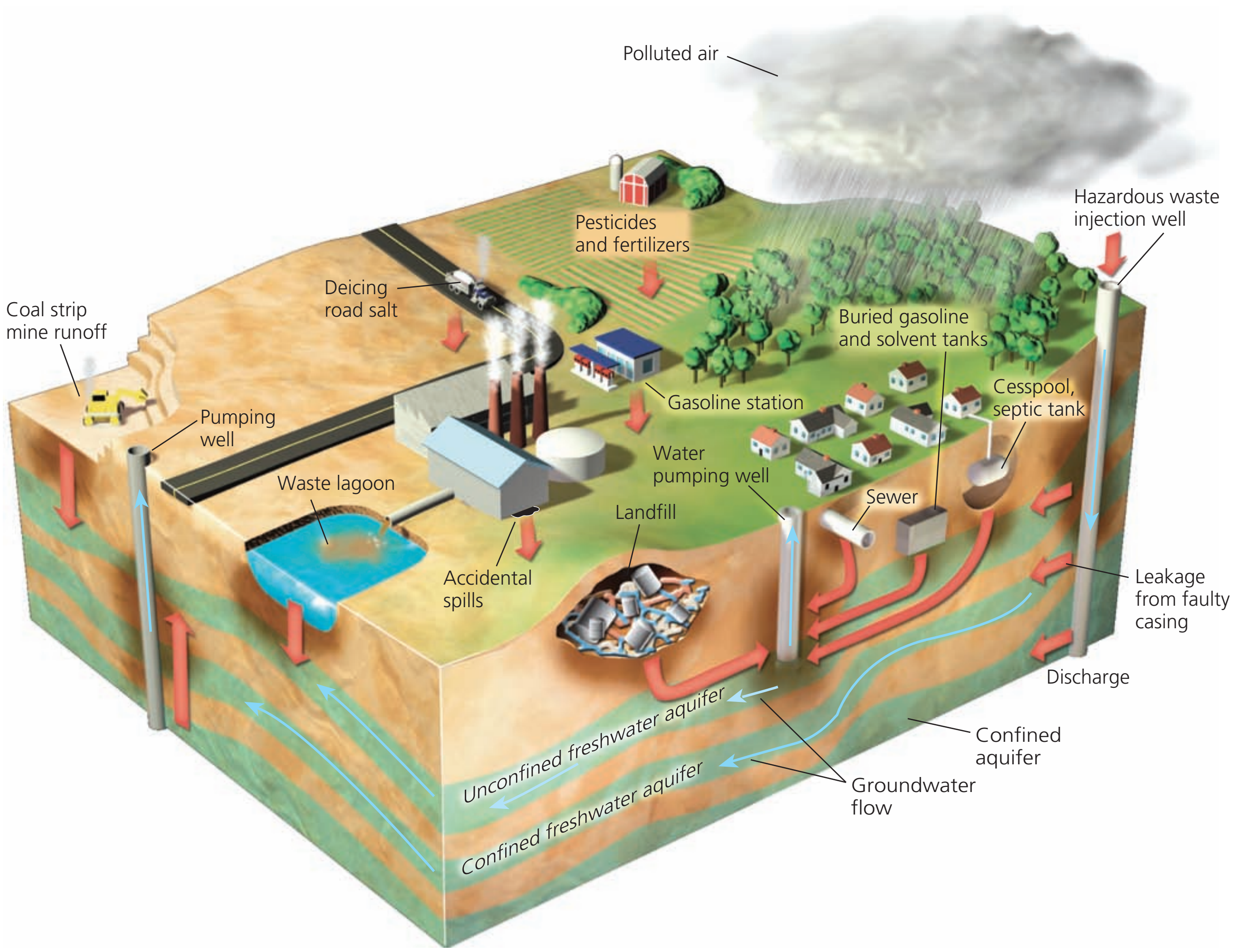


Figure 11-23 **Natural capital degradation:** principal sources of groundwater contamination in the United States and many other countries. Another source is saltwater intrusion in coastal areas from excessive groundwater withdrawal. (Figure is not drawn to scale.) **Question**: What are three sources shown in this picture that might be affecting groundwater in your area?

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. And the usually cold temperatures of groundwater slow down chemical reactions that decompose wastes.

Thus, 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.

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 are 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 deep disposal wells (Figure 11-23), some of which leak substances into aquifers used as sources of drinking water.

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.

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. 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 parts of Bangladesh, China, and India's state of West Bengal. 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 about 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, have 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 this process is evaluated.

Pollution Prevention Is the Only Effective Way to Protect Groundwater

Figure 11-24 lists ways to prevent and clean up groundwater contamination. Because of the difficulty and expense of cleaning up a contaminated aquifer, *preventing contamination is the least expensive and most effective way to protect groundwater resources* (Figure 11-24, left, and **Concept 11-5B**).

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 11-24 Methods for preventing and cleaning up contamination of groundwater. **Questions**: Which two of the preventive solutions do you think are the best ones? Why?

There Are Many Ways to Purify Drinking Water

Most developed countries have laws establishing drinking water standards. But most developing countries do not have such laws or, if they do have them, they do not always enforce them.

In developed countries, wherever people depend on surface water, 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

Simpler measures can be used 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 **sustainability principle**. Where this measure has been used, incidence of dangerous childhood diarrhea has decreased by 30–40%.

GOOD NEWS

In 2007, the Danish company Vestergaard Frandsen developed the LifeStraw, an inexpensive, portable water filter that eliminates many viruses and parasites from water drawn into it (Figure 11-25). It has been particularly useful in Africa, where aid agencies are distributing it.

GOOD NEWS

CONNECTIONS

Poverty and Water Pollution

Pollution prevention and cleanup generally get low priority in poorer countries. People are scrambling to find enough food and water just to survive. Many poor people have only a small amount of water available each day for drinking, cooking, bathing, and sanitation. Limited water resources in many poor countries are thus highly stressed and easily polluted (**Concept 11-5B**).

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 (Figure 11-26). This is not surprising because about 40%

SCIENCE FOCUS

Is Bottled Water the Answer?

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. In 2007, Americans spent more than $15 billion to buy billions of plastic bottles filled with water, some shipped from as far away as Fiji (8,800 kilometers, or 5,500 miles). This $15 billion would be enough to meet the annual drinking water needs of the roughly 1 billion people who routinely lack access to safe and clean drinking water.

Studies reveal that in the United States, a bottle of water costs, on average, at least 500 times (often 1,000 times) as much as the same amount of tap water. Yet studies also indicate that about one-fourth of it is ordinary tap water in a bottle, and that bacteria or fungi contaminate about 40% of all bottled water. And the government testing standards for bottled water in the United States are not as high as are those for tap water.

Use of bottled water also causes environmental problems, according to a 2007 study by the Worldwatch Institute. Each year, the number of plastic water bottles thrown away, if lined up end-to-end, could circle the earth's equator eight times. And only about 14% of these bottles get recycled.

According to the Pacific Institute, the oil used to pump, process, bottle, transport, and refrigerate the bottled water used in the United States each year would be enough to run 3 million cars for a year. Toxic gases and liquids are released during the manufacture of plastic water bottles and greenhouse gases and air pollutants are emitted by the fossil fuels burned to make them and to deliver bottled water (sometimes over great distances) to suppliers. And withdrawing water for bottling is helping to deplete some aquifers.

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. And individuals are refilling portable bottles with tap water and using simple filters to improve the taste and color of water where this is needed.

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 urban and suburban people served by large municipal drinking water systems, home water treatment systems are not worth the expense and maintenance hassles.

Critical Thinking

Were you aware of the harmful environmental impacts of producing bottled water? Do you drink bottled water? If so, why?

Figure 11-25 The *LifeStraw*, designed by Torben Vestergaard Frandsen, is a personal water purification device that gives many poor people access to safe drinking water. **Question**: Do you think the development of such devices should make prevention of water pollution less of a priority? Explain.

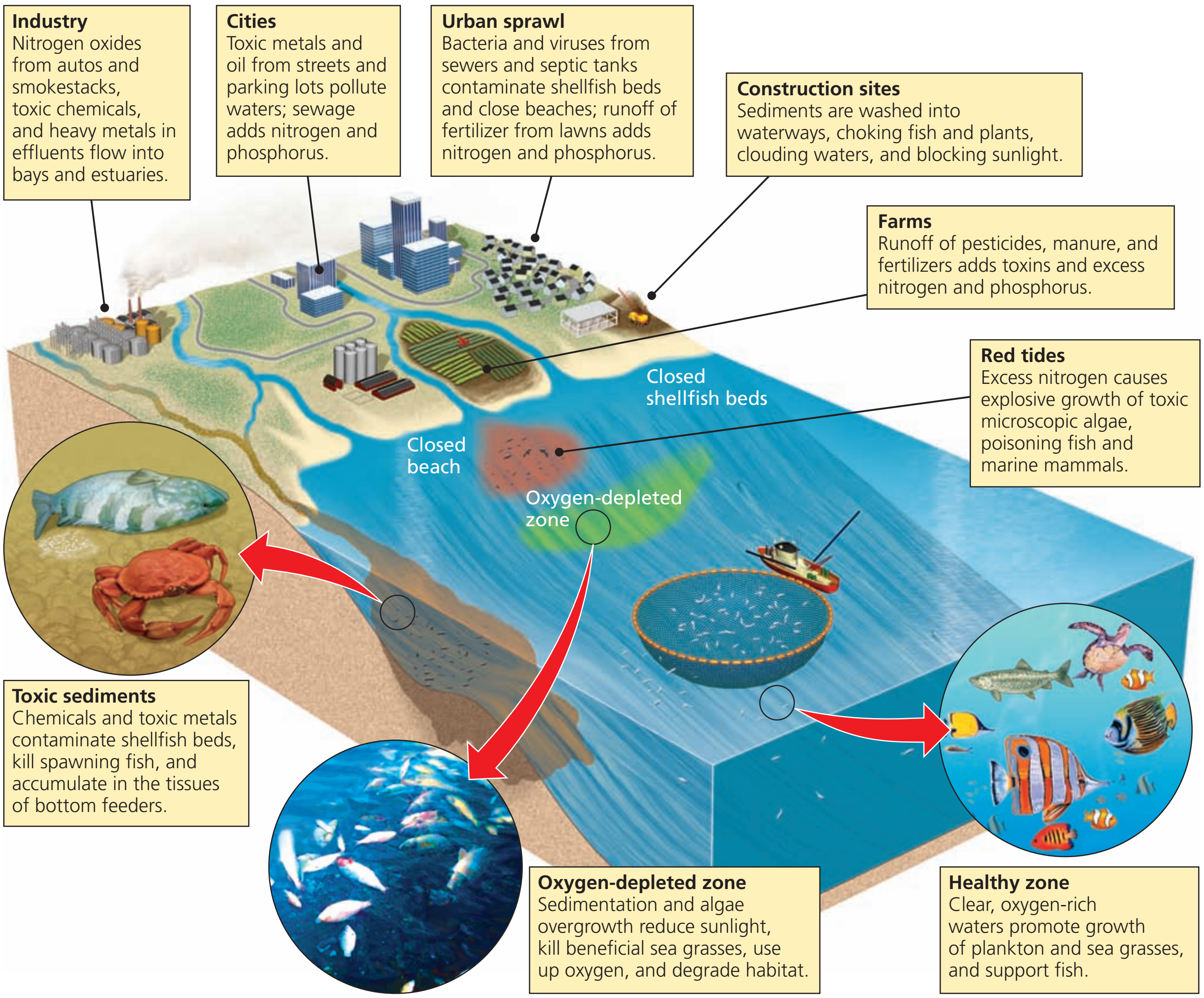


Figure 11-26 Natural capital degradation: Residential areas, factories, and farms all contribute to the pollution of coastal waters and bays. According to the U.N. Environment Programme, ill health and premature death from coastal water pollution costs the world more than $30,000 a minute. **Question**: What are three changes you could make in your lifestyle that might help to prevent this pollution?

of the world's population (53% of all Americans) live on or near a coast (Figure 6-11, p. 108), 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 U.N. Environment Programme (UNEP), an estimated 80% of marine pollution originates on land, 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 developing countries and in some coastal developed countries is dumped into oceans without treatment. This often overwhelms the ability of these coastal waters to biodegrade 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 after swimming.

Scientists also point to the underreported problem of pollution from cruise ships. A cruise liner can carry as many as 2,000 passengers and 1,000 crew members and generate as much waste (toxic chemicals, garbage, and waste oil) as a small city. Many 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 (Figure 11-26), brown, or green toxic tides. They can release waterborne and airborne toxins that damage fisheries, kill some fish-eating birds, reduce tourism, and poison seafood. Harmful algal blooms lead to the poisoning of about 60,000 Americans a year who eat shellfish contaminated by the algae.

Each year, because of harmful algal blooms, at least 400 *oxygen-depleted zones* form in coastal waters around the world, according to a 2008 study by marine scientists Robert Diaz and Rutger Rosenberg. They occur mostly in temperate coastal waters and in landlocked seas such as the Baltic and Black Seas. About 43 of these zones occur in U.S. waters (Science Focus, at right). 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.

One of the worst pollutants of ocean water is oil (Case Study, at right). This problem has only grown worse.

Figure 11-27 lists ways to prevent and reduce pollution of coastal waters. GOOD NEWS

Solutions

Coastal Water Pollution

Prevention

- Reduce input of toxic pollutants
- Separate sewage and storm lines
- Ban dumping of wastes and sewage by ships in coastal waters
- Ban ocean dumping of sludge and hazardous dredged material
- Regulate coastal development, oil drilling, and oil shipping
- Require double hulls for oil tankers

Cleanup

- Improve oil-spill cleanup capabilities
- Use nanoparticles on sewage and oil spills to dissolve the oil or sewage (still under development)
- Require secondary treatment of coastal sewage
- Use wetlands, solar-aquatic, or other methods to treat sewage

Figure 11-27 Methods for preventing and cleaning up excessive pollution of coastal waters. **Questions**: Which two of these solutions do you think are the most important? Why?

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 Mississippi, Louisiana, and Texas (Figure 11-A). The low oxygen levels suffocate fish, crabs, and shrimp that cannot move to less polluted areas.

In recent years, this oxygen-depleted zone has covered an area almost as large as the U.S. state of New Jersey. Because of the size and agricultural importance of the Mississippi River basin, there are no easy solutions to the severe cultural eutrophication of this and other overfertilized coastal zones around the world. Preventive measures include applying less fertilizer; injecting fertilizer below the soil surface; using controlled-release fertilizers that have water-insoluble coatings; planting strips of forests and grasslands along waterways to soak up excess nitrogen; restoring and creating wetlands between crop fields and streams emptying into the Mississippi River; and reducing government subsidies for using corn to make ethanol when other more energy efficient options are available (as discussed in Chapter 13).

Other measures involve improving flood control to prevent the release of nitrogen from floodplains during major floods and upgrading sewage treatment 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 by phasing in forms of renewable energy to replace the burning of fossil fuels.

Some scientists who have studied this problem fear that it could reach an ecological tipping point where most of the organisms living in this part of the Gulf of Mexico simply can no longer move far enough away to avoid the oxygen-depletion or to enable their populations to recover.

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?

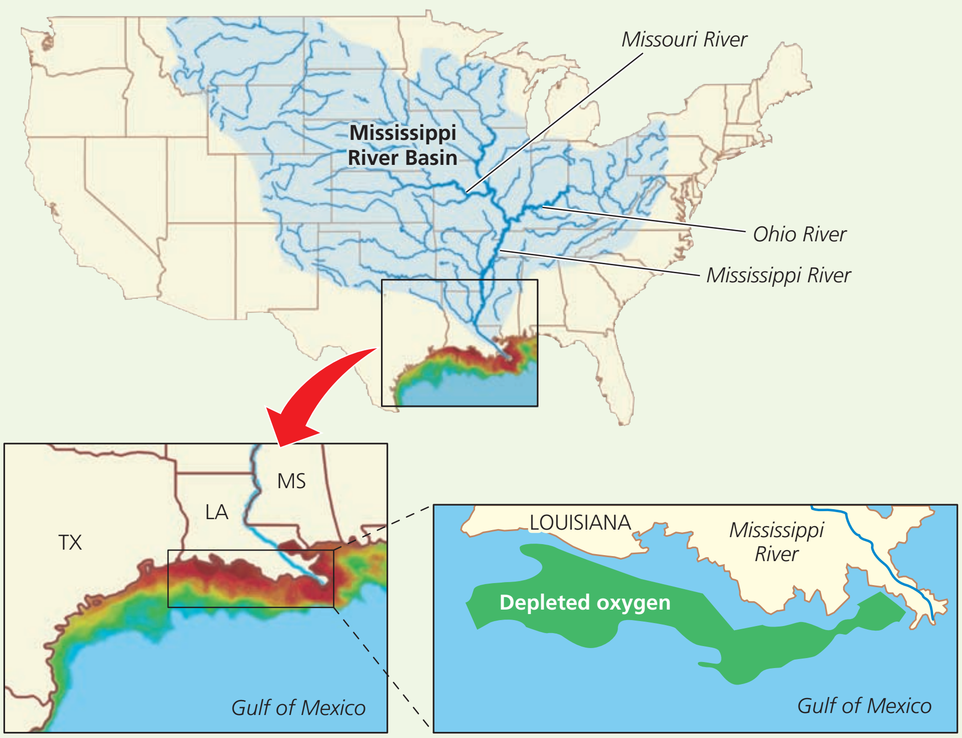


Figure 11-A **Natural capital degradation:** a large zone of oxygen-depleted water (containing less than 2 ppm dissolved oxygen) forms each year during the spring and summer in the Gulf of Mexico as a result of oxygen-depleting algal blooms. Evidence indicates that it is created mostly by huge inputs of nitrate (NO_3^-) plant nutrients from farms, cities, factories, and sewage treatment plants in the vast Mississippi River basin. The drawing (bottom left) based on a satellite image, shows the inputs of such nutrients into the Gulf of Mexico during the summer of 2006. In the image, reds and greens represent high concentrations of phytoplankton and river sediment. This problem is worsened by loss of coastal 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? (NASA)

The key to protecting the oceans is to reduce the flow of pollution from land, air, and streams that empty into these waters (**Concept 11-5B**). Thus, ocean pollution control must be linked with land-use and air pollution control policies, which in turn are linked to energy policies (discussed in Chapter 13) and climate policies (discussed in Chapter 15).

■ **CASE STUDY**

Ocean Pollution from Oil

Crude petroleum (oil as it comes out of the ground) and *refined petroleum* (fuel oil, gasoline, and other processed petroleum products) reach the ocean from a number of sources. Tanker accidents, such as the huge *Exxon Valdez* oil spill in Alaska in 1989, and blowouts at offshore drilling rigs (when oil escapes under high pressure from a borehole in the ocean floor) get most of the publicity because of their high visibility. Yet, according to a 2006 UNEP study, the amount of oil entering the marine environment from oil tanker accidents has decreased 75% since the mid-1980s and oil discharges from industry and cities have dropped by nearly 90%.

GOOD NEWS

In fact, studies *show that the largest source of ocean oil pollution is urban and industrial runoff from land*, much of it from leaks in pipelines and oil-handling facilities. At least 37%—and perhaps even half—of the oil reaching the oceans is waste oil, dumped, spilled, or leaked onto the land or into sewers by cities, industries, and people changing their own motor oil.

Volatile organic hydrocarbons in oil immediately kill many aquatic organisms, especially in their vulnerable larval forms. Other chemicals in oil form tar-like globs that float on the surface and coat the feathers of birds (especially diving birds) and the fur of marine mammals (see Photo 9 in the Detailed Contents). 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. (See *The Habitable Planet*, Video 9 at **www.learner.org/resources/series209.html** for discussion of how scientists measure the effects of oil spills on coral reefs and fish populations.)

Research shows that populations of many forms of marine life recover from exposure to large amounts of *crude oil* within about 3 years. But recovery from exposure to *refined oil*, especially in estuaries and salt marshes, can take 10–20 years. In 2006, some 17 years after the *Exxon Valdez* spill, researchers found patches of oil remaining on some parts of the shoreline of Prince William Sound.

Scientists estimate that current clean-up 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 11-5B**). One of the best ways to prevent tanker spills is to use only oil tankers with double hulls. After the *Exxon Valdez* accident, oil companies promised that they would do so. But 20 years later, in 2009, about half of the world's 10,000 oil tankers still had older and more vulnerable single hulls.

Reducing Surface Water Pollution from Nonpoint Sources

There are a number of ways to reduce nonpoint-source water pollution, most of which comes from agriculture. Farmers can reduce soil erosion by keeping cropland covered with vegetation. They can also reduce the amount of fertilizer that runs off into surface waters and leaches into aquifers 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.)

GOOD NEWS

Organic farming (Chapter 10 Core Case Study, p. 206) can also help prevent water pollution caused by nutrient overload because it does not use commercial inorganic fertilizers. And applying pesticides only when needed and relying more on integrated pest management (pp. 226–227) can reduce pesticide runoff. Farmers can control runoff and infiltration of manure from animal feedlots by planting buffers and locating feedlots and animal waste 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/biology/miller**.

Laws Can Help to 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 key water pollutants and requires polluters to get permits limiting how much of various pollutants they can discharge into aquatic systems.

The EPA is experimenting with a *discharge trading policy*, which uses market forces to reduce water pollution in the United States. Under this program, a permit holder can pollute at higher levels than allowed by 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 *cap-and-trade* system depends on how low the cap on total pollution levels is set in any given area and on how regularly the cap is lowered. They also warn that discharge trading could allow pollutants to build up to dangerous levels in areas where credits are bought. They call for careful scrutiny of the cap levels and for gradual lowering of the caps to encourage prevention of water pollution and development of better pollution control technology. Neither adequate scrutiny of the cap levels nor gradual lowering of caps is a part of the current EPA discharge trading system.

■ CASE STUDY

U.S. Experience with Reducing Point-Source Water Pollution

According to the EPA, the Clean Water Act of 1972 led to numerous improvements in U.S. water quality. Between 1992 and 2002 (the latest figures available):

GOOD NEWS

- The number 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 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, and that runoff of animal wastes from hog, poultry, and cattle feedlots and meat processing facilities pollutes seven of every ten U.S. rivers.
- Fish caught in more than 1,400 different waterways and more than a fourth of the nation's lakes are unsafe to eat because of high levels of pesticides, mercury, and other toxic substances.
- A 2007 government study found that tens of thousands of gasoline storage tanks in 43 states are leaking.

Some environmental scientists call for strengthening the Clean Water Act. Suggested improvements include shifting the emphasis to water pollution prevention instead of focusing mostly on end-of-pipe removal of specific pollutants; greatly increased monitoring for compliance with 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.

Many people oppose such proposals, contending that the Clean Water Act's regulations are already too restrictive and costly. For example, some state and local officials argue that in many communities, it is unnecessary and too expensive to test for all the water 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/biology/miller**.

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. 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 resulting partially treated wastewater is discharged into 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.

About one-fourth of all homes in the United States are served by septic tanks. They work well as long as they are not overloaded and their solid wastes are regularly pumped out.

In urban areas in the United States and most 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. Then the waste stream flows into a primary settling tank where suspended solids settle out as sludge (Figure 11-28, p. 268, left). A 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 11-28, p. 268, 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 long-lived radioactive isotopes and persistent organic substances such as some pesticides, and it does not kill pathogens.

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 may 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.

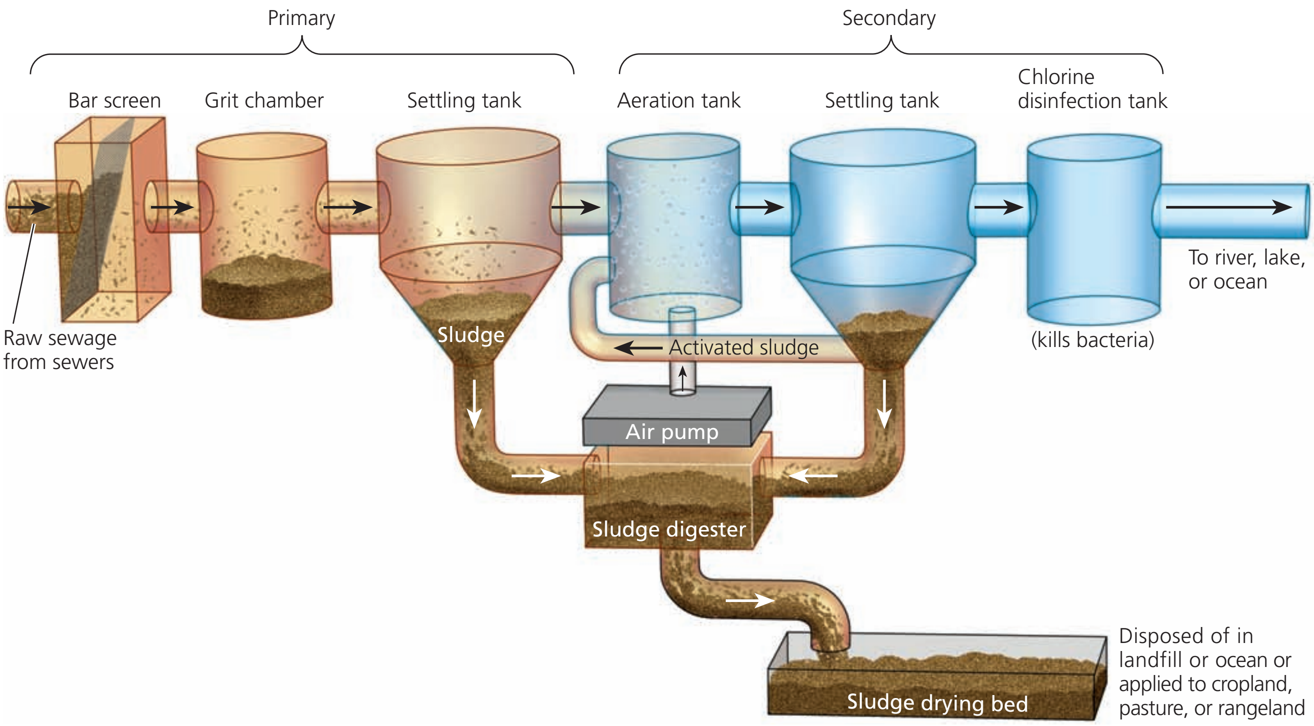


Figure 11-28 **Solutions:** primary and secondary sewage treatment. **Question**: What do you think should be done with the sludge produced by sewage treatment plants?

We Can Improve Conventional Sewage Treatment

Environmental scientist Peter Montague calls for redesigning the conventional sewage treatment system shown in Figure 11-28. 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 (**Concept 1-3**, p. 14). CONCEPT LINK

Montague suggests two major 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 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/biology/miller**.

Another suggestion is to require or encourage more households, apartment buildings, and offices to eliminate sewage outputs and reduce water usage by switching to waterless, odorless *composting toilet systems* to be installed, maintained, and managed by professionals. Plant nutrients in human waste from these toilets can be returned to the soil in keeping with the natural chemical cycling **principle of sustainability**. This can reduce the need for energy-intensive and water-polluting commercial inorganic fertilizer. The EPA lists several brands of dry composting toilets approved for use in the United States. Many communities are also using unconventional, but highly effective, *wetland-based sewage treatment systems*, which work with nature (Science Focus, at right).

There Are Sustainable Ways to Reduce and Prevent Water Pollution

It is encouraging that, since 1970, most 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. GOOD NEWS

To environmental and health scientists, the next step is to increase efforts to reduce and prevent water pollution. They would begin by asking the question: *How can we avoid producing water pollutants in the first place?* (**Concept 11-5B**). Figure 11-29 lists some ways to try 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 11-30 lists some actions you can take to help prevent and reduce water pollution.

SCIENCE FOCUS

Treating Sewage by Working with Nature

Some communities and individuals are seeking better ways to purify sewage by working with nature (**Concept 11-5B**). Biologist John Todd has developed an ecological approach to treating sewage, which he calls *living machines*.

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 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 using 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.

More than 800 cities and towns around the world and 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 17,000 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 otters, seabirds, and 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, using natural processes to remove and recycle nutrients and other chemicals, and relying on a diversity of organisms and natural processes to purify wastewater.

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?

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

- One of the world's major environmental problems is the growing shortages of freshwater in parts of the world.
- 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 pollution requires preventing it, working with nature in treating sewage, cutting resource use and waste, reducing poverty, and slowing population growth.

Solutions

Water Pollution

- Prevent groundwater contamination
- Reduce nonpoint runoff
- Reuse treated wastewater for 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 11-29 Methods for preventing and reducing water pollution (**Concept 11-5B**). **Questions**: Which two of these solutions 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

Figure 11-30 **Individuals matter:** ways to help prevent and reduce water pollution. **Questions**: Which three of these actions do you think are the most important? Why?

REVISITING The Colorado River and Sustainability

CORE CASE STUDY

SUSTAINABILITY

The **Core Case Study** that opens this chapter discusses the problems and tensions involved when a large number of U.S. states share a limited river water resource in a water-short region.

Generally, the water resource strategies of the 20th century have worked against 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.

This chapter also discussed water pollution in developed and developing countries. Pollution control for the world's surface and underground water supplies are within our reach. But even more hopeful is the possibility of shifting emphasis from cleaning up water pollution to reducing and preventing it.

The three **principles of sustainability** (see back cover) can guide us in reducing and preventing water pollution and in using water more sustainably during this century. Scientists hope to use solar energy to desalinate water and increase supplies, and solar energy is already used to purify water for drinking in some areas. Recycling more water will help us to reduce water waste. Preserving biodiversity by avoiding disruption of aquatic systems and their bordering terrestrial systems is a key factor in maintaining water supplies and water quality.

This *blue revolution,* built mostly around cutting water waste and preventing water pollution, will provide numerous economic and ecological benefits. There is no time to lose in implementing it.

The benefits of working with nature's water cycle, rather than further disrupting it, are too compelling to ignore.

SANDRA POSTEL

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 239. Discuss the stresses on the Colorado River basin in the United States that have resulted from overuse of this resource.

2. What percentage of the earth's freshwater is available to us? Define **groundwater**, **zone of saturation**, **water table**, **aquifer**, **surface water**, **surface runoff**, **watershed (drainage basin)**, **reliable surface runoff**, and **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. How many people in the world lack regular access to safe drinking water, and how many do not have access to basic sanitation?

3. 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 ways to prevent or slow groundwater depletion, including possible use of *deep aquifers*. What is a **dam**? What is a **reservoir**? What are the advantages and disadvantages of large dams and reservoirs? Describe the California Water Project. Describe the Aral Sea disaster. Define **desalination** and distinguish between distillation and reverse osmosis as methods for desalinating water. What are three limitations of desalination?

4. What percentage of the word's water is unnecessarily wasted and what are two causes of such waste? Describe four irrigation methods and list ways to reduce water waste in irrigation in developed and developing countries. List four ways to reduce water waste in industry and homes, four ways to use water more sustainably, and four ways in which you can reduce your use and waste of water.

5. 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. What are three ways to reduce the risks of flooding?

6. 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.

7. Describe how streams can cleanse themselves and how these cleansing processes can be overwhelmed. Describe the state of stream pollution in developed and developing countries. 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. 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 U.S. laws for protecting drinking water quality. Describe environmental problems caused by the widespread use of bottled water.

8. How are coastal waters and deeper ocean waters polluted? What causes harmful algal blooms and what are their harmful 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?

9. 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. How would Peter Montague improve conventional sewage treatment? What is a composting toilet system? Describe John Todd's use of living machines to treat sewage. Describe how wetlands can be used to treat sewage. List six ways to prevent and reduce water pollution. List five things you can do to reduce water pollution.

10. What are this chapter's *three big ideas*? Describe relationships between water resource and pollution 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. What role does population growth play in **(a)** water supply problems, **(b)** groundwater pollution problems, and **(c)** coastal water pollution problems?

3. 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.

4. 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.)

5. 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?

6. You are 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)** an effluent pipe from a factory going into a stream, **(b)** a parking lot at a shopping mall bordered by a stream, **(c)** a farmer's field on a slope next to a stream.

7. 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 11-28. What happens to the sludge produced by this plant? What improvements, if any, would you suggest for this plant?

8. List three ways in which you could apply **Concept 11-3** and three ways you could apply **Concept 11-5B** 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 developing countries, **(b)** sharply reduce point-source water pollution in developing countries, **(c)** sharply reduce nonpoint-source water pollution throughout the world, and **(d)** sharply reduce groundwater pollution throughout the world.

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 per 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 the global average water footprint of 123,770 liters (32,800 gallons) per person per year?

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengage.com/biology/miller** and choose Chapter 11 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, web links, information on Green Careers, and InfoTrac® College Edition articles.

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Geology and Nonrenewable Minerals

12

The Real Cost of Gold

CORE CASE STUDY

Mineral resources extracted from the earth's crust are processed into an amazing variety of products that can make life easier and provide economic benefits and jobs. But a number of harmful environmental effects result from extracting minerals from the ground and converting them to such products.

For example, gold miners typically have to remove enough rock to equal the weight of 50 automobiles in order to extract an amount of gold that would fit inside your clenched fist. Many newlyweds would be surprised to know that mining enough gold to make their wedding rings likely produced about 5.5 metric tons (6 tons) of mining waste—equaling roughly the total weight of six adult male African elephants. This waste is usually left piled near the mine site and can pollute the air and nearby surface water.

Between 1950 and 2008, global gold production more than tripled. In 2008, China, South Africa, the United States, Australia, and Indonesia were, in order, the world's top producers of gold.

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 storage ponds (Figure 12-1). After the solution is circulated 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 collection ponds can help to 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 several countries in Eastern Europe.

Several hundred thousand people living along these rivers were told not to fish or to drink or withdraw water from affected rivers or from wells along the rivers. Food industries and paper mills were shut down. Thousands of fish and other aquatic animals and plants were killed. This accident and another one that occurred in January 2001 could have been prevented if the mining company had installed a stronger containment dam and a backup collection pond to prevent leakage into nearby surface water.

In this chapter, we will look at the earth's dynamic geologic processes, the minerals such as gold that some of these processes produce, the potential supplies of these resources, environmental effects of using them, and how we might use them more sustainably.

Creatas/SuperStock

Figure 12-1 Gold mine with cyanide leach piles and ponds in the Black Hills of the U.S. state of South Dakota.

Key Questions and Concepts

12-1 What are the earth's major geological processes and hazards?

CONCEPT 12-1 Dynamic processes move matter within the earth and on its surface and can cause volcanic eruptions, earthquakes, tsunamis, and erosion.

12-2 How are the earth's rocks recycled?

CONCEPT 12-2 The three major types of rock found in the earth's crust are recycled very slowly by physical and chemical processes.

12-3 What are mineral resources and what are the environmental effects of using them?

CONCEPT 12-3 Some minerals in the earth's crust can be made 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.

12-4 How long will supplies of nonrenewable mineral resources last?

CONCEPT 12-4 Raising the price of a scarce mineral resource can lead to an increase in its supply, but there are environmental limits to this effect.

12-5 How can we use mineral resources more sustainably?

CONCEPT 12-5 We can try to find substitutes for scarce resources, reduce resource waste, and recycle and reuse minerals.

Note: Supplement 6 (p. S26) can be used with this chapter.

Civilization exists by geological consent, subject to change without notice.

WILL DURANT

12-1 What Are the Earth's Major Geological Processes and Hazards?

CONCEPT 12-1 Dynamic processes move matter within the earth and on its surface and can cause volcanic eruptions, earthquakes, tsunamis, and erosion.

The Earth Is a Dynamic Planet

Geology, one of the subjects of this chapter, is the science devoted to the study of dynamic processes occurring 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* (Figure 3-2, p. 41).

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 12-2). 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 12-3 and Concept 12-1). 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 12-3 and Figure 12-4, p. 276).

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. CONCEPT LINK indicates links to key concepts in earlier chapters. GOOD NEWS refers to good news about the environmental challenges we face.

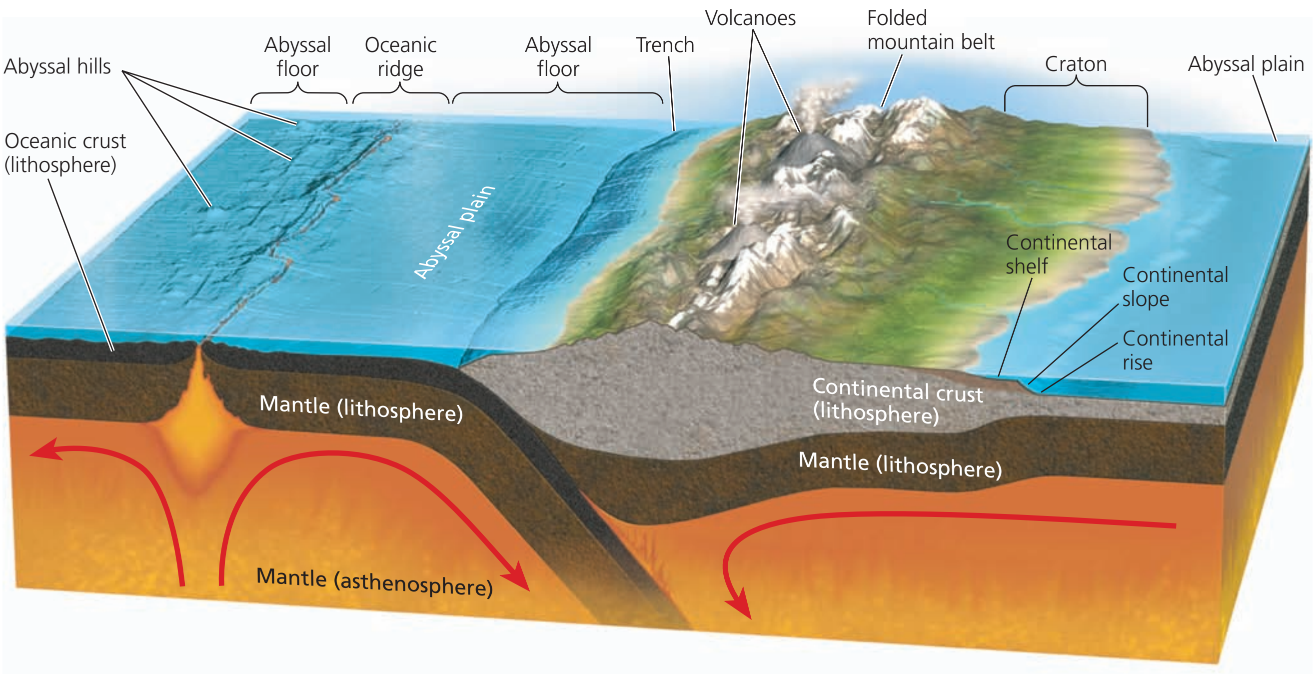
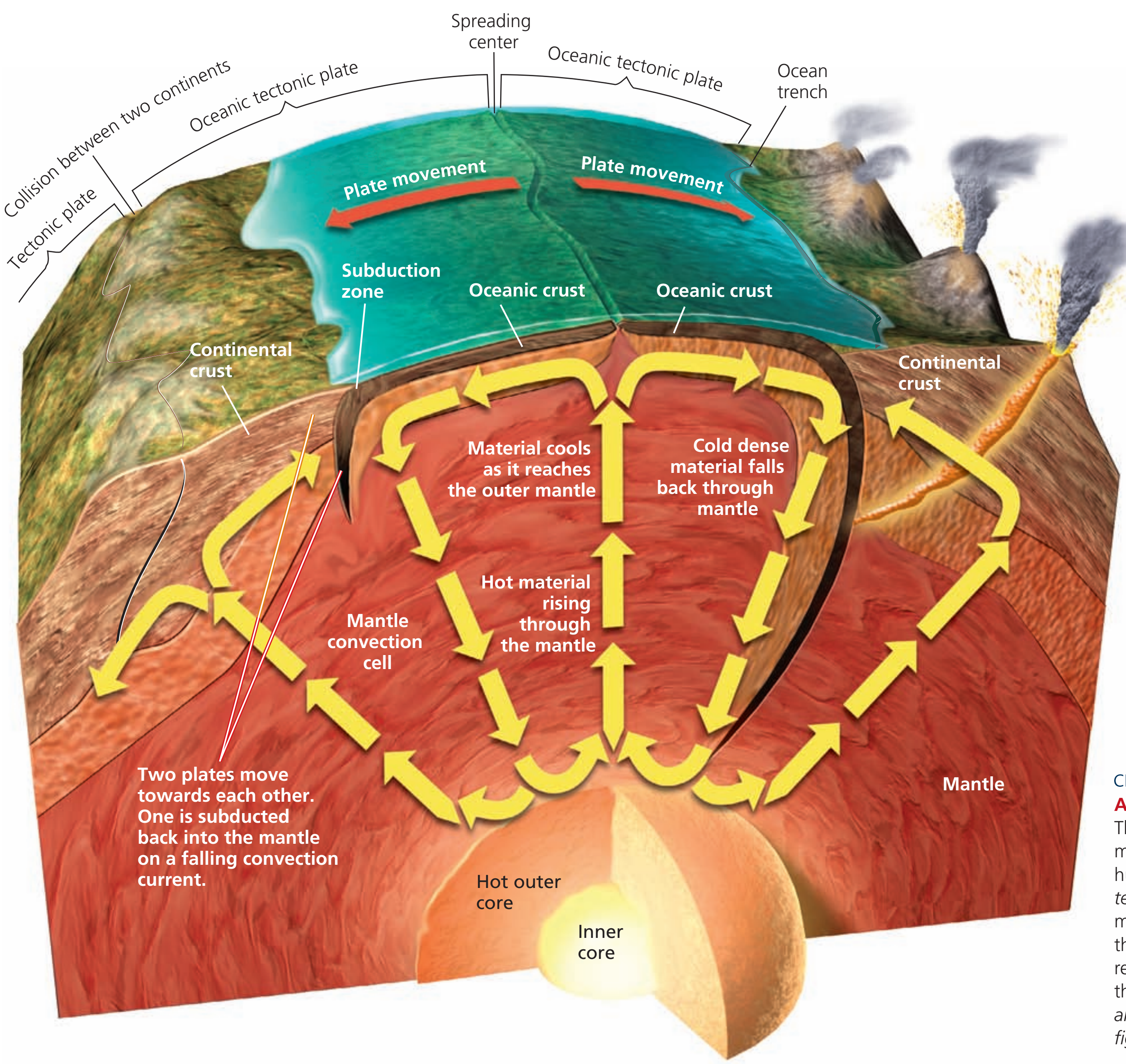


Figure 12-2 Major features of the earth's crust and upper mantle. The *lithosphere*, composed of the crust and outermost mantle, is rigid and brittle. The *asthenosphere*, a zone in the mantle, can be deformed by heat and pressure.



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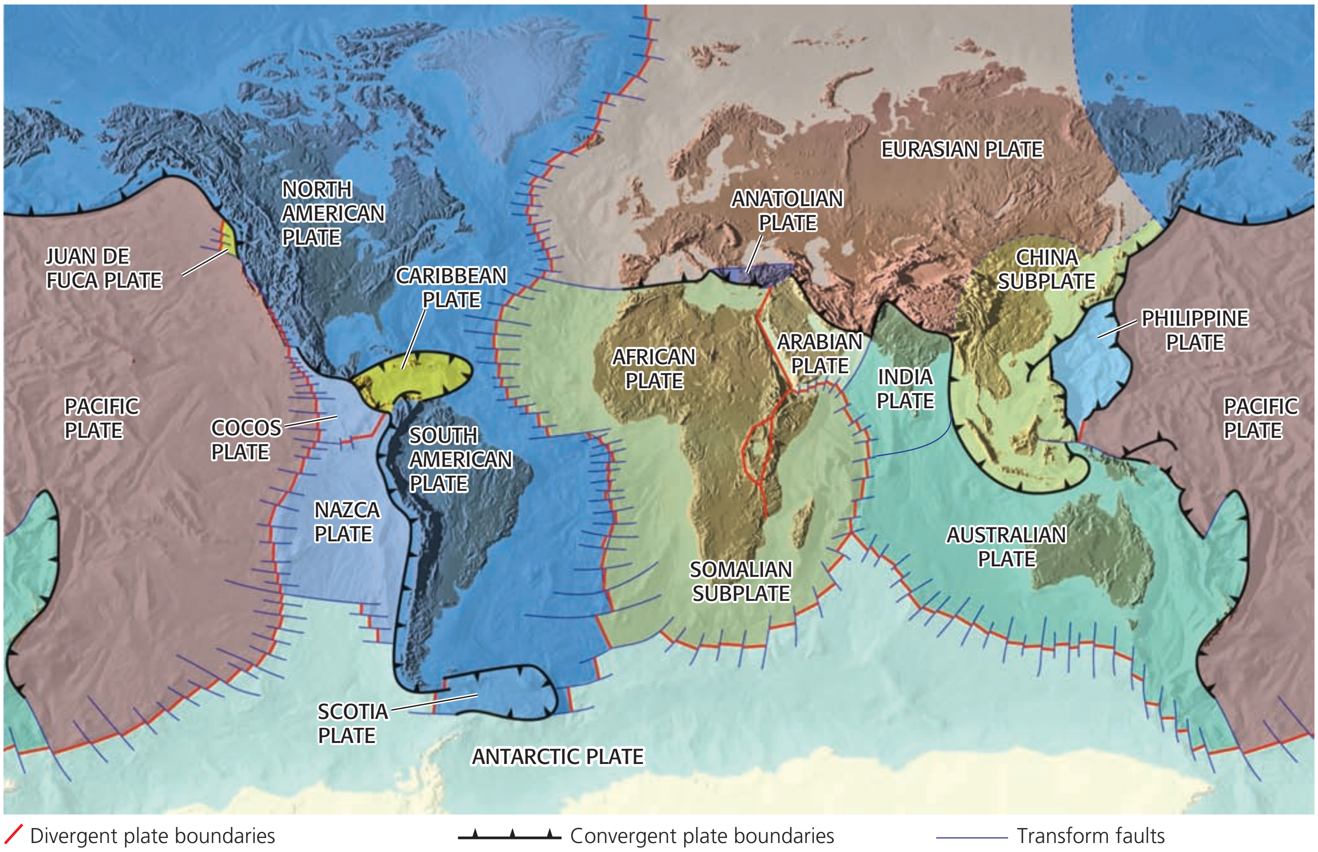
Active Figure 12-3
The earth's crust is made up of a mosaic of huge rigid plates, called *tectonic plates*, which move very slowly across the asthenosphere in response to forces in the mantle. *See an animation based on this figure at* CengageNOW.



CENGAGENOW™ **Active Figure 12-4** 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 typical speed is about the rate at which fingernails grow. Throughout the earth's history, continents have split apart and joined as tectonic plates drifted atop the earth's asthenosphere (Figure 4-6, p. 66).

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 oceanic plates move apart from one another, molten rock, or *magma*, flows up through the resulting cracks. This creates *oceanic ridges* (Figure 12-2), some of which have peaks that are higher and canyons that are deeper than those found on the earth's continents. On the other hand, when two oceanic plates collide, a *trench* ordinarily forms at the boundary between the two plates.

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 12-3) 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 magma (lava). 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 12-5).

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 12-6). Many volcanoes form along the boundaries of the earth's tectonic plates (Figure 12-4) 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 12-1**).

Kevin Schafer/Peter Arnold, Inc.

Figure 12-5 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 or go to school?

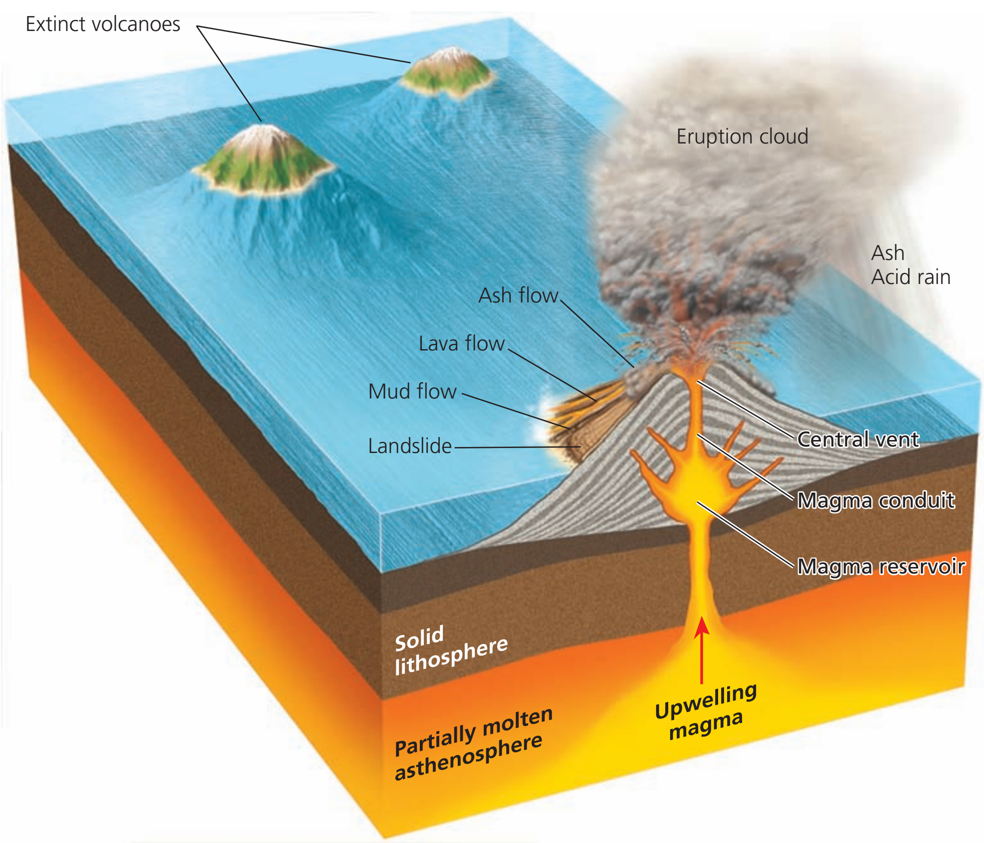


Figure 12-6 A *volcano* is created when magma in the partially molten asthenosphere rises in a plume through the lithosphere to erupt on the surface as lava, which builds a cone. Sometimes, internal pressure is high enough to cause lava, ash, and gases to be ejected into the atmosphere or to flow over land, causing considerable damage (**Concept 12-1**). Volcanoes that have erupted and then become inactive have created chains of islands.

While volcanic eruptions can be destructive, they do provide some benefits. They can result in the formation of majestic mountains and lakes (Figure 7-31, left, p. 147). And the weathering of lava contributes to fertile soils.

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 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.

GOOD NEWS

Earthquakes Are Geological Rock-and-Roll Events

Forces inside the earth's mantle and near its surface push, deform, and stress 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 12-5). 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 12-7 and **Concept 12-1**). Most earthquakes occur at the boundaries of tectonic plates (Figure 12-4) when colliding plates create tremendous pressures in the earth's crust or when plates slide past one another at transform faults.

Relief of the earth's internal stress releases energy as shock (seismic) waves, which move 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 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.

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. Figure 12-8 shows the areas of greatest earthquake risk in the United States and Figure 12-9 shows areas of such risk throughout the world.

GOOD NEWS

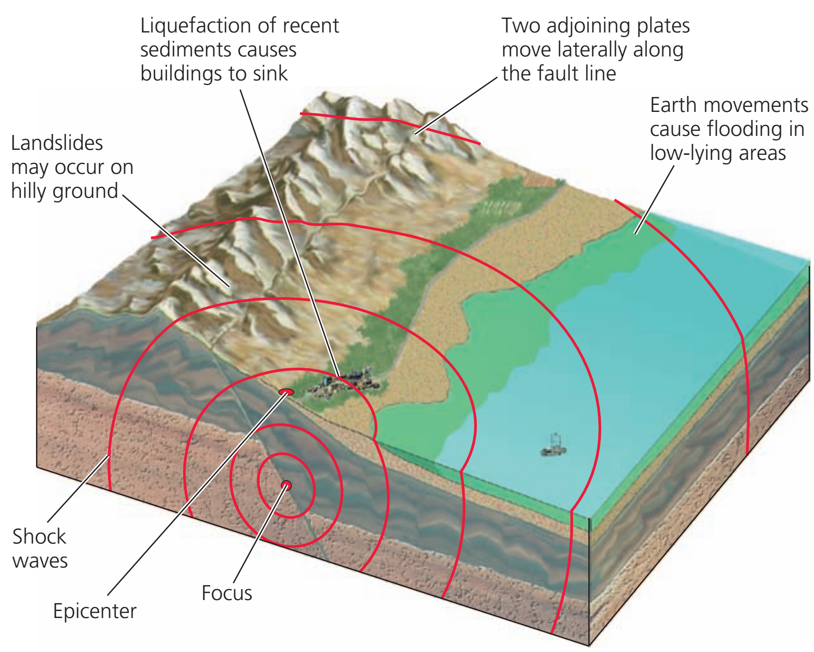


Figure 12-7 Major features and effects of an *earthquake,* one of nature's most powerful events.

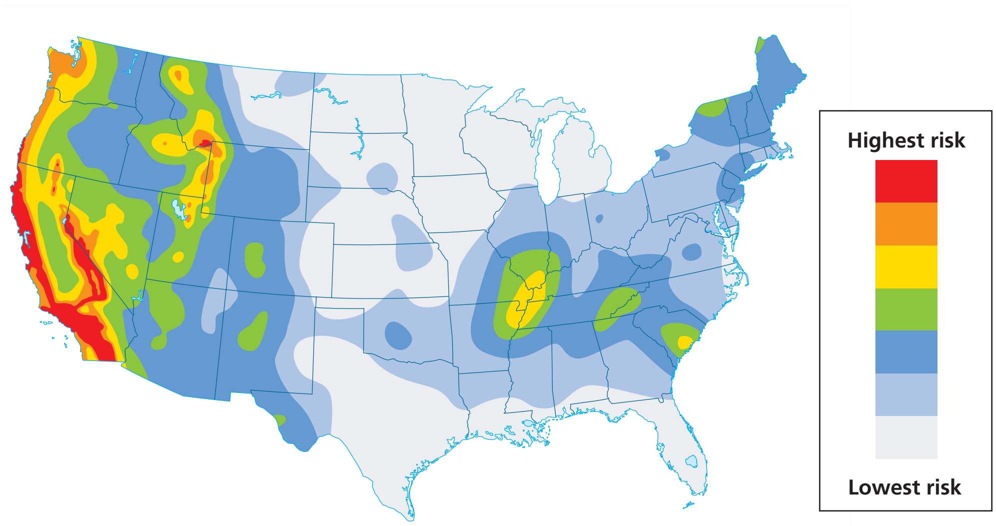


Figure 12-8 Areas of greatest earthquake (seismic) risk in the United States. In 2008, the U.S. Geological Survey estimated that the U.S. state of California has more than a 99% chance of being hit by a magnitude 6.7 earthquake within 30 years, and that Southern California has a 37% chance of suffering a magnitude 7.5 earthquake during that period. **Question**: What is the degree of risk where you live or go to school? (Data from U.S. Geological Survey)

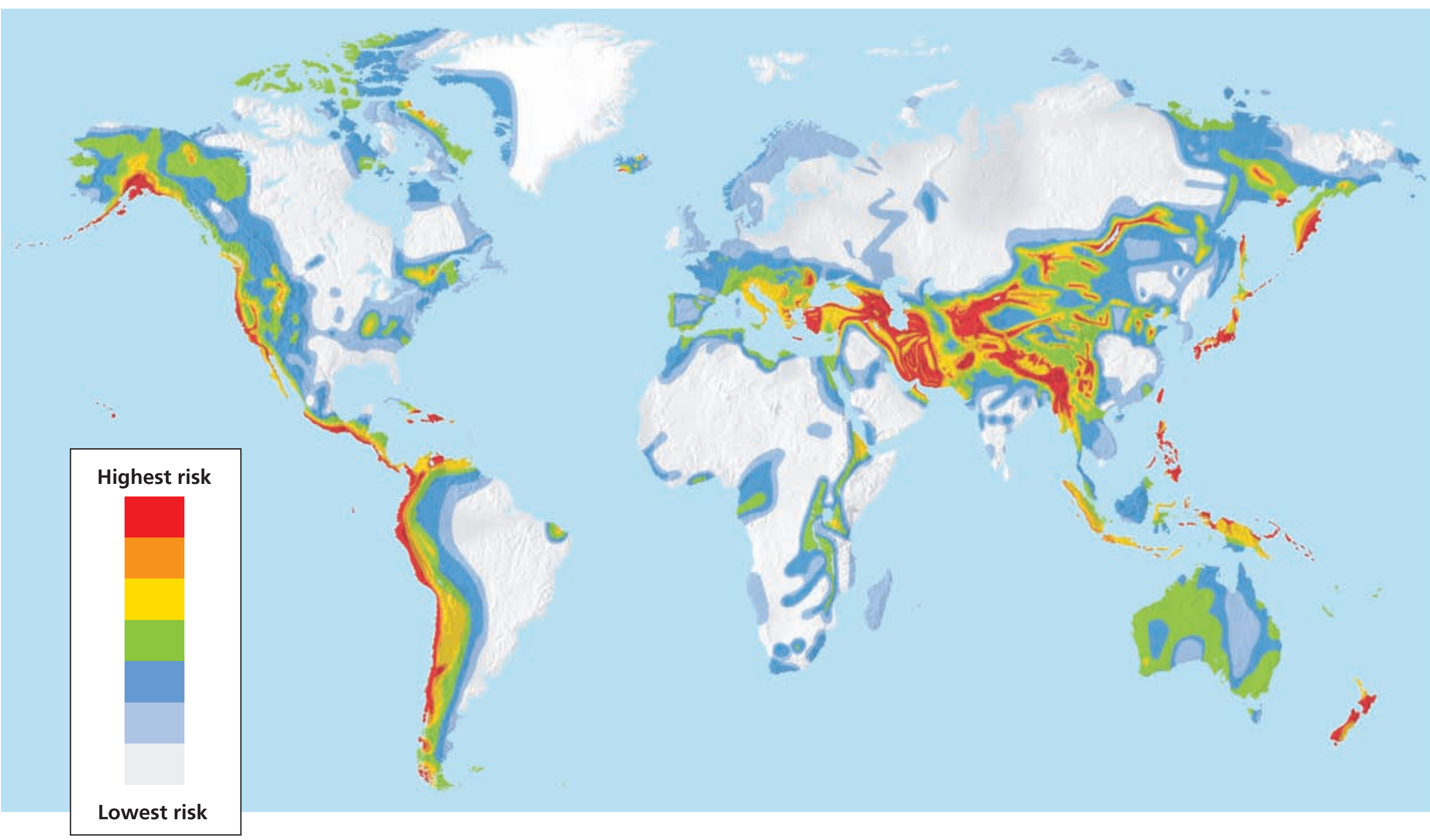


Figure 12-9 Areas of greatest earthquake (seismic) risk in the world. **Question**: How are these areas related to the boundaries of the earth's major tectonic plates as shown in Figure 12-4? (Data from U.S. Geological Survey)

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 12-10). 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 12-1**). Such earthquakes often occur offshore in subduction zones where a tectonic plate slips under a continental plate (Figure 12-3).

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, it slows 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.

Tsunamis can be detected through a network of ocean buoys or pressure recorders located on the ocean floor to provide some degree of early warning. These data are relayed to tsunami emergency warning centers. But there are far too few tsunamic recorders and emergency warning centers.

Between 1900 and late 2008, 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 a five-story building. It killed 228,000 people and devastated many coastal areas of Indonesia (Figure 12-11), Thailand, Sri Lanka, South India, and 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 waves that roll over them, reducing their force before they hit nearby shorelines. Satellite observations and ground studies done in February 2005 by the U.N. Environment Programme pointed to the role that healthy coral reefs (Figure 7-26, p. 143) and mangrove forests (Figure 7-25, p. 143) played in reducing the death toll and destruction from the 2004 tsunami. They did so by reducing the force of the tsunami's huge waves in some areas.

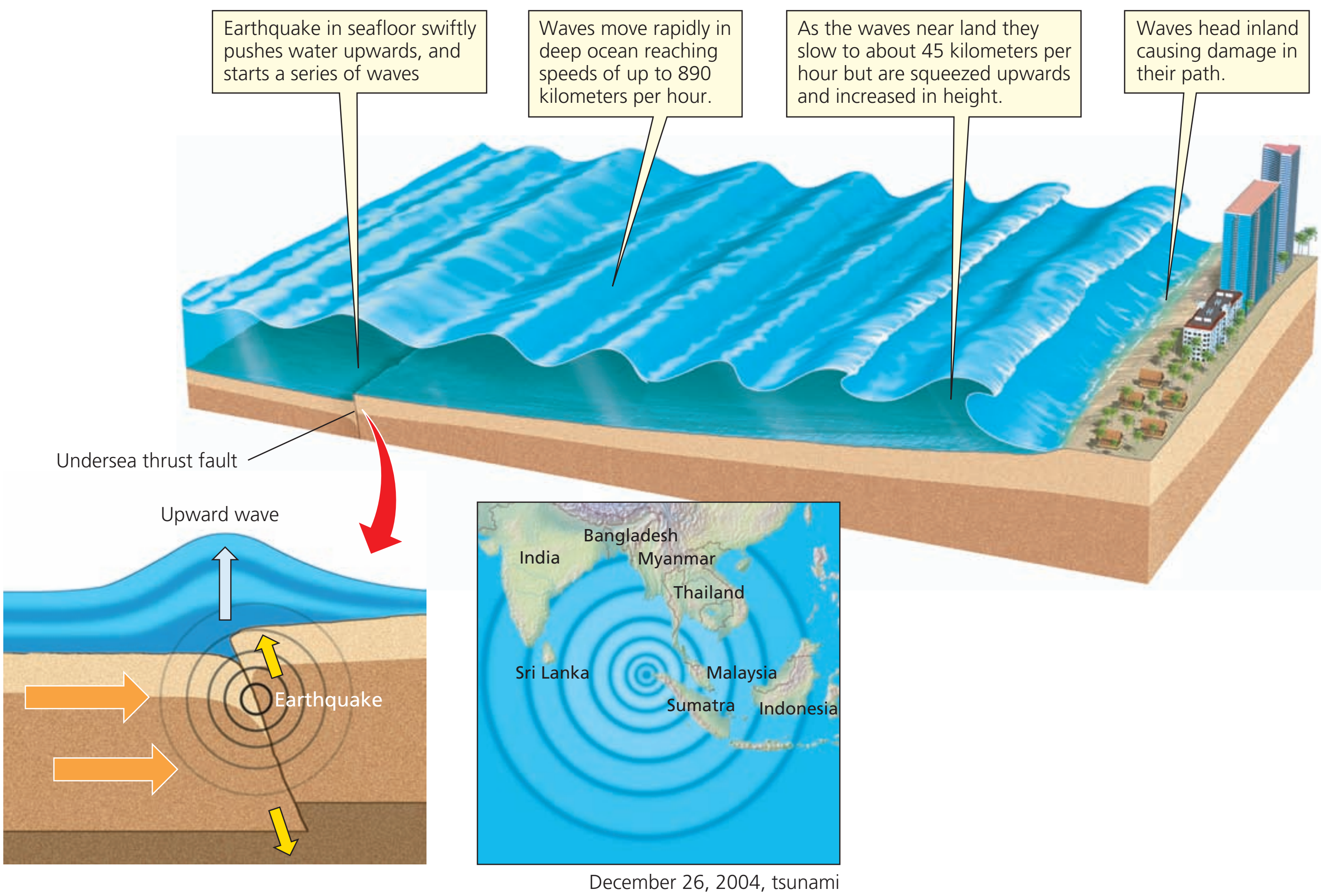


Figure 12-10 Formation of a tsunami and map of the area affected by a large tsunami in December 2004.

Figure 12-11 In December 2004, a great earthquake with a magnitude of 9.15 on the seafloor of the Indian Ocean created a tsunami that killed 168,000 people in Indonesia. 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) (**Concept 12-1**).

12-2 How Are the Earth's Rocks Recycled?

▶ **CONCEPT 12-2 The three major types of rock found in the earth's crust are recycled very slowly by physical and chemical processes.**

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 solid with a regular internal crystalline structure. A few minerals consist of a single element such as gold, silver, and diamonds (carbon). 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 3, p. S27, in Supplement 6) and quartzite (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 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. **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 layers convert the sediments 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 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 and then cools and hardens. Examples include *granite* (formed underground) and *lava rock* (formed aboveground). Although they are often covered by sedimentary rocks or soil, igneous rocks form the bulk of the earth's crust.

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).

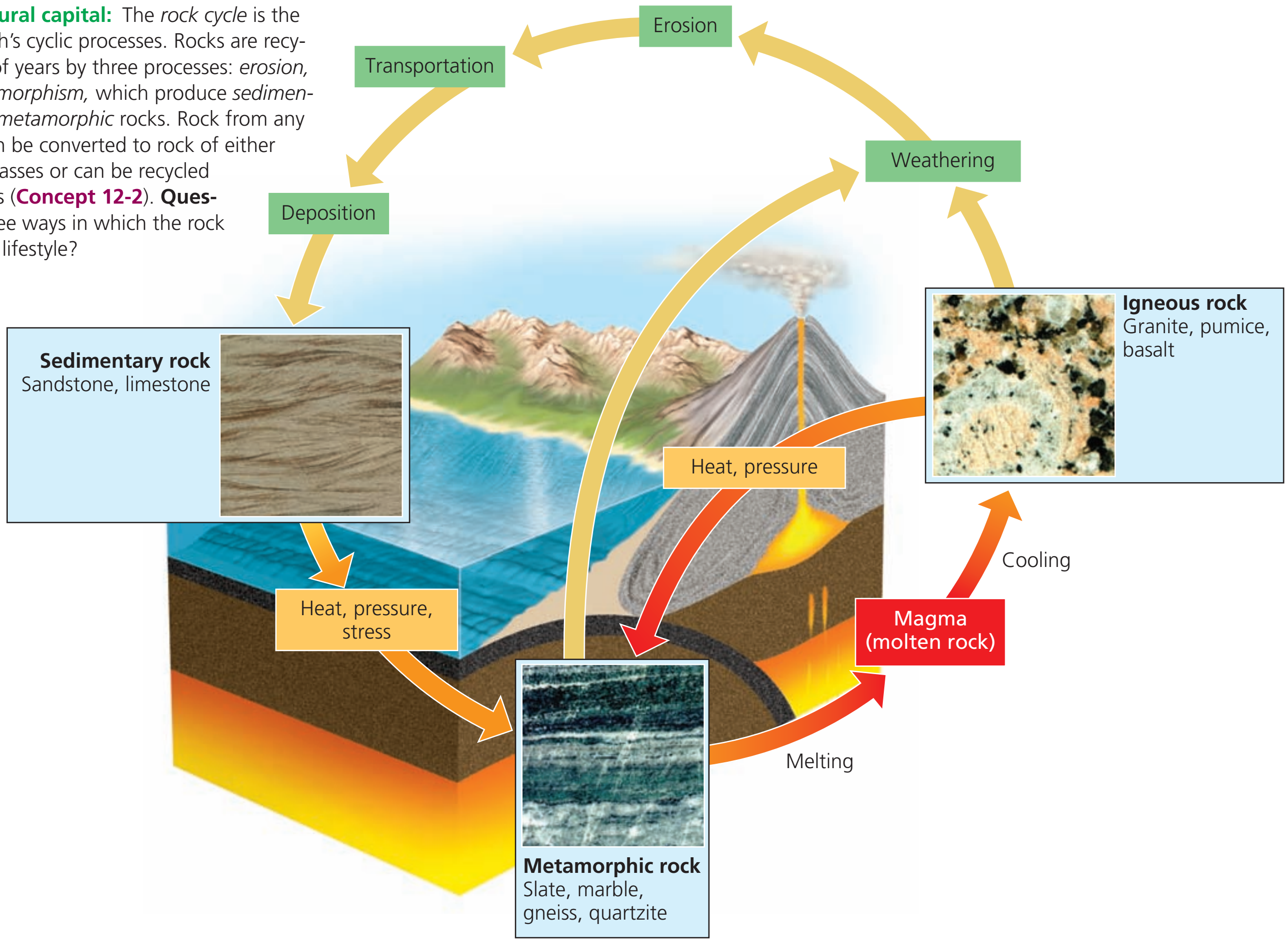


Figure 12-12 **Natural capital:** The *rock cycle* is the slowest of the earth's cyclic processes. Rocks are recycled over millions of years by three processes: *erosion, melting,* and *metamorphism,* which produce *sedimentary, igneous,* and *metamorphic* rocks. Rock from any of these classes can be converted to rock of either of the other two classes or can be recycled within its own class (**Concept 12-2**). **Question**: What are three ways in which the rock cycle benefits your lifestyle?

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 12-12). This important form of natural capital recycles the earth's three types of rocks over millions of years and is the slowest of the earth's cyclic processes (**Concept 12-2**).

The rock cycle also concentrates the planet's nonrenewable mineral resources on which our life processes depend. Without the earth's incredibly slow rock cycle, you would not exist.

12-3 What Are Mineral Resources and What Are the Environmental Effects of Using Them?

▶ **CONCEPT 12-3 Some minerals in the earth's crust can be made 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 can be extracted and processed into useful products and raw materials at an affordable cost (**Concept 12-3**). We know how to find and extract more than 100 minerals from the earth's crust. Examples are *fossil fuels* (such as coal), *metallic minerals* (such as aluminum and gold), and *nonmetallic minerals* (such as sand, and limestone). Because they take so long to form, minerals 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 are often taken for granted. *Aluminum* (Al) is used for packaging and beverage cans and as a structural material in motor vehicles, aircraft, and buildings. *Steel*, an essential material used in buildings and motor vehicles, is a mixture (alloy) of iron (Fe) and other elements that are added to give it certain properties. *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.

CORE CASE STUDY

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 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 and used to make road rock, concrete, and cement.

Most published estimates of the supply of a given mineral resource refer to its **reserves**: identified resources from which the mineral can be extracted profitably at current prices. Reserves increase when new profitable deposits are found and when higher prices or improved mining technology make it profitable to extract deposits that previously were considered too expensive to extract.

Mineral Use Has Advantages and Disadvantages

Metals can be used to produce many useful products. But the *life cycle of a metal* (Figure 12-13)—mining, processing, and using it—takes enormous amounts of energy and water and can disturb the land, erode soil, produce solid waste, and pollute the air, water, and soil (Figure 12-14, p. 284) (**Concept 12-3**). 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.

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 are 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

CONCEPT LINK

Use the second law of thermodynamics (**Concept 2-3B**, p. 34) 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 technique used depends on the location and type of the mineral resource.

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 generally, they involve 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 set aside in piles of waste material called **spoils**. 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 12-15, p. 284),

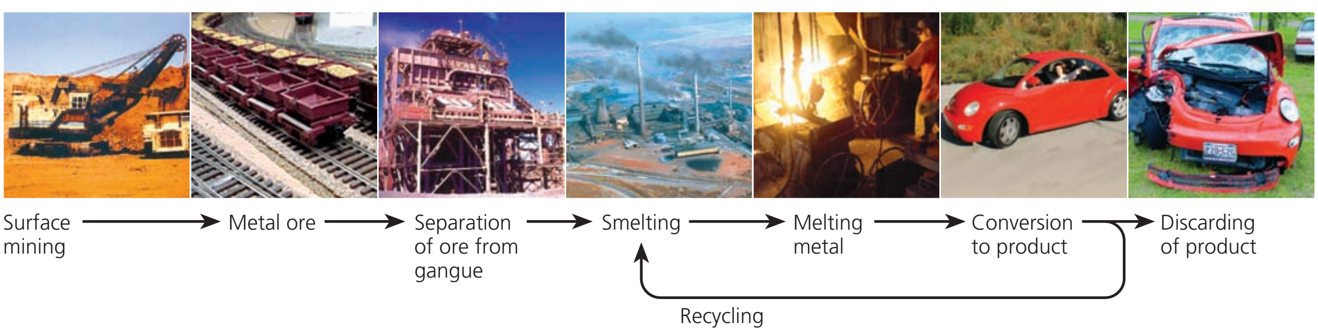


Figure 12-13 *Life cycle of a metal resource.* Each step in this process uses large amounts of energy and water and produces some pollution and waste.

Figure 12-14 Some harmful environmental effects of extracting, processing, and using nonrenewable mineral and energy resources (**Concept 12-3**). Providing the energy required to carry out each step causes additional pollution and environmental degradation.

Andre Maslennikov/Peter Arnold, Inc.

Figure 12-15 Natural capital degradation: This *open-pit* mine, located near the city of Kalgoolie in the outback of western Australia, is the world's largest gold mine (**Core Case Study**). **Question**: Should governments require mining companies to fill in and restore such sites once their ore is depleted? Explain.

machines dig very large holes and remove ores, sand, gravel, and stone such as limestone and marble. Metals such as gold (**Core Case Study**), iron, and copper are often mined in this way.

CORE CASE STUDY

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. 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 12-16) is used mostly to mine coal on hilly or mountainous terrain. A huge power shovel cuts a series of terraces into the side of a hill. Colossal 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 is left in front of a highly erodible bank of soil and rock called a *highwall*.

Another surface mining method is **mountaintop removal**. In the Appalachian Mountains of the United States, where this form of mining is prominent, explosives, large power shovels, and huge machines, 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 mineral resources are removed from underground through tunnels and shafts. It 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 12-1, 12-15, and 12-16).

CORE CASE STUDY

For example, area strip mining often leaves a series of spoils banks that look like waves of rubble (Figure 12-17). 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 it requires the long process of primary ecological succession (Figure 5-10, p. 89, and **Concept 5-4**, p. 89).

CONCEPT LINK

In mountaintop removal, great volumes of waste rock and dirt are plowed into valleys below the mountaintops. This destroys forests, buries mountain streams, and increases flood hazards. Wastewater, produced when the coal is processed, is often stored in these valleys behind dams, which can overflow or collapse and release toxic substances such as arsenic and mercury into nearby communities.

In the United States, more than 400 mountaintops, many of them in the state of West Virginia, have been removed to extract coal. The resulting spoils have buried about 1,900 kilometers (1,200 miles) of streams.

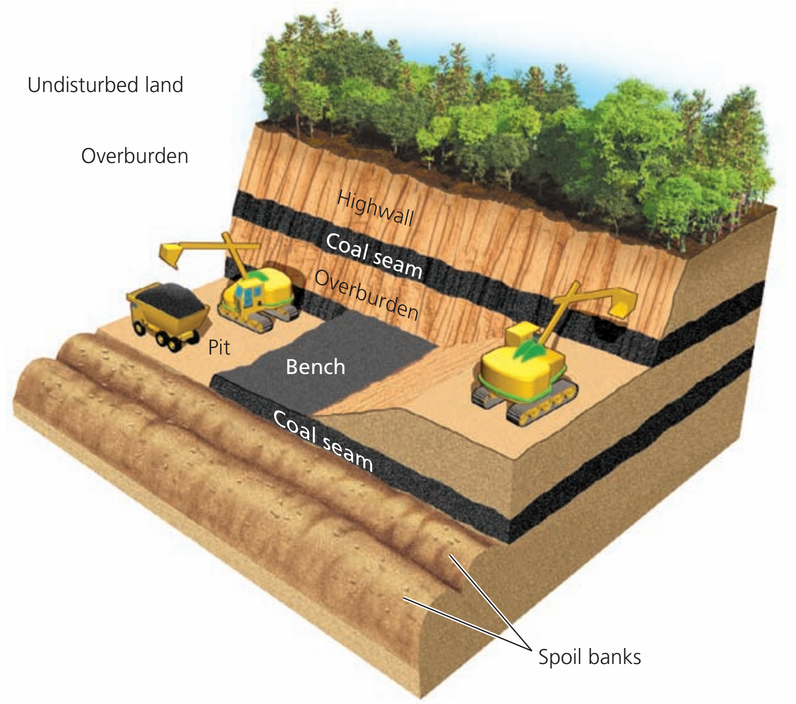


Figure 12-16 **Natural capital degradation:** *contour strip mining* of coal used in hilly or mountainous terrain.

National Archives/EPA Documerica.

Figure 12-17 **Natural capital degradation:** Spoils banks created by area strip mining of coal at an unrestored site near Mulla, Colorado (USA). Government laws require at least partial restoration of newly strip-mined areas in the United States. Nevertheless, many previously mined sites have not been restored and restoration is not possible in some arid areas. **Question**: Should the government require mining companies to restore such sites as fully as possible? Explain.

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 destructive techniques to dig large pits and dredge sediments from rivers. They 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.

CORE CASE STUDY

Surface mining sites can be cleaned up and restored (Figure 12-18), 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. DOI also estimates that cleaning up these sites could cost taxpayers as much as $70 billion. And 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 leaves much of the resource in the ground and includes hazards such as cave-ins, explosions, and fires. Miners often get diseases such as black lung, caused by prolonged inhalation of mining dust. 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 cause major water 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 naturally from spoils) to nearby streams and groundwater. (See *The Habitable Planet*, Video 6 at **www.learner.org/resources/series209.html**.) 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 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, called *gangue* (pronounced "gang"). Removing the gangue from ores produces waste piles called *tailings*. Particles of toxic metals blown by the wind or leached from tailings by rainfall can contaminate surface water and groundwater.

After removal of the gangue, heat or chemical solvents are used to extract metals from the ores. Heating ores to release metals is called **smelting** (Figure 12-13). Without effective pollution control equipment, smelters emit enormous quantities of air pollutants, including sulfur dioxide and suspended particles, which damage vegetation and acidify soils in the surrounding area. Smelters also cause water pollution and produce liquid and solid hazardous wastes that require safe disposal.


Princeton Hydro/Society for Ecological Restoration International

Before


Princeton Hydro/Society for Ecological Restoration International

After

Figure 12-18 Ecological restoration of a mining site in the U.S. state of New Jersey by Princeton Hydro.

12-4 How Long Will Supplies of Nonrenewable Mineral Resources Last?

▶ **CONCEPT 12-4 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. Geologic processes have distributed deposits of such resources unevenly among countries.

Massive exports can deplete a country's supply of nonrenewable minerals. During the 1950s, for example, South Korea exported large amounts of its iron and copper. Now the country does not have enough of these metals to support its economic growth and must import them.

Five nations—the United States, Canada, Russia, South Africa, and Australia—supply most of the nonrenewable mineral resources used by modern societies. South Africa, for example, is the world's largest producer of gold, chromium, and platinum. The United States, Germany, and Russia, with only 8% of the world's population, consume about 75% of the most widely used metals. China is rapidly increasing its use of key metals.

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. For each of 24 key nonrenewable mineral resources, the United States currently imports 50% or more of the amount used each year.

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. China is using its wealth to buy up access to such scarce and strategically important metals and other minerals. The United States has little or no reserves of these metals. Some analysts believe that nanomaterials (Science Focus, p. 288) may eventually be substituted for some of these metals.

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 12-4**). At that point, there are five choices: *recycle or reuse existing supplies*, *waste less*, *use less*, *find a substitute*, or *do without*.

According to a 2006 study by Thomas Graedel of Yale University, if all nations extract metal resources from the earth's crust at the same rate as developed nations do today, there may not be enough metal resources to meet the demand, even with extensive recycling. However, the successful development of nanotechnology, assuming we can minimize its potentially harmful environmental and health effects (Science Focus, p. 288), may help reduce such projected shortages.

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 12-4**).

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 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 developed countries. Governments in such countries often use subsidies, taxes, regulations, and import tariffs to control the supplies, demands, and prices of minerals so that a truly competitive market does not exist.

Most mineral prices are kept artificially low because governments subsidize development of their domestic mineral resources to help promote economic growth and national security. In the United States, for instance, mining companies get subsidies in the form of depletion allowances amounting to 5–22% of their gross income from mineral extraction and processing (See Case

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. At the nanoscale level, conventional materials have unconventional and unexpected properties.

Scientists envision arranging atoms of abundant substances such as carbon, silicon, silver, and titanium to create everything from medicines and solar cells to automobile bodies. Nanomaterials are currently used in more than 600 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 windows and windshields, and sunscreens. **GREEN CAREER:** Environmental nanotechnology

Nanotechnologists envision a supercomputer the size of a sugar cube that could store all the information now found in the U.S. Library of Congress; biocomposite materials smaller than a human cell that would make our bones and tendons super strong; nanovessels that could be filled with medicines and delivered to cells anywhere in the body; and designer nanomolecules that could seek out and kill cancer cells.

Nanoparticles could also be used to remove industrial pollutants in contaminated air, soil, and groundwater, and nanofilters might be used to purify water and to desalinate water at an affordable cost. The technology could also be used to turn garbage into breakfast by mimicking how nature turns wastes into plant nutrients, thus following the nutrient 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, without mining and depleting nonrenewable resources, and with many potential environmental benefits. But there are concerns over some possible unintended harmful consequences, 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.

Many analysts say we need to take two steps before unleashing nanotechnology more broadly. *First,* carefully investigate its potential ecological, economic, health, and societal 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.

If nanotechnology lives up to its potential, the businesses of mining and processing most minerals may become obsolete. This would essentially eliminate the harmful environmental effects of these activities.

Critical Thinking

How might the development of nanotechnology affect the mining of gold (**Core Case Study**)?

Study that follows). They can also reduce their taxes by deducting some of their costs for finding and developing mineral deposits.

Most consumers are unaware that the real costs of products made from mineral resources are higher than their market prices. This is because they are also paying taxes to provide government subsidies and tax breaks for mining companies and to help control the harmful environmental effects of mineral extraction, processing, and use. If these hidden costs were included in the prices of such goods, these harmful effects (Figure 12-14) would be sharply reduced, recycling and reuse would increase dramatically, and many minerals would be replaced with less harmful substitutes.

Proponents of eliminating or sharply reducing such subsidies maintain that such actions would promote more efficient resource use, waste reduction, pollution prevention, and recycling and reuse of many mineral resources. 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 and mining and pollution control regulations.

THINKING ABOUT
Minerals and Nanotechnology

How might arguments for and against subsidies and low taxes for mineral resource extraction be affected by the widespread use of nanotechnology (Science Focus, above) during the next 20 years?

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 developing; and only 1 becomes a producing 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

Revisiting the Real Cost of Gold: The U.S. General Mining Law of 1872

Some people have gotten rich 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, silver, copper, and uranium) on public lands and to help develop the then-sparsely populated West.

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.

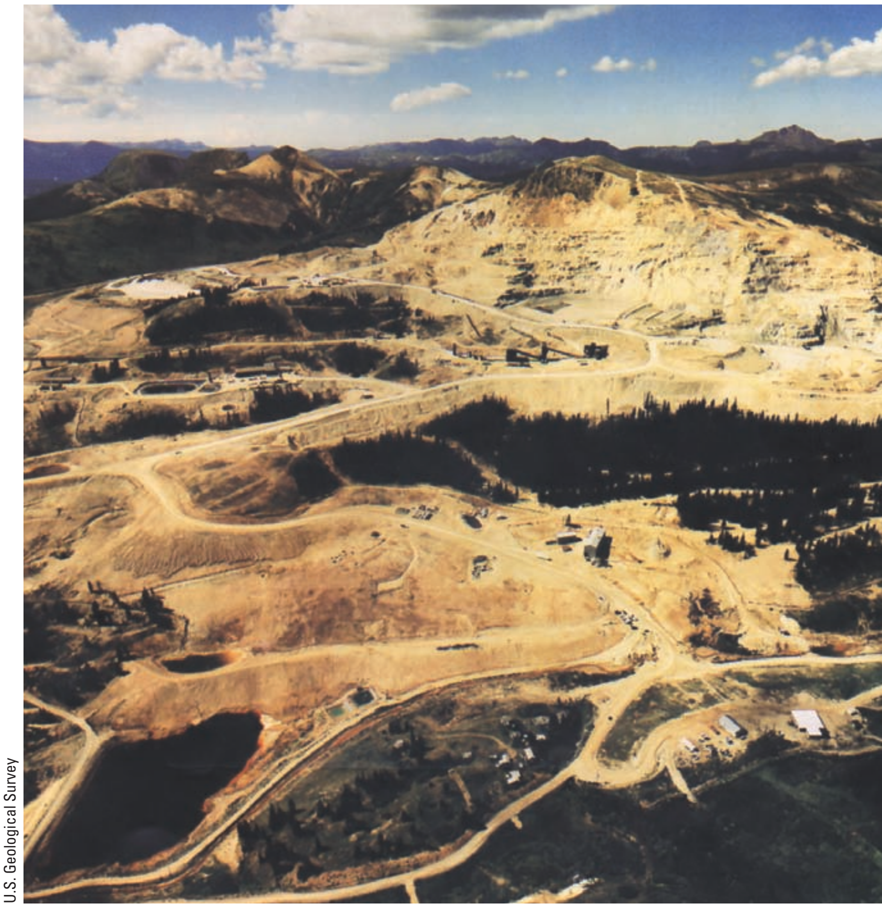
Until 1995, when a freeze on such land transfers was declared by Congress, one could pay the federal government $6–12 per hectare ($2.50–5.00 an acre) for land owned jointly by all U.S. citizens. One could then lease the land, build on it, sell it, or use it for essentially any purpose. People have constructed 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 (USA) (Figure 12-19). A Canadian company used the 1872 U.S. mining law to buy the land from the federal government at a pittance, spent $1 million to develop the site, removed $98 million worth of gold, and abandoned the polluted site.

In 1992, the 1872 law was modified to require mining companies to post bonds to cover 100% of the estimated cleanup costs in case they go bankrupt—a requirement that mining companies are lobbying Congress to overturn or greatly weaken. 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 500,000 abandoned hard rock mining sites will cost U.S. taxpayers $32–72 billion.

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.



U.S. Geological Survey

Figure 12-19 **Natural capital degradation:** the Summitville gold mining site near Alamosa, Colorado (USA), 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 this site into the nearby Alamosa River. Cleanup by the EPA will cost U.S. taxpayers about $120 million.

Critics of this 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. And they want the government to set up a fund paid for by higher royalties from hard rock mining companies to clean up abandoned mining sites.

Is Mining Lower-Grade Ores the Answer?

Some analysts contend that we can increase supplies of a mineral 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-grades 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 12-4**). One is the increased cost of mining and processing larger volumes of ore, as predicted by applying the second law of thermodynamics (p. 35). Another is the increasing shortages of freshwater—which is needed to mine and process some minerals—especially in arid and semiarid areas. A third limiting factor is the environmental impacts of the increased land disruption, waste material, and pollution produced during mining and processing (Figure 12-14).

One way to improve mining technology is to use microorganisms to extract minerals in a process called *in-place*, or *in situ*, (pronounced "in SY-too") *mining*. This biological approach, sometimes called *biomining*, removes 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 hazardous chemical water pollution such as that resulting from the use of cyanide (Figure 12-1) and mercury in gold mining (**Core Case Study**).

GOOD NEWS

CORE CASE STUDY

RESEARCH FRONTIER

Developing biomining and other new methods for extracting more minerals from ores. See **www.cengage.com/biology/miller**.

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.

Can We Get More of Our 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.

THINKING ABOUT

Extracting Minerals from Seawater

CONCEPT LINK

Use the second law of thermodynamics (**Concept 2-3B**, p. 34) to explain why it costs too much to extract most dissolved minerals from seawater.

Another potential source is hydrothermal ore deposits that form when mineral-rich, superheated water shoots out of vents in solidified magma on the ocean floor. After mixing with cold seawater, particles of metal compounds (such as sulfides, silver, zinc, and copper) precipitate out and build up as mineral deposits around the vents. Currently, it costs too much to extract these minerals, even though some deposits contain large concentrations of important metals.

Still another possible source of metals from the ocean floor is potato-size *manganese nodules* that cover about 25–50% of the Pacific Ocean floor. They could be sucked up by giant vacuum pipes or scooped up by buckets on a continuous cable operated by a mining ship.

So far, these ocean floor resources have not been developed because of high costs, squabbles over who owns them and how any profits from extracting them should be distributed among competing nations, and concerns about the effects of such mining on aquatic life.

12-5 How Can We Use Mineral Resources More Sustainably?

CONCEPT 12-5 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 12-5**). They point to nanotechnology (Science Focus, p. 288) and to the current *materials revolution* in which silicon and new materials, particularly ceramics and plastics, are being used as replacements for metals.

For example, fiber-optic glass cables that transmit pulses of light are replacing copper and aluminum wires in telephone cables. And in the future, nanowires may replace the 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 less to produce than metals, do not need painting (which reduces pollution and costs), can be molded into any shape, and increase fuel efficiency by greatly reducing the weights of motor vehicles.

Substitution is not a cure-all. For example, platinum is currently unrivaled as an industrial catalyst, 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 (**Concept 12-5**).

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, aluminum, and platinum) is to recycle or reuse them. Recycling has a much lower environmental impact than that of mining and processing metals from ores. For example, recycling aluminum beverage cans 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.

THINKING ABOUT
Metal Recycling and Nanotechnology

How might the development of a nanotechnology revolution (Science Focus, p. 288) over the next 20 years affect the recycling of metal mineral resources?

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 we can decrease our use and waste of such resources. Answering this second question could provide important ways to use mineral resources more sustainably (**Concept 12-5**). Figure 12-20 and the Case Study at right describe some of these strategies.

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. By 1998, 3M's overall waste production was down by one-third, and its air pollutant emissions per unit of production were 70% lower. The company had saved more than $750 million in waste disposal and material costs. This is an excellent example of why pollution prevention pays (**Concept 1-3**, p. 14).

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.)

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 (full-cost pricing).
- 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 12-20 Ways to achieve more sustainable use of nonrenewable mineral resources (**Concept 12-5**). **Question**: Which two of these solutions do you think are the most important? Why?

CASE STUDY

Industrial Ecosystems: Copying Nature

An important goal for a sustainable society is to make its industrial manufacturing processes cleaner and more sustainable by redesigning them to mimic how nature deals with wastes. According to the nutrient recycling **principle of sustainability**, in nature the waste outputs of one organism become the nutrient inputs of another organism, so that all of the earth's nutrients are endlessly recycled.

One way for industries to mimic nature is to recycle and reuse most minerals and chemicals instead of dumping them into the environment. Another is for industries to interact through *resource exchange webs* in which the wastes of one manufacturer become raw materials for another—similar to food webs in natural ecosystems (Figure 3-9, p. 46).

This is happening in Kalundborg, Denmark, where an electric power plant and nearby industries, farms, and homes are collaborating to save money and reduce their outputs of waste and pollution. They exchange waste outputs and convert them into resources, as shown in Figure 12-21. This cuts pollution and waste and reduces the flow of nonrenewable mineral and energy resources through their economy.

Today, about 20 ecoindustrial parks similar to the one in Kalundborg operate in various places in the world. And more are being built or planned—some of them on abandoned industrial sites, called *brownfields*. Those working 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

These and other industrial forms of *biomimicry* provide many economic benefits for businesses. By encouraging 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 harms caused by their actions. In addition, companies improve the health and safety of workers by reducing workers' exposure to toxic and hazardous materials, thereby reducing company health-care insurance costs.

Biomimicry also stimulates companies to come up with new, environmentally beneficial, and less resource-intensive chemicals, processes, and products that can be sold worldwide. And such companies convey a better image among consumers based on results rather than public relations campaigns.

THINKING ABOUT
Gold Mining

CORE CASE STUDY

How would you apply the solutions in Figure 12-21 to decreasing the need to mine gold (**Core Case Study**) and to reducing the harmful environmental effects of gold mining?

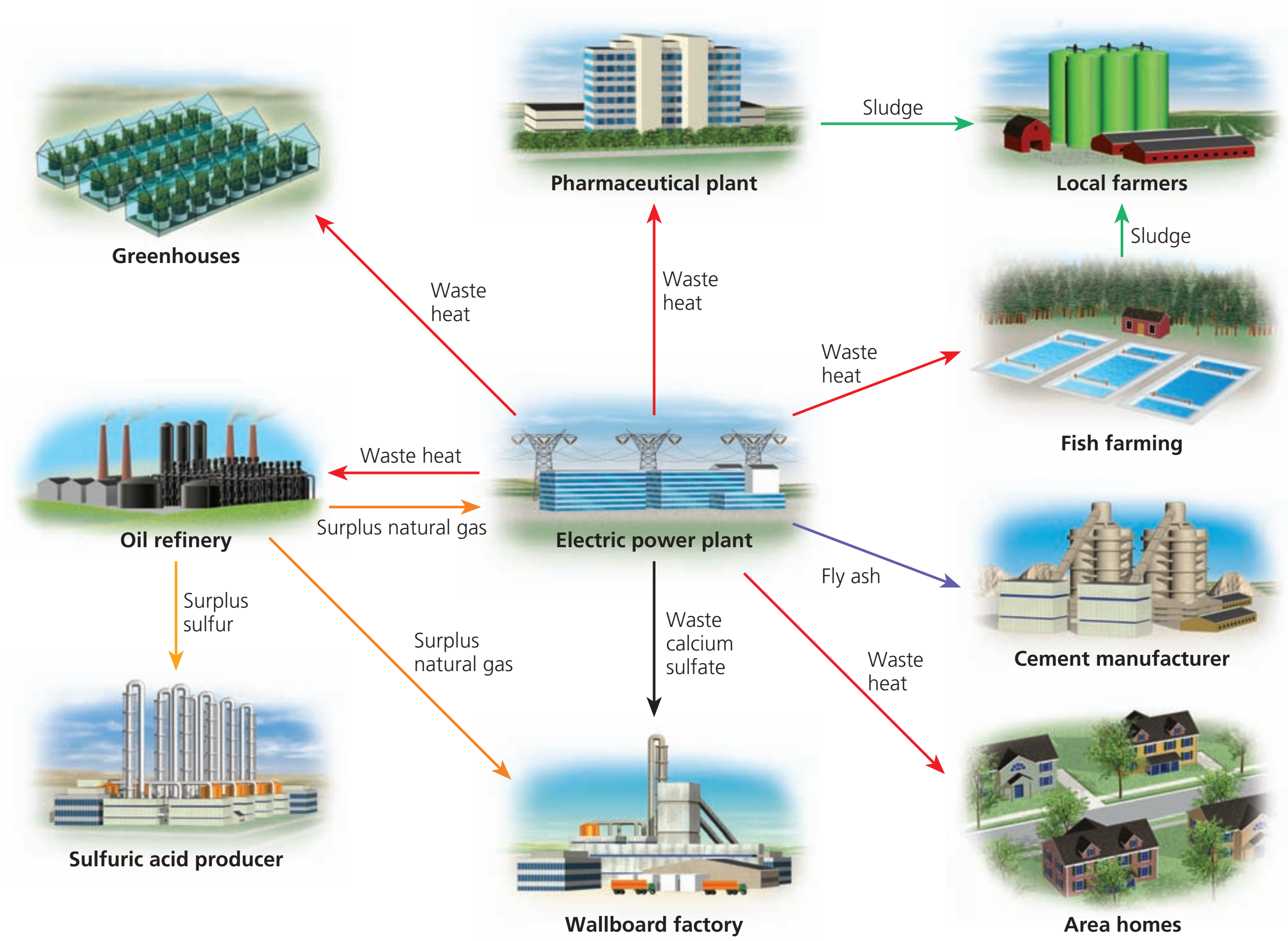


Figure 12-21 **Solutions:** an *industrial ecosystem* in Kalundborg, Denmark, reduces waste production by mimicking a food web in natural ecosystems. The wastes of one business become the raw materials for another. **Question**: Is there an industrial ecosystem near where you live or go to school? If not, think about where and how such a system could be set up.

RESEARCH FRONTIER

Developing biomimicry and other ecoindustrial tools. See **www.cengage.com/biology/miller**.

Here are the *three big ideas* for this chapter:

- 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 The Real Cost of Gold and 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 it is developed safely, nanotechnology (Science Focus, p. 288) could be used 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. Solar energy could be used increasingly to generate electricity needed 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 converting wastes to resources and exchanging them through a network resembling a food web (Figure 12-21). By putting diverse users and uses of mineral resources into such a web, we would be applying the biodiversity **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 sustaining 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. 274. Describe some of the environmental effects of gold mining.
2. Define **geology**, **core**, **mantle**, **crust**, **tectonic plate**, **asthenosphere**, and **lithosphere**. What is a transform fault? Define volcano and describe the nature and effects of a volcanic eruption. Define and describe the nature and effects of an **earthquake**. 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. Describe the nature and importance of the **rock cycle**.
4. Define **mineral resource** and list three types of such resources. 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 the major harmful environmental effects of extracting, processing, and using nonrenewable mineral resources.
5. Distinguish between **surface mining** and **subsurface mining**. Define **overburden**, **spoils**, and **open-pit**

mining. Define **strip mining** and distinguish among **area strip mining**, **contour strip mining**, and **mountaintop removal** mining. Describe the harmful environmental effects of mining. What is **smelting** and what are its major harmful environmental effects? 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?

6. Describe the advantages and disadvantages of the nanotechnology revolution. Describe the conventional view of the relationship between the supply of a mineral resource and its market price. What factors can influence this market interaction? Discuss the pros and cons of the U.S. General Mining Law of 1872.

7. Describe the opportunities and limitations of increasing mineral supplies by mining lower-grade ores. What are the advantages and disadvantages of biomining?

8. Describe the opportunities and limitations of getting more minerals from the ocean. Describe the opportunities and limitations of finding substitutes for scarce mineral resources and of recycling and reusing valuable metals.

9. Describe ways to use nonrenewable mineral resources more sustainably. Describe the Pollution Prevention Pays program of the Minnesota Mining and Manufacturing Company. Describe and give an example of an ecoindustrial ecosystem.

10. What are this chapter's *three big ideas*? Describe how the three **principles of sustainability** can be applied 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 decreasing the need to mine gold and reducing its harmful environmental effects (**Core Case Study**) could benefit you.

2. What do you think would happen if the earth's tectonic plates stopped moving around? Explain. (Think about both short-term and long-term effects.)

3. You are an igneous rock. Write a report on what you experience as you move through the rock cycle (Figure 12-12). Repeat this exercise, assuming you are a sedimentary rock and then a metamorphic rock.

4. Use the second law of thermodynamics (**Concept 2-3B**, p. 34) to analyze the scientific and economic feasibility of each of the following processes:
   - **a.** Extracting most minerals 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

5. List three ways in which a nanotechnology revolution (Science Focus, p. 288) could benefit you and three ways in which it could harm you.

6. Describe the strategy you would use to promote the spread of industrial ecosystems (Case Study, p. 291)? As part of your promotion strategy for this project, describe three benefits of such systems to your community.

7. Explain why you support or oppose each of the following proposals concerning extraction of hard rock minerals on public land in the United States (Case Study, p. 288): **(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 environmental damage caused by their activities.

8. List three ways in which you could apply **Concept 12-5** to making your lifestyle more environmentally sustainable.

9. Congratulations! You are in charge of the world. What are the three most important features of your policy for developing and using the world's nonrenewable mineral resources in the most sustainable way possible?

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

DATA ANALYSIS

Uranium (U), which is used as a fuel in the reactors of nuclear power plants, is found in various rocks at different concentrations. A high-grade ore has 2% U and a low-grade ore has 0.1% U. The estimated recoverable resources of uranium for the world 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 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.cengage.com/biology/miller** and choose Chapter 12 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, web links, information on Green Careers, and InfoTrac® College Edition articles.

CENGAGENOW™ For students with access, log on at **www.cengage.com/login** for the animations, active figures, activities, and readings indicated within the text by the CengageNOW logo. If your textbook did not come with access, visit **www.iChapters.com** to purchase.

13 Energy

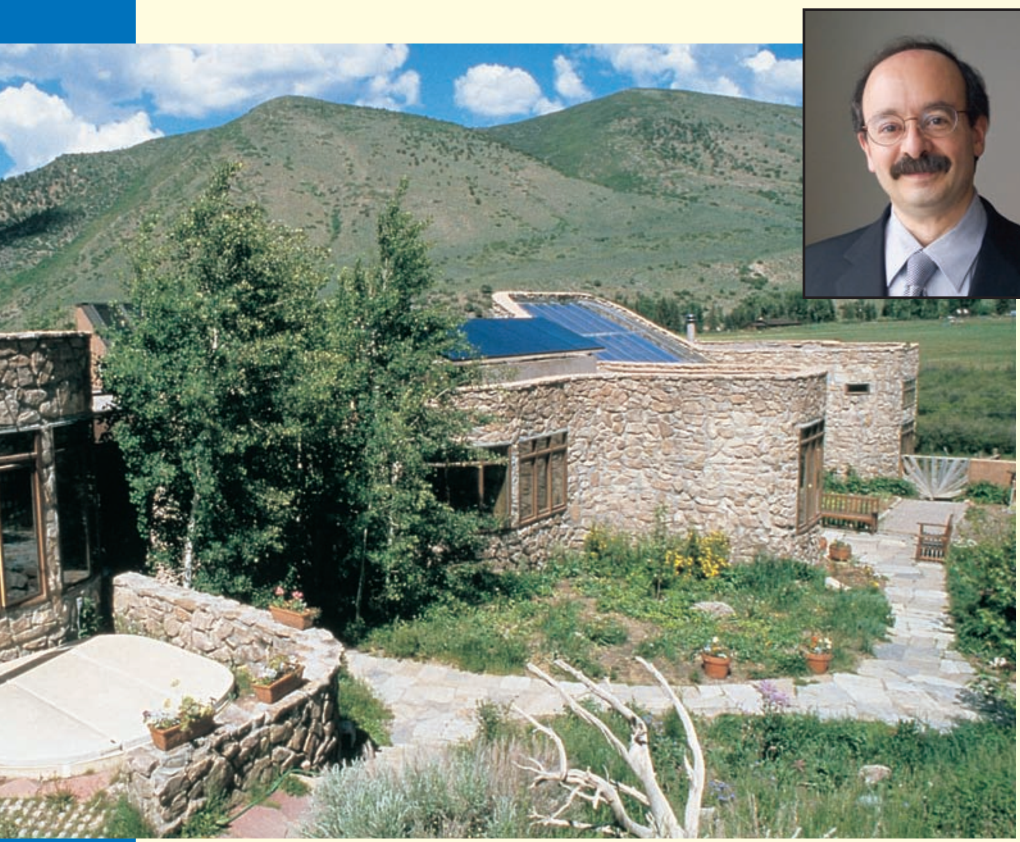
CORE CASE STUDY Amory Lovins and the Rocky Mountain Institute

In 1984, energy analyst Amory B. Lovins completed construction of a large, solar-heated, solar-powered, superinsulated, partially earth-sheltered home and office (Figure 13-1) in Snowmass, Colorado (USA), an area with extremely cold winters. The building serves as headquarters for the nonprofit Rocky Mountain Institute (RMI), a nonpartisan group of 60 scientists and analysts who do research and consulting on energy efficiency and renewable energy alternatives.

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. It gets 99% of its heat and hot water, 95% of its daytime lighting, and 90% of its household electricity from the sun. The institute's heating bill is less than $50 a year.

Excluding power for office equipment, the structure draws a little more electricity than a single 100-watt incandescent light bulb uses. This is accomplished through the use of energy-efficient lights, refrigerators, computers, and other electrical devices and solar cells that generate electricity. The savings from these energy-efficiency investments repaid their costs in only 10 months.

The RMI building is designed to work with nature. It is oriented to collect as much sunlight as possible. It contains a central greenhouse with a variety of plants, which humidifies the building and helps to heat it and purify its air. The building is continually being upgraded. In the 1990s, even more energy-efficient windows were installed in place of the original ones. In other words, this building is a shining example of how to apply the solar energy **principle of sustainability**.



Robert Millman/Rocky Mountain Institute

Figure 13-1 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). The Institute studies energy efficiency and sustainable use of energy and other resources. It also serves as an outstanding example of energy-efficient passive solar design.

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 with state governments and the U.S. military. In 2006, for example, RMI consulted with Wal-Mart to help triple the fuel efficiency of its fleet of delivery trucks, which has saved the company about $500 million a year.

Lovins has also proposed the development of *superefficient*, *ultralight*, and *ultrastrong* vehicles that can get up to 130 kilometers per liter (300 miles per gallon) using existing technology. He has calculated that within this century, we will propel our cars and heat, cool, and power our homes with electricity produced mostly by wind turbines, solar cells, and a mix of geothermal and other renewable energy resources.

In 2008, Lovins was honored as one of America's Best Leaders by U.S. News Media Group and the Harvard Kennedy School. Partly because of his work, it is possible that during your lifetime, the world will cut energy waste to the bone and get half or more of its energy from a variety of renewable-energy resources. In this chapter we will examine this exciting and challenging possibility.

Key Questions and Concepts

13-1 What major sources of energy do we use?

CONCEPT 13-1A About three-quarters of the world's commercial energy comes from nonrenewable fossil fuels and the rest comes from nonrenewable nuclear fuel and renewable sources.

CONCEPT 13-1B Net energy is the amount of high-quality energy available from a resource minus the amount of energy needed to make it available.

13-2 What are the advantages and disadvantages of fossil fuels?

CONCEPT 13-2 Oil, natural gas, and coal are currently abundant and relatively inexpensive, but using them causes air and water pollution, degrades large areas of land, and releases greenhouse gases to the atmosphere.

13-3 What are the advantages and disadvantages of nuclear energy?

CONCEPT 13-3 The nuclear power fuel cycle has a low environmental impact and a very low accident risk, but its use has been limited because of high costs, a low net energy yield, long-lived radioactive wastes, vulnerability to sabotage, and the potential for spreading nuclear weapons technology.

13-4 Why is energy efficiency an important energy source?

CONCEPT 13-4 The United States could save as much as 43% of all the energy it uses by improving the energy efficiency of industrial operations, motor vehicles, and buildings.

13-5 What are the advantages and disadvantages of renewable energy resources?

CONCEPT 13-5 Using a mix of renewable energy sources—especially sunlight, wind, flowing water, sustainable biomass, and geothermal energy—can drastically reduce pollution, greenhouse gas emissions, and biodiversity losses.

13-6 How can we make the transition to a more sustainable energy future?

CONCEPT 13-6 We can make a 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) and 9 (p. S38) 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

13-1 What Major Sources of Energy Do We Use?

▶ **CONCEPT 13-1A About three-quarters of the world's commercial energy comes from nonrenewable fossil fuels and the rest comes from nonrenewable nuclear fuel and renewable sources.**

▶ **CONCEPT 13-1B Net energy is the amount of high-quality energy available from a resource minus the amount of energy needed to make it available.**

Fossil Fuels Supply Most of Our Commercial Energy

Everything runs on energy. That includes your body, the plants and animals that supply you with food, the buildings you live and work in, cars, factories, and all of the world's economies.

Almost all of the energy that heats the earth and our buildings comes from the sun at no cost to us—one of the three **principles of sustainability** (see back cover). Without this essentially inexhaustible input of solar energy, the earth's average temperature would be –240 °C (–400 °F) and you would not be reading these words. This direct input of solar energy produces several other forms of renewable energy resources that can be thought of as indirect solar energy: *wind* (moving air masses heated by the sun), *hydropower* (flowing water kept fluid by heat from the sun), and *biomass* (solar energy converted to chemical energy and stored in trees and other plants).

Currently, most *commercial energy*—energy sold in the marketplace—comes from extracting and burning *nonrenewable energy resources* obtained from the earth's crust. About 92% of the commercial energy used in the

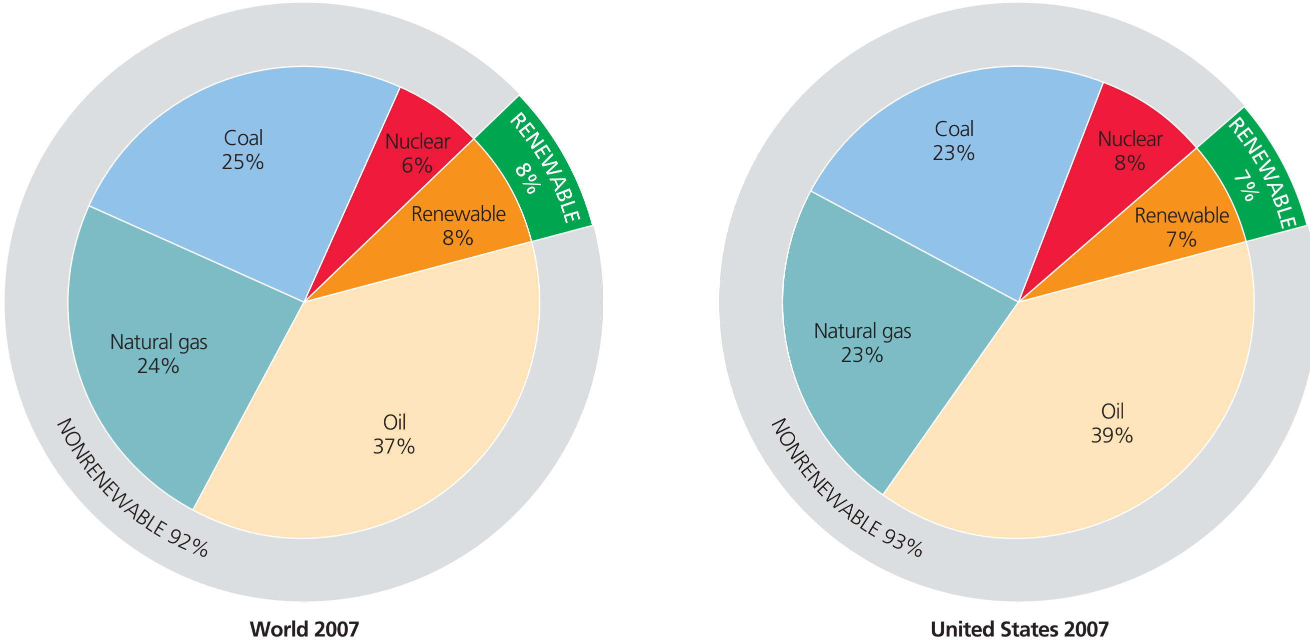


Figure 13-2 Commercial energy use by source throughout the world (left) and in the United States (right) in 2007. **Question**: Why do you think the world as a whole relies more on renewable energy than the United States does? (Data from U.S. Department of Energy, British Petroleum, Worldwatch Institute, and International Energy Agency)

world comes from such resources—86% from carbon-containing **fossil fuels** (oil, natural gas, and coal) and 6% from nuclear power (Figure 13-2, left). The remaining 8% of the commercial energy we use comes from *renewable* energy resources—biomass, hydropower, geothermal, wind, and solar energy (**Concept 13-1A**). (Supplements 2 and 9, pp. S3 and S38, include graphs and other information on trends in energy consumption in the world and in the United States, based on the most recently available data.)

Roughly half the world's people living in developing countries burn potentially renewable wood and charcoal made from wood to heat their dwellings and cook their food. Most of this biomass is collected by users and not sold in the marketplace. Thus, the actual percentage of renewable energy used in the world is higher than the 8% figure shown in Figure 13-2 (left).

CENGAGENOW™ Examine and compare energy sources used in developing and developed countries at CengageNOW.

According to scientists, all energy resources should be evaluated on the basis of their supplies, the environmental impact of our using them, and how much net useful energy they provide (Science Focus, right).

13-2 What Are the Advantages and Disadvantages of Fossil Fuels?

▶ **CONCEPT 13-2 Oil, natural gas, and coal are currently abundant and relatively inexpensive, but using them causes air and water pollution, degrades large areas of land, and releases greenhouse gases to the atmosphere.**

We Depend Heavily on Oil

Petroleum, or **crude oil** (oil as it comes out of the ground), is a black, gooey liquid consisting of hundreds of different combustible hydrocarbons along with small amounts of sulfur, oxygen, and nitrogen impurities. It is also known as *light oil*. Crude oil and natural gas are called fossil fuels because they were formed from the decaying remains (fossils) of organisms that lived 100–500 million years ago.

SCIENCE FOCUS

Net Energy Is the Only Energy That Really Counts

It takes energy to get energy. For example, before oil becomes useful to us, it must be found, pumped up from beneath the ground or ocean floor, transferred to a refinery, converted to useful fuels, and delivered to users. Each of these steps uses high-quality energy. 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 (**Concept 2-3B**, p. 34).

CONCEPT LINK

The usable amount of *high-quality energy* available from a given quantity of an energy resource is its **net energy**. It is the total amount of useful energy available from an energy resource minus the energy needed to find, extract, process, and get that energy to consumers (**Concept 13-1B**). It is calculated by estimating the total amount of energy available from the resource over its lifetime and then subtracting the amount of energy *used*, *automatically wasted* because of the second law of thermodynamics, and *unnecessarily wasted* in finding, processing, and transporting the useful energy to users.

Net energy is like the net profit earned by a business after expenses. If the business has $1 million in sales and $900,000 in expenses, its net profit is $100,000. Similarly, suppose that it takes 9 units of energy to produce 10 units of energy from 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. The higher the ratio, the greater the net energy. When the ratio is less than 1, there is a net energy loss. Figure 13-A 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 deposits 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. As this occurs, the net energy ratio of oil declines and extraction costs rise sharply in accordance with the two laws of thermodynamics.

Electricity produced by nuclear power has a low net energy ratio 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 the radioactive parts for thousands of years. Some analysts estimate that ultimately, we will have to put more energy into the nuclear fuel cycle than we will ever get out of it.

Critical Thinking

Should governments give a high priority to net energy ratios when deciding what energy resources to support? What are other factors that should be considered? Explain your thinking.

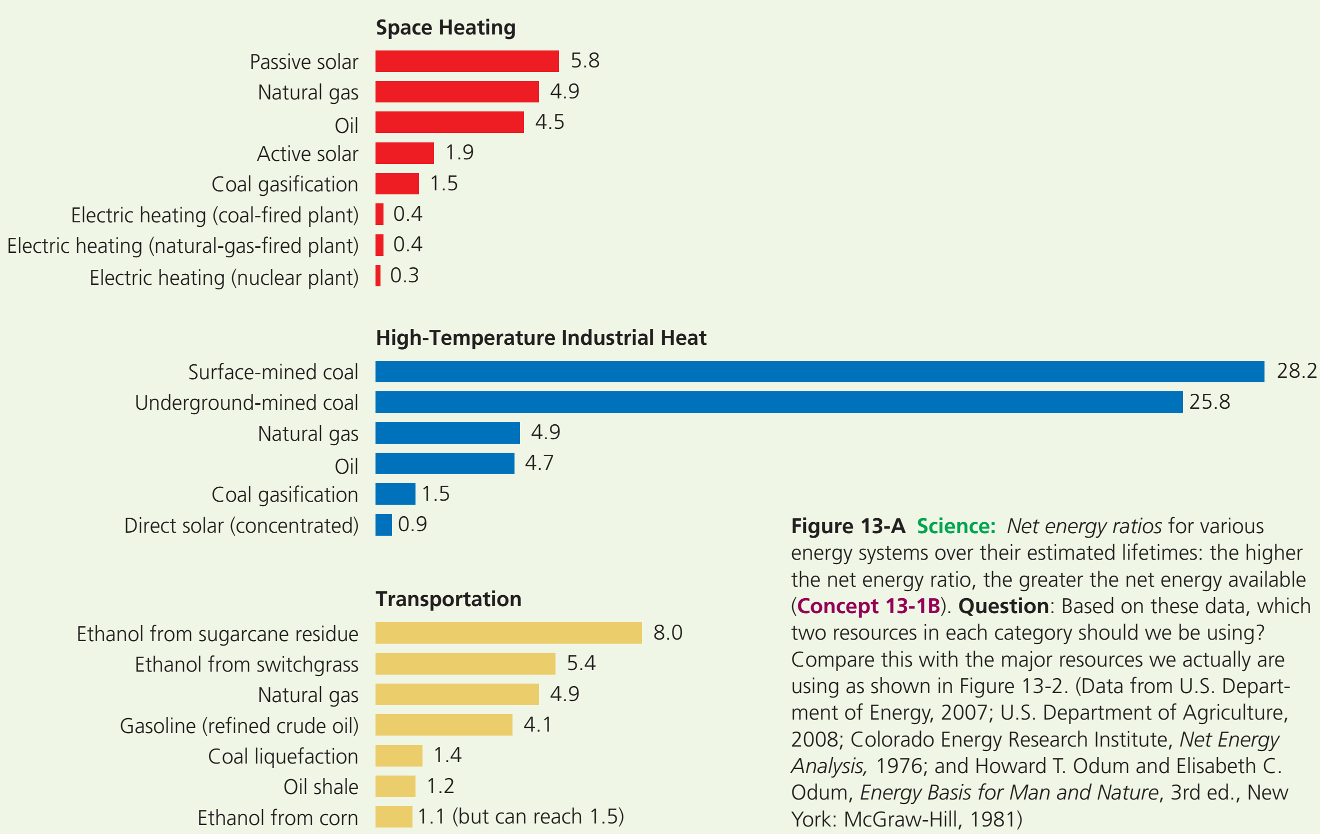
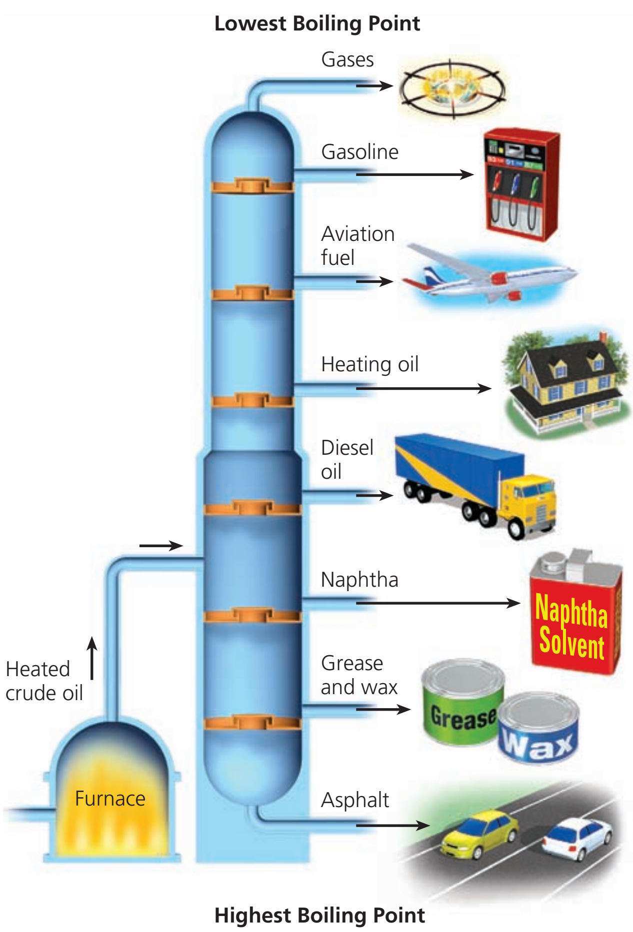


Figure 13-A **Science:** *Net energy ratios* for various energy systems over their estimated lifetimes: the higher the net energy ratio, the greater the net energy available (**Concept 13-1B**). **Question**: Based on these data, which two resources in each category should we be using? Compare this with the major resources we actually are using as shown in Figure 13-2. (Data from U.S. Department of Energy, 2007; U.S. Department of Agriculture, 2008; 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)

Deposits of crude oil and natural gas often are trapped together under a dome 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 into the deposit. Then oil, drawn by gravity out of the rock pores, flows into the bottom of the well and is pumped to the surface.

After years of pumping, usually a decade or so, the pressure in a well drops and its rate of crude oil production starts declining. 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 declining. *Global peak production* is the point in time when we reach the maximum overall rate of crude oil production for the whole world. Once we pass this point, the rate of global oil production begins declining. Then if we continue using oil faster than we can produce it, crude oil prices will rise. There is disagreement over whether we have reached or will soon reach global peak production.

After it is extracted, 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 13-3) in a complex process called *refining*.



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.

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 Will Supplies of Crude Oil Last?

Crude oil is now the single largest source of commercial energy in the world and in the United States (Figure 13-2). Stretched end to end, the average number of barrels of crude oil the world used each day in 2008 would circle the equator twice!

Proven oil reserves are identified deposits from which crude oil can be extracted profitably at current prices with current technology. Geologists project that known and projected global reserves of crude oil will be 80% depleted sometime between 2050 and 2100, depending on consumption rates. (The remaining 20% is usually too costly to remove. See Figure 3, p. S40, in Supplement 9 for a brief history of the Age of Oil.)

We have three options: look for more oil, use and waste less oil, or use other energy sources. Many analysts think we should vigorously pursue all three options.

age footstock/SuperStock

Figure 13-3 **Science:** *refining crude oil*. Components of petroleum are removed at various levels, depending on their boiling points, in a giant distillation column. The most volatile components with the lowest boiling points are removed at the top of the column. The photo shows an oil refinery in U.S. state of Texas.

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 78% of the world's proven crude oil reserves and thus will 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.

Saudi Arabia has the largest portion of the world's crude oil reserves (20%). It is followed by Canada (16%), which converts *heavy oil* extracted from tar sands into synthetic crude oil. In order, other countries with large proven crude oil reserves are Iran, Iraq, Kuwait, the United Arab Emirates, Venezuela, and Russia. About 77% of the world's proven crude oil reserves are in the hands of government-owned companies. Private companies such as ExxonMobil and BP control only about 7% of the world's oil reserves and thus have relatively little control over oil supplies and prices.

The basic problem is that production of crude oil from existing reserves has exceeded new oil discoveries since 1984 and global crude oil production has generally leveled off since 2005. Crude oil production peaked in the United States and in Venezuela in 1970, in Norway in 2000, and in Mexico in 2004, and it may soon peak in China and even in Saudi Arabia. Of the world's 64 major oil fields, 54 are now in decline.

Some people say that there is a lot of oil to be found. But they are talking mostly about small, dispersed, and harder-to-extract deposits of crude oil and deposits of heavy oil that must be extracted from tar sand and oil shale. These resources are much more expensive to develop than most of today's crude oil deposits are, and they have much lower net energy yields. Also, using them results in a much higher environmental impact.

Others argue that even if much more affordable crude oil is somehow found, it will not prevent the serious consequences of the high exponential growth (p. 15) in global oil consumption. According to the U.S. Department of Energy (DOE), if global oil consumption continues to grow exponentially at about 2.3% per year, then

- Saudi Arabia, with the world's largest known crude oil reserves, could supply the world's entire oil needs for about 7 years.
- The remaining estimated reserves under Alaska's North Slope—the largest ever found in North America—would meet current world demand for only 6 months or U.S. demand alone for less than 3 years.
- The estimated reserves in Alaska's Arctic National Wildlife Refuge (ANWR) (see Figure 2, p. S39, in Supplement 9) would meet the current world demand for only 1–5 months and U.S. demand for 7–24 months (Figure 13-4).

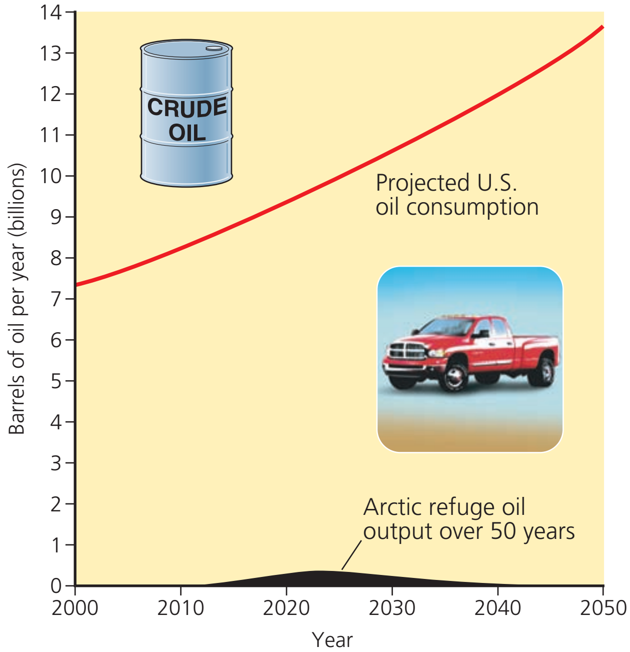


Figure 13-4 The amount of crude oil that *might* be found in the Arctic National Wildlife Refuge, if developed and extracted over 50 years, is only a tiny fraction of projected U.S. oil consumption. In 2008, the DOE projected that developing this oil would take 10–20 years and lower gasoline prices at the pump by at most 6 cents per gallon. (Data from U.S. Department of Energy, U.S. Geological Survey, and Natural Resources Defense Council)

Bottom line: *To keep using crude oil at the projected rate of increase, we must discover global crude oil reserves equivalent to a new Saudi Arabian supply every 5 years.* Many oil geologists say this is highly unlikely.

The United States Uses Much More Oil Than It Produces

The United States gets about 93% of its energy from fossil fuels, with 39% coming from crude oil (See Figure 13-2, right and Figure 2, p. S39, in Supplement 9). The United States produces about 9% of the world's crude oil but uses 25% of the world's production. And the *U.S. has only about 2% 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 explain why in 2008 the United States imported 58% of its crude oil (compared to 24% in 1970). This results in a massive annual transfer of wealth from the United States to oil-producing countries.

CONNECTIONS

Oil Consumption and Terrorism

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. This means that, in buying oil from those sources, countries that are concerned with fighting terrorism are funding the enemy. 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.*

Government and independent geologists estimate that if the United States opens up virtually all of its public lands and coastal regions to oil exploration, it will find an amount of crude oil that is small, relative to the country's demand for oil. And this oil would be developed only at very high production costs, with low net energy yields and high environmental impacts. 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*.

Crude Oil Has Advantages and Disadvantages

Figure 13-5 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 (Figure 12-14, p. 284), including land disruption, air pollution, greenhouse gas emissions, water pollution, and loss of biodiversity.

A critical and growing problem is that burning oil or any carbon-containing fossil fuel releases CO_2 into the atmosphere and, according to most climate scientists, this will contribute to projected climate change. Currently, burning oil, mostly as gasoline and diesel fuel for transportation, accounts for 43% of global CO_2 emissions.

HOW WOULD YOU VOTE?

Do the advantages of relying on crude oil as the world's major energy resource outweigh its disadvantages? Cast your vote online at **www.cengage.com/biology/miller**.

Trade-Offs

Conventional Oil

Advantages	Disadvantages
Ample supply for 42–93 years	Need to find substitutes within 50 years
Low cost	Large government subsidies
High net energy yield	Environmental costs not included in market price
Easily transported within and between countries	Artificially low price encourages waste and discourages search for alternatives
Low land use	Pollutes air when produced and burned
Technology is well developed	Releases CO_2 when burned
Efficient distribution system	Can cause water pollution

Figure 13-5 Advantages and disadvantages of using crude oil as an energy resource. **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

Will Heavy Oils from Tar Sand and Oil Shale Save Us?

Tar sand, or **oil sand**, is a mixture of clay, sand, water, and a combustible organic material called *bitumen*—a thick, sticky, tar-like 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 (Figure 7-15, bottom photo, p. 135) roughly equal to the area of the U.S. state of North Carolina. Other deposits are in Venezuela, Colombia, Russia, and the U.S. state of Utah.

About 20% of Alberta's tar sand is close enough to the surface to be strip-mined, but removing it has a huge environmental impact. Before the mining takes place, the boreal forest (an important habitat for migratory birds and other wildlife) is clear-cut, its wetlands are drained, and its rivers and streams are diverted. Next the overburden of sandy soil, rocks, peat, and clay is stripped away to expose tar sand deposits. Then five-story-high electric 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, crude oil suitable for refining.

Producing synthetic oil from tar sand has a massive environmental impact. For every barrel of synthetic crude oil produced from tar sands, developers remove an amount of overburden roughly equal to the weight of an African elephant. As a result, more earth is being removed in Canada's Athabasca Valley than anywhere else in the world. The process creates open mining pits large enough to be seen in satellite images. It also produces a great deal of air pollution; much of the mining region's air is filled with dust, steam, smoke, gas fumes, and a tarry stench. According to a 2009 study by Cambridge Energy Research Associates, the entire process also releases up to 15% more CO_2 per barrel of the product than is released in the production of conventional crude oil.

In addition, the process uses large amounts of water and creates lake-size tailing ponds of polluted toxic sludge and wastewater. Each year, many migrating birds die trying to get water and food from the ponds. And the dikes of compacted sand surrounding the tailings ponds could leak and release large volumes of toxic sludge onto nearby land and into the Athabasca River.

In addition to its high environmental impact, this way of producing oil takes a great deal of energy—mostly by burning natural gas and using diesel fuel to run the massive machinery—and therefore has a low net energy yield. In other words, producing synthetic oil from tar sands is one of the world's least efficient, dirtiest, and most environmentally harmful processes. In 2008, the United States imported about 19% of its oil from Canada, about half of it produced from tar sands.

Oily rocks are another potential supply of heavy oil. Such rocks, called *oil shales* (Figure 13-6, 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 13-6, 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 mostly in government-owned land in the U.S. states of Colorado, Wyoming, and Utah in an area known as the Green River formation. 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 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 crude oil.

U.S. Department of Energy

Figure 13-6 Oil shale rock (left) and the shale oil (right) extracted from it. 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
Moderate cost (tar sand)	High cost (oil shale)
Large potential supplies, especially tar sands in Canada	Low net energy yield
Easily transported within and between countries	Environmental costs not included in market price
Efficient distribution system in place	Large amounts of water needed for processing
Technology well-developed (tar sand)	Severe land disruption
	Severe water pollution
	Air pollution and CO_2 emissions when produced and burned

Figure 13-7 Advantages and disadvantages of using heavy oils from tar sand and oil shale as energy resources (**Concept 13-2**). **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

So why should we ever worry about running out of oil? The problem is that most of these 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. So its net energy is low, even lower than that of synthetic oil from tar sands. And it takes a lot of water to produce shale oil. The massive U.S. deposits are mostly in arid areas of the West, where water is in short supply and likely to become even scarcer because of intense and prolonged drought projected for this area throughout most of this century. Most of this water would have to come from the already overtapped Colorado River system (Chapter 11 Core Case Study, p. 238). 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 13-7 lists the advantages and disadvantages of using heavy oil from tar sand and oil shale as energy resources.

THINKING ABOUT
Heavy Oils

Do the advantages of relying on heavy oils from tar sand and oil shale outweigh their disadvantages? Explain.

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 and butane. This versatile fuel can be burned to heat space and water, to produce electricity, and to propel vehicles.

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. This adds climate-changing CO_2 to the atmosphere without providing any useful energy.

When a natural gas field is tapped, propane and butane gases are liquefied 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.

Russia has about 25% of the world's proven natural gas reserves, followed by Iran (16%) and Qatar (14%). The United States has only 3.3% of the world's proven natural gas reserves (see Figure 2, p. S39, in Supplement 9) but uses about 27% of the world's annual production. The United States imports about 16% of its natural gas, mostly from Canada. Japan, South Korea, and many European nations import most of their natural gas from Russia.

As with any fossil fuel, burning natural gas releases carbon dioxide into the atmosphere. However, it releases much less CO_2 per unit of energy than does producing and burning coal, crude oil, or synthetic crude oil from tar sand and oil shale.

So that it can be transported across oceans, natural gas is converted to **liquefied natural gas** (**LNG**) at a very low temperature and high pressure. This highly flammable liquid is then put aboard refrigerated tanker ships. After arriving at its destination, it is heated and converted back to the gaseous state at regasification plants before it is 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 process it and deliver it to users.

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. Known reserves in the United States used at current rates would last 82–118 years.

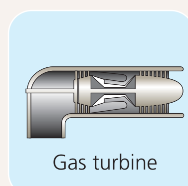
Figure 13-8 lists the advantages and disadvantages of using conventional natural gas as an energy resource.

Trade-Offs

Conventional Natural Gas

Advantages

- Ample supplies
- High net energy yield
- Low cost
- Less air pollution than other fossil fuels
- Lower CO_2 emissions than other fossil fuels
- Easily transported by pipeline
- Low land use
- Good fuel for fuel cells, gas turbines, and motor vehicles



Disadvantages

- Nonrenewable resource
- Releases CO_2 when burned
- Government subsidies
- Environmental costs not included in market price
- Methane (a greenhouse gas) can leak from pipelines
- Difficult to transfer from one country to another
- Can be shipped across ocean only as highly explosive LNG

Figure 13-8 Advantages and disadvantages of using conventional natural gas as an energy resource. **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

For example, it can be used to fuel vehicles. The vehicles just need fairly inexpensive engine modifications, but the major problem is that there are not many natural gas fueling stations.

Because of its advantages over oil, coal, and nuclear energy, some analysts see conventional natural gas (but not LNG) as a temporary fuel to help us make the transition to a more sustainable energy future. Such a future could be based on improved energy efficiency and greater reliance on a mix of noncarbon renewable energy resources, as we discuss farther on in this chapter.

We also have access to *unconventional natural gas* such as *coal bed methane gas* found in coal beds near the earth's surface across parts of the United States and Canada (most yellow areas in Figure 2, p. S39, in Supplement 9). But the environmental impacts of producing it—scarring of land and air and water pollution—are causing a public backlash against using this energy source in parts of the United States.

Another unconventional source is *methane hydrate*—methane trapped in icy, cage-like structures of water molecules. They are buried in some areas of tundra under arctic permafrost, in places such as Alaska and Siberia, and deep beneath the ocean bottom. 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 projected climate change.

Coal Is a Plentiful but Dirty Fuel

Coal—the rock that burns—was formed in several stages out of the remains of land plants that were buried 300–400 million years ago and exposed to intense heat and pressure over millions of years (Figure 13-9).

Coal is burned in power plants (Figure 13-10, p. 306) to generate about 40% of the world's electricity, 50% of the electricity used in the United States, and 70% of that in China. It is also burned in industrial plants to make iron, steel, and other products. In order, the three largest coal-burning countries are China, the United States, and India.

Coal is the world's most abundant fossil fuel. 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. The United States—the Saudi Arabia of coal—has 27% of the world's proven coal reserves (see Figure 2, p. S39, in Supplement 9). Russia has 17%, followed by China with 13%, India (10%), and Australia (9%). These five countries have 76% of the world's coal.

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 put that estimate at 100 years.

Without expensive pollution control devices, burning coal severely pollutes the air (see Photo 1 in the Detailed Contents). Coal is mostly carbon but contains small amounts of sulfur, which are released into the air as sulfur dioxide (SO_2) when the coal burns. Burning coal also releases large amounts of particulates (soot). In the United States, fine-particle pollution from coal-burning power plants prematurely kills more than 24,000 people a year, or 66 people every day, according to a 2004 study by the Clean Air Task Force. Most of these people have asthma or some other illness and their respiratory systems are greatly stressed by SO_2 and particulate pollutants.

Coal burning power and industrial plants are among the heaviest emitters of the greenhouse gas CO_2 (Figure 13-11, p. 306). 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. Each year, the CO_2 emissions from all U.S. coal-fired power plants are greater than the total CO_2 emissions from all of the country's passenger vehicles.

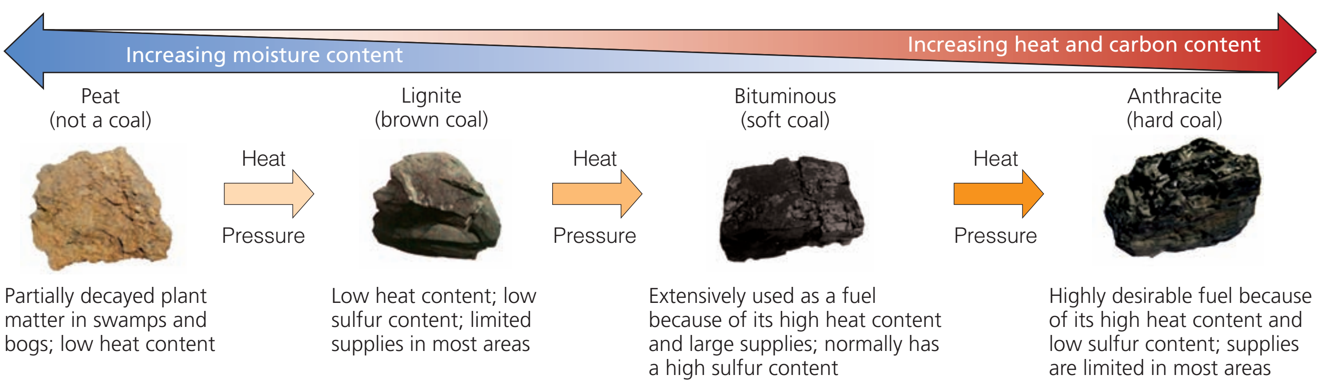


Figure 13-9 Stages in coal formation over millions of years. Peat is a soil material made of moist, partially decomposed organic matter and is not classified as a coal, although it too is used as a fuel. The different major types of coal vary in the amounts of heat, carbon dioxide, and sulfur dioxide released per unit of mass when they are burned.

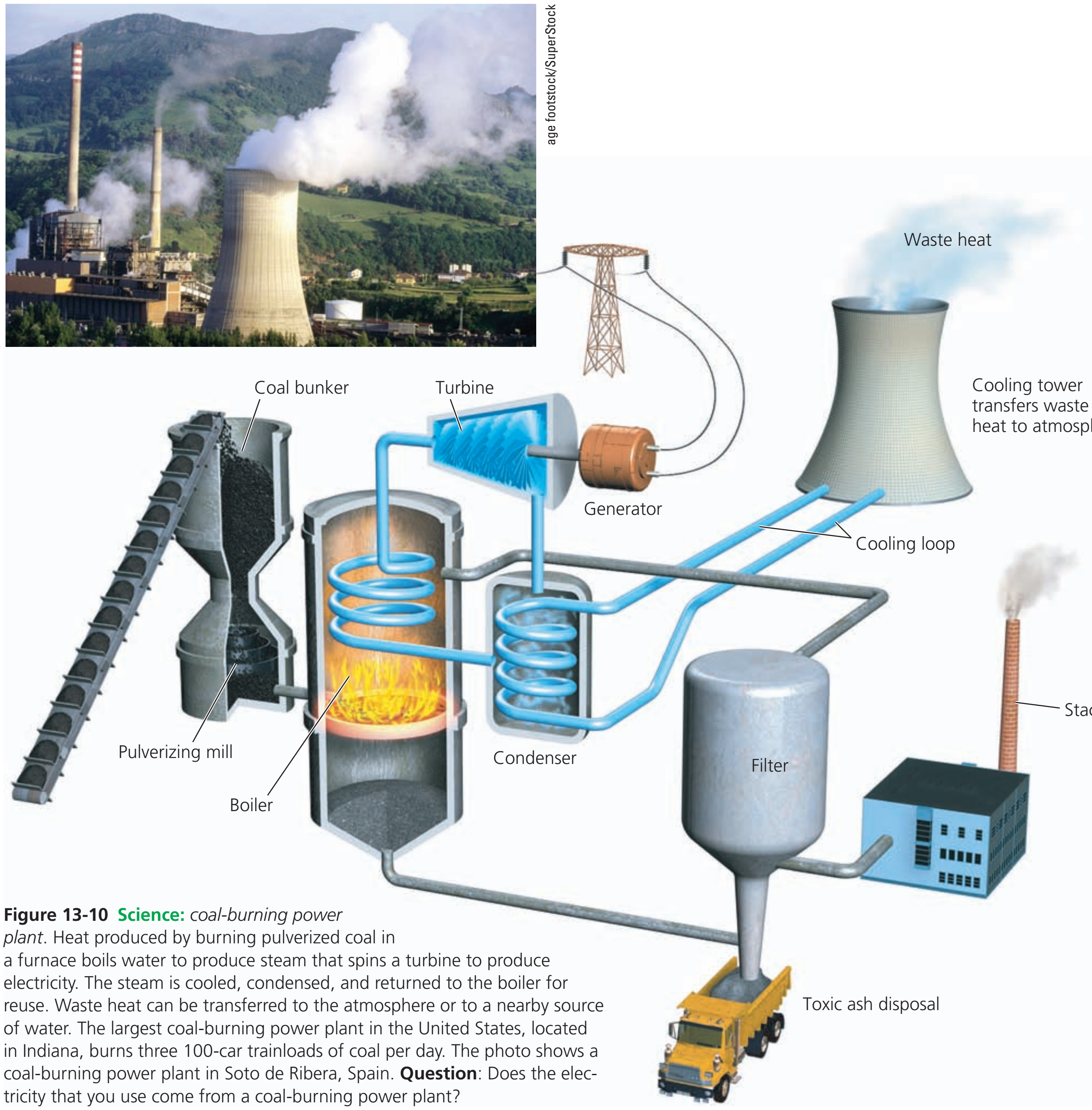


Figure 13-10 **Science:** *coal-burning power plant*. Heat produced by burning pulverized coal in a furnace boils water to produce steam that spins a turbine to produce electricity. The steam is cooled, condensed, and returned to the boiler for reuse. Waste heat can be transferred to the atmosphere or 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. 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?

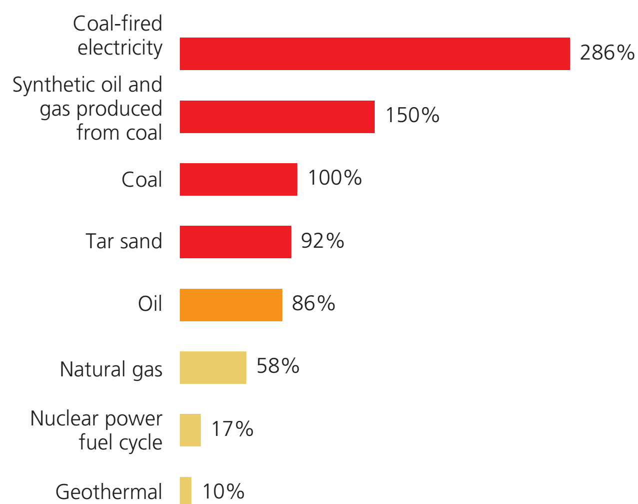


Figure 13-11 CO_2 emissions per unit of electrical energy produced for various energy resources, expressed as percentages of emissions released by burning coal directly. These emissions can enhance the earth's natural greenhouse effect (Figure 3-3, p. 41) and promote climate change. **Question**: Which 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)

Another problem is that burning coal emits trace amounts of toxic and indestructible mercury and radioactive materials. Indeed, a coal-burning power plant releases much more radioactivity into the atmosphere than does a nuclear power plant with the same energy output. And burning coal is responsible for roughly a third of the toxic mercury emitted into the atmosphere, according to a 2009 report by the United Nations Environment Programme. Finally, burning coal produces a highly toxic ash that must be safely stored, essentially forever. (See the following Case Study.)

The use of coal is growing, especially in China, which has relied on coal to help fuel its rapid economic growth. In 2009, on average, China was building the equivalent of one large coal-fired power plant every week. Mostly because it burns so much coal, 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 causing 650,000 to 700,000 premature deaths a year there.

However, since 2008, China leads the world in building more efficient (44%) coal-burning power plants at a rate of one per month. And the Chinese government requires power companies to retire an older, less efficient and more polluting power plant for each new one that they build.

Figure 13-12 lists the advantages and disadvantages of using coal as an energy resource. *Bottom line*: Coal is plentiful and cheap (as long as its harmful environmental costs are not included in its market price). But mining and burning coal have severe impacts on the earth's air, water, land, climate, and human health.

CASE STUDY

The Growing 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, as does nuclear power (discussed later in this chapter).

Burning coal 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 ash produced by coal-fired power plants in the United States would fill enough rail cars to make a train that would be over 13,800 kilometers (8,600 miles) long—more than three times the distance between New York City and Los Angeles, California.

Some of this ash is sold and blended into cement and concrete, used as a base for paving roads, or converted into wallboard for use in homes and offices. But almost 60% of it is either buried, sometimes in active or abandoned mines, or made into a wet slurry that is stored in holding ponds. From the ponds, it can slowly leach into groundwater or break through its earthen dam and severely pollute nearby rivers, groundwater, and towns. Currently, the EPA has no regulations for classifying

Trade-Offs

Coal

Advantages	Disadvantages
Ample supplies (225–900 years)	Severe land disturbance, air pollution, and water pollution
High net energy yield	Severe threat to human health when burned
Low cost	Environmental costs not included in market price
Well-developed technology	Large government subsidies
Air pollution can be reduced with improved technology	High CO_2 emissions when produced and burned
	Radioactive particle and toxic mercury emissions

Figure 13-12 Advantages and disadvantages of using coal as an energy resource. **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

and storing coal ash as a hazardous waste. Wet storage of this waste is cheap and the U.S. government does not regulate the roughly 300 existing storage ponds.

The hazards of unregulated coal ash storage became clear on December 22, 2008, when a rupture occurred in one wall of a coal ash storage pond not too far from Knoxville, Tennessee (USA). The pond released a volume of coal ash sludge that would fill 1,600 Olympic-size swimming pools. The area flooded by this toxic sludge was larger than the combined areas of 300 football fields. The wall of brown and toxic muck—acting like a sludge tsunami—destroyed or damaged 40 homes and other buildings, tainted waterways and soil with arsenic and other toxic chemicals, and disrupted the lives of everyone in a nearby rural community.

This is not the first time that such a spill has happened. In 2007, the EPA determined that toxic metals and other harmful chemicals in coal ash have contaminated groundwater used by 63 communities in 26 U.S. states. A 2009 study of coal ash ponds by the Environmental Integrity Project (EIP) recommended phasing out all wet storage of toxic coal ash. It called for classifying coal ash as a hazardous waste and for immediate inspection, monitoring, and federal regulation of all existing and planned storage sites.

For years, coal companies have successfully opposed such regulations. They argue that it would raise the price of electricity generated by their plants and make coal less competitive with other cleaner energy alternatives. Environmental scientists and economists agree that the costs of burning coal would rise, but they point out that regulation would promote more free-market competition among various energy alternatives and reduce the harmful environmental impacts of coal use.

The Clean Coal Campaign

The U.S. coal industry is rich and politically powerful. And for decades it has understandably fought to preserve its profits by opposing measures such as stricter air pollution standards for coal-burning plants and classifying coal ash as a hazardous waste. During the past 2 decades, it has also led the fight against classifying climate-changing CO_2 as a pollutant.

Since 2008, the U.S. coal industry has funded a $40 million publicity campaign built around the misleading phrase "clean coal." In reality there is no such thing as clean coal. Saying that coal can be clean is like saying that pollution can be good for you.

Some types of coal burn more cleanly than others, and coal can be burned more cleanly than it typically is now. But no matter how it is burned, mining the coal will always involve destroying mountaintops or other ecosystems and polluting water and air. Burning it will always involve some CO_2 emissions and will always create toxic coal ash sludge, and dangerous sludge ponds will only grow in number and volume.

Another element of the clean coal campaign is promotion of technologies for capturing and storing CO_2 emitted by power plants. We explore these proposed options in Chapter 15, but it is important to know that any CO_2 storage plan would have to include foolproof ways to store the CO_2 forever. If even small portions of the huge volume of CO_2 that would have to be stored ever leaked out, it would rapidly accelerate projected climate change. Therefore many environmental scientists argue that this plan is very likely not workable and cannot be relied upon as a way to make coal a cleaner fuel.

At any rate, shifting to so-called cleaner coal will significantly raise the price of coal-fired electricity. Coal is a relatively cheap fuel, but only as long as its high environmental costs are not included in the market prices for the electricity it produces. According to 2007 estimates by the U.S. Energy Administration and the Worldwatch Society, when such costs are added, burning coal becomes the second most expensive way to produce electricity after solar cells. And this does not include higher costs of regulating coal ash (Case Study, p. 307).

More important, these estimates do not include the much higher costs of capturing and storing CO_2. In 2008, FBR Capital Markets estimated that removing and storing CO_2 from coal plant emissions would more than double the price of electricity from coal-fired power plants, which would make it too expensive to use, compared to most other alternatives. This is the key reason why, for almost 2 decades, the U.S. coal and utility industries have not built a single demonstration plant to test this technology.

For these reasons, many environmental scientists argue strongly that mining and burning coal is and probably always will be the dirtiest way to produce electricity.

HOW WOULD YOU VOTE?

Should using coal to produce electricity be phased out over the next 30–40 years? Cast your vote online at **www.cengage.com/biology/miller**.

We Can Convert Coal into Gaseous and Liquid Fuels

Solid coal can be converted into **synthetic natural gas** (**SNG**) by a process called *coal gasification*, which removes sulfur and most other impurities from coal. It is also converted into liquid fuels such as methanol and synthetic gasoline through a process called *coal liquefaction*. These fuels, called *synfuels*, are often referred to as cleaner versions of coal. But compared to burning coal directly, producing synfuels requires mining 50% more coal. And producing and burning them could add 50% more carbon dioxide to the atmosphere (Figure 13-11). As a result, synfuels have a low net energy yield and cost more to produce per unit of energy than producing coal costs.

Trade-Offs

Synthetic Fuels

Advantages

Large potential supply

Vehicle fuel

Moderate cost

Lower air pollution than coal when burned

Disadvantages

Low to moderate net energy yield

Higher cost than coal

Requires mining 50% more coal

Environmental costs not included in market price

High environmental impact

Large government subsidies

High water use

Higher CO_2 emissions than coal

Figure 13-13 Advantages and disadvantages of using synthetic natural gas (SNG) and liquid synfuels produced from coal (**Concept 13-2**). **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

Also, it takes large amounts of water to produce synfuels. In other words, ramping up use of these fuels would worsen two of the world's major environmental problems: projected climate change caused by CO_2 emissions and increasing water shortages in many parts of the world (Figure 11-5, p. 242, and Figure 11-6, p. 243).

Figure 13-13 lists the advantages and disadvantages of using liquid and gaseous synfuels produced from coal (**Concept 13-2**). Like energy from tar sands, oil shales, and LNG, synfuels from coal are running up against environmental limits and low net energy yields automatically imposed by the first and second laws of thermodynamics (p. 35).

13-3 What Are the Advantages and Disadvantages of Nuclear Energy?

CONCEPT 13-3 The nuclear power fuel cycle has a low environmental impact and a very low accident risk, but its use has been limited because of high costs, a low net energy yield, long-lived radioactive wastes, vulnerability to sabotage, and the potential for spreading nuclear weapons technology.

How Does a Nuclear Fission Reactor Work?

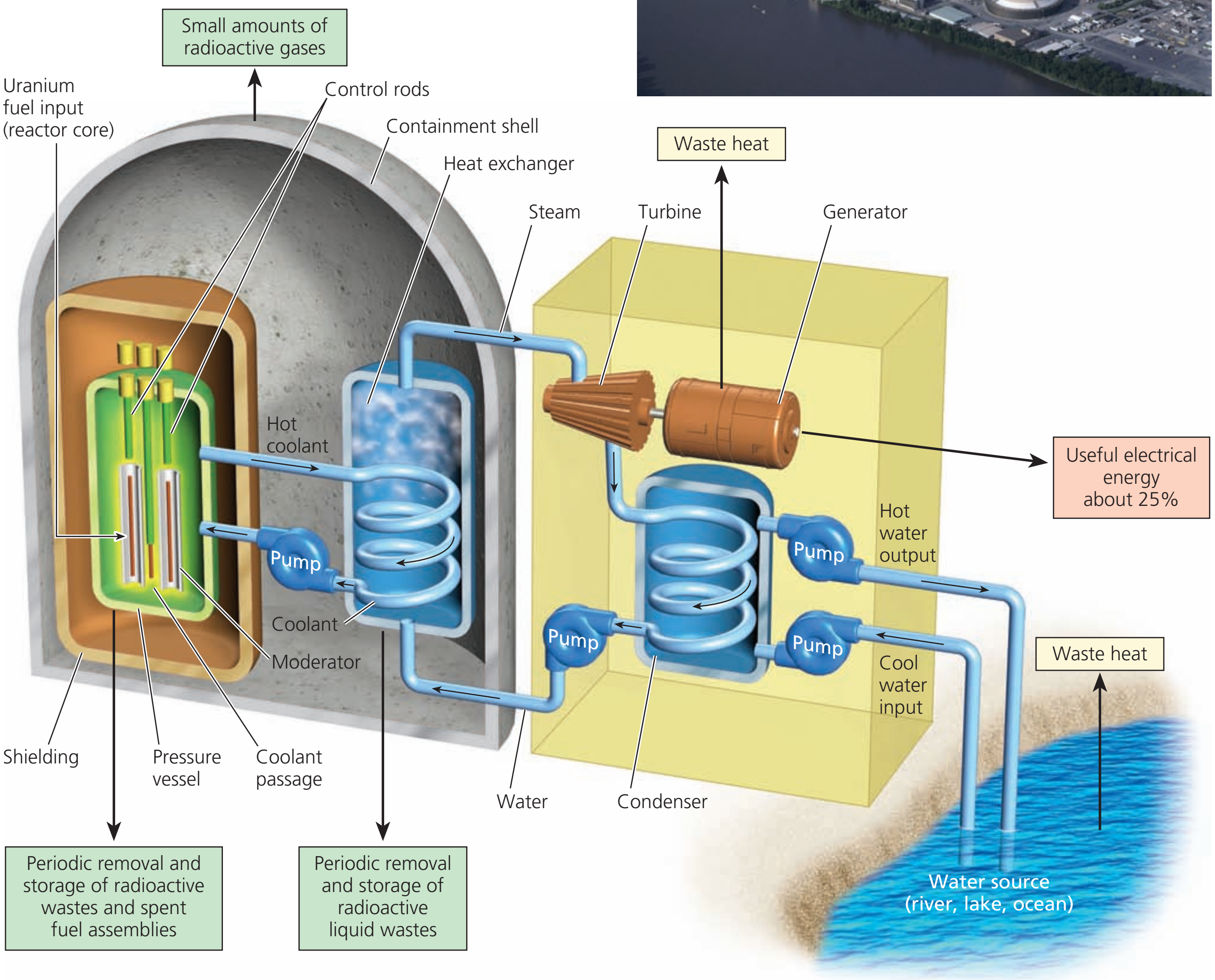
To evaluate the advantages and disadvantages of nuclear power, we must know how a nuclear power plant and its accompanying nuclear fuel cycle work. A nuclear power plant is a highly complex and costly system designed to perform a relatively simple task: to boil water to produce steam that spins a turbine and generates electricity.

What makes it complex is the use of a controlled nuclear fission reaction (Figure 2-6, center, p. 33) to provide the heat. The fission reaction takes place in a *reactor*. The most common reactors, called *light-water reactors* (LWRs, see Figure 13-14, p. 310), produce 85% of the world's nuclear-generated electricity (100% in the United States).

LWRs are highly inefficient, losing about 75% of the energy available in their nuclear fuel as waste heat to the environment, just in generating electricity. Before

Figure 13-14 Science: light-water-moderated and -cooled nuclear power plant with a pressurized water reactor. Some nuclear plants withdraw water for cooling from a nearby source of water and return the heated water to that source, as shown here. Other nuclear plants that do not have access to a source of cooling water transfer the waste heat 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). A serious accident there in 1979 almost caused a meltdown of the plant's reactor. **Question**: How does this plant differ from the coal-burning plant in Figure 13-10?

Robert Llewellyn/SuperStock



that point, 9% of the energy content of the fuel is lost when the 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.

The fuel for a reactor is made from uranium ore mined from the earth's crust. After it is mined, uranium ore must be enriched to increase the concentration of its fissionable uranium-235 by anywhere from 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, which keeps fuel rods and other materials from melting and releasing massive amounts of radioactivity into the environment. An LWR includes an emergency

U.S. Department of Energy/Nuclear Regulatory Commission

U.S. Department of Energy/Nuclear Regulatory Commission

Figure 13-15 **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). After they have cooled considerably, some fuel rods are stored upright on concrete pads (right) in dry-storage containers made of steel or concrete. **Questions**: Do you think these are safe storage methods? Why or why not?

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 core within the reactor. It also protects the core from some external threats such as tornadoes and plane crashes. This gives you an idea of why such plants cost so much to build—about $12 billion for a typical plant—and this cost is rising rapidly.

When reactors are shut down and refueled about once a year, intensely hot and radioactive spent fuel rod assemblies are removed and stored outside of the nuclear reactor building in *water-filled pools* (Figure 13-15, left) or in *dry casks* (Figure 13-15, right). These intensely radioactive materials must be stored safely for thousands of years, as we discuss later.

The overlapping and multiple safety features of a modern nuclear reactor greatly reduce the chance of a serious nuclear accident. They also make it very expensive to build and maintain a nuclear power plant and to take it apart and safely store its intensely radioactive materials when its useful life is over.

What Is the Nuclear Fuel Cycle?

A nuclear power plant is only one part of the **nuclear fuel cycle** (Figure 13-16, p. 312), 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 for thousands of years until their radioactivity falls to safe levels.

The final step in the cycle occurs when, after 15–60 years, a reactor comes to the end of its useful life, mostly because of corrosion and radiation damage to its metal parts, and must be retired. It cannot simply be shut down and abandoned, because its structure contains large quantities of intensely radioactive materials that must be kept out of the environment 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 13-1B**). 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 operations.

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 2008, 439 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 4, p. S41, in Supplement 9 shows the trend in electricity production by nuclear power plants in the

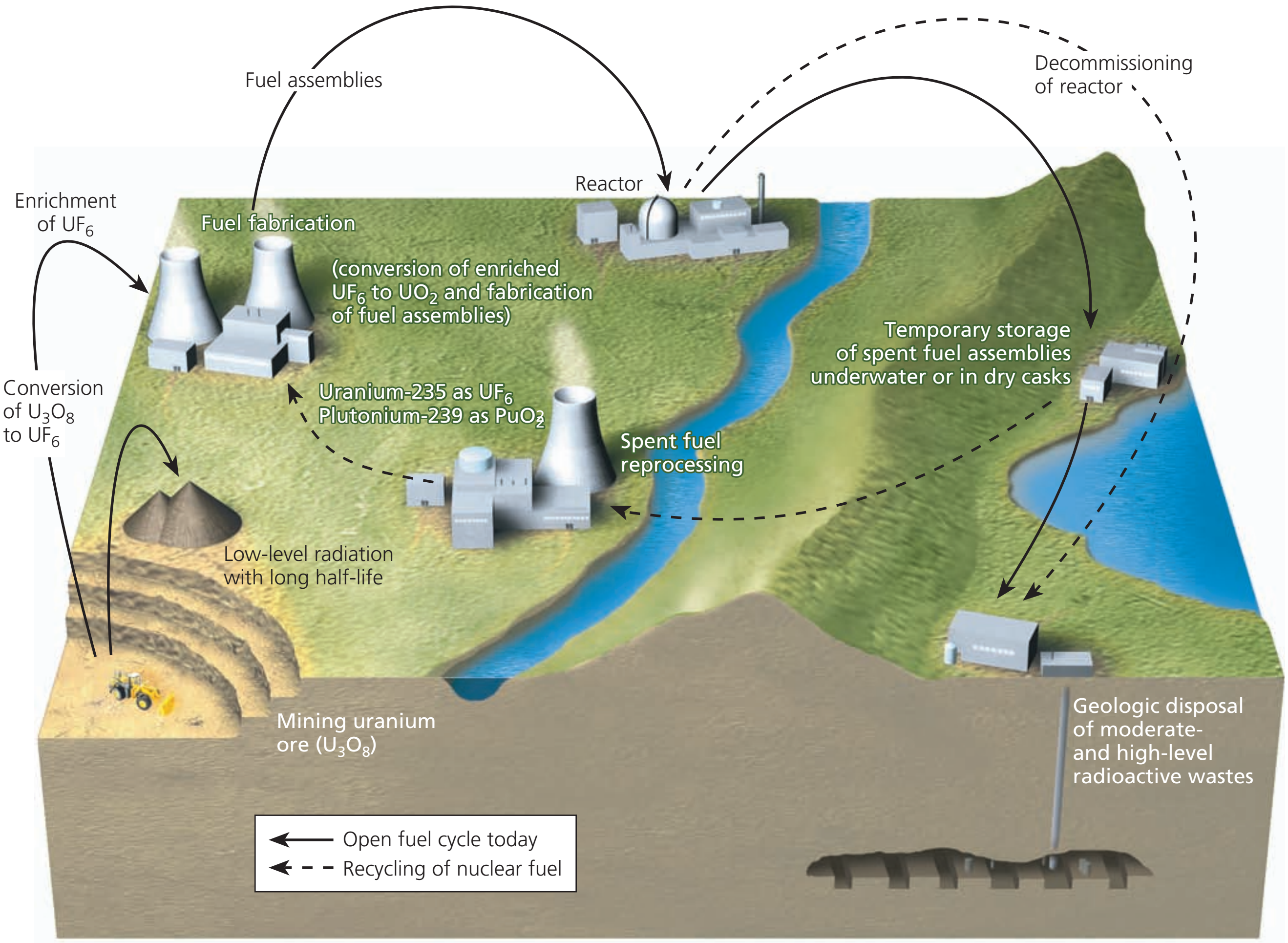


Figure 13-16 **Science:** *the nuclear fuel cycle.* As long as a reactor is operating safely, the power plant itself has a fairly low environmental impact and a very low risk of an accident. But considering the whole nuclear fuel cycle, costs are high, radioactive wastes must be stored safely for thousands 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 material for nuclear weapons (**Concept 13-3**). Also, an amount of energy equal to about 92% of the energy content of the nuclear fuel is wasted in the nuclear fuel cycle. **Question**: Do you think the market price of nuclear-generated electricity should include all the costs of the fuel cycle or should governments pay much of these costs as they do now? Explain.

United States between 1960 and 2008. In 2008, 104 licensed commercial nuclear power reactors in 31 states generated about 8% of the country's overall energy and 19% of its electricity. This percentage is expected to decline over the next 2–3 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 payments by taxpayers, this industry would not exist in the United States. And 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 developed countries is extremely low. However, explosions and partial or complete meltdowns are possible, as we learned from the accidents in 1979 at the Three Mile Island nuclear plant in the U.S. state of Pennsylvania (see photo in Figure 13-14) and in 1986 at the Chernobyl nuclear plant in Ukraine (see the following Case Study).

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 reactors in a nuclear power plant in Ukraine (then part of the Soviet Union) blew the massive roof off a reactor building. The reactor partially melted down and its graphite moderator 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 eventually encircled the planet.

According to U.N. studies, the Chernobyl disaster was caused by poor reactor design (not used in the United States or in most other parts of the world) and by human error, and it had serious consequences. By 2005, 56 people had died prematurely from exposure to radiation released by the accident. The estimated numbers of long-term deaths from the accident range from 9,000, by World Health Organization estimates, to 212,000 as estimated by the Russian Academy of Medical Sciences. Because of poor record keeping and inadequate medical tracking, we probably will never know the actual death toll.

After the accident, some 350,000 people had to abandon their homes because of contamination by radioactive fallout. In addition to fears 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 incidences of thyroid cancer, leukemia, and immune system abnormalities in children exposed to Chernobyl's radioactive fallout.

Chernobyl taught us a hard lesson: A major nuclear accident anywhere has effects that reverberate throughout much of the world. One more major nuclear power accident anywhere in the world could have a devastating impact on the future of nuclear power.

CENGAGENOW™ Watch how winds carried radioactive fallout around the world after the Chernobyl meltdown at CengageNOW.

Conventional Nuclear Power Has Advantages and Disadvantages

Figure 13-17 lists the major advantages and disadvantages of nuclear power (**Concept 13-3**). In particular, using nuclear power to produce electricity has some important advantages over coal-burning power plants (Figure 13-18, p. 314).

Let us examine some of the challenges involved in using nuclear power.

Stored Spent Radioactive Fuel Rods Are Vulnerable to Terrorist Acts

Very hot and highly radioactive spent fuel rods produced by nuclear power plants are typically cooled in pools of water at nuclear power plant sites (Figure 13-15, left). After 5 years of such cooling, they can be transferred to

Trade-Offs

Conventional Nuclear Fuel Cycle

Advantages	Disadvantages
Large fuel supply	Cannot compete economically without huge government subsidies
Low environmental impact (without accidents)	Low net energy yield
Emits 1/6 as much CO_2 as coal	High environmental impact (with major accidents)
Moderate land disruption and water pollution (without accidents)	Environmental costs not included in market price
Moderate land use	Risk of catastrophic accidents
Low risk of accidents because of multiple safety systems (except for Chernobyl-type reactors)	No widely acceptable solution for long-term storage of radioactive wastes
	Subject to terrorist attacks
	Spreads knowledge and technology for building nuclear weapons

Figure 13-17 Advantages and disadvantages of using the nuclear power fuel cycle (Figure 13-16) to produce electricity (**Concept 13-3**). **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

Trade-Offs

Coal vs. Nuclear

Coal	Nuclear
Ample supply	Ample supply of uranium
High net energy yield	Low net energy yield
Very high air pollution	Low air pollution
High CO_2 emissions	Lower CO_2 emissions
High land disruption from surface mining	Much lower land disruption from surface mining
High land use	Moderate land use
Low cost (with huge subsidies)	High cost (even with huge subsidies)

Figure 13-18 Comparison of the risks of using nuclear power 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 next door to a coal-fired power plant or a nuclear power plant? Explain.

sealed dry casks made of heat-resistant metal alloys and concrete (Figure 13-15, right).

A 2005 study by the U.S. National Academy of Sciences warned that storage pools and dry casks at 68 nuclear power plants in 31 U.S. states are especially vulnerable to sabotage or terrorist attack. A spent-fuel pool typically holds 5–10 times more long-lived radioactivity than the radioactive core inside a plant's reactor. These pools and casks are usually located outside of reactor buildings and thus are not protected as well as the reactor core 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 U.S. population—live within 121 kilometers (75 miles) of an aboveground spent-fuel storage site. For some time, critics have been calling for the immediate construction of much more secure structures to protect spent-fuel storage pools and casks. But this would add to the already very high cost of electricity produced by nuclear power and has not been done.

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? Why do you think this has not been done?

CONNECTIONS
Nuclear Power Plants and the Spread of Nuclear Weapons

The United States and 14 other countries have been selling nuclear reactors and uranium fuel enrichment technology in the international marketplace for decades. Much of this information and equipment can be used to produce 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 the knowledge and ability to build them. Some see this as the single most important reason for not expanding the use of nuclear power.

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 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 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 a way to protect ourselves and hundreds of generations to come from the intensely radioactive wastes that have already been produced. This underscores the principle that we should not commit ourselves to any technology that produces harmful wastes that must be safely stored essentially forever. But we have violated that principle and are stuck with the incredibly long-term consequences.

Most scientists and engineers agree in principle that deep burial is the safest and cheapest way to store high-level radioactive waste. However, after almost 60 years of research and evaluation, no country has built such a repository. And some scientists contend that it is not possible to show that any method will work for thousands of years (Case Study, at right).

Spent fuel rods could be processed to remove radioactive plutonium. This would reduce the storage time for radioactive wastes from up to 240,000 to about 10,000 years. But this is costly and produces plutonium, which could be used by countries or terrorists to make nuclear weapons. This is the main reason for why, after spending billions of dollars, the United States abandoned this approach in 1977.

Some analysts have suggested shooting our intensely radioactive wastes into space or into the sun. But 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
Dealing with 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 2009, 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. The total projected cost of the repository is at least $96 billion, which would add more to the high cost of the nuclear power fuel cycle.

Critics charge that the selection of the earthquake-prone Yucca Mountain site was based more on political convenience than on scientific suitability. Some scientists have 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. This could carry radioactive wastes leaking from corroded containers into groundwater, irrigation systems, and drinking water wells, and contaminate them for thousands of years. In 1998, Jerry Szymanski, formerly the DOE's top geologist at Yucca Mountain and now an outspoken opponent of the site, said that if water flooded the site, it could cause an explosion so large that "Chernobyl would be small potatoes."

Opponents also contend that the Yucca Mountain waste site should not be opened because it could decrease national security. The plan calls for wastes to be put into specially designed casks and shipped by truck or rail cars to the Nevada site. This would require about 19,600 shipments of wastes from nuclear power plants across much of the country over an estimated period of 38 years before the site is filled. At the end of this period, the amount of newly collected radioactive waste stored at nuclear power plant sites would be about enough to fill another such repository. Critics contend that it would be much more difficult and costly to protect such a large number of shipments from terrorist attacks than to provide more secure ways to store such wastes in dry casks at nuclear power plant sites or other regional sites.

In 2009, the administration of President Barack Obama agreed with such criticisms. Its proposed budget would essentially cut off funding for the Yucca Mountain project while the administration evaluates other shorter-term alternatives.

Bottom line: After almost 60 years of research, there is no consensus on how to store growing amounts of radioactive wastes safely for thousands of years.

HOW WOULD YOU VOTE? ✓

Should highly radioactive spent fuel be stored in casks at high-security regional sites or near nuclear power plants instead of being shipped to a single site for underground burial? Cast your vote online at **www.cengage.com/biology/miller**.

What Do We Do with Worn-out Nuclear Power Plants?

Scientists have proposed three ways to deal with worn-out nuclear power plants. One strategy is to dismantle the plant after it closes and store its radioactive parts in a secure repository, which no country has built so far. 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 for thousands of years.

A third option is to enclose the entire plant in a concrete and steel tomb. This is what was done with the Chernobyl reactor that exploded, but after a few years, the tomb began crumbling and leaking radioactive wastes. It is being rebuilt at great cost and is unlikely to last even several hundred years.

Regardless of the method chosen, retiring nuclear plants adds to the total costs of the nuclear power fuel cycle and reduces its already low net energy yield. Experience indicates that dismantling a plant and storing the resulting radioactive wastes costs 2–10 times more than building the plant in the first place.

At least 228 of the world's 439 large commercial reactors are scheduled for retirement by 2012. Of the 104 U.S. nuclear reactors, 20 are nearing retirement. However, under political pressure from the nuclear industry, since 2006, the Nuclear Regulatory Commission (NRC) has been extending the operating licenses from 40 years to 60 years for many U.S. plants. Opponents contend this could increase the risk of nuclear accidents in aging reactors.

Can Nuclear Power Lessen Dependence on Imported Oil and Help Slow Projected Climate Change?

Some proponents of nuclear power in the United States claim it will help reduce the country's dependence on imported crude oil. Other analysts argue that it will not, because only about 1.5% of the electricity used in the United States (and in most other countries) is generated by burning oil.

Nuclear power advocates also contend that increased use of nuclear power will reduce the threat of projected climate change by greatly reducing or eliminating emissions of CO_2. The nuclear power industry has mounted a false and misleading, but effective public relations campaign telling the public that nuclear power does not emit CO_2 and other greenhouse gases. Scientists point out that this argument is only partially correct. Nuclear plants themselves do not emit CO_2, but the nuclear fuel cycle does (Figure 13-11). Such emissions are much lower than those from coal-burning power plants. However, 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 13-11 indicate.

In 2007, a leading think tank, the Oxford Research Group, said that in order to play an effective role in slowing projected climate change, a new nuclear reactor would have to be built somewhere in the world every week for the next 70 years—an impossibility for logistical, political, and economic reasons. In addition, a new very costly repository like the abandoned Yucca Mountain site would have to be built every few years to store the resulting highly radioactive nuclear waste. Analysts contend that cutting energy waste and increasing the use of a variety of renewable noncarbon energy resources to produce electricity are much better, cheaper, and faster ways to reduce CO_2 emissions.

Are New Second-Generation Nuclear Reactors the Answer?

Partly to address economic and safety concerns, the U.S. nuclear industry has persuaded Congress to provide more government subsidies and guaranteed loans to help them build hundreds of smaller, second-generation plants using standardized designs. The industry claims these 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, cut nuclear wastes in half, and reduce the risk of proliferation of nuclear weapons. But much research needs to be done to test such claims.

To be acceptable, some analysts believe that any new generation nuclear reactor must satisfy five criteria: (1) it must be built so that a runaway chain reaction is impossible; (2) its fuel must be of the sort that cannot be used to make nuclear weapons; (3) its spent fuel must be easy to dispose of without burdening future generations with radioactive waste; (4) taking its entire fuel cycle into account, it must generate a higher net energy yield than other energy alternatives do and compete in the open marketplace without government subsidies, tax breaks, and loan guarantees; and (5) its entire fuel cycle must generate fewer greenhouse gas emissions than other energy alternatives. So far, no existing or proposed reactors even come close to meeting these requirements.

Will Nuclear Fusion Save Us?

Nuclear fusion is a nuclear change in which two isotopes of light elements, such as hydrogen, are forced together at extremely high temperatures until they fuse to form a heavier nucleus, releasing energy in the process (Figure 2-7, bottom, p. 34). Some scientists hope that controlled nuclear fusion will provide an almost limitless source of high-temperature heat and electricity.

With nuclear fusion, there would be no risk of meltdown or release of large amounts of radioactive materials from a terrorist attack, and little risk of additional proliferation of nuclear weapons, because bomb-grade materials are not required for fusion energy. Fusion power might also be used to destroy toxic wastes, supply electricity for ordinary use, and decompose water to produce hydrogen fuel, which holds promise as an energy source.

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 it uses.

In 2006, the United States, China, Russia, Japan, South Korea, and the European Union agreed to spend at least $12.8 billion in a joint effort to build a large-scale experimental nuclear fusion reactor by 2018 and to see if it can produce a net energy yield. But in 2008 the estimated cost of this project doubled. If everything goes well, the plant 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, it is unlikely that nuclear fusion will be an important energy source any time in the near future. Indeed, some skeptics joke that "nuclear fusion is the power of the future and always will be."

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 conventional fission reactor designs, along with nuclear fusion. Others would support expansion of nuclear power only when the five criteria listed at left are met. Some analysts call for phasing out all or most government subsidies, tax breaks, and insurance and loan guarantees for nuclear power.

According to World Bank economists and many investors, conventional and proposed second-generation nuclear power plants cannot compete in today's energy market unless they are shielded from open competition by government subsidies and tax breaks (as is the case in every country that has nuclear power plants). Basically, this stems from the fact that the net energy yield for the nuclear fuel cycle is very low.

This explains why most nuclear power development takes place in countries such as France, China, and Japan where central governments fund and control its development. Many governments like nuclear power because it gives them control over electricity production. This shields nuclear power producers from having to compete in the open marketplace with other cheaper alternatives. In France the government essentially controls, builds, and manages the nuclear reactors that supply 77% of the country's electricity. And annual polls show that up to 60% of the French public favor phasing out nuclear power. (See the Guest Essay by Amory Lovins on this subject at CengageNOW™.) It can also protect them from effective scrutiny by the general public.

Some governments also use nuclear power technology as a way to produce the plutonium and highly enriched uranium needed to make nuclear weapons. Except for the United States, Great Britain, and the former Soviet Union, every nation with nuclear weapons has produced them using civilian nuclear power technology.

In the United States, both the U.S. Congressional Budget Office and the private investment firm Standard and Poors warn that investing in loans to build new nuclear power plants is an unwise financial risk for private companies, unless the government is willing to guarantee the loans. In that case, taxpayers instead of investors would take the financial risks. To critics such as energy expert Amory Lovins (**Core Case Study**), electricity from nuclear power touted in the 1950s as being "too cheap to meter" has now become "too expensive to matter." CORE CASE STUDY

To critics, the nuclear fuel cycle fails three crucial tests. First, it has a very low net energy yield and thus must be propped up financially by taxpayers. Second, it produces deadly wastes that must be safely stored for thousands of years. Third, it spreads technology that can be used to make nuclear weapons. The nuclear power industry downplays or disputes such claims.

These and other drawbacks explain why many analysts say it makes more sense to invest limited government funds in spurring the rapid development of improved energy efficiency and renewable energy resources that are much safer and can be developed more quickly. We turn now to look at these alternatives.

HOW WOULD YOU VOTE?

Should dependence on nuclear power be expanded or phased out in the country where you live? Cast your vote online at **www.cengage.com/biology/miller**.

13-4 Why Is Energy Efficiency an Important Energy Resource?

CONCEPT 13-4 The United States could save as much as 43% of all the energy it uses by improving the energy efficiency of industrial operations, motor vehicles, and buildings.

We Waste Huge Amounts of Energy

Many analysts urge us to increase our supply of energy and save money by wasting less energy. The best way to do this is to improve **energy efficiency**: the measure of how much work we can get from each unit of energy we use. Improving energy efficiency means using our brains and technology to do more and better work with less energy and money—a win–win solution.

You may be surprised to learn that roughly 84% of all commercial energy used in the United States is wasted (Figure 13-19, p. 318). About 41% of this energy is wasted unavoidably because of the degradation of energy quality imposed by the second law of thermodynamics (**Concept 2-3B**, p. 34). CONCEPT LINK

The other 43% is wasted unnecessarily, mostly due to the inefficiency of incandescent lights, furnaces, industrial motors, coal and nuclear power plants, most motor vehicles, and other devices. Another reason for this waste is that many people live and work in leaky, poorly insulated, badly designed buildings—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 buying gas-guzzling sport utility vehicles (SUVs), trucks, and minivans and moving from cities to larger and often energy-inefficient houses in far-flung suburbs, where they must depend on cars for getting around. Now, three of every four Americans commute to work, mostly in such large vehicles, and only 5% rely on more energy-efficient mass transit. As a result, two-thirds of the oil consumed in the United States is used for transportation, and 58% of this oil is imported. By contrast Japan, Germany, and France are two to three times more energy efficient than the United States is.

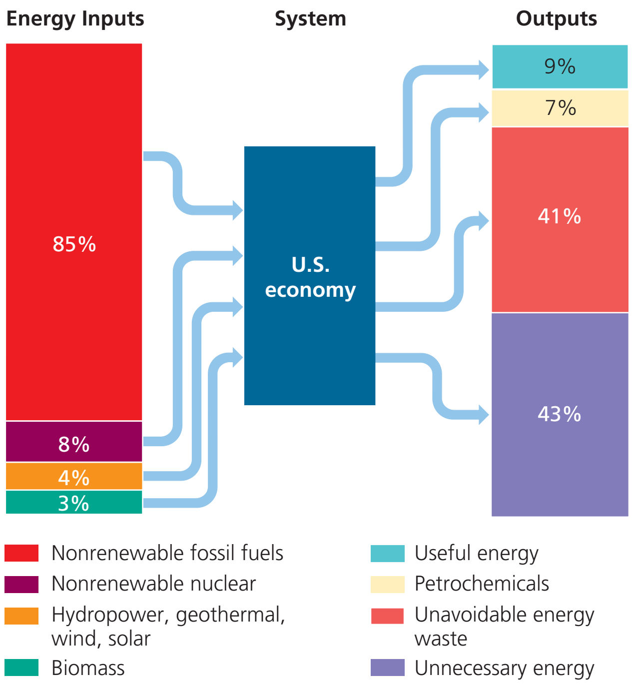


Figure 13-19 Flow of commercial energy through the U.S. economy. Only 16% of all commercial energy used in the United States ends up performing useful tasks or being converted to petrochemicals; the rest is unavoidably wasted because of the second law of thermodynamics (41%) or is wasted unnecessarily (43%). **Question**: What are two examples of unnecessary energy waste? (Data from U.S. Department of Energy, 2007)

Solutions

Reducing Energy Waste

- Prolongs fossil fuel supplies
- Reduces oil imports and improves energy security
- Very high net energy yield
- Low cost
- Reduces pollution and environmental degradation
- Buys time to phase in renewable energy
- Creates local jobs

Figure 13-20 Advantages of reducing unnecessary energy waste and thereby improving energy efficiency. Global improvements in energy efficiency could save the world an average of about $1.9 million per minute! **Questions**: Which two of these advantages do you think are the most important? Why?

Reducing energy waste has numerous economic and environmental advantages (Figure 13-20). To most energy analysts, *reducing energy waste is the quickest, cleanest, and usually the cheapest, way to provide more energy, reduce pollution and environmental degradation, and slow projected climate change.*

Four widely used devices waste large amounts of energy unnecessarily:

- An *incandescent light bulb* 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*.
- A motor vehicle with an *internal combustion engine* wastes about 80% of the energy in its fuel.
- A *nuclear power plant* (Figure 13-14), producing electricity for space heating or water heating, wastes about 75% of the energy in its nuclear fuel and probably 92% when we include the additional energy used in the nuclear fuel cycle.
- A *coal-fired power plant* (Figure 13-10) wastes about 66% of the energy released by burning coal to produce electricity and probably 75–80% if we include the energy needed to dig up the coal and transport it to the plant.

We can do much better than this. Energy experts call for us to use our scientific and engineering brainpower to replace these *energy-wasting dinosaurs* with more energy-efficient and less environmentally harmful alternatives over the next few decades. Perhaps you can play a role in making this important shift in how we get our energy.

In 2009, Amory Lovins (**Core Case Study**) CORE CASE STUDY estimated that investments in energy efficiency could save the United States "at least half of the oil and gas and three-quarters of the electricity it uses at one-eighth the cost the country is now paying for these forms of energy."

We Can Save Energy and Money in Industry

GOOD NEWS

Some industries save energy and money by using *cogeneration*, or *combined heat and power (CHP)*, systems. 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 plant or other nearby buildings, rather than released into the environment and wasted. The energy efficiency of these systems is as high as 80% (compared to 30–40% for coal-fired boilers and nuclear power plants).

Another way to save energy and money in industry is to *replace energy-wasting electric motors*, which consume 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.

A fourth way for industry to save energy is to *switch from low-efficiency incandescent lighting* to higher-efficiency fluorescent lighting and, in the near future, to even more efficient LED lighting.

There is also a great deal of waste in the transmission of electricity to industries and communities. Grid systems of high-voltage transmission lines carry electricity from power plants, wind turbines, and other electricity producers to these users. Some energy experts place top priority on converting and expanding the outdated U.S. electrical grid system into what they call a *smart grid*—an energy-efficient, digitally controlled, high-voltage grid that is responsive to local and regional changes in demand and supply (Connections, below).

Building more high-voltage transmission lines throughout the country is politically unpopular and will be vigorously opposed by some states and communities. For that reason, some analysts call for focusing on upgrading and making existing grid systems smarter, rather than building more lines. Also, some critics warn that expanding and upgrading the grid could actually increase the use of electricity produced by burning dirty coal, instead of enhancing the use of renewable energy. This could happen if the harmful environmental costs of using coal are not included in its market price.

CONNECTIONS

Saving Energy with a Smarter Electrical Grid

A super-efficient smarter electrical grid would be based on a two-way flow of energy and information between producers and users of electricity. Such a system would use meters to determine how much electricity users need and when they need it. And 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. Some of these features exist in some regional grid systems, but experts call for unifying national grids in this way.

Utility companies have wasted large amounts of energy by encouraging electricity use instead of efficiency. Since the 1980s, several state utility commissions in the United States have provided financial rewards to utilities for the kilowatts they save customers by improving their energy efficiency, instead of rewarding them for selling more and more kilowatts. Some analysts call for making this a national policy.

We Can Save Energy and Money in Transportation

Transportation accounts for two-thirds of U.S. oil consumption, and there is a lot of room for improvement to efficiency in transportation.

One reason for this inefficiency is that U.S. government fuel efficiency standards 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 vehicles decreased to about 9 kilometers per liter (kpl) (21 miles per gallon [mpg]) (see Figure 13-21, left, p. 320). 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 those for cars.

Fuel economy standards for new vehicles in Europe, Japan, China, and Canada are much higher than are those in the United States (Figure 13-21, right). A 2008 law raised U.S. CAFE standards to 15.1 kpl (35.5 mpg), to be attained by 2016–2020. But this will still be much lower than standards in many other countries are now. 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 2009, more than half of all U.S. consumers owned SUVs, pickup trucks, minivans, and other large, inefficient vehicles. And vehicles getting at least 15 kpl (35 mpg) accounted for less than 1% of all car and truck sales in the United States. Another reason for this is that most U.S. consumers do not realize that gasoline costs them much more than the price they pay at the pump. In 2005, according to a study by the International Center for Technology Assessment, hidden costs of gasoline for U.S. consumers were about $3.18 per liter ($12 per gallon), and such costs have risen since then.

These hidden costs include government subsidies 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 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 politically unpopular in the United States. But 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 influence elected representatives to keep gas taxes low, thereby keeping the true costs of gasoline hidden from consumers and preventing such a solution.

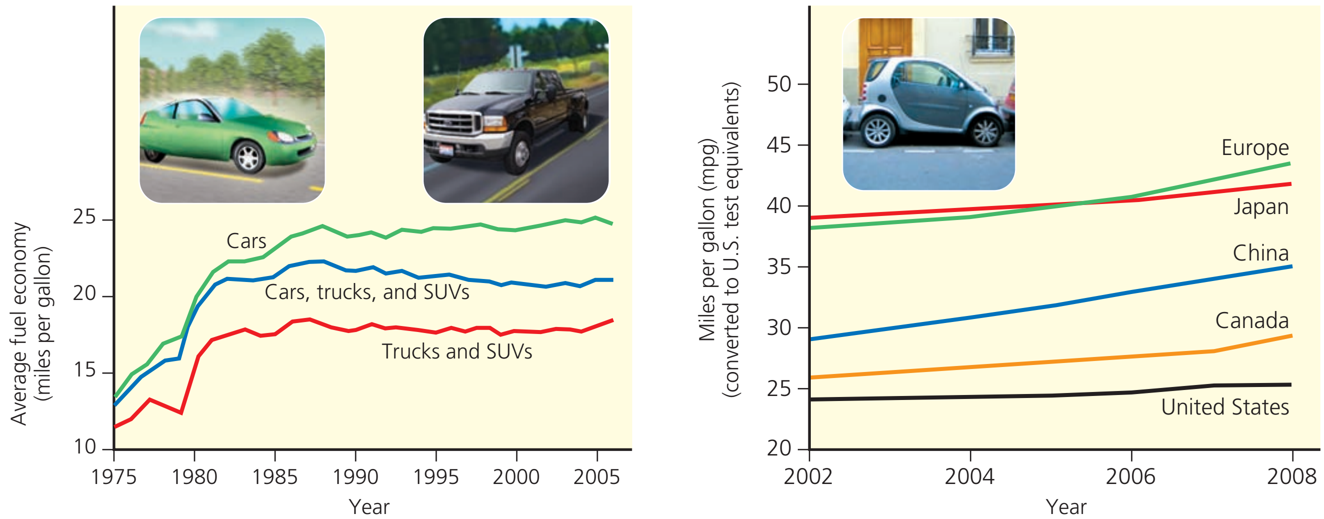


Figure 13-21 Average fuel economy of new vehicles sold in the United States, 1975–2008 (left) and fuel economy standards in other countries, 2002–2008 (right). In 2009, President Obama called for an average of 15.1 kpl (35.5 mpg) for new cars, vans, and SUVs in the United States by 2016. This is lower than China's current fuel economy standard for new vehicles and much lower than the 18.1 kpl (42.5 mpg) standard that China has set for 2016. (U.S. Environmental Protection Agency and National Highway Traffic Safety Administration, International Council on Clean Transportation, 2008)

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 and income taxes were reduced to offset such taxes? 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 *feebate*—a combination of a fee and a rebate—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 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 or other 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, oil and car companies have been able to keep the U.S. Congress from implementing such a program.

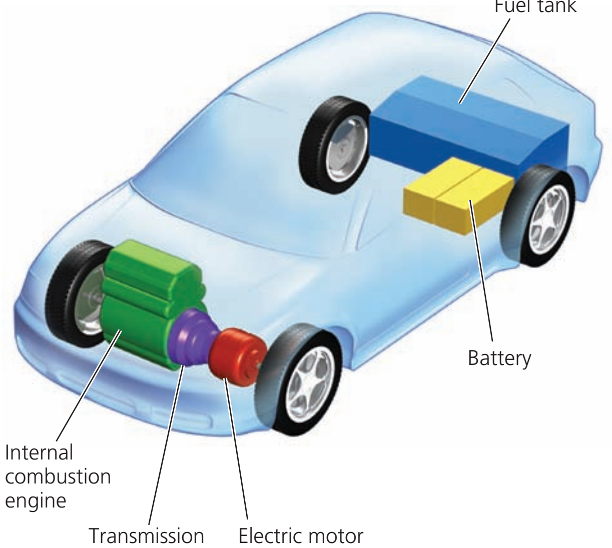
More Energy Efficient Vehicles Are on the Way

There is growing interest in developing *superefficient and ultralight cars* that could eventually get 34–128 kpl (80–300 mpg). (See Amory Lovins' Guest Essay on this topic at CengageNOW).

One of these vehicles is the energy-efficient, gasoline–electric *hybrid car* (Figure 13-22, left)—invented in 1905 by Belgium inventor Henri Pieper. It has a small gasoline-powered motor and an electric motor used to provide the energy needed for acceleration and hill climbing. The most efficient models, such as the 2010 Toyota Prius, get a combined city/highway mileage of up to 21 kpl (50 mpg) and emit about 65% less CO_2 per kilometer 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 a conventional electrical outlet and recharged (Figure 13-22, right). By running only 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. The small gasoline engine is a backup that only generates electricity to recharge the battery pack. Manufacturers hope to have a variety of plug-in hybrids available by 2010–2012. A Chinese car company is mass-producing and selling a plug-in hybrid car in China. Within a few years, China plans to become one of the world's leading producers of hybrid and all-electric cars and buses.

Replacing most of the current U.S. vehicle fleet 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%, according to a 2006 DOE study. If the batteries in this national car fleet were recharged mostly by electricity from renewable resources such as wind, U.S. emissions of CO_2 would drop by 80–90%. And people will be able to connect conventional and plug-in hybrids to their houses and use them as emergency electricity generators when the



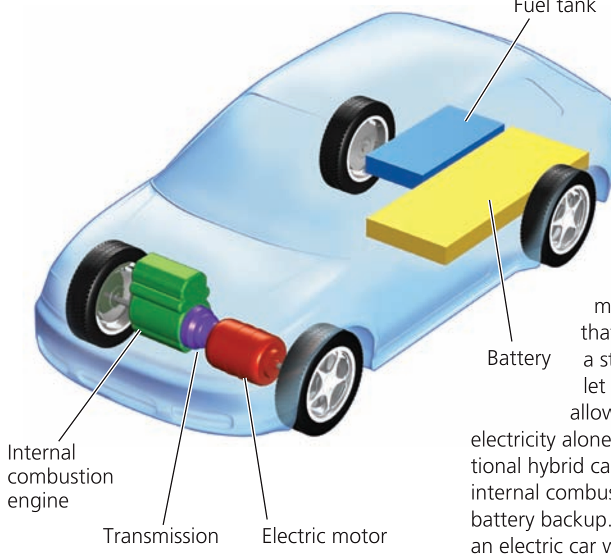


Figure 13-22 **Solutions:** general features of a car powered by a *hybrid gasoline–electric engine* (left). A *plug-in hybrid* vehicle (right) would have a smaller internal combustion engine and a second and more powerful battery that can be plugged into a standard 110-volt outlet and recharged. This allows it to run farther on electricity alone. In effect, a conventional hybrid car is a car with a small internal combustion engine with a battery backup. A plug-in hybrid is an electric car with a smaller internal combustion engine used only to recharge the battery pack.

power goes off. **GREEN CAREER:** plug-in hybrid car technology; battery engineer

The next stage in the development of superefficient cars may be an electric vehicle that uses a *fuel cell*. 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 wind turbines and solar cells.

Most major automobile companies have developed prototype fuel-cell cars, which might eventually help to replace the energy-wasting internal combustion engine. But such cars are unlikely to be widely available until 2020 or later and will probably be very expensive. Some skeptics joke that mass production of cars burning hydrogen in fuel cells will always be at least 10–20 years in the future. They call for putting limited government and private funding into improving and phasing in plug-in hybrid cars, more than into fuel-cell technology, at least in the near term. **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 used in bicycle helmets and in some racing cars. Currently, costs for such materials are high but could drop because of mass production and further research.

RESEARCH FRONTIER

Developing better and more affordable hybrid and fuel-cell vehicles. See **www.cengage.com/biology/miller**.

Other ways to save energy in transportation include shifting from diesel-powered to electrified rail systems, building accessible mass transit systems within cities, and constructing high-speed rail lines between cities as is done in Japan and much of Europe.

Another approach is to encourage bicycle use by building bike lanes along highways and city streets. Amory Lovins estimates that the U.S. could cut its oil imports from countries in the Middle East in 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.

Finally, text-messaging, e-mails, YouTube, video conferencing, and other ways to communicate electronically reduce the need to travel by car and air. Thus, they reduce gasoline use and greenhouse gas emissions.

We Can Design Buildings That Save Energy and Money

According to a 2007 U.N. study, better architecture and energy savings in buildings could save 30–40% of the energy used globally. For example, orienting a building so it can get more of its heat from the sun can save up to 20% of heating costs and as much as 75% when the building is well insulated and airtight (Figure 13-1)—a simple application of the solar energy **principle of sustainability** (see back cover).

GOOD NEWS

CORE CASE STUDY

SUSTAINABILITY

The 13-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 the 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 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. *Green buildings* have been widely used in Europe for almost 2 decades and are beginning to catch on in the United States. In 2008, Amory Lovins (**Core Case Study**) was hired to improve the energy sustainability of New York City's Empire State Building.

The Rocky Mountain Institute headquarters demonstrates that 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.

Since the mid-1980s, there has been growing interest in *straw bale houses* (see Photos 10 and 11 in the Detailed Contents). The walls of these superinsulated houses are made by stacking compacted bales of low-cost straw (a renewable resource) and then covering the bales on the outside and inside with plaster or adobe. (See the Guest Essay about straw bale and solar energy houses by Nancy Wicks at CengageNOW.)

In China, Broad Air Conditioning has developed non-electric efficient air conditioners that run on natural gas, biogas, or waste heat, and use a zero-pollution refrigerant agent. They are used to cool buildings in over 60 countries, including the tallest buildings in South America and Beijing, China and the largest airports in Asia and Europe. The company also produces solar powered air conditioners.

Green building certification standards now exist in 21 countries, thanks to the efforts of the World Green Building Council, which was established in 1999. Since 2001, the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) program has accredited more than 25,000 building professionals in energy and environmental design. It has also established guidelines and awards its much-coveted silver, gold, and platinum standard certifications to buildings meeting certain standards. **GREEN CAREERS:** Green architecture; zero energy home architect

In the near future, we will have smart homes in which furnaces cut off when windows are open and motion detectors turn lights on and off. Window panes will automatically darken or lighten to adjust to outdoor light. Nanotechnology will produce very thin sheets of light aerogel superinsulation. And highly efficient LED lighting will replace incandescent and compact fluorescent bulbs.

We Can Save Energy and Money in Existing Buildings

There are many ways to save energy and money in existing buildings. A good first step for any building is to have an expert suggest ways to improve energy efficiency. This 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 13-23). During hot weather, these windows and cracks let heat in, increasing the use of air conditioning. Adding insulation and plugging leaks are two of the quickest, cheapest, and best ways to save energy and money in any building.

VANSCAN® Continuous Mobile Thermogram by Daedalus Enterprises, Inc.

Figure 13-23 A *thermogram*, or infrared photo, showing heat loss (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?

CONNECTIONS

Insulation and Mushrooms

GOOD NEWS

In 2009 Gavin McIntyre and Eben Bayer developed a strong, low-cost form of insulation made from billions of tiny mushroom roots grown for about 2 weeks in beds of agricultural wastes. This biomaterial can replace expensive and environmentally harmful foam and other plastics used to insulate buildings.

- *Use energy-efficient windows.* Replacing leaky windows with energy-efficient windows can cut expensive heat losses from a house by two-thirds, lessen cooling costs in the summer, and reduce heating system CO_2 emissions.
- *Heat houses more efficiently.* In order, the most energy-efficient ways to heat space are 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; 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.
- *Heat water more efficiently.* One approach is a roof-mounted solar hot water heater, now being widely used in China, Israel, and a number of other countries. Another option is a *tankless instant water heater* (about the size of a suitcase) fired by natural gas or LPG (not electricity). These devices, widely used in many parts of Europe, heat water instantly and provide it only when needed.
- *Use energy-efficient appliances.* According to the Environmental Protection Agency, if all U.S. households used the most efficient frost-free refrigerator now available, 18 large coal or nuclear power plants could close. Microwave ovens can cut electricity use for cooking (with electric stoves) by 25–50% and convection ovens cut energy use by about 20%. Clothes dryers with moisture sensors cut energy use by 15%. Refrigerators with a freezer on the bottom instead of the top cut electricity use and operating costs in half. Front-loading clothes washers use 55% less energy and 30% less water than top-loading models use and cut operating costs in half. A 42-inch plasma TV set left in standby mode uses more electricity than a large refrigerator. Consumers can reduce this energy use and save money by plugging electronic devices with a standby feature into a smart power strip that cuts off power when such devices are turned off.
- *Use energy-efficient lighting.* Newer compact fluorescent lightbulbs (CFLs) cut energy use by 75% and last up to ten times longer than incandescent bulbs. According to the U.S. Department of Energy, 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 countries plan to phase out sales of incandescent bulbs over the next 5–10 years. As prices come down over the next 2 decades, all bulbs may be replaced by even more efficient, pea-sized, light-emitting diodes (LEDs) that last 60 times longer than incandescent bulbs and 10 times longer than CFLs.

CONNECTIONS

Using Compact Fluorescent Bulbs Reduces Mercury Pollution

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 CFLs is a tiny fraction of the amount of mercury released by coal-fired power plants, which produce electricity to light many energy-wasting incandescent bulbs. While the mercury in CFLs can be recycled (see **www.epa.gov/bulbrecycling**), the mercury continuously spewed into the atmosphere by coal-burning power plants cannot be retrieved. And some of it can end up in our lungs and in our food, especially in fish. Thus, shifting to CFLs actually reduces the amount of mercury released into the atmosphere.

Figure 13-24 (p. 324) summarizes ways in which you can save energy in the place where you live.

GOOD NEWS

Why Are We Still Wasting So Much Energy?

Cutting energy waste will not solve our energy problems but it is an important first step. So with such an impressive array of benefits (Figure 13-20), why is there 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 they receive and because market prices do not include the harmful environmental and health costs of their production and use. As a result, people are more likely to waste energy and less likely to invest in improving energy efficiency.

Another reason is that there are few large and long-lasting 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 and educating the public about the environmental and economic advantages of cutting energy waste. Other factors are inadequate energy-efficiency building codes and appliance standards.

HOW WOULD YOU VOTE?

Should the country where you live greatly increase its emphasis on improving energy efficiency? Cast your vote online at **www.cengage.com/biology/miller**.

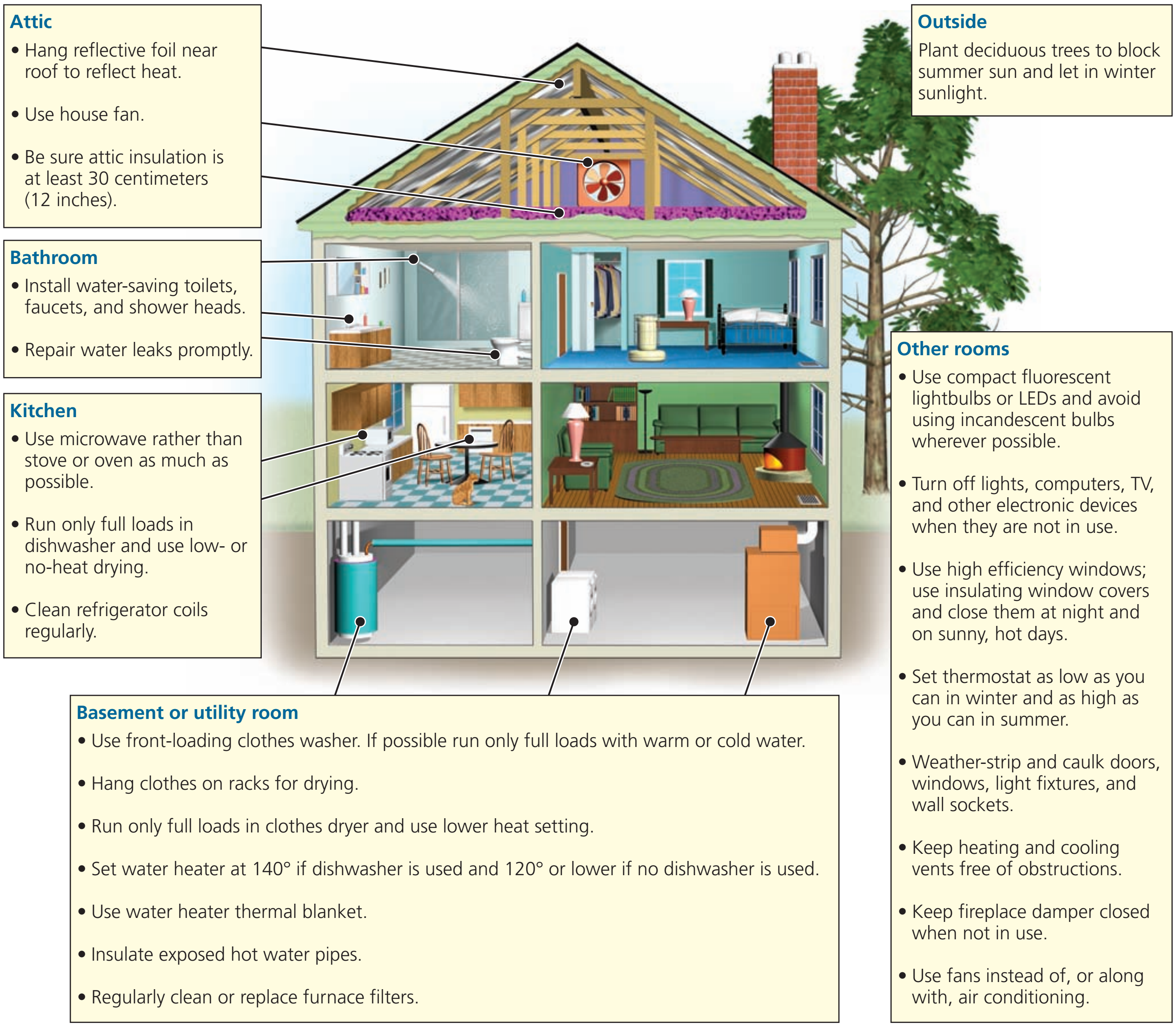


Figure 13-24 **Individuals matter:** you can save energy where you live.

13-5 What Are the Advantages and Disadvantages of Renewable Energy Resources?

▶ **CONCEPT 13-5 Using a mix of renewable energy sources—especially sunlight, wind, flowing water, sustainable biomass, and geothermal energy—can drastically reduce pollution, greenhouse gas emissions, and biodiversity losses.**

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*. We can get renewable solar energy directly from the sun or indirectly from wind, moving water, and biomass, none of which would exist without direct solar energy. Another form of renewable energy is geothermal energy from the earth's interior.

Studies show that with increased and consistent government backing in terms of investments in research and development and subsidies and tax breaks, 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 renewable sugarcane residue, and could phase out its use of gasoline within a decade. In 2007, it also got 46% of all of its energy and 87% of its electricity from renewable energy. Several studies show that with a crash program, the United States could get 20% of its total energy and at least 25% of its electricity from renewable sources by 2020.

Making a major shift toward a variety of locally available renewable energy resources over the next few decades would result in a more decentralized and efficient energy economy that would be less vulnerable to supply cutoffs from terrorist attacks and natural disasters. It would also improve economic and national security for many countries by reducing their dependence on imported crude oil and natural gas. And it would greatly reduce pollution, slow projected climate change, 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? One reason is that, 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 for renewables have increased in recent years.

A second reason is that, although subsidies and tax breaks for fossil fuels and nuclear power have essentially been guaranteed for many decades, those for renewable energy have to be renewed every few years. This makes it risky for companies to invest in renewable energy. Another reason is that 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.

If these economic handicaps—*unbalanced and intermittent subsidies* and *inaccurate pricing*—were eliminated, energy analysts say that many forms of renewable energy would be cheaper than fossil fuels or nuclear energy and would quickly take over the marketplace.

Throughout the rest of this chapter, we explore these renewable energy options. **GREEN CAREER:** Renewable energy engineer

We Can Heat Buildings and Water with Solar Energy

Buildings and water can be heated by passive and active solar heating systems (Figure 13-25).

A **passive solar heating system** absorbs and stores heat from the sun directly within a well-insulated structure without the need for pumps or fans to distribute the heat (Figure 13-25, left). The Rocky Mountain Institute headquarters (**Core Case Study**) is an excellent example of this. The sun's heat collected by its central greenhouse and the building's other windows is stored in the masonry, the floor, large water tanks, and the earth under the house and slowly released into the interior. This and other sources of heat, such as lights, appliances, and people, provide almost all the heat that is needed throughout most of the year for the entire building. (See the Guest Essay by Nancy Wicks at CengageNOW.)

CORE CASE STUDY

An **active solar heating system** uses 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 (Figure 13-25, right). Some of the collected heat can be used directly. The rest can be stored in a large insulated container, filled with gravel, water, clay, or a heat-absorbing chemical, for release as needed.

Figure 13-26 (p. 326) lists the major advantages and disadvantages of using passive or active solar heating systems for heating buildings. They can be used to heat new homes in areas with adequate sunlight. (See Figure 5, p. S41, in Supplement 9.) But solar energy

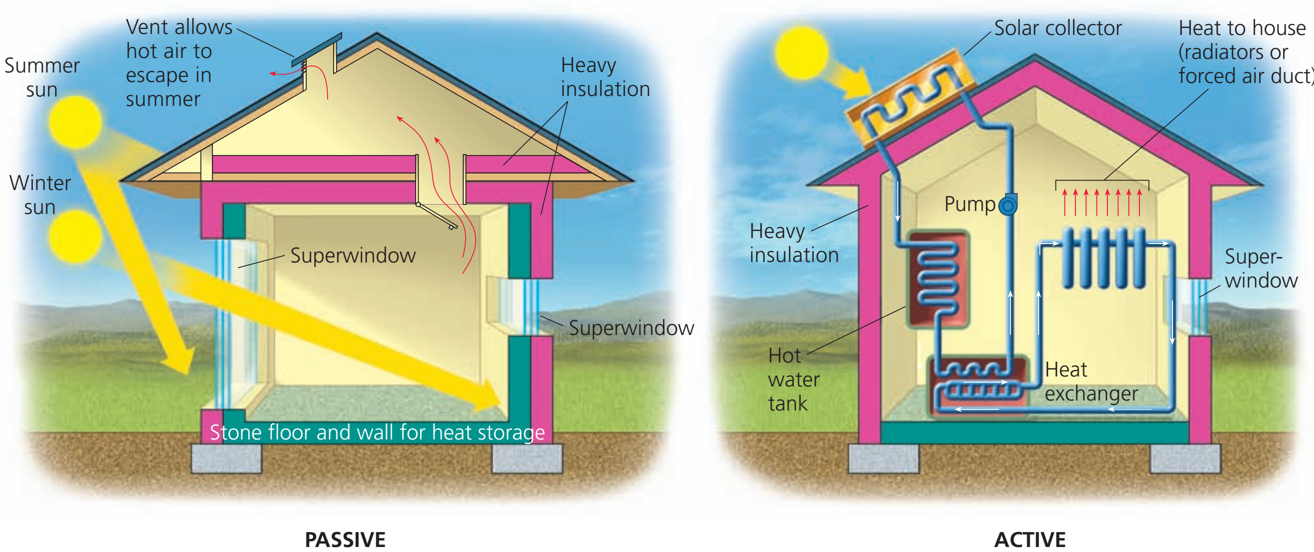


Figure 13-25 **Solutions:** passive and active solar heating for a home.

Trade-Offs

Passive or Active Solar Heating

Advantages

- Energy is free
- Net energy is moderate (active) to high (passive)
- Quick installation
- No CO_2 emissions
- Very low air and water pollution
- Very low land disturbance (built into roof or windows)
- Moderate cost (passive)

Disadvantages

- Need access to sun 60% of time
- Sun can be blocked by trees and other structures
- Environmental costs not included in market price
- Need heat storage system
- High cost (active)
- Active system needs maintenance and repair
- Active collectors unattractive

Figure 13-26 Advantages and disadvantages of heating a house with passive or active solar energy (**Concept 13-5**). **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

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.

Active solar collectors using a fairly simple technology can also provide hot water. By 2030, half of all households in China are expected to be using inexpensive rooftop solar water heaters—an excellent example of applying the solar energy **principle of sustainability** (see back cover).

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. And a living roof (see Photo 6 in the Detailed Contents) can make a huge difference in keeping a building cool. When there is no breeze, superinsulation and high-efficiency windows help to keep hot air outside. Here are some other ways to keep cool:

- Block the high summer sun with window overhangs or awnings (Figure 13-25, left).
- Use a light-colored roof to reflect as much as 80% of the sun's heat (compared to only 8% for a dark-colored roof).
- Use geothermal heat pumps for cooling (and heating in winter)

We Can Use Sunlight to Produce High-Temperature Heat and Electricity

Solar thermal systems concentrate and transform energy from the sun into high-temperature thermal energy (heat), which can then be used to heat water and produce steam to generate electricity. These systems are used mostly in desert areas with ample sunlight (see Figure 5, p. S41, in Supplement 9). Figure 13-27 summarizes some advantages and disadvantages of concentrating solar energy to produce high-temperature heat or electricity.

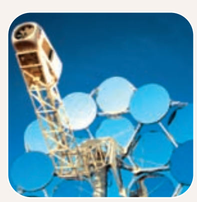
One type of solar thermal system uses a *central receiver system*, such as that shown in the top drawing in

Trade-Offs

Solar Energy for High-Temperature Heat and Electricity

Advantages

- Moderate environmental impact
- No CO_2 emissions
- Fast construction (1–2 years)
- Costs reduced with natural gas turbine backup



Disadvantages

- Low efficiency
- Low net energy
- High costs
- Environmental costs not included in market price
- Needs backup or storage system
- Needs access to sun most of the time
- May disturb desert areas

Figure 13-27 Advantages and disadvantages of using solar energy to generate high-temperature heat and electricity (**Concept 13-5**). **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

Figure 13-27. Huge arrays of computer-controlled mirrors, called *heliostats*, track the sun and focus sunlight on a central heat collection tower that produces steam, which powers a turbine and produces electricity (see Photo 12 in the Detailed Contents). Excess heat can be stored in vats of molten salts for use when the sun goes down. Such plants are in operation or are being built in desert areas of southern Spain, Australia, the United States, and Israel.

In another type of system, sunlight is collected and focused on oil-filled pipes running through the middle of a large area of curved solar collectors (bottom drawing, Figure 13-27). This concentrated sunlight can generate temperatures high enough to produce steam for running turbines and generating electricity. Again, excess heat can be stored in molten salts for later use. Such plants are operating in southern Spain, North Africa, and California.

Inexpensive *solar cookers* can focus and concentrate sunlight to cook food and sterilize water, especially in rural, sunny areas (Figure 13-28). 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 fires, thus helping to reduce deforestation from fuelwood harvesting, saving time and labor needed to collect firewood, and reducing indoor air pollution from smoky fires.

Figure 13-28 Solutions: woman in India uses a solar cooker to prepare a meal for her family.

We Can Use Sunlight to Produce Electricity

Solar energy can be converted directly into electrical energy by **photovoltaic** (**PV**) **cells**, commonly called **solar cells** (Figure 13-29). Most solar cells are thin wafers of purified silicon with trace amounts of metals that allow them to function as semiconductors to produce electricity. A typical solar cell has a thickness ranging from less than that of a human hair to 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.

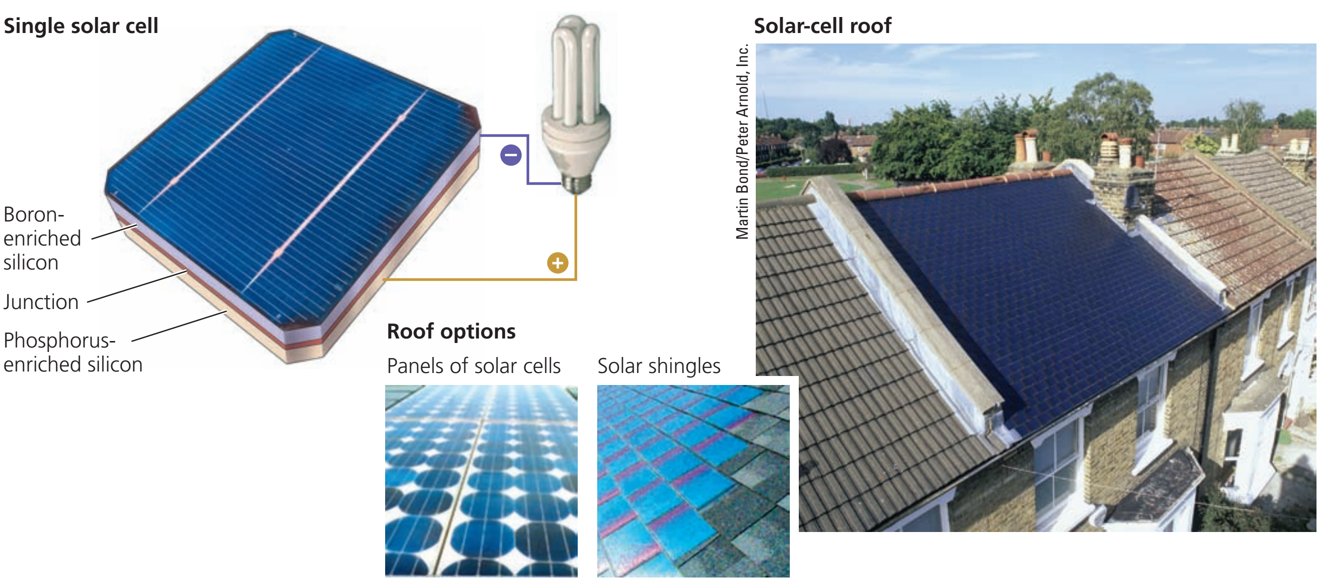


Figure 13-29 Solutions: Photovoltaic (PV) or solar cells can provide electricity for a house or building using solar-cell roof shingles, as shown in this house in Richmond Surrey, England. Solar-cell roof systems that look like a metal roof are also available. In addition, new thin-film solar cells can be applied to windows and outside walls.

Peter Arnold, Inc.

Figure 13-30 **Solutions:** solar cells used to provide electricity for a remote village in Niger, Africa. **Question**: Do you think your government should provide aid so poor countries can obtain such solar cells? Explain.

Trade-Offs

Solar Cells

Advantages	Disadvantages
Fairly high net energy yield	Need access to sun
Work on cloudy days	Low efficiency
Quick installation	Need electricity storage system or backup
Easily expanded or moved	Environmental costs not included in market price
No CO_2 emissions	High costs (but should be competitive in 5–15 years)
Low environmental impact	High land use (solar-cell power plants) could disrupt desert areas
Last 20–40 years	DC current must be converted to AC
Low land use (if on roof or built into walls or windows)	
Reduces dependence on fossil fuels	

Figure 13-31 Advantages and disadvantages of using solar cells to produce electricity (**Concept 13-5**). **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

Solar cells have no moving parts, are safe and quiet, require little maintenance, and produce no pollution or greenhouse gases during operation. The material used in solar cells can be made into paper-thin rigid or flexible sheets that can be incorporated into traditional-looking roofing materials (Figure 13-29, right) and attached to walls, windows, and clothing.

The Rocky Mountain Institute headquarters (**Core Case Study**) uses photovoltaic panels on the building's roof to generate its own electricity. The system includes a tracking mechanism and small electric motors to keep the panels pointed toward the sun during daylight hours. The system collects 30–40% more energy than stationary panels can collect.

CORE CASE STUDY

Nearly 1.6 billion people, or one of every four people in the world, live in developing countries in rural villages that are not connected to an electrical grid. With easily expandable banks of solar cells, these people can now get electrical service (Figure 13-30). For example, with financing from the World Bank, India is installing solar-cell systems in 38,000 villages that are located long distances from power grids.

GOOD NEWS

Large solar-cell power plants are in operation in Portugal, southern Spain, Germany, South Korea, and the southwestern United States (see Photo 12 in the Detailed Contents). By 2008, China was the world's third largest producer of solar cells, after Germany (with solar panels on 500,000 roofs) and Japan, and it plans to be the largest producer by 2025. Figure 13-31 lists the advantages and disadvantages of using solar cells.

Solar cells emit no greenhouse gases. But they are not carbon-free because fossil fuels are used to produce and transport the panels. Solar cells also contain toxic materials that need to be recovered when the cells wear out after 20–25 years of use or when they are replaced with better technology. A growing number of solar cell producers in Europe and the United States are agreeing to take back and recycle the solar panels they sell after they wear out.

Currently, the main problem with using solar cells to produce electricity is the high cost. According to 2007 estimates by the U.S. Energy Information Administration and a variety of sources compiled by the Worldwatch Institute, when operating costs and estimated harmful environmental costs are combined, wind, geothermal, and hydropower are the three cheapest ways to produce electricity, and nuclear power, coal, and solar cells are the most expensive. However, coal and nuclear power advocates dispute such estimates. The current high cost of producing electricity from solar cells is expected to drop considerably because of increased mass production and new and more efficient designs. **GREEN CAREER:** Solar-cell technology

RESEARCH FRONTIER

Developing more efficient and affordable solar cells. See **www.cengage.com/biology/miller**.

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/biology/miller**.

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 (Figure 3-12, p. 49).

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 huge pipes at controlled rates, spinning turbines and producing electricity (Figure 11-2, p. 238, and Figure 11-10, p. 246).

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 16% of the world's electricity, including 99% of Norway's, 75% of New Zealand's, and 21% of China's electricity. It supplied 7% of 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.

According to the World Commission on Dams, hydropower plants currently being built around the world will produce electricity equal to that from several thousand large, coal-fired power plants. Since 1999 China has built more than 60% of the world's hydropower projects. China is also involved in building or funding more than 200 dams around the world, often in exchange for access to natural resources such as fossil fuels, metals, timber, farm land, and profitable construction contracts. Within 30 to 50 years, renewable hydropower may replace nonrenewable coal as the chief producer of electricity in China. Brazil has four large dams

Trade-Offs

Large-Scale Hydropower

Advantages	Disadvantages
Moderate to high net energy	High construction costs
High efficiency (80%)	High environmental impact from flooding land to form a reservoir
Large untapped potential	Environmental costs not included in market price
Low-cost electricity	High CH_4 emissions from rapid biomass decay in shallow tropical reservoirs
Long life span	Danger of collapse
No CO_2 emissions during operation in temperate areas	Uproots people
Can provide flood control below dam	Decreases fish harvest below dam
Provides irrigation water	Decreases flow of natural fertilizer (silt) to land below dam
Reservoir useful for fishing and recreation	

Figure 13-32 Advantages and disadvantages of using large dams and reservoirs to produce electricity (**Concept 13-5**). **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

along rivers in its Amazon Basin and plans to build as many as 70 more.

But some analysts expect the contribution of large-scale hydropower plants to fall slowly over the next several decades as many existing reservoir systems fill with silt and become useless faster than new plants are built. Also, there is growing concern over emissions or burps of methane, a potent greenhouse gas, from the decomposition of submerged trees and vegetation in hydropower plant reservoirs, especially in warm tropical areas.

Figure 13-32 lists the advantages and disadvantages of using large-scale hydropower plants to produce electricity (**Concept 13-5**).

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/biology/miller**.

The use of *microhydropower generators* may become an increasingly important way to produce electricity for local use. 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

GOOD NEWS

the turbine to produce electric current. They can be placed in any stream or river without altering its course to provide electricity at a very low cost with almost zero environmental impact.

Using Wind to Produce Electricity Is an Important Step Toward Sustainability

The difference in solar heating of the earth between the equator and the poles together with the earth's rotation create flows of air called *wind* (Figure 7-3, p. 124). This indirect form of solar energy can be captured by wind turbines on land and at sea and converted into electrical energy (Figure 13-33). Because today's wind turbines can be as tall as 40-stories and have very long blades, they can tap into the stronger, more reliable, and less turbulent winds found at higher altitudes.

Since 1990, wind power has been the world's second fastest-growing source of energy, after solar cells. In order, the largest wind power producers in 2008 were the United States, Germany, Spain, and India. Denmark and Norway are also major producers of wind power.

In 2004, Stanford University engineers Cristina L. Archer and Mark Z. Jacobson mapped the global potential for wind energy. Their data indicate that capturing only one-fifth of the wind energy at the world's best sites could generate more than seven times the amount of electricity currently used in the world. This would enable the phasing out of energy-wasting coal-burning and nuclear power plants during this century.

GOOD NEWS

Analysts expect to see increasing use of offshore wind farms (Figure 13-33, right) because wind speeds over water are often stronger and steadier than those over land, and any noise produced is muffled by surf sounds. This also eliminates the need for negotiations among multiple landowners over the siting of turbines and electrical transmission lines. Underwater lines would transmit the electricity to the shore.

Figure 8, p. S43, in Supplement 9 shows the land and offshore areas with the most potential for use of 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 entire country's electricity needs. In 2009, a U.S. Department of Energy study estimated that offshore wind turbines off U.S. coastlines, especially the East Coast, could meet all of the country's electricity demand.

GOOD NEWS

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 support 500,000 jobs, sharply reduce air pollution and greenhouse gas emissions by an amount equal to that emitted by 140 million motor vehicles, help phase out more environmentally harmful coal and nuclear power plants, and save consumers an estimated $12 billion a year.

Wind is abundant, widely distributed, and mostly carbon-free and pollution-free. A wind farm can be built within 9 to 12 months and expanded as needed, and it can be controlled by a single laptop computer. And the DOE and the Worldwatch Society estimate that, when the environmental costs of various energy resources are included in comparative cost estimates, wind energy is the cheapest way to produce electricity (**Concept 13-5**).

Like any energy source, wind power has some drawbacks. Areas with the greatest wind power potential are

Wind turbine **Wind farm** **Wind farm (offshore)**

Figure 13-33 Solutions: A single wind turbine (left) can be used to produce electricity. Increasingly, they are being used in interconnected arrays of ten to hundreds of turbines. These *wind farms* or *wind parks* can be located on land (middle) or offshore (right). Land lying under these turbines can still be used to grow crops or raise cattle. **Questions**: Would you object to having a wind farm located near where you live? Why or why not?

often sparsely populated and located far from energy-thirsty cities. Thus, to take advantage of the potential for electricity from wind energy, countries such as the United States will have to invest in a long overdue upgrading and expansion of their outdated and energy-wasting electrical grid systems, unless most wind farms are developed offshore. The resulting large increase in the number of transmission towers and lines will cause controversy in some areas and could result in many delaying lawsuits. But wind power proponents say that the alternative of continuing to rely on use of polluting and climate-changing coal to produce most of the country's electricity is far worse.

Another problem is that winds can die down and thus require a backup source of power, such as natural gas, for generating electricity. However, a large number of wind farms in different areas connected to an updated and smarter electrical grid could usually take up the slack when winds die down in any one area. And winds at sea are much steadier and stronger. An offshore wind farm off the coast of the U.S. state of Delaware should be in operation by 2012.

Scientists are also working on ways to store wind energy. One way is to store it in the batteries of a nationwide fleet of plug-in electric or gasoline-electric hybrid vehicles (Figure 13-22, right), which would be recharged mostly at night by cheaper, off-peak, wind-generated electricity.

Electricity produced by wind can also be passed through water and used to produce hydrogen fuel, which could be thought of as "stored" wind power. Another option is to use electricity from wind power 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 and evaluated in Germany and in the U.S. state of Alabama.

CONNECTIONS

Birds and Wind Turbines

Studies indicate that wind turbines kill up to 100,000 birds each year in the United States. Most wind turbines involved in these deaths were built 20 years ago from now outdated designs, and some were built in bird migration corridors. Wind power developers now study bird migration paths 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. In fact, wind power is a very minor cause of bird deaths compared to a number of other causes. Each year, according to Defenders of Wildlife, more than 1.4 billion birds are killed by collisions with buildings and other human structures and by cars, trucks, and cats. And each year coal burning power plants kill about 14.5 million birds and nuclear power plants about 327,000 according to a 2009 study by Professor Benjamin Sovacool. Together these numbers total about 1.5 billion birds a year in the United States—15,000 times the number of birds killed by wind turbines.

Trade-Offs

Wind Power

Advantages	Disadvantages
Moderate to high net energy yield	Steady winds needed
High efficiency	Backup systems needed when winds are low
Moderate capital cost	Plastic components produced from oil
Low electricity cost (and falling)	Environmental costs not included in market price
Very low environmental impact	High land use for wind farm
No CO_2 emissions	Visual pollution
Quick construction	Noise when located near populated areas
Easily expanded	Can kill birds and interfere with flights of migratory birds if not sited properly
Can be located at sea	
Land below turbines can be used to grow crops or graze livestock	

Figure 13-34 Advantages and disadvantages of using wind to produce electricity (**Concepts 13-5**). 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?

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 Canada, many farmers and ranchers welcome them and some have become wind developers themselves. A single wind turbine on 0.1 hectare (0.25 acre) of land can produce about $300,000 worth of electricity a year. Farmers typically receive $3,000 to $10,000 a year in royalties for each turbine erected on their land. And they can still use that land for growing crops or grazing cattle.

Figure 13-34 lists 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/biology/miller**.

We Can Get Energy by Burning Solid Biomass

Biomass consists of plant materials (such as wood and agricultural waste) and animal wastes that can be burned directly as a solid fuel or converted into gaseous or liquid biofuels.

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), animal manure, and other forms of biomass used for heating and cooking, supply about 10% of the world's energy, 35% of the energy used in developing countries, and 95% of the energy needs in the poorest countries.

Wood is a renewable fuel only if it is not harvested faster than it is replenished. The problem is, about 2.7 billion people in 77 developing countries face a *fuelwood crisis* and often are forced to meet their fuel needs by harvesting wood faster than it can be replenished.

One way to produce solid biomass fuel is to plant fast-growing trees, shrubs, perennial grasses, and water hyacinths in *biomass plantations*. But repeated cycles of growing and harvesting these plantations can deplete the soil of key nutrients. And clearing forests and grasslands for such plantations destroys or degrades biodiversity. In addition, plantation species such as European poplar trees and the American mesquite tree are invasive species that can escape from plantations and takeover adjacent farms and natural land. In agricultural areas, *crop residues* (such as sugarcane residues, rice husks, cotton stalks, and coconut shells) and *animal manure* can be collected and burned or converted into gaseous or liquid biofuels.

As with any energy resource, solid biomass has its advantages and disadvantages. One problem is that clearing forests for 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.

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/biology/miller**.

We Can Convert Plants and Plant Wastes to Liquid Biofuels

Liquid biofuels such as *biodiesel* (see Case Study at right) and *ethanol* (ethyl alcohol), which are produced from plants and plant wastes, can be used in place of petroleum-based diesel fuel and gasoline. The biggest producers of liquid biofuels—Brazil, the United States, the European Union, and China—plan to double their production by 2020.

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 help countries 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 through existing fuel networks, and can be used in motor vehicles at little or no additional cost.

However, in a 2007 U.N. 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 make biofuels for cars rather than to feed livestock and people.

CONNECTIONS

Biofuels and Global Warming

In 2007, Nobel Prize–winning chemist Paul Crutzen warned that intensive farming of biofuel crops could speed up 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 nitrous oxide (N_2O), a greenhouse gas 300 times more potent per molecule than CO_2.

The challenge is to grow crops for food and biofuels by using more sustainable agriculture (Figure 10-23, p. 232). This could greatly decrease land degradation, air and water pollution, and emissions of carbon dioxide and other greenhouse gases. It would also help to preserve biodiversity. And any system for producing a biofuel should have a favorable net energy yield so that it can compete in the energy marketplace without government subsidies.

GOOD NEWS

Some scientists are also looking for ways to produce biofuel almost identical to gasoline from various types of oil-rich algae (**www.oilalgae.com**). Algae grow rapidly at any time of the year and can be cultivated in seawater, wastewater ponds, or greenhouses. The algae remove CO_2 from the atmosphere and convert it to oil, proteins, and other useful products and require much less land than biofuel plantations do. The challenge is to cut the very high cost of producing oil by this method. Stay tuned.

Another possibility under investigation is to genetically engineer microbes to produce biofuel. Scientists have also identified a compound that can be used to convert chemicals in agricultural wastes into a gas that can in turn be converted into gasoline.

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 can be produced from vegetable oil extracted from soybeans, rapeseeds, sunflowers, oil palms, jatropha shrubs, and used coffee grounds. It can also be made from fats such as 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.

Aided by government subsidies, biodiesel production is growing rapidly in the United States. But soybean and canola crops grown for biodiesel production require huge areas of land. And using industrialized agriculture to produce these crops results in topsoil loss and fertilizer runoff. It also requires energy (mostly from crude oil and natural gas), which reduces the net energy yield and increases emissions of the greenhouse gases nitrous oxide and CO_2.

Brazil, Malaysia, and Indonesia produce biodiesel from palm oil, extracted from large plantations of African oil palm, 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 plant oil palm plantations in these countries poses a serious threat to their biodiversity. It also reduces CO_2 uptake by eliminating rain forests that store large amounts of carbon to grow crops that store much less carbon. And African oil palm is an invasive plant that has taken over adjacent farms and forest areas in parts of Brazil.

Figure 13-35 lists the advantages and disadvantages of using biodiesel as a vehicle fuel, compared to gasoline.

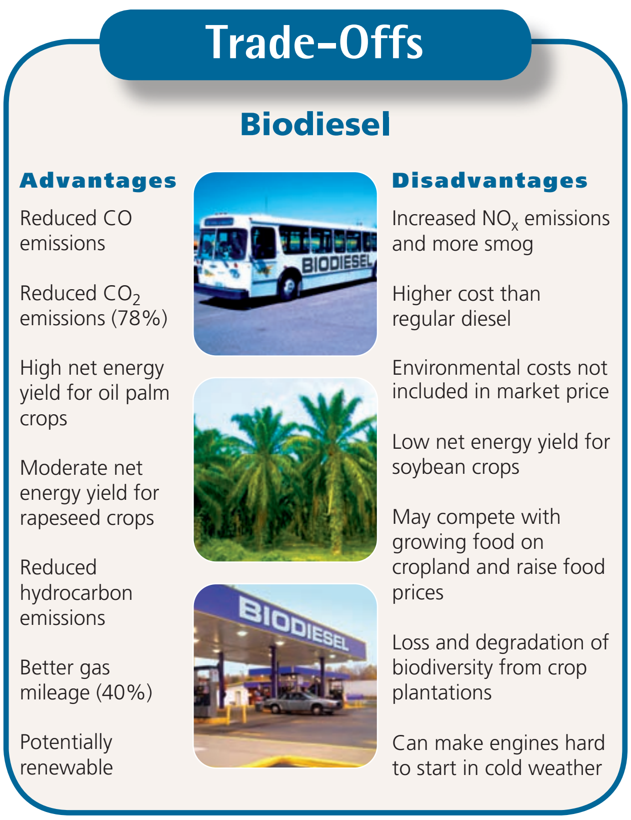


Figure 13-35 General advantages and disadvantages of using biodiesel as a vehicle fuel, compared to gasoline. **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

CONNECTIONS

French Fries and Car Fuel

In the United States, used cooking oil and grease from fast-food and other restaurants has become so valuable that rustlers are stealing it to sell it or to refine it into biodiesel themselves in backyard stills. Such grease heists have been reported in 20 states.

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 starch in plant material to 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*, a residue produced when sugarcane is crushed, and this ethanol yields 8 times the amount of energy used to 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 larger areas of its rapidly disappearing wooded savanna Cerrado region (Case Study, p. 213)—one of the world's biodiversity hot spots (Figure 9-19, p. 196). 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 oil and gasoline needed to produce sugarcane, very high soil erosion after sugarcane plantations are harvested, and large water use. Producing 0.27 gallons (1 liter) of ethanol requires 7,000 liters (1,860 gallons) of water—equal to about 47 bathtubs of water. And the water that runs off of sugarcane plantations contains some of the fertilizers, herbicides, and pesticides applied at high levels to help increase sugarcane crop yields.

In the United States, most ethanol is made from corn. 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. This low net energy yield also helps explain why Brazil, getting a net energy yield of 8, can produce ethanol from sugarcane at about half the cost of producing it from corn in the United States.

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 price of food items such as corn tortillas in Mexico has risen sharply. This 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 further raise the prices of corn-based foods such as bread, pasta, tortillas, poultry, beef, pork, and dairy products. This would increase the number of hungry and malnourished people who could no longer afford to buy these foods. The corn used to make the ethanol to fill a 94-liter (25-gallon) car fuel tank would feed one person for a year.

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. A 2009 study by researchers at Purdue University concluded that improvements in corn crop yields and more efficient refineries would reduce such CO_2 emissions but would still leave them higher than those from burning gasoline. If these estimates are correct, switching from gasoline to biofuels such as corn ethanol will accelerate projected climate change.

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/series20.html**). In this process, enzymes convert the cellulose from plant material such as leaves, stalks, husks, and wood chips to sugars that can be processed to produce ethanol. Using inedible cellulose material to produce ethanol dodges the food vs. biofuels dilemma.

A plant that could be used for cellulosic ethanol production is *switchgrass* (Figure 13-36), a tall perennial grass native to North American prairies that grows faster than corn. It is disease resistant and drought tolerant and can be grown without the use of nitrogen fertilizers on land unfit for crops. 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 more energy than it takes to grow it—a yield much greater than the 1.1–1.5 net energy yield for corn.

GOOD NEWS

Jeff Vanuga/Natural Resources Conservation Service/USDA

Figure 13-36 **Natural capital:** The cellulose in this rapidly growing switchgrass in Manhattan, Kansas (USA) can be converted into ethanol. 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.

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. However, cellulosic ethanol expert, Robert Ranier, points out that replacing half of U.S. gasoline consumption with cellulosic ethanol would require about seven times the land area currently used for all corn production. And Tim Searchinger and other researchers estimate 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.

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 13-37 lists the 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/biology/miller**.

RESEARCH FRONTIER

Developing more energy-efficient, cheaper, and more sustainable ways to produce liquid biofuels. See **www.cengage.com/biology/miller**.

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 (Figure 12-2, p. 275). We can tap into this stored energy to heat and cool buildings and to produce electricity. 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.

A *geothermal heat pump* system can heat and cool a house by exploiting the temperature differences between the earth's surface and underground almost anywhere in the world at a depth of 3–6 meters (10–20 feet), where the earth's temperature typically is 10–20 °C (50–60 °F) 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

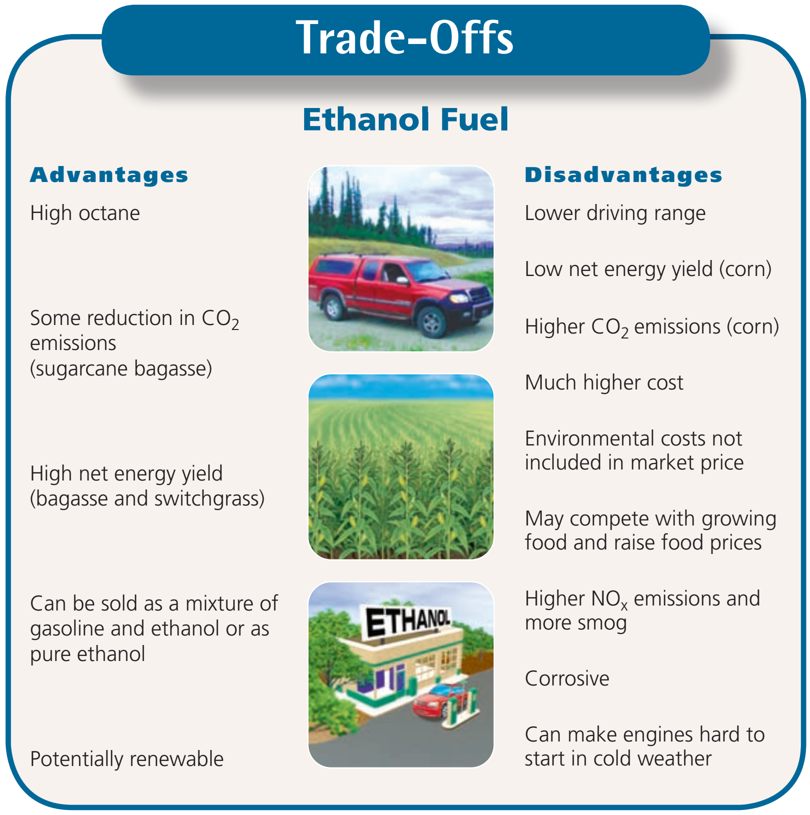


Figure 13-37 General advantages and disadvantages of using ethanol as a vehicle fuel, compared to using gasoline. **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

way to heat or cool a space after superinsulation. It produces no air pollutants and emits no CO_2. (For more information see **www.ghpc.org** and **www.econar.com**.)

We can also tap into deeper, more concentrated *hydrothermal reservoirs* of geothermal energy. This is done by drilling wells into the reservoirs and using a pipe to pump dry steam, wet steam, or hot water to the surface. It can then be used to heat homes and buildings, provide hot water, grow vegetables in greenhouses, raise fish in aquaculture ponds, and spin turbines to produce electricity. (See Figure 9, p. S43, in Supplement 9.)

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 10, p. S44, in Supplement 9). It meets the electricity needs of about 6 million Americans—a number roughly equal to the combined populations of Los Angeles, California, and Houston, Texas—and supplies almost 6% of California's electricity.

Another potential energy source is *deep geothermal energy* stored in 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 reinjected into the earth. According to the U.S. Geological Survey, tapping just 2% of this deep source in the United States could produce more than

Trade-Offs

Geothermal Energy

Advantages

Very high efficiency

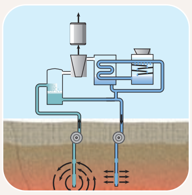
Moderate net energy at accessible sites

Lower CO_2 emissions than fossil fuels

Low cost at favorable sites

Low land use and disturbance

Moderate environmental impact



Disadvantages

Scarcity of suitable sites

Can be depleted if used too rapidly

Environmental costs not included in market price

CO_2 emissions

Moderate to high local air pollution

Noise and odor (H_2S)

High cost except at the most concentrated and accessible sources

Figure 13-38 Advantages and disadvantages of using geothermal energy for space heating and for producing electricity or high-temperature heat for industrial processes. **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

2,000 times the country's current annual use of electricity. The limiting factor is cost, which could be brought down by more research and improved technology. **GREEN CAREER:** Geothermal engineer

RESEARCH FRONTIER

Finding better and affordable ways to tap different sources of geothermal energy. See **www.cengage.com/biology/miller**.

Figure 13-38 lists the advantages and disadvantages of using geothermal energy (**Concept 13-5**). Some analysts see geothermal energy, coupled with improvements in energy efficiency and use of solar cells and wind farms to produce electricity, as keys to a more sustainable energy future.

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/biology/miller**.

Will Hydrogen Save Us?

Some scientists and executives of major oil and automobile companies say the fuel of the future is hydrogen gas (H_2). Most attention has been focused on fuel cells that combine H_2 and oxygen gas (O_2) to produce electricity and water vapor ($2\ H_2 + O_2 \rightarrow 2\ H_2O$), which is emitted into the atmosphere. Widespread use of hydrogen as a fuel would eliminate most of the urban outdoor air pollution problems we face today. It would also greatly reduce the threat of projected climate change, because it emits no CO_2—as long as the H_2 is not produced with the use of fossil fuels or the nuclear fuel cycle. Hydrogen also provides more energy per gram than does any other fuel, making it the ideal aviation fuel by allowing planes to greatly decrease fuel weight.

So what is the catch? There are three challenges in turning the vision of widespread use of hydrogen as a fuel into reality. *First*, because hydrogen is chemically locked up in water and in organic compounds such as methane and gasoline, it takes energy and money to produce H_2 from these compounds. In other words, H_2 is not an energy resource like coal or oil. It is a fuel produced by using energy, and thus *its net energy yield will always be negative*. *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 (Science Focus, p. 288) 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 conventional 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 (Figures 13-12 and 13-17). We can also make H_2 from coal and strip it from organic compounds found in fuels such as gasoline or natural gas. However, according to a 2002 study by a team of scientists, producing H_2 from coal and organic compounds would add much more CO_2 to the atmosphere per unit of heat generated than does burning these carbon-containing fuels directly.

Most proponents of hydrogen believe that if we are to realize its environmental benefits, the energy used to produce H_2 must come from low-polluting, renewable sources that emit little or no CO_2 (Science Focus at right).

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 that is the basis of most prototype hydrogen fuel-cell cars now being tested by major automobile companies. Some analysts project that a variety of fuel-cell cars, running on affordable H_2 produced from natural gas, could be available by 2020 and in widespread use by 2030. Also, merely replacing the gasoline fuel injector with an H_2 injector would allow current internal combustion engines to run on H_2 if more affordable fuel cells become available.

CORE CASE STUDY

GOOD NEWS

Larger stationary fuel cells can provide electricity and heat for commercial and industrial users. A 45-story office building in New York City gets much of its heat from two large fuel-cell stacks. And Japan has built a

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 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 relatively small amount of electricity. This breakthrough could make it affordable to use electricity produced by wind turbines or solar cells to produce H_2 and thus to store the energy produced by the wind and sun in the H_2.

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, which when heated, release H_2. Scientists are also evaluating ways to store H_2 by absorbing it onto the surfaces of activated charcoal or carbon nanofibers, which also release H_2 when heated. Another possibility is to store H_2 inside nanosize glass microspheres that can easily be filled and refilled. Yet another possibility is the development of *ultracapacitors* that could quickly store large amounts of electrical energy, which could then be used to propel cars or to produce H_2 on demand. More research is needed to convert these possibilities into realities.

Metal hydrides, sodium borohydride, charcoal powders, ammonia borane, carbon nanotubes, and glass microspheres containing H_2 will not explode or burn if a vehicle's fuel tank or system is ruptured in an accident. H_2 stored in such ways is a much safer fuel than gasoline, diesel fuel, natural gas, and concentrated ethanol. Also, use of ultralight car bodies made of composites and energy-efficient aerodynamic design 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 on demand by exposing pellets of an aluminum-gallium alloy to water, without producing toxic fumes. 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, and thus would not have to be transported or stored.

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.

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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, when electricity rates are sometimes lower. 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. In 2007, about 2,200 Japanese homeowners got their electricity and hot water from such fuel cell units, which produce H_2 from the methane in natural gas. Japan plans to make such fuel cell systems available for about one-fourth of its households by 2020. **GREEN CAREER:** Hydrogen energy

RESEARCH FRONTIER

Developing better and more affordable ways to produce hydrogen from renewable energy resources and ways to store and distribute it. See **www.cengage.com/biology/miller**.

Figure 13-39 lists the advantages and disadvantages of using hydrogen as an energy resource.

HOW WOULD YOU VOTE?

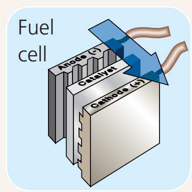
Do the advantages of producing and burning hydrogen as an energy resource outweigh the disadvantages? Cast your vote online at **www.cengage.com/biology/miller**.

Trade-Offs

Hydrogen

Advantages

- Can be produced from plentiful water
- Low environmental impact
- Renewable if produced from renewable energy resources
- No CO_2 emissions if produced from water
- Good substitute for oil
- Competitive price if environmental and social costs are included in cost comparisons
- Easier to store than electricity
- Safer than gasoline and natural gas
- Nontoxic
- High efficiency (45–65%) in fuel cells



Disadvantages

- Not found as H_2 in nature
- Energy is needed to produce fuel
- Negative net energy
- CO_2 emissions if produced from carbon-containing compounds
- Environmental costs not included in market price
- Nonrenewable if generated by fossil fuels or nuclear power
- High costs (that may eventually come down)
- Will take 25 to 50 years to phase in
- Short driving range for current fuel-cell cars
- No fuel distribution system in place
- Excessive H_2 leaks may deplete ozone in the atmosphere

Figure 13-39 Advantages and disadvantages of using hydrogen as a fuel for vehicles and for providing heat and electricity. **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

13-6 How Can We Make a Transition to a More Sustainable Energy Future?

▶ **CONCEPT 13-6 We can make a 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

Energy policies must be developed 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 (Science Focus, p. 299) for the resource?
- How much will it cost to develop, phase in, and use 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, human health, and the earth's climate? Should these harmful costs be included 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 must be safely stored for very long periods of time?

In 1977, Amory Lovins (**Core Case Study**) published his ground-breaking book *Soft Energy Paths*. In it, he compared what he called *hard energy paths*—based on increasing use of nonrenewable fossil fuels and nuclear energy—to what he called *soft energy paths*—based on improving energy efficiency and increased use of a variety of renewable energy resources.

CORE CASE STUDY

Lovins was called an impractical egghead dreamer. Three decades later his soft path concept is the centerpiece of global, national, and corporate energy strategies. Today, more than 100 major corporations, 100 utility companies, and 60 governments seek advice from Lovins and his institute.

Our energy future—the energy path we choose—depends primarily on what energy resources governments and private companies decide to *promote*, coupled with political and economic pressure from citizens and consumers. In considering possible energy futures, scientists and energy experts have come to three general conclusions. First, *there will be a gradual shift from large, centralized macropower systems to smaller, decentralized micropower systems* (Figure 13-40) such as wind turbines, household solar-cell panels, rooftop solar water heaters, small natural gas turbines, and fuel cells for cars, houses, and commercial buildings.

Currently, most countries have a centralized system of large power plants, refineries, pipelines, and other infrastructure that is 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 Figure 2, bottom, p. S39, in Supplement 9) 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. It would improve national and economic security, because countries would rely on diverse, dispersed, domestic, and renewable energy resources instead of on a small number of large power plants that are vulnerable to storm damage, earthquakes, and sabotage.

The second general conclusion of experts is that *a combination of greatly improved energy efficiency and the temporary use of a natural gas will best help us to make the transition to a diverse mix of locally available renewable energy resources over the next several decades* (**Concept 13-6**). By using a variety of often locally available renewable energy resources, we would be applying the diversity **principle of sustainability** by not putting all of our "energy eggs" in a single basket.

SUSTAINABILITY

Third, *because of their supplies and artificially low prices, fossil fuels will continue to be used in large quantities*. There are 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 air pollution and greenhouse gas emissions. The other is to find ways to include the harmful environmental costs of using fossil fuels in their market prices—as less environmentally harmful alternatives are phased in.

Figure 13-41 (p. 340) lists strategies for making the transition to a more sustainable energy future over the next 50 years (**Concept 13-6**).

GOOD NEWS

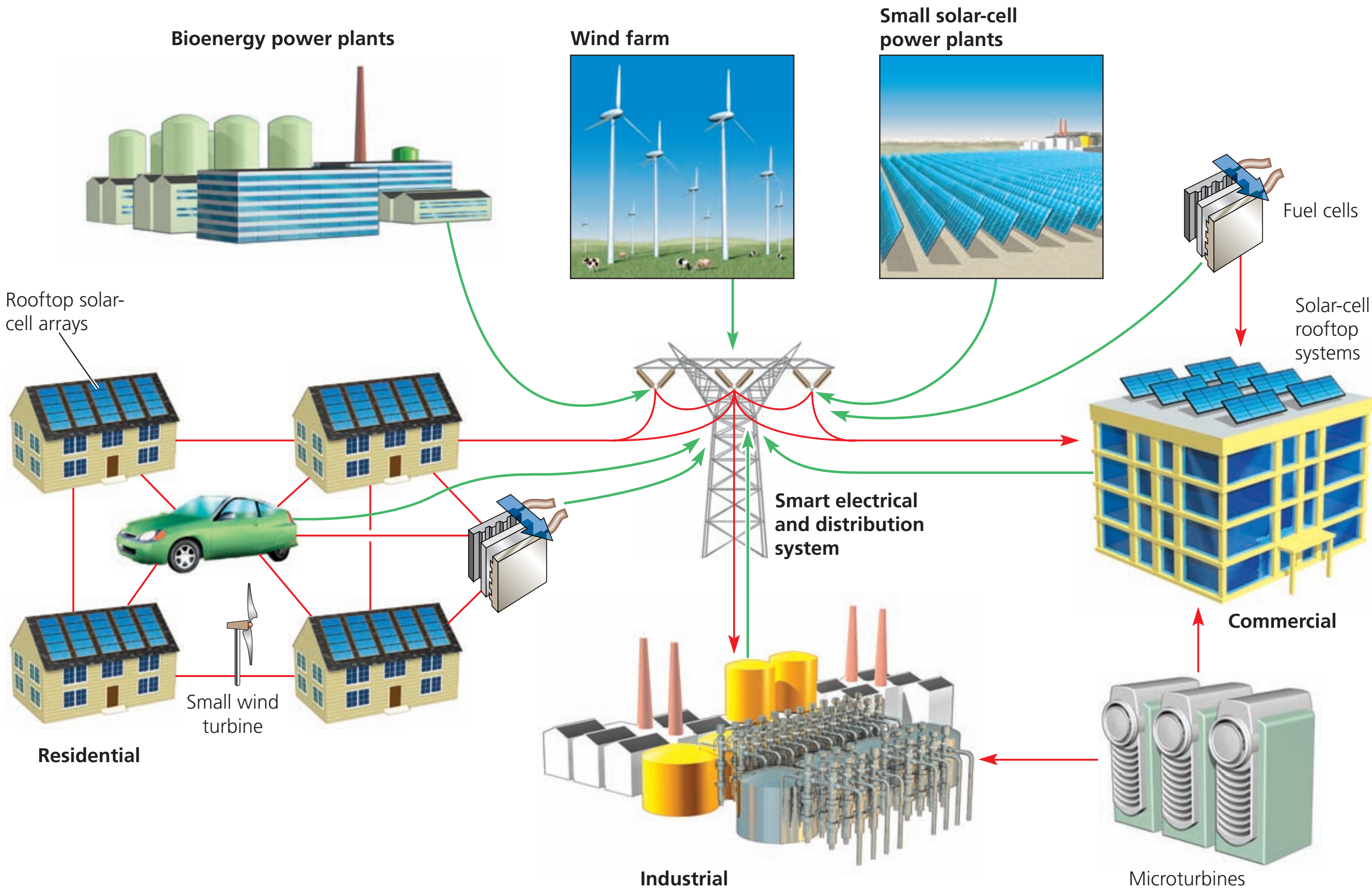


Figure 13-40 **Solutions:** *decentralized power system* in which electricity is produced by a large number of dispersed, small-scale *micropower systems.* Some would produce power on site; others would feed the power they produce into a modern electrical distribution system. Over the next few decades, 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 more decentralized power system?

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 dampen the short-term and long-term use of particular energy resources.

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 (R & D) subsidies, tax breaks, and loan guarantees to encourage the early development of those resources and by enacting regulations to 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 and in most other developed countries. This approach 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 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 now provided worldwide for fossil fuels and nuclear energy—both of which are mature industries that could be left to stand on their own without government support. These analysts call for greatly increasing subsidies for developing renewable energy and energy-efficiency technologies. But 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 providing significant subsidies and tax breaks 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

Solutions

Making the Transition to a More Sustainable Energy Future

Improve Energy Efficiency

Increase fuel-efficiency standards for vehicles, buildings, and appliances

Mandate government purchases of efficient vehicles and other devices

Provide large tax credits or feebates for buying efficient cars, houses, and appliances

Offer large tax credits for investments in energy efficiency

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

Include environmental costs in prices for all energy resources

Encourage government purchase of renewable energy

Greatly increase renewable energy research and development

Reduce Pollution and Health Risk

Cut coal use 50% by 2020

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 13-41 Suggestions of various energy analysts for helping us to make the transition to a more sustainable energy future (**Concept 13-6**). **Questions**: Which five of these solutions do you think are the most important? Why?

or taxes on its use. Such measures can increase government revenues, encourage improvements in energy efficiency, reduce dependence on imported energy, and decrease 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 often hidden environmental costs of various energy resources.

CONNECTIONS

Germany and Solar Energy: Economics, Politics, and Education in Action

Why does cloudy Germany have more solar water heaters and solar cell panels than sunny France and Spain? One reason is that the German government has made the public aware of the environmental benefits of these technologies. Another is that it has provided consumers with substantial economic incentives for using them.

We have the creativity, wealth, and most of the technology needed to make the transition to a more sustainable energy future within your lifetime. 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 pocketbooks by refusing to buy inefficient and environmentally harmful energy alternatives and by letting company executives know about their choices. Figure 13-42 lists some ways in which you can contribute to making the transition to a more sustainable energy future.

Here are the *three big ideas* for this chapter:

- Energy resources should be evaluated on the basis of their potential supplies, how much net useful energy they provide, and the environmental impact of using them.
- Using a mix of renewable energy sources—especially sunlight, 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 requires 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.

What Can You Do?

Shifting to More Sustainable Energy Use

- Get an energy audit done for your house or office
- Drive a car 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 13-42 **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?

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 land and aquatic systems, and emitting large quantities of pollutants and greenhouse gases. 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. From the day they laid the foundation of their headquarters building more than 25 years ago to the research and consulting they do around the world today, they have focused on improving energy efficiency and using solar energy. They also help businesses and communities to incorporate recycling and reuse of material resources into their daily operations. And they advise those same clients on how to apply the lessons of biodiversity to their ways of doing business.

Lovins and his colleagues urge us to make the transition to a more sustainable energy future by choosing soft energy paths and thereby applying the three **principles of sustainability**. This means

- Relying much more on direct and indirect forms of solar energy
- Recycling and reusing materials and thus reducing wasteful and excessive consumption of energy and matter
- 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. 297. Describe the work of Amory Lovins at the Rocky Mountain Institute. What major energy resources do the world and the United States rely on? What are **fossil fuels**? What is **net energy** and why is it important in evaluating energy resources?
2. What is **crude oil** (**petroleum**) and how is it extracted from the earth and refined? What is a **petrochemical** and why are such chemicals important? What are the major advantages and disadvantages of using crude oil as an energy resource? What is **tar sand**, or **oil sand**, and how is it extracted and converted to heavy oil? 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?

3. Define **natural gas**, **liquefied petroleum gas** (**LPG**), and **liquefied natural gas** (**LNG**). What are the major advantages and disadvantages of using natural gas as an energy resource?

4. What is **coal** and how is it formed? What are the major advantages and disadvantages of using coal as an energy resource? Explain why there is no such thing as clean coal. What is **synthetic natural gas** (**SNG**)? What are the major advantages and disadvantages of using liquid and gaseous synfuels produced from coal?

5. How does a nuclear fission reactor work and what are its major safety features? Describe the **nuclear fuel cycle**. What factors have hindered the development of nuclear power? Describe the Chernobyl nuclear power plant accident. How can we deal with the highly radioactive wastes produced by nuclear power plants? What can we do with worn out nuclear power plants? What are the major advantages and disadvantages of relying on the nuclear power fuel cycle as a way to produce electricity? What is nuclear fusion and what is its potential as an energy resource? Summarize the arguments for and against relying more on nuclear power. How does the nuclear power fuel cycle fit into these arguments?

6. What is **energy efficiency**? 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. Describe three ways to save energy and money in **(a)** industry, **(b)** transportation, **(c)** new buildings, and **(d)** existing buildings. 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.

7. Distinguish between **passive solar heating** and **active solar heating** and discuss the major advantages and disadvantages of such systems. What are three ways to cool houses naturally? Discuss the major advantages and disadvantages of using 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? What is **geothermal energy**?

8. What are the major advantages and disadvantages of using **(a)** flowing water to produce electricity in hydropower plants, **(b)** wind to produce electricity, **(c)** wood to provide heat and electricity, **(d)** biodiesel to power vehicles, **(e)** ethanol to power vehicles, **(f)** geothermal energy, and **(g)** hydrogen fuel?

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.

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

CRITICAL THINKING

1. Imagine that you live at the Rocky Mountain Institute headquarters building, 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.

2. 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, and then sought cleaner energy sources later when they became more affluent. China says it is being asked to clean up before it becomes affluent enough to do this, 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 developed nations play in helping it to reduce its dependence on coal and to rely on more environmentally sustainable energy sources?

3. 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 of crude oil resources and to encourage use of other alternatives; **(c)** increase dependence on coal; **(d)** phase out coal by 2050; **(e)** increase dependence on nuclear power; **(f)** phase out all nuclear power plants by 2025.

4. List five ways in which you unnecessarily waste energy during a typical day, and explain how these actions violate the three **principles of sustainability** (see back cover).

5. 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? Suppose you decide not to build a house. How

would you use the money to promote environmental sustainability?

6. 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 (**Concept 2-3b**, p. 34) and net energy (Figure 13-A) to evaluate this claim. CONCEPT LINK

7. Should buyers of energy-efficient motor vehicles receive large rebates funded by fees levied on gas guzzlers? Explain.

8. Explain why you agree or disagree with the following proposals made by various energy analysts:
   a. Government subsidies for all energy alternatives should be eliminated so that all energy choices can compete in a true free-market system.
   b. 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) should be phased out. They should be replaced with subsidies and tax breaks for improving energy efficiency and developing solar, wind, geothermal, hydrogen, and biomass energy alternatives.
   c. Development of solar, wind, and hydrogen energy should be left to private enterprise and should receive little or no help from the federal government, but nuclear energy and fossil fuels should continue to receive large federal government subsidies and tax breaks.

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

In 2008, the average fleet-wide 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 2.4 kilograms of CO_2 are released when 1 liter of gasoline is burned (20 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¢ 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.cengage.com/biology/miller** and choose Chapter 13 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, web links, information on Green Careers, and InfoTrac® College Edition articles.

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14 Environmental Hazards and Human Health

CORE CASE STUDY What's in a Baby Bottle? 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 and 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) used in a variety of products including baby bottles (Figure 14-1) and sipping cups, reusable water bottles, sports drink and juice bottles, microwave dishes, food storage containers, and as a can liner in nearly all canned food and beverage products.

In addition to the possible health threats from exposure to BPA, the widely used bottles made of polycarbonate and other plastics often end up as litter on beaches (Figure 14-2) and in the ocean where they can harm various aquatic animals.

Research indicates that 93% of Americans and most citizens in other industrialized countries have trace levels of BPA in their bodies. 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 exposure to chemicals, as well as questions about health threats from exposure to disease-causing bacteria, viruses, and protozoa and questions about other hazards that kill millions of people each year.

Figure 14-1 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, sipping cups, and the plastic lining of baby formula cans.

Figure 14-2 Discarded plastic bottles and other forms of solid waste litter beaches, pose a threat to beach users, and wash into the ocean where they threaten marine animals.

Key Questions and Concepts

14-1 What major health hazards do we face?

CONCEPT 14-1 People face health hazards from biological, chemical, physical, and cultural factors, and from the lifestyle choices they make.

14-2 What types of biological hazards do we face?

CONCEPT 14-2 The most serious infectious diseases are flu, AIDS, tuberculosis, diarrheal diseases, and malaria.

14-3 What types of chemical hazards do we face?

CONCEPT 14-3 There is growing concern about chemicals that can cause cancers and birth defects and disrupt the human immune, nervous, and endocrine systems.

14-4 How can we evaluate chemical hazards?

CONCEPT 14-4A Scientists use live laboratory animals, case reports of poisonings, and epidemiological studies to estimate the toxicity of chemicals, but these methods have limitations.

CONCEPT 14-4B Many health scientists call for much greater emphasis on pollution prevention to reduce our exposure to potentially harmful chemicals.

14-5 How do we perceive risks and how can we avoid the worst of them?

CONCEPT 14-5 We can reduce the major risks we face by becoming informed, thinking critically about risks, and making careful choices.

Note: Supplements 3 (p. S6) and 6 (p. S26) can be used with this chapter.

The dose makes the poison.

PARACELSUS, 1540

14-1 What Major Health Hazards Do We Face?

CONCEPT 14-1 People face health hazards from biological, chemical, physical, and cultural factors, and from the lifestyle choices they 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 in terms of *probability*—a mathematical statement about the likelihood that 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).

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 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 14-3 summarizes how risks are assessed and managed.

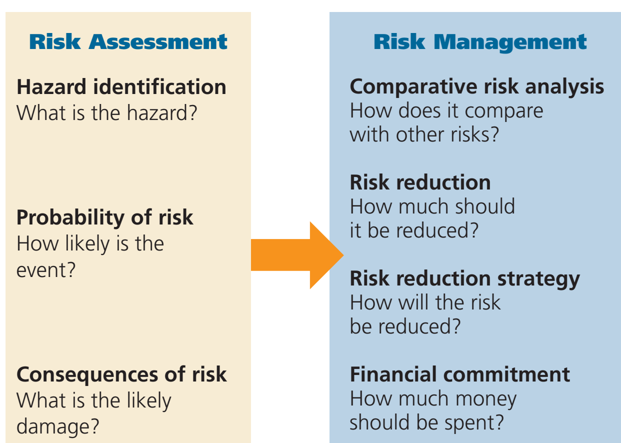


Figure 14-3 **Science:** *risk assessment* and *risk management*. **Question**: What is an example of how you have applied this process in your daily living?

We Face Many Types of Hazards

All of us take risks every day. 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 14-1**):

- *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
- *Physical 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?

14-2 What Types of Biological Hazards Do We Face?

CONCEPT 14-2 The most serious infectious diseases are flu, AIDS, tuberculosis, diarrheal diseases, and malaria.

Some Diseases Can Spread from One Person to Another

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. Examples include cardiovascular (heart and blood vessel) diseases, most cancers, asthma, and diabetes.

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. Examples are tuberculosis, flu, malaria, and measles. 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 tuberculosis, flu, and measles.

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. This has been achieved mostly by a combination of better health care, the use of antibiotics to treat infectious diseases caused by bacteria, and the development of vaccines to prevent the spread of some infectious viral diseases. This has helped us to increase the average life expectancy in most countries. GOOD NEWS

Infectious Diseases Are Still Major Health Threats

Despite these improvements in human health care, infectious diseases remain as serious health threats, especially in developing countries. Figure 14-4 shows major pathways for infectious diseases in humans. Such diseases can then be spread through air, water, food, and body fluids such as feces, urine, blood, and droplets sprayed by sneezing and coughing.

A large-scale outbreak of an infectious disease in an area or country is called an *epidemic*, and a global epidemic such as tuberculosis or AIDS is called a *pandemic*. Figure 14-5 shows the annual death toll from the world's seven deadliest infectious diseases (**Concept 14-2**).

A growing problem is that many disease-carrying bacteria have developed genetic immunity to widely used antibiotics (Science Focus, p. 348). 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). One of every three persons on the planet is infected with

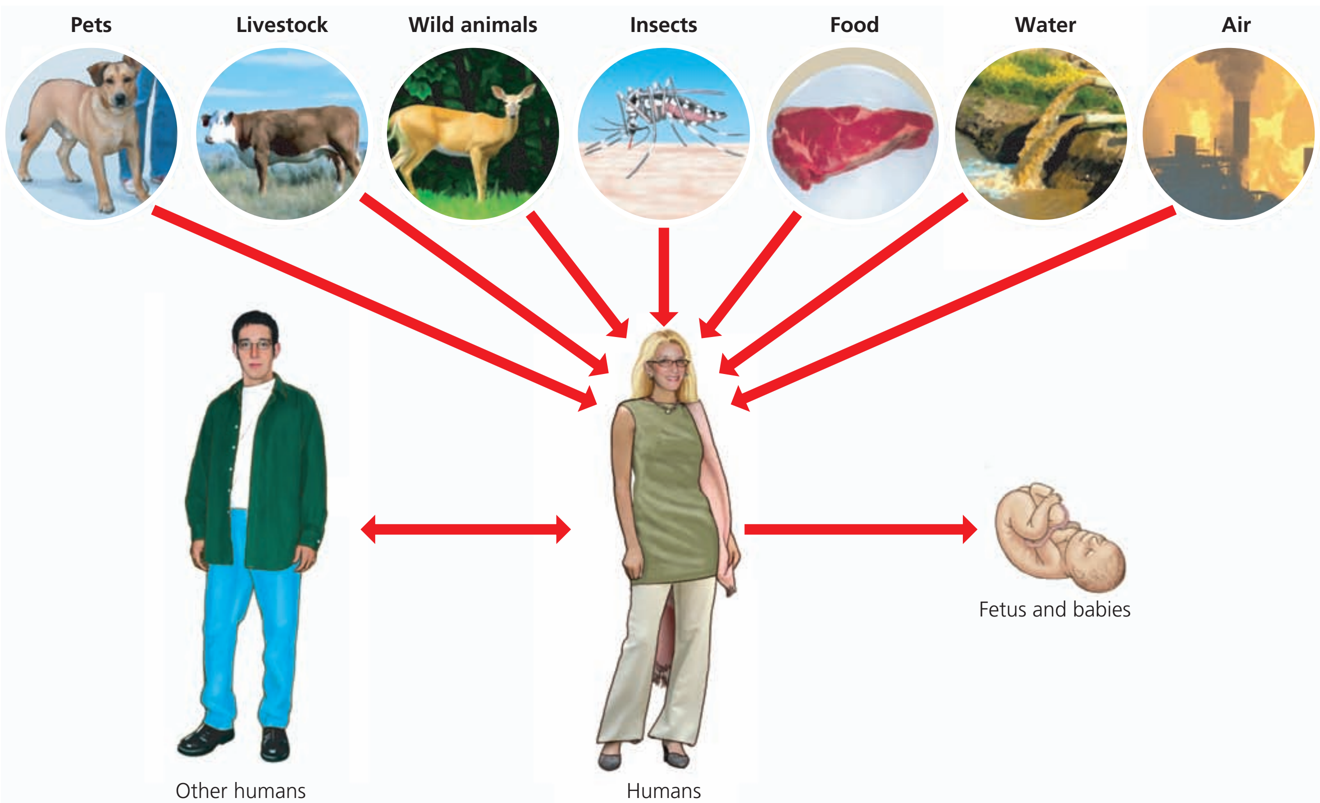


Figure 14-4 **Science:** pathways for infectious disease in humans. **Question**: Can you think of other pathways not shown here?

the TB bacterium and 5–10% of them will eventually become sick with active TB, according to World Health Organization (WHO) estimates. In 2008, about 9.3 million people developed active TB, most of them in poor countries in Asia and Africa.

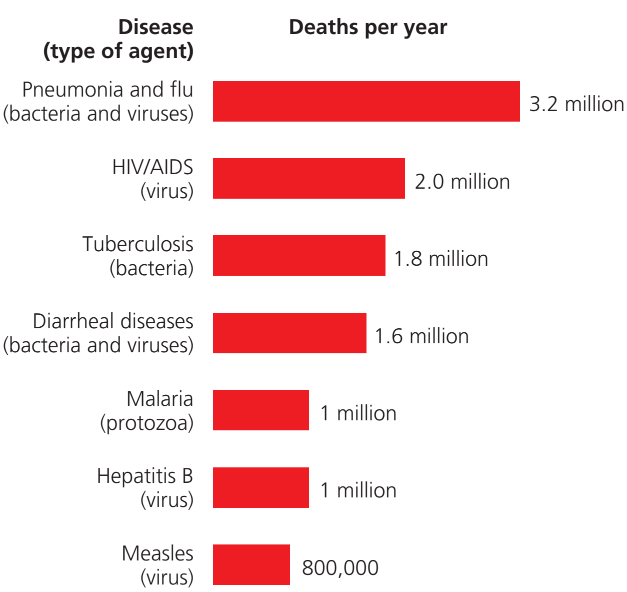


Figure 14-5 *Global outlook:* The World Health Organization estimates that each year, the world's seven deadliest infectious diseases kill 11.1 million people—most of them poor people in developing countries. This is an average of about 30,400 mostly preventable deaths every day. It would be roughly equal to 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, 2009)

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 10–15 other people. Without treatment, about half of the people with active TB die from bacterial destruction of their lung tissue.

According to the WHO, this highly infectious bacterial disease strikes about 9 million people per year and kills 1.6 million—about 84% of them in developing 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 developing countries, where 95% of the new cases occur. And the most common TB test fails to detect TB in about 40% of the world's new TB patients. However, in 2009, engineering students invented a small device that can diagnose TB in seconds at a cost of less than a dollar. If proven successful, it could help slow the global TB pandemic.

A second problem is that most strains of the TB bacterium have developed genetic resistance to the majority of the effective antibiotics (Science Focus, p. 348). Also, population growth, urbanization, and air travel have greatly increased person-to-person contacts, and TB is spreading faster in urban 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. 349) greatly weakens its victims' immune systems, which allows TB bacteria to multiply in AIDS victims. As a result, people

SCIENCE FOCUS

Genetic Resistance to Antibiotics Is Increasing

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 become genetically resistant to an increasing number of antibiotics through natural selection (**Concept 4-2A**, p. 63, and Figure 4-5, p. 65). In addition, some drug-resistant bacteria can quickly transfer their resistance to nonresistant bacteria by exchanging genetic material.

CONCEPT LINK

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.

Yet another factor is overuse of antibiotics. Many doctors prescribe antibiotics for colds, flu, and the majority of sore throats, which are viral diseases that cannot be treated with antibiotics. In many countries, antibiotics are available without a prescription, which promotes unnecessary use. The widespread use of antibiotics to control disease and to promote growth in livestock and dairy animals, has also increased bacterial resistance to some antibiotics. And the growing use of antibacterial hand soaps and other cleansers is probably promoting genetic resistance 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 (Case Study, p. 346).

Each year, genetic resistance to antibiotics plays a role in the deaths of at least 90,000 of the 2 million people who pick up mostly preventable infections while they are in U.S. hospitals, according to the U.S. Centers for Disease Control and Prevention. This serious problem is much worse in hospitals in many other countries.

A bacterium known as methicillin-resistant *staphylococcus aureus*, or MRSA, has become resistant to most common antibiotics. This staph infection first appears on the skin as a red, swollen pimple or boil that may be painful and have pus. 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. In 2007, the Centers for Disease Control and Prevention reported that more than 94,000 people in the United States had MRSA infections, which contributed to the premature deaths of almost 19,000 people—more than the 15,000 people killed by AIDS that year in the United States.

Critical Thinking

What are three things that could be done to slow the rate at which disease-causing organisms develop resistance to antibiotics?

with AIDS are 30 to 50 times more likely to develop active TB.

Slowing the spread of the disease requires early identification and treatment of people with active TB, especially those with a chronic cough. Treatment with a combination of four drugs can cure 90% of individuals with active TB for as little as $20 per person. To be effective, the drugs must be taken every day for 6–9 months. Because the symptoms disappear after a few weeks, many patients think they are cured and 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 *multidrug resistant TB* has been increasing. According to the WHO, this drug-resistant form of TB is now found in 55 countries (including the United States), and each year, there are more than 500,000 new cases and 116,000 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 and to potentially anyone who takes a train or a plane and is exposed to undiagnosed people with this so-far-incurable form of TB.

Most people with active TB live in the world's poorest countries. 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, there are efforts to develop better antibiotics, being undertaken by governments and private groups such as the Bill and Melinda Gates Foundation.

GOOD NEWS

Some Viral Diseases 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 14-2**), which is transmitted by the body fluids or airborne emissions of an infected person. Flu viruses regularly contribute to the deaths of about 1 million people a year—about 36,000 of them in the United States. In the past, especially potent flu viruses have developed. Some of these have killed up to 80% of people infected by them, including healthy young adults. The global flu pandemic of 1918, for example, killed 20–50 million people within a few months and caused economic and social disruption.

The second biggest viral killer is the *human immunodeficiency virus* (HIV) (see Case Study at right). On a global scale, HIV infects about 2.5 million people each year, and the resulting complications from AIDS kill about 2 million people annually. It is transmitted by unsafe sex, sharing of needles by drug users, infected mothers who pass the virus to their offspring before or during birth, and exposure to infected blood.

The third largest viral killer is the *hepatitis B virus* (HBV), which damages the liver and kills about a million people each year. It is transmitted in the same ways that HIV is spread.

In recent years, several other viruses that cause previously unknown diseases have received widespread media coverage. One is the *West Nile virus*, which is transmitted to humans by the bite of a common mosquito that becomes 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 2008, it caused severe illness, including encephalitis and meningitis, in more than 12,000 people and killed more than 1,100 people. Fortunately, the chance of being infected and killed by this disease is low (about 1 in 2,500).

A second highly publicized virus is the *severe acute respiratory syndrome* (*SARS) virus*, which first appeared in humans in China in 2002. SARS, which has flu-like symptoms, can quickly turn into life-threatening pneumonia and is easily spread from person to person. During 6 months in 2003, the disease began spreading beyond China, where it infected at least 8,500 people and caused 812 deaths. Swift local action by the WHO and other health agencies helped to contain the spread of this disease by July 2003. But without careful vigilance, it could break out again.

Health officials are concerned about the spread of West Nile virus, SARS, and other *emerging viral diseases* and are working hard to control them. But in terms of annual infection rates and deaths, the three most dangerous viruses by far are still flu, HIV, and HBV (**Concept 14-2**).

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.

Another growing hazard is diseases that spread from one animal species to another and from wild and domesticated animal species to humans. Examples include avian flu, HIV, SARS, and West Nile virus. Most people do not realize that pets such as rabbits, hamsters, and turtles can transfer various infectious diseases to humans. This development has spurred the growth of the relatively new field of *ecological medicine*.

Yet another growing health hazard is infectious diseases caused by parasites, especially malaria (see Case Study on p. 350)

■ **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 tuberculosis (TB) and rare forms of cancer such as *Kaposi's sarcoma*. The virus is transmitted from one person to another by unsafe sex, sharing of needles by drug users, infected mothers who pass the virus on to their offspring before or during birth, and exposure to infected blood.

Since the HIV virus was identified in 1981, this viral infection has spread exponentially around the globe. According to the WHO, in 2008, a total of about 33 million people worldwide (1 million in the United States) were living with HIV. Over two-thirds of them were in African countries located south of the Sahara Desert (sub-Saharan Africa).

Also, 2008 saw about 2.7 million new cases of AIDS (40,000 in the United States)—an average of about 7,400 new cases per day—half of them in people between the ages of 15 and 24. Within 7–10 years after they are infected, at least half of all HIV-infected people develop AIDS. This long incubation period means that infected people often spread the virus for several years without knowing they are infected.

Currently, there is no vaccine to prevent HIV infection and no cure for AIDS. If you get AIDS, you will almost certainly die from it. Drugs help some infected people live longer, but 90% of those suffering from AIDS cannot afford to use these drugs.

Between 1981 and 2008, more than 27 million people—roughly the number of people living in the U.S. states of Texas and Iowa—died of AIDS-related diseases. During this same period, there were almost 600,000 AIDS-related deaths in the United States—a number about equal to the population of the U.S. city of Milwaukee, Wisconsin. Each year AIDS claims about 2 million more lives (15,000 in the United States)—an average of nearly 5,500 premature deaths every day.

AIDS has reduced the life expectancy of the 750 million people living in sub-Saharan Africa from 62 to 47 years—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 in African countries such as Botswana (Figure 6-9, p. 104) leads to diminished education and health care, decreased food production and economic development, and disintegrating families.

According to the WHO, a global strategy to slow the spread of AIDS should have five major priorities. *First*, reduce the number of new infections below the number of deaths. *Second*, concentrate on the groups in a society that are most likely to spread the disease such as sex workers, intravenous drug users, and soldiers. *Third*, provide free HIV testing and pressure people from high-risk groups to get tested. *Fourth*, implement mass-advertising and education programs geared toward adults and school children to help prevent the disease. *Fifth*, provide free or low-cost drugs to help slow the progress of the disease.

HOW WOULD YOU VOTE? ✓

Should developed and developing nations mount an urgent global campaign to reduce the spread of HIV and to help countries afflicted by the disease? Cast your vote online at **www.cengage.com/biology/miller**.

CENGAGENOW™ Examine the HIV virus and how it replicates by using a host cell at CengageNOW.

CASE STUDY

Malaria—Death by Parasite-Carrying Mosquitoes

About one of every five people in the world—most of them living in poor African countries—is at risk from malaria (Figure 14-6). This should also concern 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 mosquito species. It infects and destroys red blood cells, causing intense fever, chills, drenching sweats, anemia, severe abdominal pain, headaches, vomiting, extreme weakness, and greater susceptibility to other diseases. It kills an average of at least 2,700 people per day (**Concept 14-2**). (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 *Plasmodium* parasite, ingests blood that contains the parasite, and later bites an uninfected person (Figure 14-7). *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 blood transfusions and by drug users sharing needles.

The malaria cycle repeats itself until immunity develops, treatment is given, or the victim dies. *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 were breeding 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, clearing and developing tropical forests leads to the spread of malaria among workers and the settlers who follow. Also people with HIV are more vulnerable to malaria, and people with malaria are more vulnerable to HIV.

CONNECTIONS

Projected Climate Change and Malaria

Projected climate change is also likely to increase 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.

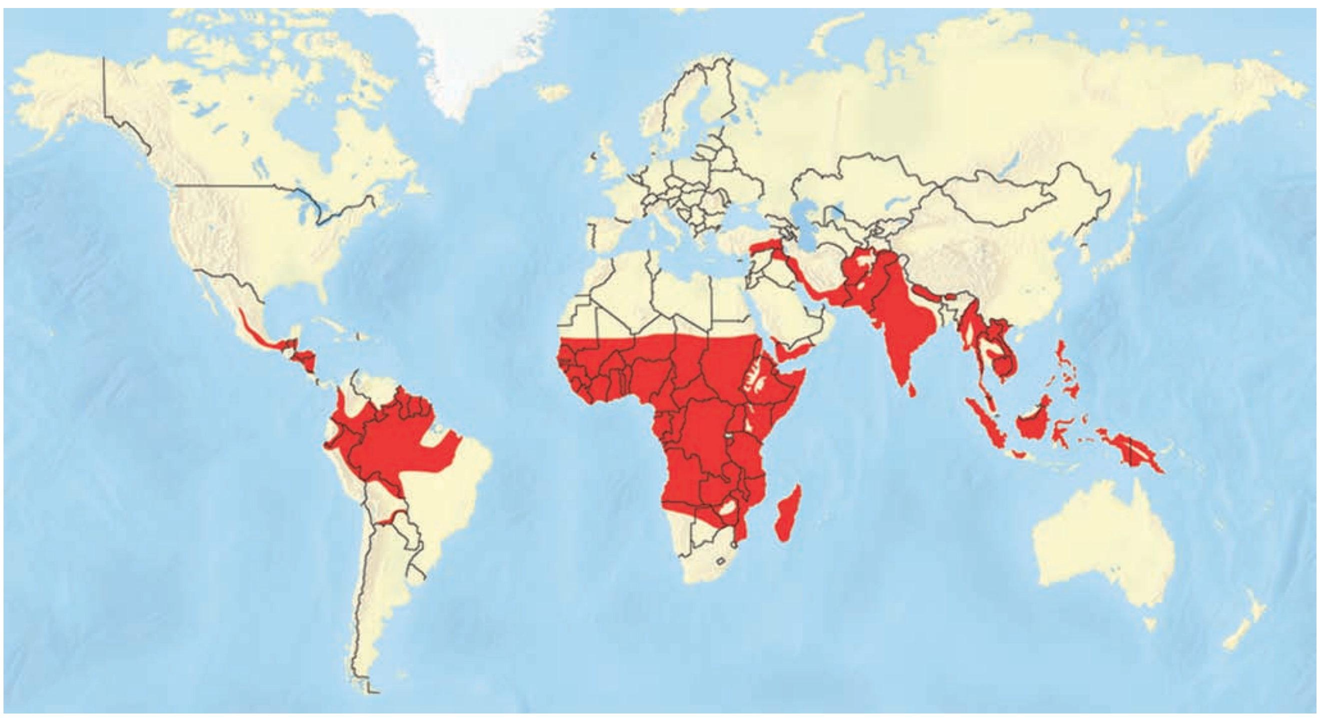


Figure 14-6 *Global outlook:* distribution of malaria. About 40% of the world's population lives in areas in which malaria is prevalent. Malaria kills at least 1 million people a year, which is roughly equivalent to wiping out the entire population of the U.S. city of Dallas, Texas, each year. More than 80% of these victims live in sub-Saharan Africa—most of them children younger than age 5 (**Concept 14-2**). (Data from the World Health Organization and U.S. Centers for Disease Control and Prevention, 2007)

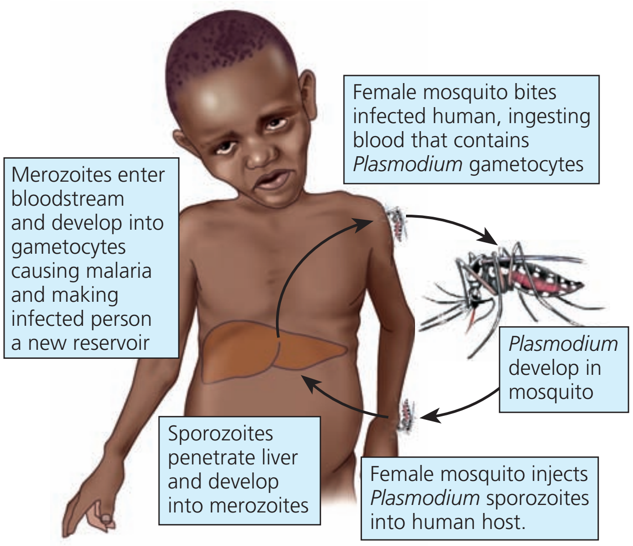


Figure 14-7 **Science:** the life cycle of malaria. Plasmodium parasites circulate from mosquito to human and back to mosquito.

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.

Another approach is to provide poor people in malarial regions with free or inexpensive, long-lasting, insecticide-treated bed nets (Figure 14-8) and window screens. Also, zinc and vitamin A supplements could be used to boost resistance to malaria in children. And we can greatly reduce the incidence of malaria by spraying the insides of homes with low concentrations of the pesticide DDT twice a year at a low cost. Under an international treaty enacted in 2002, DDT and five similar pesticides are being phased out in developing countries. However, in 2006 the WHO supported the use of DDT for malaria control.

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."

© Mark Edwards/Peter Arnold, Inc.

Figure 14-8 A boy in Brazil's Amazon sleeps under an insecticide-treated mosquito net to reduce the risk of getting bitten by malaria-carrying mosquitoes. Such nets cost about $5 each and can be donated through groups such as **www.MalariaNoMore.org**.

CENGAGENOW™ Watch through a microscope what happens when a mosquito infects a human with malaria at CengageNOW.

RESEARCH FRONTIER

Ecological medicine. See **www.cengage.com/biology/miller**.

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 developing countries who were immunized with vaccines to prevent tetanus, measles, diphtheria, typhoid fever, and polio increased from 10% to 90%—saving about 10 million lives each year.

GOOD NEWS

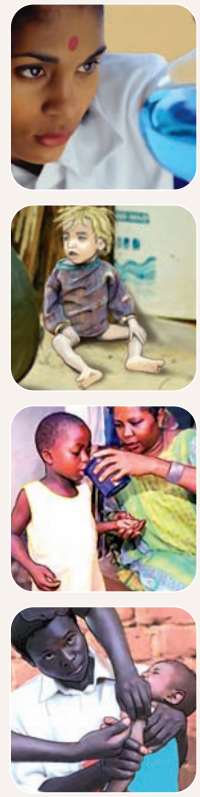
Figure 14-9 (p. 352) lists measures promoted by health scientists and public health officials to help prevent or reduce the incidence of infectious diseases—especially in developing countries. An important breakthrough has been the development of simple *oral rehydration therapy* to help prevent death from dehydration for victims of severe diarrhea, which causes about one-fourth of all deaths of children younger than age 5. It 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. In 2006, the WHO estimated that implementing the solutions in Figure 14-9 could save the lives of as many as 4 million children younger than age 5 each year.

Figure 14-9 Ways to prevent or reduce the incidence of infectious diseases, especially in developing countries. **Question**: Which three of these approaches do you think are the most important?

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



CONNECTIONS

Drinking Water, Latrines, and Infectious Diseases

More than a third of the world's people—2.6 billion—do not have decent 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 U.N. estimates that this could be done for about $20 billion a year—about what people in wealthier countries, who have almost universal access to cheap clean water, spend each year on bottled water.

However, the WHO estimates that only 10% of global medical research and development money goes toward preventing infectious diseases in developing countries, even though more people worldwide 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 almost $2 billion to improve global health, with primary emphasis on infectious diseases in developing countries. **GREEN CAREER:** Infectious disease prevention

GOOD NEWS

14-3 What Types of Chemical Hazards Do We Face?

CONCEPT 14-3 **There is growing concern about chemicals 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 U.S. Environmental Protection Agency (EPA) listed arsenic, lead, mercury, vinyl chloride (used to make PVC plastics), and polychlorinated biphenyls (PCBs) 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, chloroform, formaldehyde, gamma radiation, nickel, PCBs, radon, certain chemicals in tobacco smoke, ultraviolet (UV) radiation, X-rays, and vinyl chloride.

Typically, 10–40 years may elapse between the initial exposure to a carcinogen and the appearance of detectable 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. According to the American Cancer Society, in 2007, there were at least 12 million new cancer cases (56% of them in developing countries) and 7.6 million cancer deaths—an average of about 21,000 a day. As the world's population ages these numbers are very likely to rise.

The second major type of toxic agent, **mutagens**, includes chemicals or forms of radiation that cause mutations, or changes, in the DNA molecules found in cells, or that increase the frequency of such changes. 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 with such preservatives. Harmful mutations occurring in reproductive cells can be passed on to offspring and to future generations.

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, cadmium, formaldehyde, lead, mercury (Science Focus, p. 354), mescaline, PCBs, 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. Figure 14-10 shows potential pathways on which toxic chemicals such as PCBs move through the living and nonliving environment.

Some Chemicals May Affect Our Immune, Nervous, and Endocrine 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 14-3**).

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, methyl mercury (Science Focus, p. 354), arsenic, lead, and certain pesticides.

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 these chemical messengers turn on and turn off 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 cells, using a part of the cell called a *receptor*, and to transmit its chemical message. 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 disrupt the endocrine system in people and some other animals. These molecules are called *hormonally active agents* (HAAs).

CORE CASE STUDY

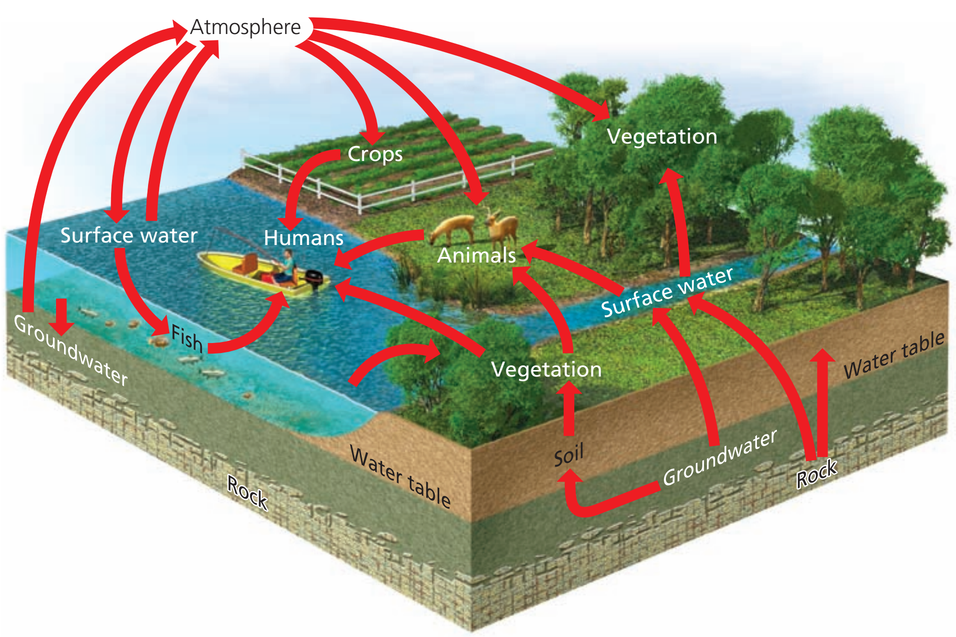


Figure 14-10 Potential pathways on which toxic chemicals can move through the living and nonliving environment.

SCIENCE FOCUS

Mercury's Toxic Effects

Mercury (Hg) and its compounds are all toxic. Research indicates that long-term exposure to high levels of mercury can permanently damage the human nervous system, brain function, kidneys, and lungs. And fairly low levels of mercury can 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 and coal-burning industrial facilities.

Even with fairly strict air pollution standards, mercury emissions from coal-burning power plants in the United States emit about 49 metric tons (54 tons) of mercury a year, according to the EPA. In China—the world's largest coal user—mercury emissions from coal burning power plants and factories are much larger because of a lack of air quality laws and enforcement. Some of the indestructible particles of mercury released in China end up in the air, water, and soil in the western United States.

Because mercury is an element, it cannot be broken down or degraded. Therefore this indestructible global pollutant accumulates in soil, water, and the bodies of people and other animals that feed high on food chains and webs. This includes polar bears, toothed whales, and seals living in the Arctic, which is a global mercury hotspot.

In the atmosphere, some elemental mercury is converted to more toxic inorganic and organic mercury compounds that can be deposited in aquatic environments. In acidic aquatic systems, bacteria can convert inorganic mercury compounds to highly toxic methylmercury, which can be biologically magnified in food chains and webs (Figure 8-15, p. 166). As a result, high levels of methylmercury (CH_3Hg^+) are often found in the tissues of large fishes such as albacore (white) tuna, sharks, swordfish, king mackerel, tilefish, walleye, and marlin.

Humans are exposed to mercury in three ways. *First*, they may inhale vaporized elemental mercury (Hg) or particles of inorganic mercury salts such as HgS and $HgCl_2$. *Second*, they may eat fish contaminated with highly toxic methylmercury (CH_3Hg^+). *Third*, high fructose corn syrup (HFCS) is 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. And another 2005 study by food safety researcher David Wallinga 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 this chemical 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 other neurological problems because of such exposure. Methylmercury may also harm the heart, kidneys, and immune system of 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. The EPA also warned that one-fourth of the nation's rivers, one-third of its lakes (including all of the Great Lakes), and three-fourths of its coastal waters are contaminated with mercury. Figure 14-A lists ways to prevent or reduce human exposure to mercury.

In 2003, the U.N. Environment Programme recommended phasing out coal-burning power plants and waste incineration throughout the world as rapidly as possible. Other recommendations are to reduce or eliminate mercury used in batteries and paints and in factories that produce chlorine by no later than 2020. Substitute materials are available for such uses. In 2009, the United States endorsed negotiations for developing an international treaty to help control mercury pollution.

Critical Thinking

Should we phase out all coal burning as rapidly as possible as a way to sharply reduce mercury pollution? Explain. How might your lifestyle change if this were done?

Solutions

Mercury Pollution

Prevention

- Phase out waste incineration
- Remove mercury from coal before it is burned
- Switch from coal to natural gas and renewable energy resources such as wind, solar cells, and hydrogen
- Convert coal to liquid or gaseous fuel
- Phase out use of mercury in batteries, TVs, compact fluorescent lightbulbs, and all other products unless they are recycled

Control

- Sharply reduce mercury emissions from coal-burning plants and incinerators
- Heavily tax each unit of mercury emitted by coal-burning plants and incinerators
- Require labels on all products containing mercury
- Collect and recycle mercury-containing electric switches, relays, compact fluorescent lightbulbs, and dry-cell batteries

Figure 14-A 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?

Examples of HAAs include aluminum, atrazine and several other herbicides, DDT, mercury (Science Focus, at left), PCBs, phthalates, and BPA. Some hormone imposters such as BPA (**Core Case Study**) are chemically similar to estrogens (female sex hormones) and can disrupt the endocrine system by attaching to estrogen receptor molecules. Others, called *hormone blockers*, disrupt the endocrine system by preventing natural hormones such as androgens (male sex hormones) from attaching to their receptors. 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 such species are generally becoming more feminine. A likely culprit is long-term exposure to low levels of gender-bending synthetic chemicals that we have added to the environment. There is also growing concern about another group of HAAs—pollutants that can act as *thyroid disrupters* and cause growth, weight, 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 damage, early puberty, prostrate disease, breast cancer, heart disease, liver damage, reduced sperm count, impaired immune function, type 2 diabetes, hyperactivity, increased aggressiveness, impaired learning, increased addiction to drugs such as amphetamines, decreased sex drive in males, and obesity in unborn test animals exposed to BPA. On the other hand, 12 studies funded by the chemical industry found no evidence or only weak evidence for adverse effects from low-level exposure to BPA in test animals.

In 2008, the U.S. Food and Drug Agency (FDA) concluded that BPA from 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. It also said the agency used flawed methods in reaching its conclusions and did not allow an adequate margin of safety in setting standards for fetuses and children.

In 2008, Canada classified BPA as a toxic substance and announced a ban on its use in baby bottles (Figure 14-1) and plans to develop strict regulations for its use in can liners. Some baby bottle manufacturers in Europe and the United States have voluntarily stopped using BPA in baby bottles. In 2009, Chicago, Illinois became the first U.S. city to ban the use of BPA in baby bottles and sipping cups. Makers of BPA claim that the chemical poses no known risk to human health.

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 used as solvents in many consumer products. Phthalates are found in many perfumes, cosmetics, baby powders, body lotions, 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 tubes used in hospitals.

A 2008 study by Sheela Sathyararani and her colleagues tested urine from the diapers of 163 infants aged 2 months to 28 months. They found that 81% of the urine had measurable amounts of seven or more phthalates contained in baby powders, baby lotions, 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 suppression, and abnormal sexual development. The European Union and at least 14 other countries have banned phthalates. But scientists in the United States are divided on its risks to human health and reproductive systems. U.S. toy makers say that phthalates, which have been used for more than 20 years in baby items, pose no threats. In addition, they warn that substitutes could make plastic toys more brittle and subject to breaking, which could cause harm.

Some scientists hypothesize that certain problems may be related to increased levels of hormone disruptors in our bodies. Examples include sharp decreases in male sperm counts and male sperm mobility detected in 20 countries on six continents, increased rates of testicular cancer and birth defects in males, and increased breast cancer rates in women. Much more research will be needed to test these hypotheses.

The scientific and economic controversies over possible health risks from exposure to chemicals such as BPA (**Core Case Study**) 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 products that we use. Resolving these uncertainties will take decades of research.

Meanwhile, some scientists believe that as a precaution, 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.

RESEARCH FRONTIER

Evaluating the health effects of HAAs and looking for substitutes for such chemicals. See **www.cengage.com/biology/miller**.

14-4 How Can We Evaluate Chemical Hazards?

▶ **CONCEPT 14-4A Scientists use live laboratory animals, case reports of poisonings, and epidemiological studies to estimate the toxicity of chemicals, but these methods have limitations.**

▶ **CONCEPT 14-4B 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

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 concept 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.*

This is a difficult question to answer because of the many variables involved in estimating the effects of human exposure to chemicals. 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 Case Study, at right.) Toxicity also depends on *genetic makeup*, which determines an individual's sensitivity to a particular toxin. Some individuals 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 and get into water supplies and 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 wildlife are likely to come in contact with them and that they are more likely to remain in the body and have long-lasting harmful health effects.

Biological magnification, in which the concentrations of some potential toxins in the environment increase as they pass through the successive trophic levels of food chains and webs, is another factor in toxicity. Organisms at low trophic levels might ingest only small amounts of a toxin, but animals on the next trophic level up that eat those organisms will take in larger amounts of that toxin, and this effect will grow with each succeeding trophic level (Figure 8-15, p. 166). Examples of chemicals that can be biomagnified include long-lived, fat-soluble, organic compounds such as DDT and PCBs.

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; and many natural chemicals such as mercury and lead are deadly.

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.

■ **CASE STUDY**

Protecting Children from Toxic Chemicals

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 cause cancers in humans or animals, 217 damage the brain and nervous systems in test animals, and 208 cause 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.

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. *And 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 face a risk 10 times higher than that faced by 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 Nonanimal 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 somewhat like humans' systems do. Also, they are small and can reproduce rapidly under controlled laboratory conditions.

Animal tests take 2–5 years, 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 least, to ensure that they are treated in the most humane manner possible.

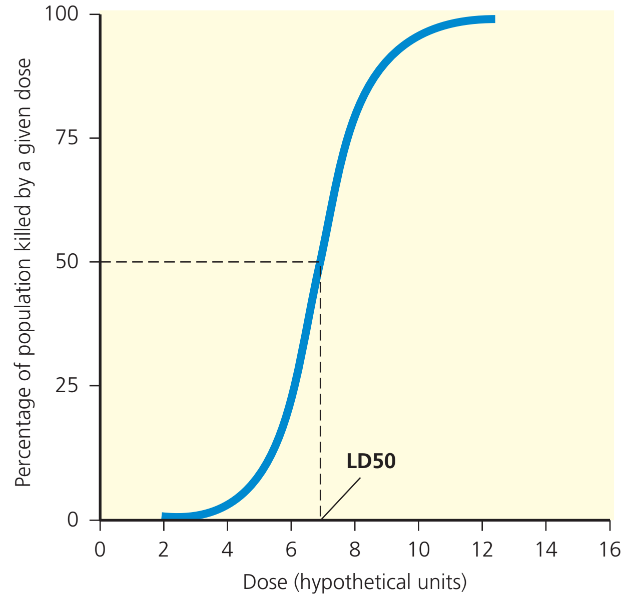


Figure 14-11 **Science:** hypothetical dose-response curve showing determination of the LD50, the dosage of a specific chemical that kills 50% of the animals in a test group. Toxicologists use this method to compare the toxicities of different chemicals.

Scientists estimate the toxicity of a chemical by determining the effects of various doses of a chemical on test organisms and plotting the results in a **dose-response curve** (Figure 14-11). 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 14-1). Some poisons can cause serious harm or death after a single exposure at very low dosages. Others cause such

Table 14-1

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.

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.

Studying the effects of low dosages of chemicals is extremely difficult and controversial. Scientists usually use mathematical models to *extrapolate*, or estimate the effects of low-dose exposures based on the measured results of high-dose exposures. Then they extrapolate these results from test organisms to humans to estimate LD50 values for acute toxicity (Table 14-1).

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 the biological activity of more than one million compounds a day to help determine their possible toxic effects. Such non-animal testing methods are also faster and cheaper than animal tests.

GOOD NEWS

RESEARCH FRONTIER

Computer modeling and other alternatives to animal testing. See **www.cengage.com/biology/miller**.

THINKING ABOUT
Animal Testing

Should laboratory-bred mice, rats, and other animals be used to determine toxicity and other effects of chemicals? Explain.

The problems with estimating toxicities by using laboratory experiments get even more complicated (**Concept 14-4A**). 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. And adding the problem of evaluating *mixtures of potentially toxic substances*, separating out which are the culprits, and determining how they can interact with one another is overwhelming from a scientific and economic standpoint. For example, just studying the interactions of 3 of the 500 most widely used industrial chemicals would take 20.7 million experiments—a physical and financial impossibility.

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 death 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. And *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 14-12) that have built up to trace levels in their blood and other parts of their bodies.

Should we be concerned about trace amounts of various synthetic chemicals in air, water, food, and our bodies? The honest answer is that, in most cases, we do not know because there is too little data and because of the difficulty of determining the effects of exposures to low levels of these chemicals (**Concept 14-4A**).

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. They point out that average life expectancy has been increasing in most countries, especially developed countries, for decades. Some scientists contend that the concentrations of such chemicals are so low that they are harm-

CORE CASE STUDY

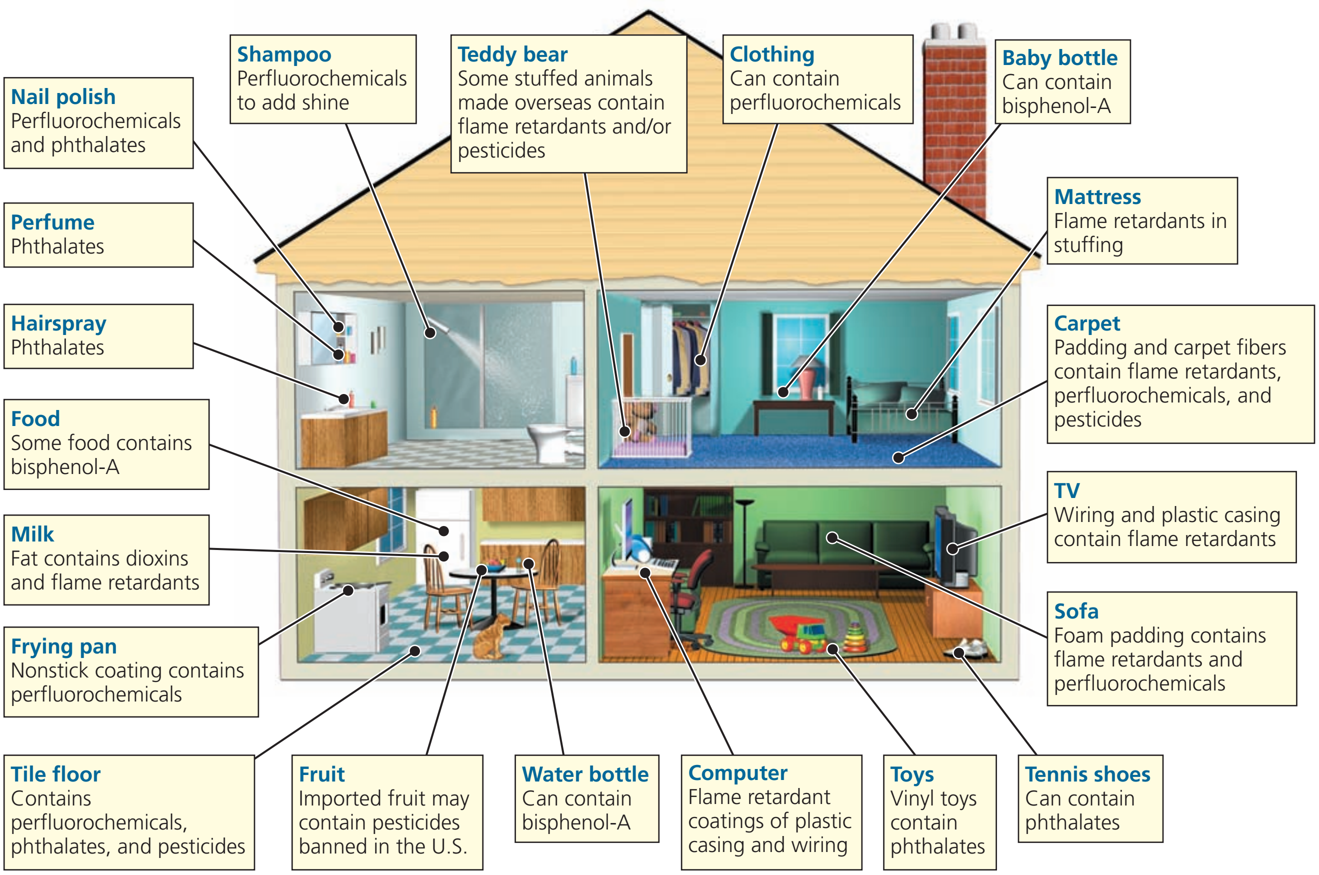


Figure 14-12 Some potentially harmful chemicals found in most homes. Most people have traces of these chemicals in their blood and body tissues. We do not know the long-term effects of exposure to low levels of such chemicals. (Data from U.S. Environmental Protection Agency, Centers for Disease Control and Prevention, and New York State Department of Health) **Questions**: Does the fact that we do not know much about long-term harmful effects of these chemicals make you more likely or less likely to minimize your exposure to them? Why?

less. Others are not so sure, especially when we are exposed to trace levels of hormone imposters because most natural hormones exist only in trace amounts in the human body.

Chemists are now able to detect much smaller amounts of potentially toxic chemicals in air, water, and food than they had previously been able to detect. 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 uncovering levels of chemicals that have been around for a long time.

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 14-4A**). 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 and ionizing radiation 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 about 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, teratogens, or mutagens. 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 regulate about 99.5% of the commercially used 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* (**Concept 14-4B** and **Concept 1-4**, p. 15). 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, below). Another option is to recycle them within production processes to keep them from reaching the environment, as the U.S. companies 3M and DuPont have been doing.

CONCEPT LINK

Pollution prevention is a strategy for implementing the *precautionary principle* (p. 174). According to this principle, when there is reasonable but incomplete scientific evidence of significant or irreversible harm to humans or the environment from a proposed or existing chemical or technology, we should take action to prevent or reduce the risk instead of waiting for more conclusive (reliable) scientific evidence (**Concept 14-4B**).

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 in the United States and most countries. *First*, new chemicals and technologies would be assumed to be harmful until scientific studies could show otherwise. *Second*, existing chemicals and technologies that appear to have a strong chance of causing significant harm would be removed from the market until their safety could be established. 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 this direction, especially in the European Union. In 2000, negotiators agreed to a global treaty that would ban or phase out use of 12 of the most notorious *persistent organic pollutants (POPs)*, also called the *dirty dozen* (See **http://www.pops.int/**). The list includes DDT and eight other persistent pesticides, PCBs, dioxins, and furans. In 2009, 9 more POPs were added, some of which are widely used in pesticides and flame retardants.

Animal studies have shown that the harmful effects of various POPs include tumors and cancers, birth defects, compromised immune systems, feminization of males and masculinization of females, abnormally functioning thyroid glands, and reproductive failure. Because such evidence is controversial, these chemicals qualify for being phased out as a reasonable precaution. New chemicals will be added to the list when the harm they could potentially cause is seen as outweighing their usefulness. This treaty went into effect in 2004 but has not been ratified and implemented by the United States.

In 2006, the European Union enacted new regulations that require the registration of 30,000 untested and unregulated potentially harmful chemicals. The most hazardous substances will no longer be approved for use if safer alternatives exist. And when there is no alternative, producers must present a research plan aimed at finding one. Many environmental scientists applaud this use of the precautionary principle and pollution prevention, but some say the regulation does not go far enough and has too many loopholes.

Manufacturers and businesses contend that widespread application of this approach would make it too

INDIVIDUALS MATTER

GOOD NEWS

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 (Figure 3-3, p. 41). It protects 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 principle of pollution prevention 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. 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 new cleaning technique has reduced circuit board defects by about 75% at the company. And 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.

expensive and almost impossible to introduce any new chemical or technology. They argue that we will never have a risk-free society.

Proponents of increased reliance on using pollution prevention agree that we can go 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 14-4B**). They also point out that using this principle focuses the efforts and creativity of scientists, engineers, and businesses on finding solutions to pollution problems based on prevention rather than on cleanup.

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 more people consuming more things 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/biology/miller**.

14-5 How Do We Perceive Risks and How Can We Avoid the Worst of Them?

CONCEPT 14-5 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 14-3, left), ranking risks (*comparative risk analysis*), determining options and making decisions about reducing or eliminating risks (*risk management*; Figure 14-3, right), and informing decision makers and the public about risks (*risk communication*).

Statistical probabilities based on past experience, animal testing, and other tests are used to estimate risks from older technologies and chemicals. To evaluate new technologies and products, risk evaluators use more

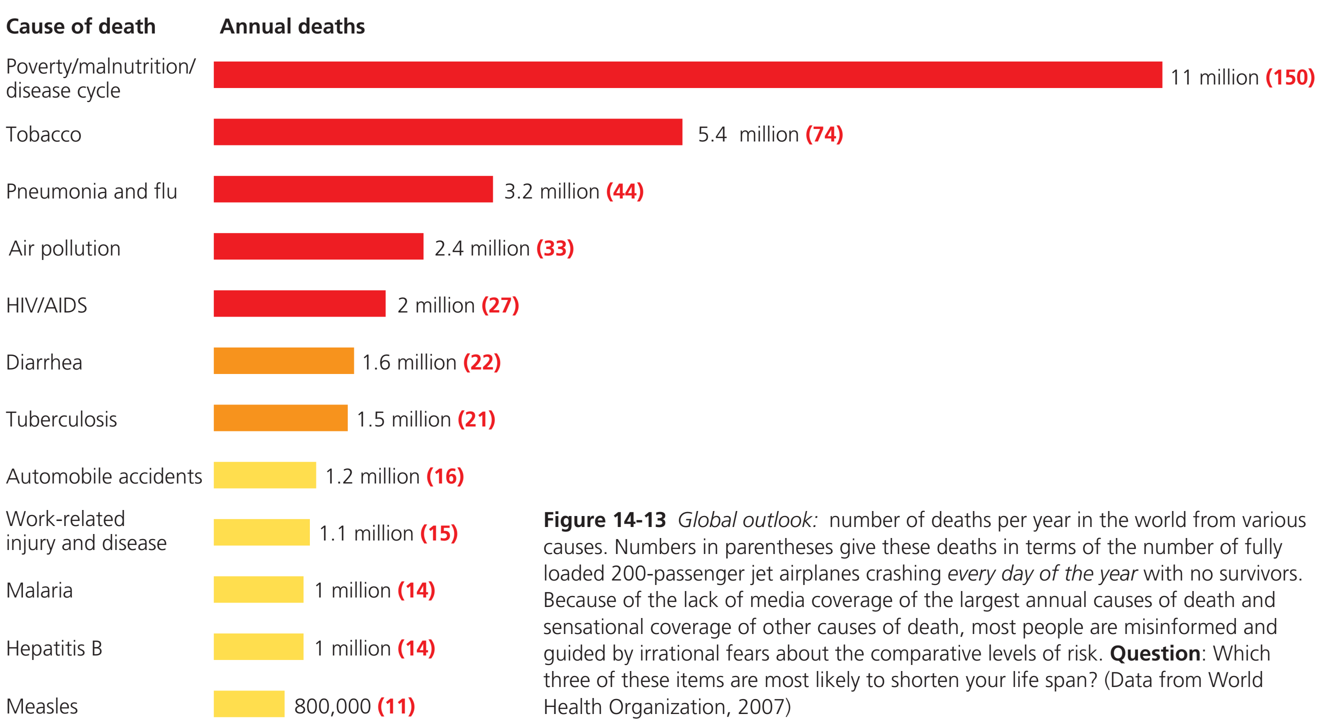


Figure 14-13 *Global outlook:* number of deaths per year in the world from various causes. Numbers in parentheses give these deaths in terms of the number of fully loaded 200-passenger jet airplanes crashing *every day of the year* with no survivors. Because of the lack of media coverage of the largest annual causes of death and 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)

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 14-13) and reduced life span (Figure 14-14), *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, and often-fatal infectious diseases transmitted by unsafe drinking water.

After poverty and gender, the greatest risks of premature death mostly result from lifestyle choices that people make (Figures 14-13 and 14-14) (**Concept 14-1**). The best ways to reduce one's risk of premature death and serious health problems are to avoid smoking and exposure to smoke (see Case Study, at right), 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 14-5**).

For example, 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. Each year the number of lives this would save roughly equals the entire population of the U.S. city of Chicago, Illinois.

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.

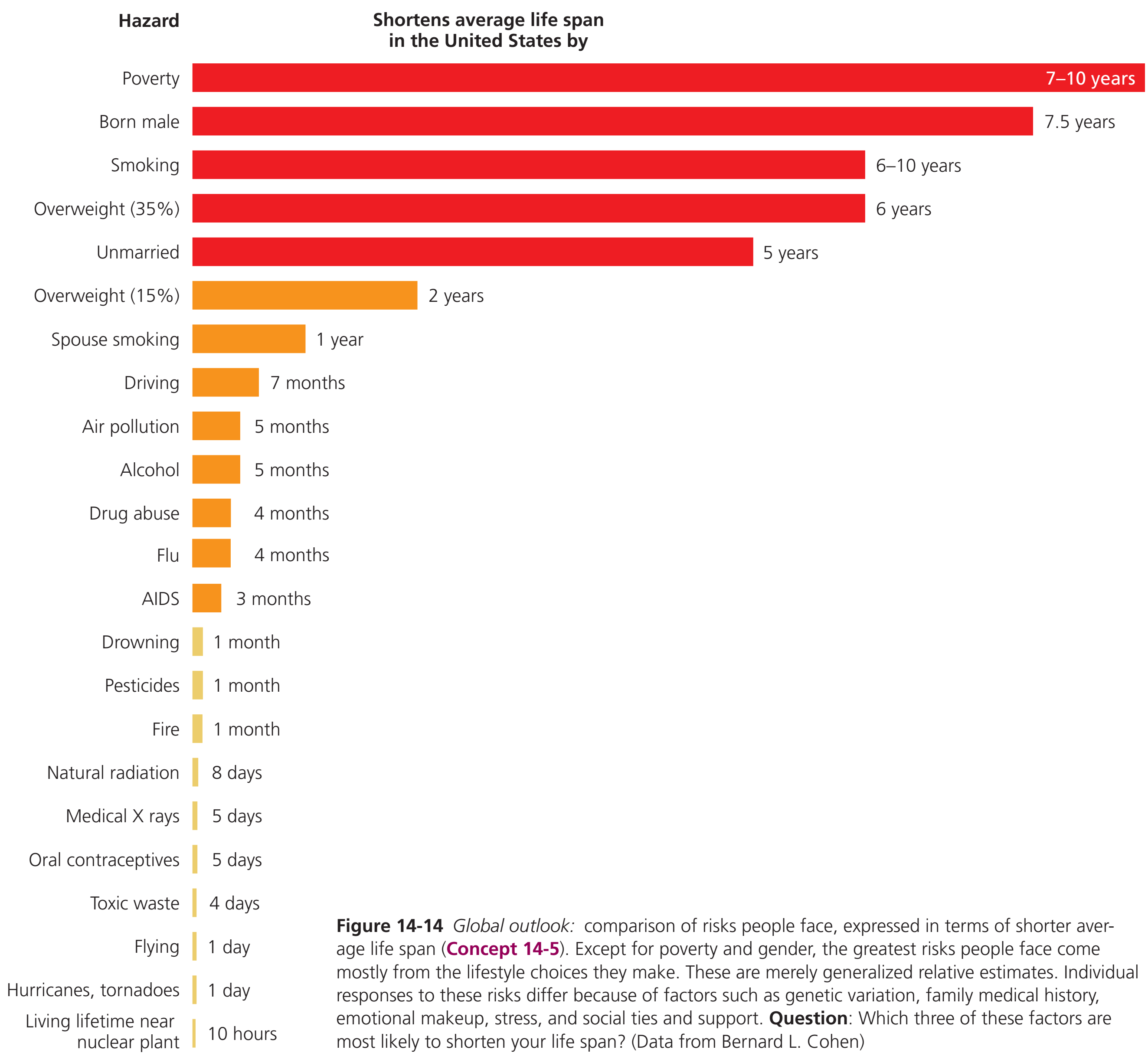


Figure 14-14 *Global outlook:* comparison of risks people face, expressed in terms of shorter average life span (**Concept 14-5**). Except for poverty and gender, the greatest risks people face come mostly from the lifestyle choices they make. These are merely generalized relative estimates. Individual 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)

■ **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.*

The WHO estimates that each year tobacco contributes to the premature deaths of at least 5.4 million people (about half from developed and half from developing countries) from 25 illnesses including heart disease, stroke, lung cancer, 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 14-15).

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 70% higher risk of suffering from Alzheimer's disease.

According to the WHO, life-long 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 developing countries, especially China, where 30% of the world's smokers live, and India, where 11% of all smokers live. (About 4.5% of the world's smokers live in the United States.)

According to the U.S. Centers for Disease Control and Prevention (CDC), smoking kills about 442,000 Americans per year—an average of 1,211 premature deaths per day, or nearly one every minute (Figure 14-16, p. 364). This death toll is roughly equivalent to six fully loaded 200-passenger jet planes crashing *every day* with no survivors—a human tragedy that rarely makes the news.

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.

A study published in 2004 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 again, the longer one smokes, the harder it is to quit.

Analysts call for regulating tobacco through the U.S. Food and Drug Administration, which Congress did in 2009. They also advocate eliminating all federal subsidies and tax breaks to tobacco farmers and tobacco companies, greatly increasing cigarette tax revenues, and using that money to finance an aggressive antitobacco advertising and education program. Because of increased awareness of the harmful effects of smoking, the average number of cigarettes smoked per person in the United States dropped by almost 60% between 1976 and 2007.

GOOD NEWS

HOW WOULD YOU VOTE?

Do you favor classifying and regulating nicotine as an addictive and dangerous drug? Cast your vote online at **www.cengage.com/biology/miller**.

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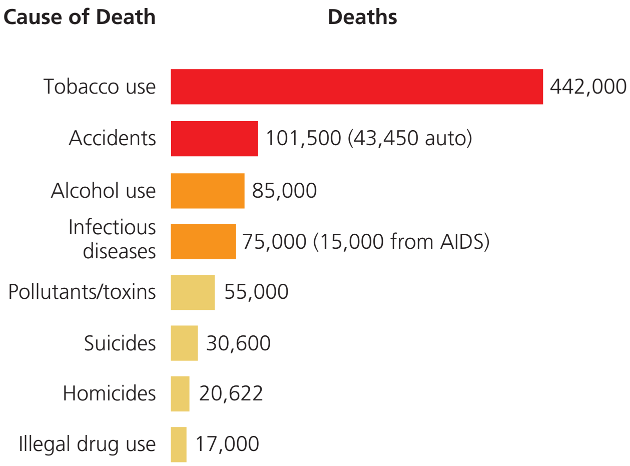


Figure 14-16 Annual deaths in the United States from tobacco use and other causes in 2004 (the latest data available). Smoking is by far the nation's leading cause of preventable death, causing more premature deaths each year than all the other categories in this figure combined. (Data from U.S. National Center for Health Statistics and Centers for Disease Control and Prevention and U.S. Surgeon General, 2007)

Estimating Risks from Technologies Is Not Easy

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:

System reliability (%) = Technology reliability × 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 Three Mile Island and Chernobyl (Case Study, p. 312) nuclear power plant accidents.

One way to make a system more foolproof or fail-safe 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 deliberately caused to malfunction.

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 most people in many countries do each day is drive or ride in a car.

Yet some of these same people may be terrified about their chances of being killed by a *gun* (1 in 28,000 in the United States), *flu* (1 in 130,000), *nuclear power plant accident* (1 in 200,000), *West Nile virus* (1 in 1 million), *lightning* (1 in 3 million), *commercial airplane crash* (1 in 9 million), *snakebite* (1 in 36 million), or *shark attack* (1 in 281 million).

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 underestimate numbers of deaths from flu, diabetes, asthma, stroke, and automobile accidents. Many people also fear a new, unknown product or technology more than they do an older, more familiar one.

The second factor in our judging risk is the *degree of control* we have. 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 bad traffic than they do 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.

Third is *whether a risk is catastrophic,* not chronic. We usually are more frightened by news of a single catastrophic accident 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 not believe that talking on the cell phone impairs 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 14-5**):

- *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 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 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 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 lying in tanning booths.

GOOD NEWS

Here are the *three big ideas* for this chapter:

- We face significant hazards from infectious diseases such as flu, AIDS, tuberculosis, diarrheal diseases, and malaria, 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. And we evaluated the risks from other chemical, biological, physical, cultural, and lifestyle hazards to human health.

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, biomass, and geothermal energy. We can reduce our exposure to harmful chemicals used in the manufacturing of various goods by cutting resource use and waste and 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 would also be helping 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. 345. Describe the potential risks from exposure to trace amounts of hormone mimics such as bisphenol A.

2. Distinguish among **risk**, **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 a **nontransmissible disease**, **infectious disease**, and **transmissible 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. 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 threats from the hepatitis B, West Nile, and SARS viruses. 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. 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 can be done 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 five principles that can help us evaluate and reduce risk.

10. What are this chapter's *three big ideas*? Discuss how lessening the threats of harm from chemicals such as hormone mimics can be achieved 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 they be banned 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 get worked up 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 immunity 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 the effects of toxic chemicals.
   - **d.** We should not worry about exposure to a chemical such as bisphenol A (BPA) because it has not been absolutely scientifically proven that BPA has killed anyone.

4. Workers in a number of industries are exposed to higher levels of various toxic substances than are the general public. Should workplace levels allowed for such chemicals be reduced? 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 on p. 363. 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)** the area 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. Would you support legislation requiring the use of pollution prevention based on the precautionary principle in deciding what to do about risks from chemicals in the country where you live? Explain.

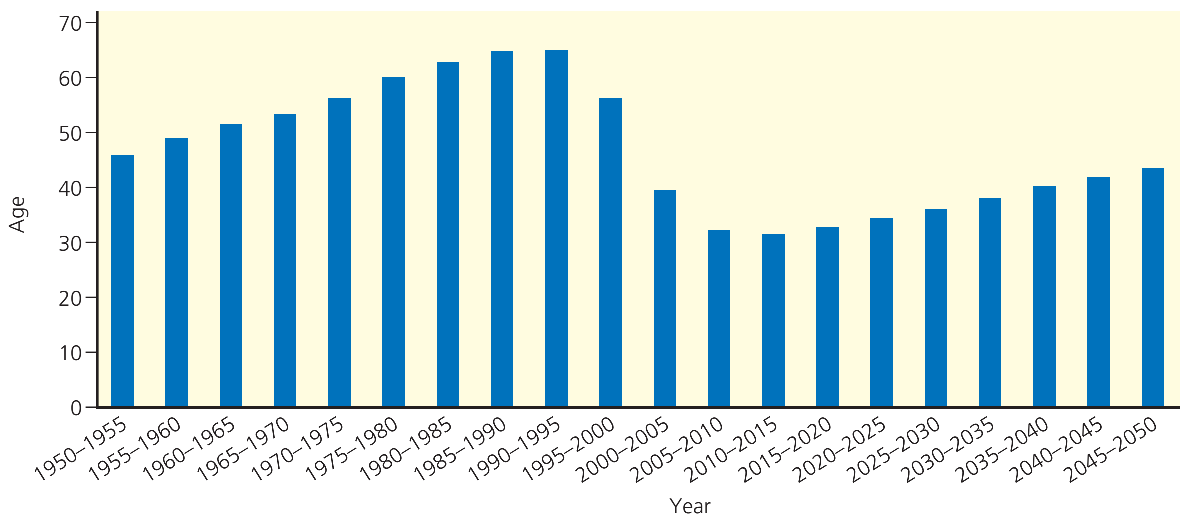
8. Congratulations! You are in charge of the world. List the three most important features of your program to reduce the risks from exposure to **(a)** infectious disease organisms and **(b)** toxic and hazardous chemicals.

9. List three ways in which you could apply **Concept 14-5** 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. Answer the questions below.



Source: Data from United Nations and U.S. Census Bureau, 2004

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

STUDENT COMPANION SITE Visit this book's website at **www.cengage.com/biology/miller** and choose Chapter 14 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, web links, information on Green Careers, and InfoTrac® College Edition articles.

CENGAGENOW™ For students with access, log on at **www.cengage.com/login** for the animations, active figures, activities, and readings indicated within the text by the CengageNOW logo. If your textbook did not come with access, visit **www.iChapters.com** to purchase.

15 Air Pollution, Climate Change, and Ozone Depletion

CORE CASE STUDY South Asia's Massive Brown Cloud

Air pollution is no longer viewed as mostly a localized urban problem. Satellite images and a 2002 study by the U.N. Environment Programme (UNEP) found a massive dark brown cloud of pollution—called the *Asian Brown Cloud*—stretching nearly continuously across much of India, Bangladesh, and the industrial heart of China to the western Pacific Ocean.

This 3-kilometer (2-mile) -thick cloud covers an area about the size of the continental United States. It contains dust, smoke, and ash resulting from drought and the clearing and burning of forests for planting crops. It also contains soot, mostly from the burning of biomass such as wood and animal dung; acidic compounds from vehicle exhaust; and fly ash and particles of toxic metals such as mercury and lead, produced mostly from the burning of coal.

Instead of blue skies, many of the people living under this cloud see brown or gray polluted skies much of the year (Figure 15-1). The cloud is changing weather patterns in China, causing drying in the north and increased flooding in the south. This effect and some pollutants in the cloud are projected to increase crop losses by up to 40% in Asia. And UNEP scientists estimate that pollution in this cloud contributes to at least 700,000 premature deaths every year.

Another problem is that the Asian Brown Cloud does not stay put. U.S. satellites have tracked the spread of a dense cloud of pollutants from northern China across the Pacific Ocean to the west coast of the United States.

This serious regional air pollution problem is made worse by the fact that rapidly rising levels of carbon dioxide and other greenhouse gases produced by human activities are warming the atmosphere, according to most of the world's leading climate experts. According to computer climate models, the projected increase in atmospheric temperatures during this century will affect the earth's regional and global climates, economies, and human lifestyles. If the projected climate change takes place, it will alter water distribution and shift areas where we can grow food. It will also force many people to move because of excessive heat or flooding from rising sea levels, and it will degrade biodiversity.

To many scientists, economists, and a growing number of business executives and elected officials, projected climate change is a global emergency that needs our immediate attention. A few analysts say that the problem is overblown but most climate scientists consider it to be the biggest challenge that humanity faces during this century.

Another global problem that has required urgent action is depletion of the ozone layer. Life as we know it could not exist if there were no ozone in the stratosphere to filter out most of the sun's harmful ultraviolet radiation. But chemicals produced by human activities have been depleting stratospheric ozone. In this chapter, we look at the related problems of air pollution, climate change, and depletion of ozone in the stratosphere.

ullstein-Hiss/Peter Arnold, Inc.

Figure 15-1 Air pollution in Shanghai, China, in 2004.

Key Questions and Concepts

15-1 **What is the nature of the atmosphere?**

CONCEPT 15-1 The two innermost layers of the atmosphere are the *troposphere,* which supports life, and the *stratosphere,* which contains the protective ozone layer.

15-2 **What are the major air pollution problems?**

CONCEPT 15-2A Three major outdoor air pollution problems are *industrial smog* mostly from burning coal, *photochemical smog* from motor vehicle and industrial emissions, and *acid deposition* from coal burning and motor vehicle exhaust.

CONCEPT 15-2B The most threatening indoor air pollutants are smoke and soot from wood and coal fires (mostly in developing countries) and chemicals used in building materials and products.

15-3 **How should we deal with air pollution?**

CONCEPT 15-3 Legal, economic, and technological tools can help us to clean up air pollution, but the best solution is to prevent it.

15-4 **How might the earth's climate change in the future?**

CONCEPT 15-4 Considerable scientific evidence indicates that emissions of greenhouse gases into the earth's atmosphere from human activities will lead to significant climate change during this century.

15-5 **What are some possible effects of projected climate change?**

CONCEPT 15-5 The projected change in the earth's climate during this century could have severe and long-lasting consequences, including increased drought and flooding, rising sea levels, and shifts in locations of agriculture and wildlife habitats.

15-6 **What can we do to slow projected climate change?**

CONCEPT 15-6 To slow the rate of projected climate change, we can increase energy efficiency, sharply reduce greenhouse gas emissions, rely more on renewable energy resources, and slow population growth.

15-7 **How have we depleted ozone in the stratosphere and what can we do about it?**

CONCEPT 15-7A Widespread use of certain chemicals has reduced ozone levels in the stratosphere and allowed more harmful ultraviolet radiation to reach the earth's surface.

CONCEPT 15-7B To reverse ozone depletion, we need to stop producing ozone-depleting chemicals and adhere to the international treaties that ban such chemicals.

Note: Supplements 2 (p. S3), 4 (p. S14), 6 (p. S26), 8 (p. S33), and 9 (p. S38) 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

15-1 What Is the Nature of the Atmosphere?

▶ **CONCEPT 15-1 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 at the bottom of a thin envelope of gases surrounding the earth, called the *atmosphere*. It is divided into several spherical layers (Figure 15-2, p. 370).

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 8 kilometers (5 miles) over the poles. If the earth were the size of an apple, this lower layer containing

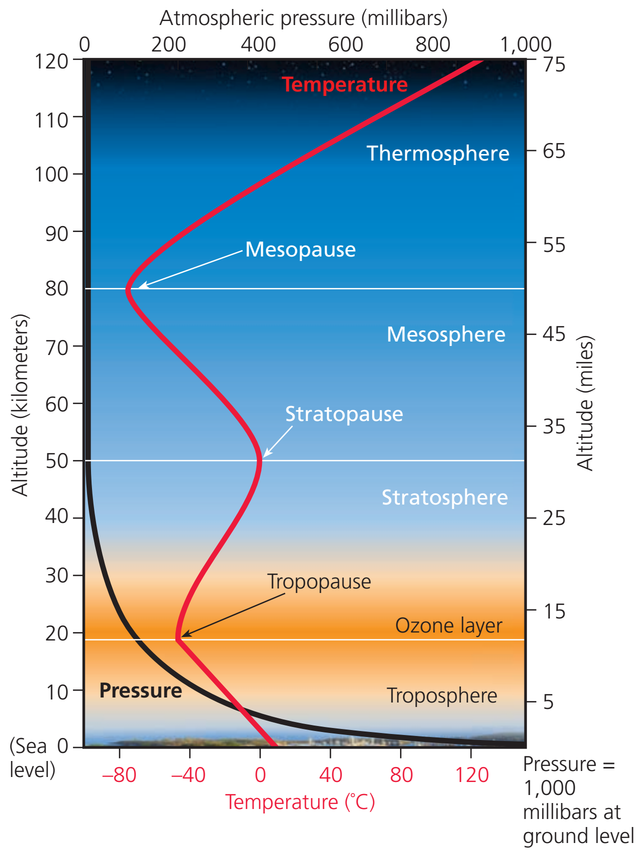


Figure 15-2 **Natural capital:** The earth's atmosphere is a dynamic system that includes four layers. The average temperature of the atmosphere varies with altitude (red line) and with differences in the absorption of incoming solar energy. Most ultraviolet radiation from the sun is absorbed by ozone, found primarily in the stratosphere in the *ozone layer* 17–26 kilometers (11–16 miles) above sea level. **Question**: What would happen to life as we know it if the ozone layer in the stratosphere disappeared? Explain.

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), 0.93% argon (Ar), 0.038% carbon dioxide (CO_2), and trace amounts of dust and soot particles and 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 8, p. S33) and long-term *climate* (**Concept 7-1**, p. 123). CONCEPT LINK

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 15-2). 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 17–30 kilometers (11–19 miles) above sea level. Stratospheric ozone is produced when some of the oxygen molecules there interact with ultraviolet (UV) radiation emitted by the sun ($3\ O_2 + UV \rightleftarrows 2\ O_3$). This "global sunscreen" of ozone in the stratosphere keeps about 95% of the sun's harmful UV radiation (Figure 3-3, p. 41) from reaching the earth's surface.

15-2 What Are the Major Air Pollution Problems?

▶ **CONCEPT 15-2A Three major outdoor air pollution problems are *industrial smog* mostly from burning coal, *photochemical smog* from motor vehicle and industrial emissions, and *acid deposition* from coal burning and motor vehicle exhaust.**

▶ **CONCEPT 15-2B The most threatening indoor air pollutants are smoke and soot from wood and coal fires (mostly in developing countries) and chemicals used in building materials and products.**

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. Air pollutants come from natural and human sources. Natural sources include dust blown by wind, 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 chemicals emitted from some volcanic eruptions and forest fires can temporarily reach harmful levels in areas where they occur.

Most human inputs of outdoor air pollutants occur in industrialized and urban areas where people, cars, and factories are concentrated. These pollutants are generated mostly by the burning of fossil fuels in power and industrial plants (stationary sources, Figure 1-8, p. 14) and in motor vehicles (mobile sources).

Scientists classify outdoor air pollutants into two categories. **Primary pollutants** are harmful chemicals emitted directly into the air from natural processes and human activities (Figure 15-3, center). While in the atmosphere, some primary pollutants react with one another and with other normal components of air to form new harmful chemicals, called **secondary pollutants** (Figure 15-3, right).

What Are the Major Outdoor 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. Major sources are motor vehicle exhaust, burning of forests and grasslands, tobacco smoke, and open fires and inefficient stoves used for cooking.

CO reacts with hemoglobin in red blood cells and reduces the ability of blood to transport oxygen to body cells and tissues. Chronic exposure can trigger heart attacks and aggravate lung diseases such as asthma and emphysema. At high levels, CO can cause headache, nausea, drowsiness, mental impairment, 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 (Figure 3-13, p. 51). The rest comes from human activities, mostly the burning of fossil fuels and clearing of CO_2-absorbing forests and grasslands. Until recently CO_2 has not been classified as an air pollutant. But there is considerable and growing scientific evidence that increasing levels of CO_2 (see Figure 11, p. S44, in Supplement 9) caused by human activities are playing a role in changing the earth's climate, as discussed in Sections 15-4 through 15-6 of this chapter. In 2009, the U.S. Environmental Protection Agency (EPA) announced that it plans to regulate climate-changing carbon dioxide as an air pollutant because of the projected effects of climate change on human health.

Nitrogen oxides and nitric acid. *Nitric oxide* (NO) is a colorless gas that forms when nitrogen and oxygen gas in air react at the high-combustion temperatures in automobile engines and coal-burning power and industrial plants. Lightning and certain bacteria in soil and water also produce NO as part of the nitrogen cycle (Figure 3-14, p. 52).

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. *Nitrous oxide* (N_2O), a greenhouse gas, is emitted from

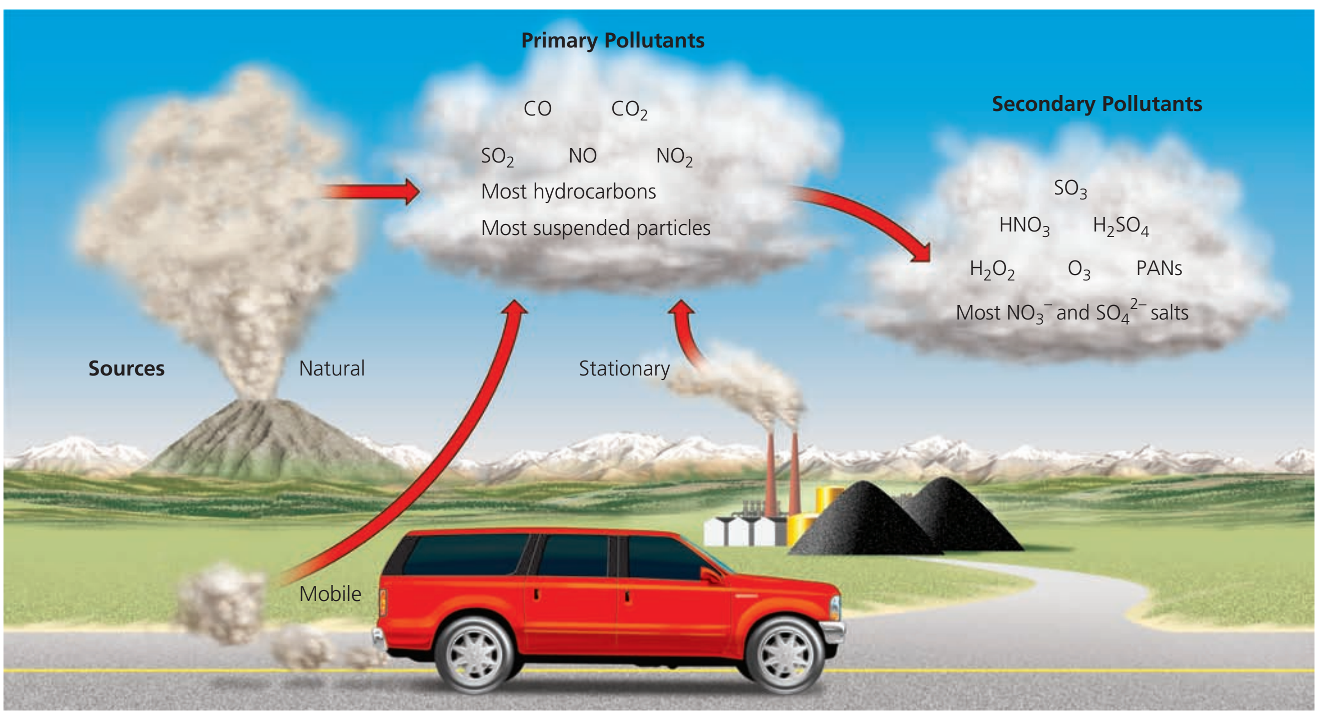


Figure 15-3 *Sources and types of air pollutants.* Human inputs of air pollutants come from *mobile sources* (such as cars) and *stationary sources* (such as industrial and power plants). Some *primary air pollutants* react with one another and with other chemicals in the air to form *secondary air pollutants.*

fertilizers and animal wastes and is produced by burning fossil fuel.

At high enough levels, nitrogen oxides can irritate the eyes, nose, and throat; aggravate lung ailments such as asthma and bronchitis; and suppress plant growth and reduce visibility when they are converted to nitric acid and nitrate salts.

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 (Figure 3-16, p. 54). The other two-thirds (and as much as 90% in some urban areas) come from human sources, mostly combustion of sulfur-containing coal in electric power and industrial plants and oil refining and smelting 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. 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. And they are a major component of the Asian Brown Cloud (**Core Case Study**). SO_2 emissions that feed into the cloud have increased by more than a third in the past decade, according to a 2007 U.S. National Academy of Sciences report. CORE CASE STUDY

Particulates. *Suspended particulate matter* (SPM) consists of a variety of solid particles and liquid droplets small and light enough to remain suspended in the air for long periods. The Environmental Protection Agency (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, road construction, and tobacco smoke. Such particulates are a major component of the Asian Brown Cloud (**Core Case Study**). CORE CASE STUDY

These particles can irritate the nose and throat, damage the lungs, aggravate asthma and bronchitis, and shorten life. Toxic particulates of chemicals such as lead, cadmium, and PCBs, can cause mutations, reproductive problems, and cancer. Particulates also reduce visibility, corrode metals, and discolor clothes and paints.

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 the sun's harmful UV radiation. Both are the same chemical. Much 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 Section 15-7 of this chapter.

Volatile organic compounds (VOCs). Organic compounds that exist as gases in the atmosphere or that evaporate 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 (Figure 3-3, p. 41).

About a third of global methane emissions come 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 components of gasoline, plastics, and other products.

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 that give the resulting smog a gray color (Figure 15-1), which is why it is sometimes called *gray-air smog* (**Concept 15-2A**).

Today, urban industrial smog is rarely a problem in most developed countries where coal and heavy oil are burned only in large boilers with reasonably good pollution control or with tall smokestacks that transfer the pollutants to downwind rural areas. However, industrial smog remains a problem in industrialized urban areas of China (Figure 15-1), India (Photo 1, in the Detailed Contents), Ukraine, and some 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 Asian pollution cloud (**Core Case Study**). CORE CASE STUDY

The history of air pollution control in Europe and the United States shows that industrial smog can be reduced 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.

GOOD NEWS

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,

$$\text{VOCs} + NO_x + \text{heat} + \text{sunlight} \rightarrow \begin{array}{l} \text{ground level ozone } (O_3) \\ + \text{ other photochemical oxidants} \\ + \text{ aldehydes} \\ + \text{ other secondary pollutants} \end{array}$$

The formation of photochemical smog 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 mixture of pollutants, dominated by ground-level ozone, usually builds up to peak levels by late morning, irritating people's eyes and respiratory tracts. Some of its pollutants, known as *photochemical oxidants*, can damage lung tissue.

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 and Salt Lake City in the United States; Sydney, Australia; São Paulo, Brazil; Bangkok, Thailand; Mexico City, Mexico; and Santiago, Chile (Figure 15-4). The already poor air quality in urban areas of many developing countries is worsening as the number of motor vehicles has risen. 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* help 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.

Julio Etchart/Peter Arnold, Inc.

Figure 15-4 *Global outlook:* photochemical smog in Santiago, Chile. **Question**: How serious is photochemical smog where you live?

Six other factors can *increase* outdoor air pollution. First, *urban buildings* slow wind speed and reduce dilution and removal of pollutants. Second, *hills and mountains* reduce the flow of air in valleys below them (Figure 15-4) 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.

A fifth factor—the so-called *grasshopper effect*—occurs when air pollutants are transported by evaporation and winds from tropical and temperate areas through the atmosphere to the earth's polar areas, where they are deposited. 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.

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 disperse the pollutants. 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.

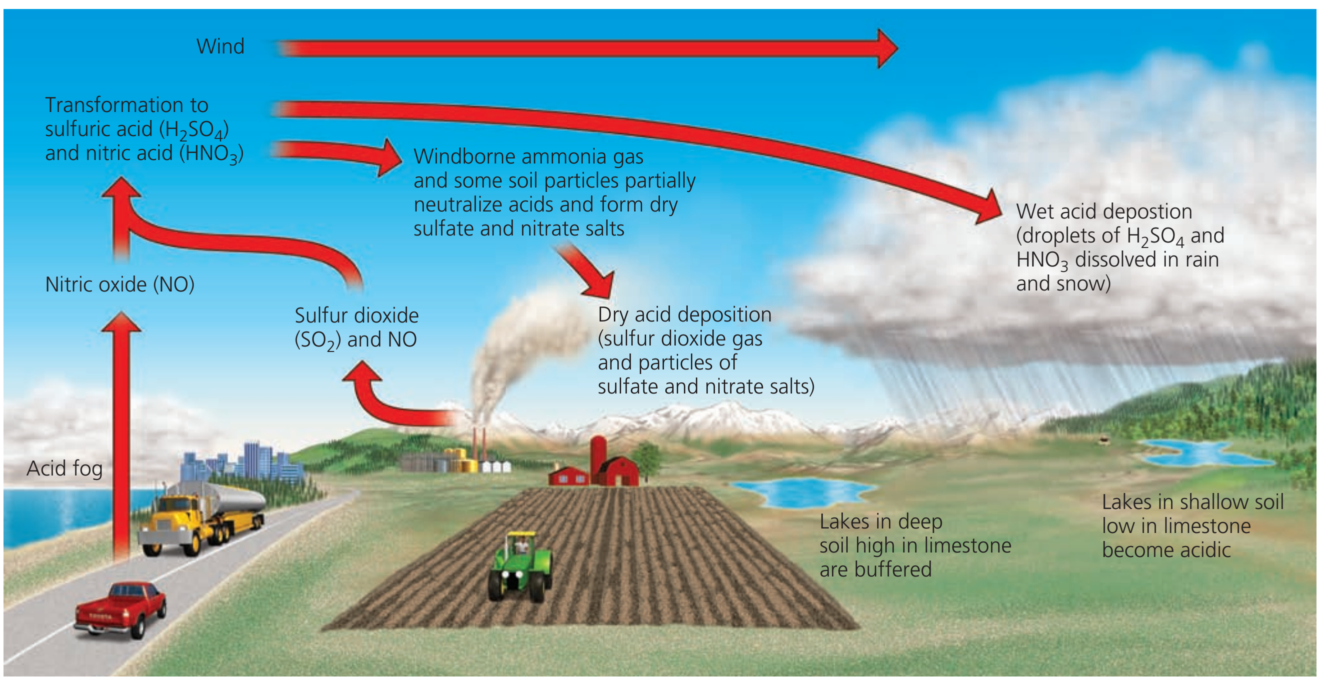
CENGAGENOW™ Learn more about thermal inversions and what they can mean for people in some cities at CengageNOW.

Acid Deposition Is a Serious Regional Air Pollution Problem

Most coal-burning power plants, ore smelters, and other industrial plants in developed countries use tall smokestacks to emit sulfur dioxide, suspended particles, and nitrogen oxides high into the atmosphere where wind can mix, dilute, and disperse them.

These tall smokestacks reduce *local* air pollution, but they can increase *regional* air pollution downwind. The primary pollutants (SO_2 and NO_x) emitted high into the atmosphere may be transported as far as 1,000 kilometers (600 miles) by prevailing winds. During their trip, they form secondary pollutants such as droplets of sulfuric acid, nitric acid vapor, and particles of acid-forming sulfate and nitrate salts (Figure 15-3).

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, and *dry deposition* consisting of acidic particles. The resulting mixture is called **acid deposition** (Figure 15-5)—sometimes called *acid rain*. Most dry



CENGAGENOW™ **Active Figure 15-5 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?

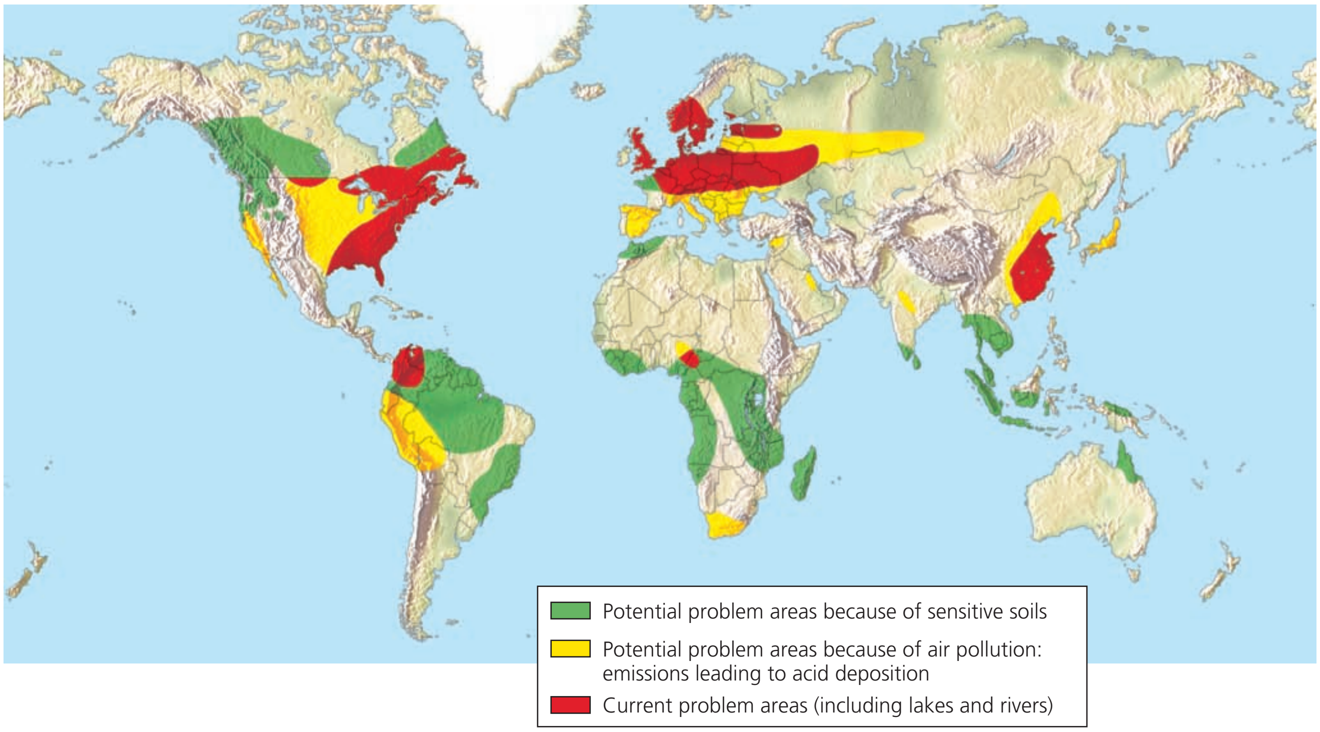


Figure 15-6 Regions where acid deposition is now a problem and regions with the potential to develop this problem. Such regions have large inputs of air pollution (mostly from power plants, industrial plants, and ore smelters) or are sensitive areas with soils and bedrock that cannot neutralize (buffer) 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, 2007)

deposition occurs within 2–3 days fairly near the emission sources, whereas most wet deposition takes place within 4–14 days in more distant downwind areas.

Acid deposition is a *regional* air pollution problem (**Concept 15-2A**) in areas that lie downwind from coal-burning facilities and in urban areas with large numbers of cars, as shown in Figure 15-6. In some areas, soils contain compounds that can react with and neutralize, or *buffer*, some inputs of acids. The areas most sensitive to acid deposition are those with thin, acidic soils that provide no such natural buffering (Figure 15-6, 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, especially 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, typical precipitation in the eastern United States is at least 10 times more acidic than natural precipitation is.

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 into Switzerland, Austria, Norway, and other neighboring countries.

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 and South Korea. It also contributes to the Asian Brown Cloud (**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 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 and other animals. Currently, 45 U.S. states have issued warnings telling people to avoid eating fish caught from waters that are contaminated with toxic mercury (Science Focus, p. 354).

Acid deposition harms aquatic ecosystems. 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 threatened in this way.

Acid deposition (often along with other air pollutants such as ozone) can affect forests in two ways. One is by leaching essential plant nutrients such as calcium and magnesium from soils. The other is by releasing ions of aluminum, lead, cadmium, and mercury, which are toxic to the trees. These two effects rarely kill trees directly, but they can 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 bathed almost continuously in highly acidic fog and clouds.

CENGAGENOW™ Examine how acid deposition can harm a pine forest and what it means to surrounding land and waters at CengageNOW.

We Know How to Reduce Acid Deposition

Figure 15-7 summarizes ways to reduce acid deposition. According to most scientists studying the problem, the best solutions are *prevention approaches* that reduce or eliminate emissions of sulfur dioxide, nitrogen oxides, and particulates.

We know how to reduce acid deposition (Figure 15-7, left) but 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 have a strong incentive to use it as a major energy resource. And owners of coal-burning power plants argue that adding the latest pollution control equipment, using low-sulfur coal, or removing sulfur from coal before burning it would increase the cost of electricity for consumers.

Air pollution laws in the United States have reduced 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.

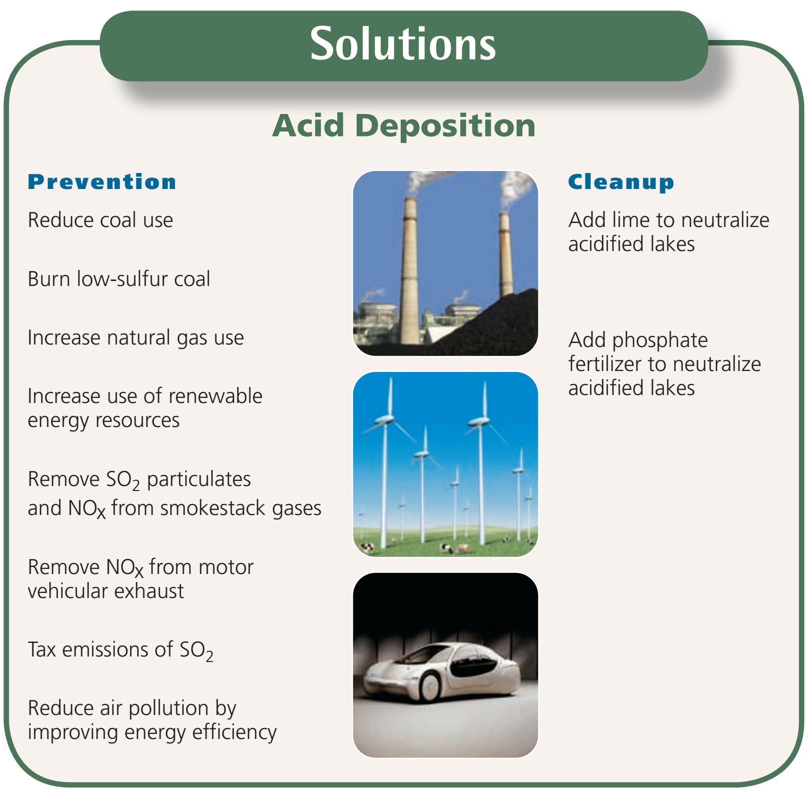


Figure 15-7 Methods for reducing acid deposition and its damage. **Questions:** Which two of these solutions do you think are the most important? Why?

CONNECTIONS

Low-Sulfur Coal, Climate Change, 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 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.

Indoor Air Pollution Is a Serious Problem

In developing countries, the indoor burning of wood, charcoal, dung, crop residues, coal, and other cooking and heating fuels in open fires or in unvented or poorly vented stoves exposes people to dangerous levels of particulate air pollution (**Concept 15-2B**). According to the World Health Organization (WHO) and the World Bank, *indoor air pollution is the world's most serious air pollution problem, especially for poor people*.

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 15-8 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 two to five times higher inside U.S. homes and commercial buildings than they are outdoors, and as much as 100 times higher in some cases. *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 more than 21,000 premature cancer deaths per year in the United States. The WHO reports that world-

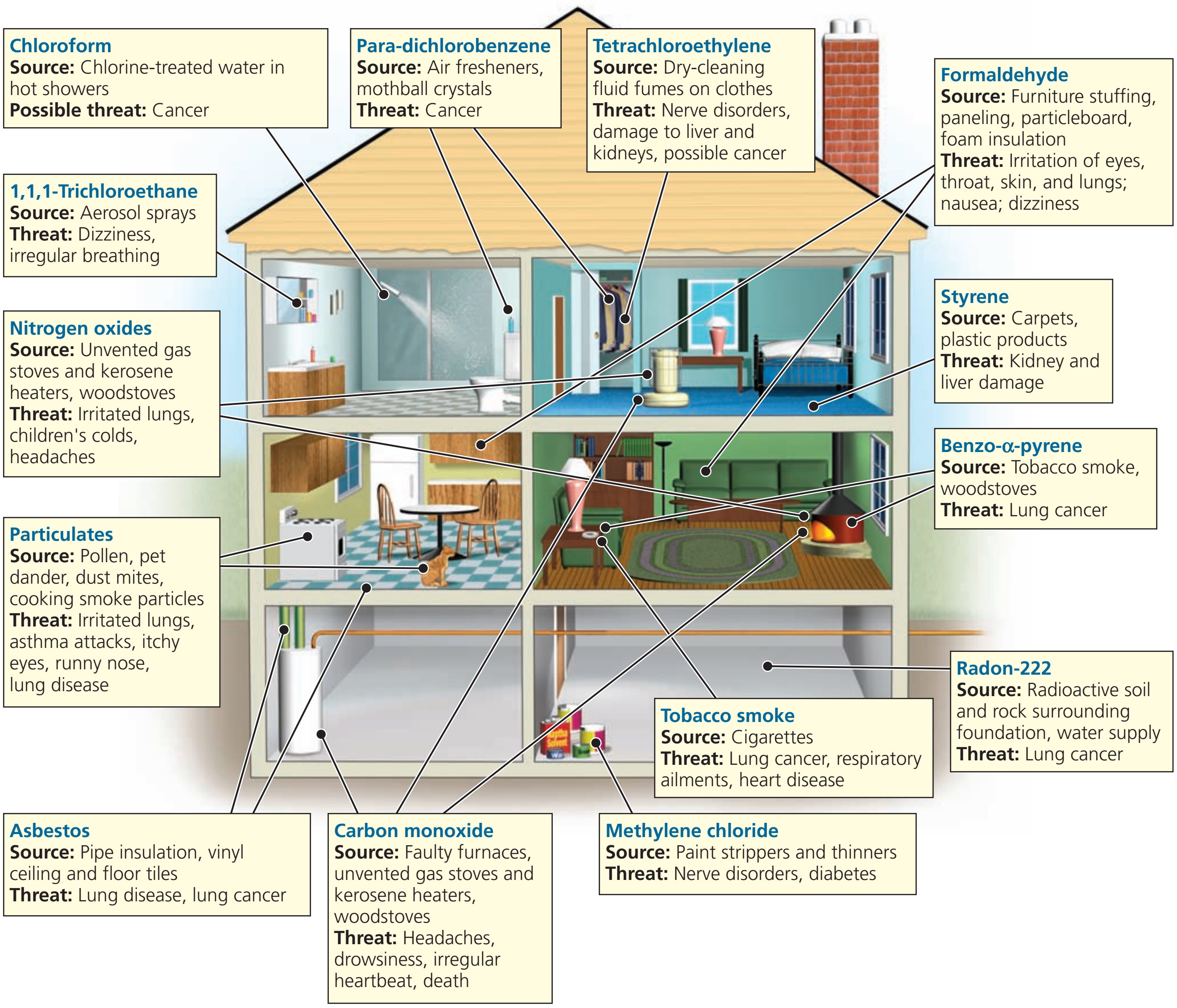


Figure 15-8 Some important indoor air pollutants (**Concept 15-2B**). **Question**: To which of these pollutants are you exposed? (Data from U.S. Environmental Protection Agency)

wide deaths due to indoor air pollution total about 1.6 million per year, or 1 every 20 seconds. 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. **GREEN CAREER:** Indoor air pollution specialist

According to the EPA and public health officials, the four most dangerous indoor air pollutants in developed areas are *tobacco smoke* (Case Study, p. 363); *formaldehyde* emitted from many building materials and household products; *radioactive radon-222 gas*, which can seep into houses from underground rock deposits (Figure 15-8); and *very small (ultrafine) particles*.

RESEARCH FRONTIER

Learning more about indoor air pollutants and how to prevent them. See **www.cengage.com/biology/miller**.

Your Body's Natural Defenses against Air Pollution Can Be Overwhelmed

Your respiratory system (Figure 15-9, p. 378) 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 they trap to your throat where they are swallowed or expelled.

Prolonged or acute exposure to air pollutants, including tobacco smoke, can overload or break down

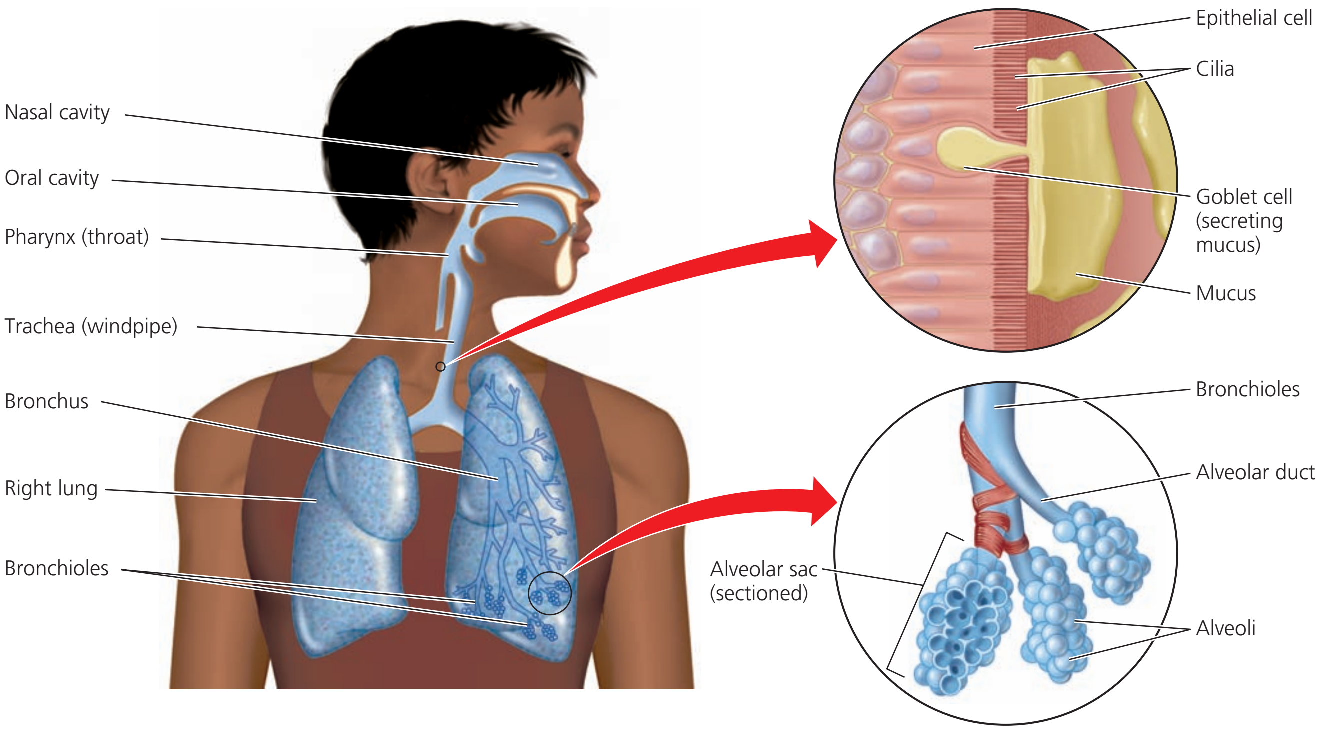


Figure 15-9 Major components of the human respiratory system.

these natural defenses. Fine and ultrafine particulates get lodged deep in the lungs, contributing to lung cancer, asthma attack, heart attack, and stroke. 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.

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 6,600 deaths per day—from the effects of air pollution. Most of these deaths occur in Asia, with 656,000 deaths per year in China alone, according to a 2007 World Bank study. About two-thirds of these deaths result from breathing indoor air pollutants, which can cause heart attacks, respiratory diseases, and lung cancer.

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 to 5 fully loaded, 200-passenger airliners crashing *each 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 about 60,000 to 70,000 premature deaths a year in the United States (Figure 15-10).

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. A large diesel truck emits as much particulate matter as 150 cars. And particulate emissions from a diesel-powered train equal those from about 1500 cars. The average daily emissions of PM-10 particulates from diesel-powered ships and trucks at California's Port of Los Angeles equal the daily particulate emissions from 500,000 cars.

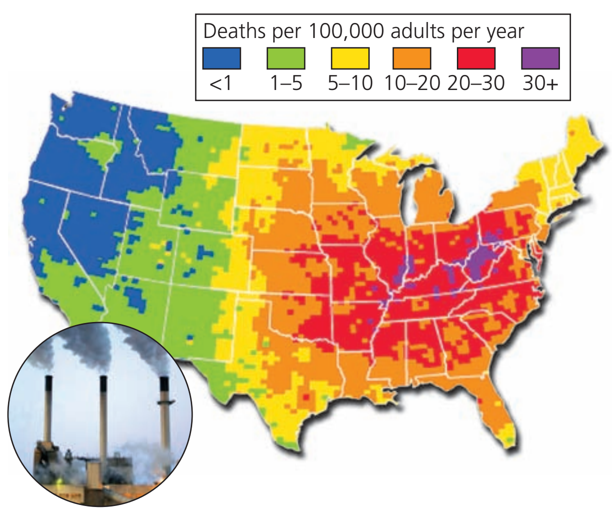


Figure 15-10 Premature deaths from air pollution in the United States, mostly from very small, fine, and ultra-fine particles added to the atmosphere by coal-burning power plants. **Questions**: Why are the highest death rates in the eastern half of the United States? What is the risk where you live or go to school? (Data from U.S. Environmental Protection Agency, 2005)

15-3 How Should We Deal with Air Pollution?

▶ **CONCEPT 15-3 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 15-3**). 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. Each standard specifies the maximum allowable level for a pollutant, averaged over a specific period.

GOOD NEWS

The good news is that, according to a 2009 EPA report (see **http://www.epa.gov/air/airtrends/aqtrends.html**), the combined emissions of these six major pollutants decreased significantly between 1980 and 2008, even with significant increases during the same period in gross domestic product, vehicle miles traveled, population, and energy consumption. The decreases in emissions during this period were 97% for lead, 56% for CO, 56% for SO_2, 40% for NO_x, 68% for PM-10, and 25% for ground-level ozone.

While the U.S. regulatory model has been successful in reducing outdoor air pollution, environmental scientists point to areas where it still could stand improvement (see the following Case Study).

■ CASE STUDY
U.S. Air Pollution Laws Can Be Improved

GOOD NEWS

The reduction of outdoor air pollution in the United States since 1970 has been a remarkable success story mostly as a result 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 the success of U.S. air pollution control laws but point to several remaining problems:

- The United States continues to rely mostly on pollution cleanup rather than prevention.
- The United States is far behind European Union countries, Japan, and China in fuel efficiency standards for motor vehicles (Figure 13-21, right, p. 320).
- Regulation of emissions from motorcycles and two-cycle gasoline engines remains inadequate. For example, the EPA estimates that using a typical riding gas-powered lawn mower for 1 hour creates as much air pollution as driving 34 cars for an hour.
- Ultra-fine particles, which are a major contributor to premature deaths from air pollution, are not adequately regulated.
- Airports are exempt from many air pollution regulations.
- Urban ozone levels are still too high in many areas.
- The laws have failed to deal seriously with indoor air pollution.
- There is a need for better enforcement of the Clean Air Acts.

Executives of some companies that would be affected by implementing 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 estimates of the costs of implementing U.S. air pollution control standards have been much higher than the actual costs. In addition, implementing such standards has boosted economic growth and created jobs 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/biology/miller**.

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-burning 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 SO_2 than its allotment has a surplus of pollution credits. That utility can use its credits to offset SO_2 emissions at another of its plants, or it can keep them for future plant expansions or sell them to other utilities or private citizens or groups.

Proponents of this approach say it is cheaper and more efficient than government regulation of air pollution control. Critics of this approach contend that it allows utilities with older, dirtier power plants to buy their way out of their environmental responsibilities and continue polluting. And without strict government oversight, this approach makes cheating possible, because it is based largely on self-reporting of emissions.

The ultimate success of any emissions trading approach depends on two things: 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 significant overall improvement in air quality.

Between 1990 and 2006, the emissions trading system helped to reduce SO_2 emissions from electric power plants in the United States by 53% at a cost of less than one-tenth the cost projected by the industry.

Emissions trading is also being used for NO_x. But environmental and health scientists strongly oppose a cap-and-trade program for controlling emissions of mercury 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 toxic mercury.

There Are Many Ways to Reduce Outdoor Air Pollution

Figure 15-11 summarizes ways to reduce emissions of sulfur oxides, nitrogen oxides, and particulate matter from stationary sources such as electric power plants and industrial plants that burn coal.

Between 1980 and 2006, emissions of SO_2 from U.S. electric power plants were decreased by 66%, emissions of NO_x by 41%, and PM-10 emissions by 28%, mostly through the use of output cleanup methods (Figure 15-11, right). However, approximately 20,000 older coal-burning plants, industrial plants, 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. Officials of states subject to downwind pollution from such plants have been trying to get Congress to correct this shortcoming since 1970. But because of strong lobbying efforts by U.S. coal and electric power industries, they have not been successful.

HOW WOULD YOU VOTE?

Should older coal-burning power and industrial plants have to meet the same air pollution standards that new facilities have to meet? Cast your vote online at **www.cengage.com/biology/miller**.

Figure 15-12 lists ways to reduce emissions from motor vehicles, the primary factor in the formation of photochemical smog.

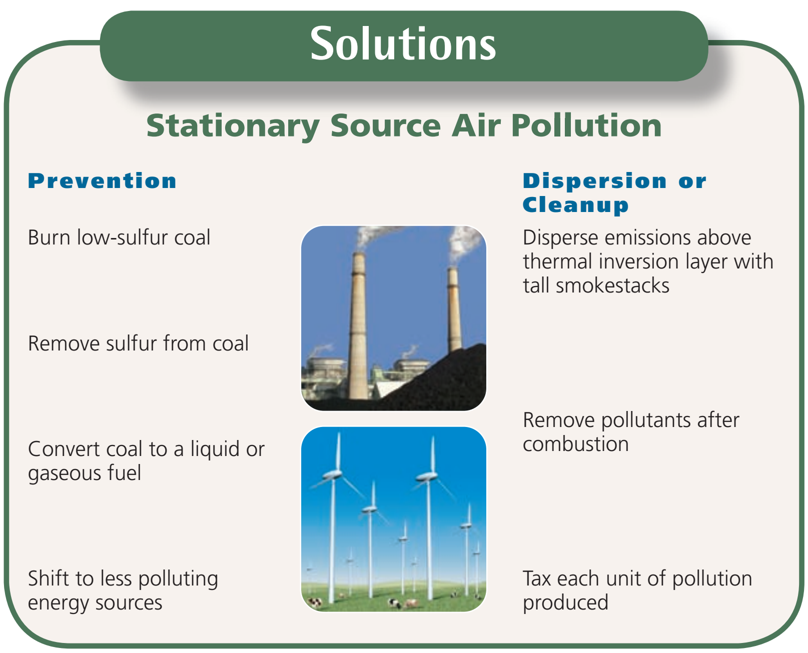


Figure 15-11 Methods for reducing emissions of sulfur oxides, nitrogen oxides, and particulate matter from stationary sources such as coal-burning electric power plants and industrial plants (**Concept 15-3**). **Questions**: Which two of these solutions do you think are the most important? Why?

Solutions

Motor Vehicle Air Pollution

Prevention

Use mass transit

Walk or bike

Use less polluting fuels

Improve fuel efficiency

Get older, polluting cars off the road

Give large tax write-offs or rebates for buying low-polluting, energy efficient vehicles

Cleanup

Require emission control devices

Inspect car exhaust systems twice a year

Set strict emission standards

Figure 15-12 Methods for reducing emissions from motor vehicles (**Concept 15-3**). 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?

Solutions

Indoor Air Pollution

Prevention

Clean ceiling tiles and line AC ducts to prevent release of mineral fibers

Ban smoking or limit it to well-ventilated areas

Set stricter formaldehyde emissions standards for carpet, furniture, and building materials

Prevent radon infiltration

Use office machines in well-ventilated areas

Use less polluting substitutes for harmful cleaning agents, paints, and other products

Cleanup or Dilution

Use adjustable fresh air vents for work spaces

Increase intake of outside air

Change air more frequently

Circulate a building's air through rooftop greenhouses

Use efficient venting systems for wood-burning stoves

Use exhaust hoods for stoves and appliances burning natural gas

Figure 15-13 Ways to prevent and reduce indoor air pollution (**Concept 15-3**). **Questions**: Which two of these solutions do you think are the most important? Why?

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 (**Concept 15-2B**). Air pollution experts suggest several ways to prevent or reduce indoor air pollution, as shown in Figure 15-13.

In developing countries, indoor air pollution from open fires and leaky, inefficient stoves that burn wood, charcoal, or coal could be reduced. More people could use inexpensive clay or metal stoves that burn fuels more efficiently and vent their exhaust to the outside, or they could use stoves that use solar energy to cook food (Figure 13-28, p. 327).

Figure 15-14 lists some ways in which you can reduce your exposure to indoor air pollution.

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
- 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 15-14 **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?

We Need to Emphasize Pollution Prevention

Since 1970, most of the world's 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 to *preventing* air pollution (**Concept 1-4**, p. 15). 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?"* Figure 15-15 shows ways to prevent outdoor and indoor air pollution over the next 30–40 years (**Concept 15-3**).

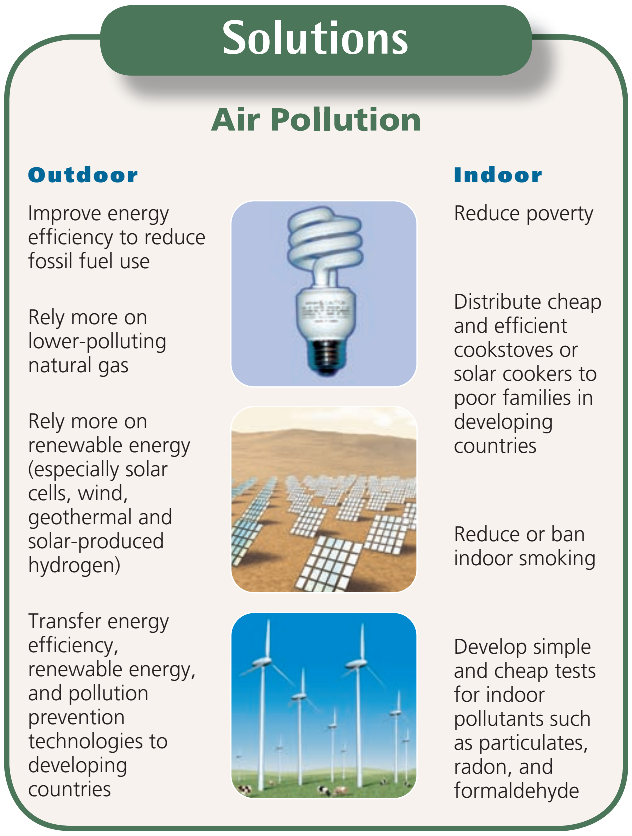


Figure 15-15 Ways to prevent outdoor and indoor air pollution over the next 30–40 years (**Concept 15-3**). **Questions**: Which two of these solutions do you think are the most important? Why?

15-4 How Might the Earth's Climate Change in the Future?

CONCEPT 15-4 Considerable scientific evidence indicates that emissions of greenhouse gases into the earth's atmosphere from human activities will lead to significant climate change during this century.

Don't Confuse Weather and Climate

In talking about climate change it is very important to distinguish between weather and climate (p. 123). *Weather* consists of short-term changes in atmospheric variables such as the temperature and precipitation in a given area over a period of hours or days (see Supplement 8, p. S33). By contrast, *climate* is determined by the *average* weather conditions of the earth or of a particular area, especially temperature and precipitation, over decades to thousands of years. The minimum period considered is usually 3 decades.

During any period of 30 or more years, there will be hot years and cooler years as weather fluctuates widely from day to day and from year to year. Climatologists studying climate change look at data on these fluctuating weather conditions, for a particular area or for the earth, to see if there has been a general rise or fall in average temperature and precipitation over 30 to 100 years, or longer. Climate change skeptics often point to one or a few colder-than-average years as evidence that atmospheric warming is not real. But by confusing weather with climate, they can mislead the general public.

Climate Change Is Not New

Climate change is neither new nor unusual. Over the past 3.5 billion years, the planet's climate has been altered by volcanic emissions, changes in solar input, continents moving slowly atop shifting tectonic plates (Figure 4-6 and **Concept 4-3**, p. 66), impacts by large meteors, and other factors.

Over the past 900,000 years, the atmosphere has experienced prolonged periods of *global cooling* and *global warming* (Figure 15-16, top left). These alternat-

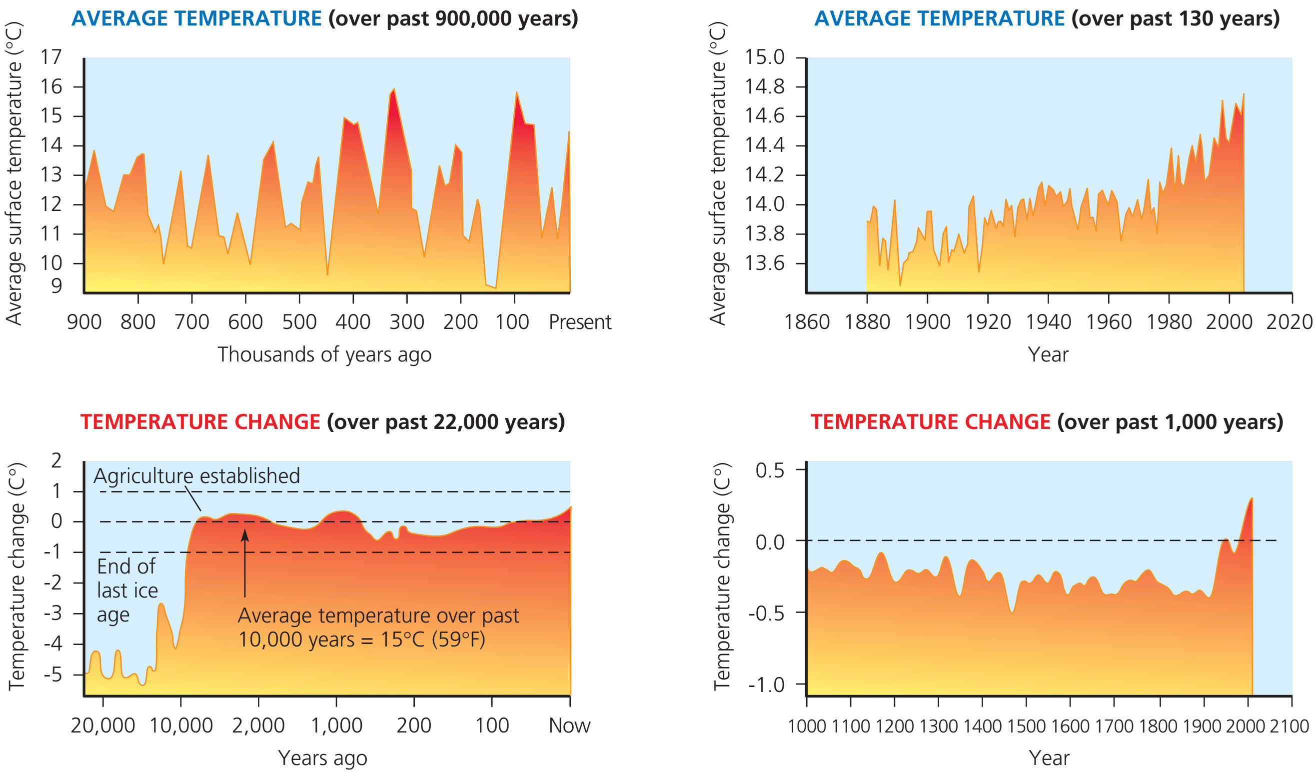


Figure 15-16 **Science:** estimated changes in the average global temperature of the atmosphere near the earth's surface over different periods of time. The graphs in the top half of this figure are rough estimates of global average temperatures, and the two graphs on the bottom are estimates of changes in the average temperature over long periods of time. They are based on limited evidence, but they do indicate general trends. **Question**: Assuming these are good estimates, what are two conclusions you can draw from these diagrams? (Data from Goddard Institute for Space Studies, Intergovernmental Panel on Climate Change, National Academy of Sciences, National Aeronautics and Space Agency, National Center for Atmospheric Research, and National Oceanic and Atmospheric Administration)

ing cycles of freezing and thawing are known as *glacial and interglacial* (between ice ages) *periods*.

For roughly 10,000 years, we have had the good fortune to live in an interglacial period characterized by a fairly stable climate and a fairly steady average global surface temperature (Figure 15-16, bottom left). These conditions allowed the human population to flourish as agriculture was developed, and later, as cities grew. For the past 1,000 years, the average temperature of the atmosphere has remained fairly stable but began rising during the last century (Figure 15-16, bottom right) when people began clearing more forests and burning more fossil fuels. Figure 15-17, top right, shows that most of the recent increase in temperature has taken place since 1975.

Past temperature changes such as those depicted in Figure 15-16 are estimated by analysis of a number of types of evidence, including radioisotopes in rocks and fossils; tiny bubbles of ancient air found in ice cores from glaciers (Figure 15-17); tree rings; and temperature measurements taken regularly since 1861. (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.)

U.S. Geological Survey

Figure 15-17 **Science:** *Ice cores* are extracted by drilling deep holes into ancient glaciers at various sites such as this one in Antarctica (the South Pole). Scientists analyze tiny air bubbles, layers of soot, and other materials trapped in different layers of such ice cores to uncover information about past composition of the lower atmosphere, temperature trends such as those shown in Figure 15-16, greenhouse gas concentrations, solar activity, snowfall, and forest fire frequency.

Scientific Consensus: Human Activities Can Contribute to Climate Change

Life on the earth and the world's economies are totally dependent on the natural greenhouse effect (Figure 3-3, p. 41)—one of the planet's most important forms of natural capital. It occurs primarily because of the presence of four natural *greenhouse gases—water vapor* (H_2O), *carbon dioxide* (CO_2), *methane* (CH_4), and *nitrous oxide* (N_2O)—that warm the atmosphere. Without this natural greenhouse effect, the world would be too cold to support the forms of life we find here today.

CENGAGE**NOW**™ See how greenhouse gases tend to warm the lower atmosphere and raise its annual average temperature at CengageNOW.

In 1988, the United Nations and the World Meteorological Organization established the Intergovernmental Panel on Climate Change (IPCC) to document past climate changes and project future changes. The IPCC network includes more than 2,500 climate experts from more than 130 countries. Its 2007 report was based on more than 29,000 sets of data, much of it collected since 2002. In this report, the IPCC listed a number of findings indicating that it is *very likely* (at least 90% certain) that the lower atmosphere is getting warmer and that human activities, especially the burning of carbon-containing fossil fuels, have played an important role in increasing the average temperature of the atmosphere since the 1950s.

Here is some of the evidence that IPCC and other climate scientists have used to support the major conclusions of the 2007 IPCC report:

- 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 15-16, top right).
- Annual greenhouse gas emissions from human activities rose 70% between 1970 and 2008 (see Figure 11, p. S44, in Supplement 9), and these increases correlate closely with temperature increases during this period (Figure 15-16, top right).
- In some parts of the world, glaciers are melting (Figure 15-18) and floating sea ice (Figure 15-19) is shrinking, both at increasing rates, rainfall patterns are changing, and extreme and prolonged drought is increasing.
- During the last century, the world's average sea level rose by 10–20 centimeters (4–8 inches), mostly because of runoff from melting land-based ice and the expansion of ocean water as its temperature increased.
- The 10 warmest years ever recorded have occurred since 1997.

More recent data about the melting of arctic sea ice and ice sheets in Greenland have alarmed many climate scientists who now warn that the 2007 IPCC report and current climate models have underestimated the likely effects of climate change. Sea level rises, for example, are projected to be 2–3 times what the IPCC projected

National Snow and Ice Data Center at Boulder, CO (USA)

National Snow and Ice Data Center at Boulder, CO (USA)

Figure 15-18 Melting of Alaska's Muir Glacier in the popular Glacier Bay National Park and Preserve between 1948 and 2004. Mountain glaciers are now melting almost everywhere in the world. **Question**: How might melting glaciers in Alaska and other parts of the world affect your life?

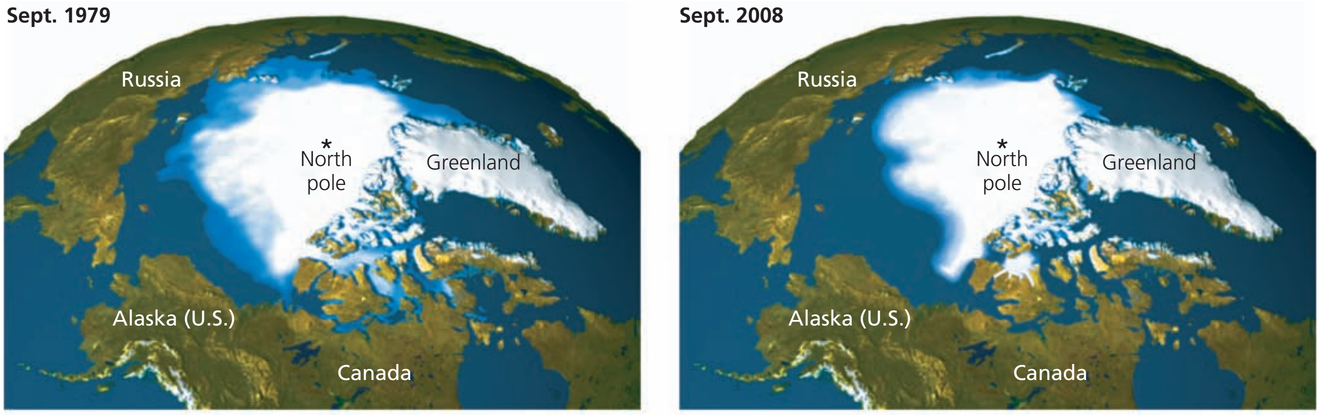


Figure 15-19 The *big melt*. Each summer, some of the floating sea ice in the Arctic Sea melts and then refreezes during winter. But in recent years, rising average atmospheric and ocean temperatures have caused more and more ice to melt. Satellite data show a 39% drop in the average cover of summer arctic sea ice between 1979 and 2007. Such summer ice may be gone by 2037, and perhaps earlier. A bit of good news is that because sea ice floats, it does not contribute to a rising sea level when it melts. (Data U.S. Goddard Space Flight Center, NASA, National Snow and Ice Data Center)

in 2007. This is because of new measurements showing that ice sheets in Greenland and Western Antarctica are melting much faster than the IPCC realized in 2007. And CO_2 emissions are increasing faster than the IPCC had projected.

Such findings have convinced the great majority of climate experts that human activities play an important role in climate change projected for this century. In 2009, University of Illinois researchers reported on a survey of more than 3,000 earth scientists, the largest such survey ever done. Some 82% of all scientists questioned, and 97% of the climatologists questioned, said that human activities were a serious factor contributing to atmospheric warming and projected climate change. Many of the world's top climate researchers rely on complex models of the earth's climate system designed to project future changes (Science Focus, p. 386).

As always in science, there are some skeptics who question any scientific consensus and doubt the validity of current climate models. Throughout the history of science, skeptics have played an important role in pushing scientists in all fields to improve their measurements and models and to take a closer look at their assumptions and hypotheses.

But only a few of the current skeptics are widely published and highly respected climate experts. Most of the critics are scientists with little expertise in this very complex field, including a number of meteorologists who are experts on day-to-day weather but not on long-term climate. Some of these climate skeptics are scientists who have received financial support from politically powerful oil, coal, utility, and automobile companies. These companies would like to avoid government regulation or taxation of carbon emissions thought to play a key role in projected climate change, because it could force them to increase prices of their products.

RESEARCH FRONTIER

Computer modeling of climate change. See **www.cengage.com/biology/miller**.

CO_2 Emissions Are the Major Culprit

Data from the National Oceanic and Atmospheric Administration (NOAA) show that the atmospheric concentration of carbon dioxide emitted largely by the burning of fossil fuels rose from a level of 285 parts per million (ppm) around 1850 at the start of the Industrial Revolution, to 388 ppm in 2009 (see Figure 11, p. S44, in Supplement 9).

According to a 2007 study by scientists Christopher Field and Gregg Marland, if CO_2 emissions continue to increase at the current exponential rate of about 3.3% per year, levels in the atmosphere are likely rise to 560 ppm by 2050 and soar to 1,390 ppm by 2100. Climate models project that such dramatic increases would bring about significant changes in the earth's climate by changing the carbon cycle (Figure 3-13, p. 51) so that CO_2 is added to the atmosphere faster than it is removed. This would cause major ecological and economic disruption in the latter half of this century. If these projections are correct, we would move from talking about projected *climate change* to having acute concern over severe *climate disruption*.

Scientific studies and 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 Jim Hansen, we need to bring CO_2 levels down to 350 ppm to maintain a planet with fairly constant atmospheric temperatures similar to that on which our civilization developed over the last 10,000 years (Figure 15-16, bottom left). (Go to **www.350.org** for more information.)

SCIENCE FOCUS

Using Models to Project Future Changes in Atmospheric Temperature and Climate

To project the effects of increasing levels of greenhouse gases on average global temperatures, climate 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 other factors that affect the earth's average atmospheric temperature and thus its climate. They run these ever-improving models on supercomputers and compare the results to past climate change (Figure 15-16), from which they project future changes in the earth's average atmospheric temperature. Figure 15-A gives a greatly simplified summary of major interactions in the global climate system that are used in climate models.

Such models provide projections of what is *very likely* (with at least 90% certainty) or *likely* (with 66–89% certainty) to happen to the average temperature of the lower atmosphere. How well the results correspond to the real world depends on the validity of the assumptions and variables built into the models and on the accuracy of the data used.

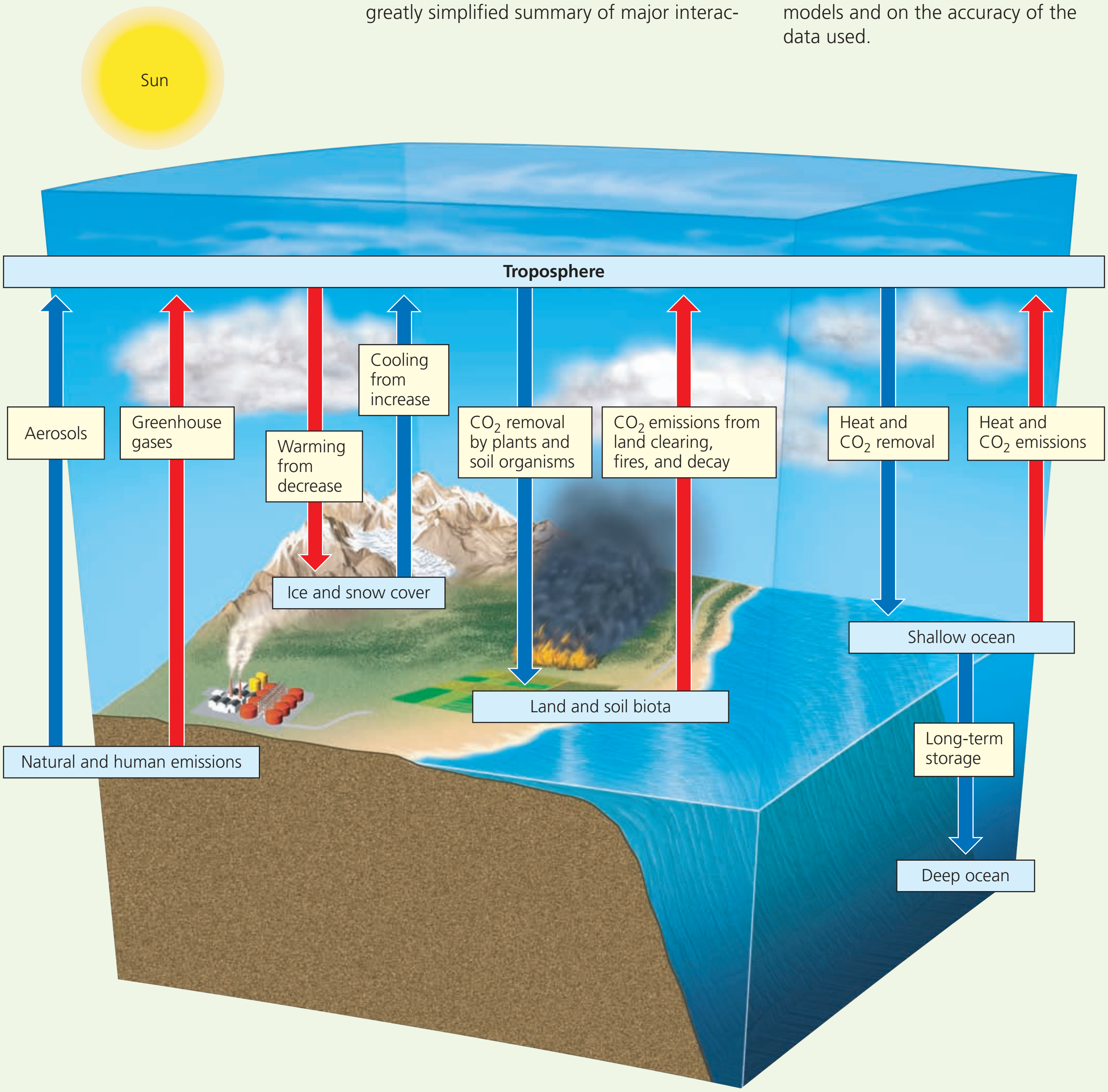


Figure 15-A **Science:** simplified model of some major processes that interact to determine the average temperature and greenhouse gas content of the lower atmosphere and thus the earth's climate. Red arrows show processes that warm the atmosphere and blue arrows show those that cool the atmosphere. **Question**: Why do you think a decrease in snow and ice cover would increase the average temperature of the atmosphere?

In 1990, 1995, 2001, and 2007, the IPCC published reports on how global temperatures have changed in the past (Figure 15-16) and made projections of how they are likely to change during this century and how such changes might affect the earth's climate. The 2007 report and later runs of 19 different climate models suggest that it is *very likely* (with at least 90% certainty) that the mean atmospheric temperature at the earth's surface will rise by 2–4.5 C° (3.6–8.1 F°) between 2005 and 2100 (Figure 15-B), with about 3 C° (5.4 F°) being the most likely increase. These models indicate that, to avoid this, the world would have to halt deforestation and make drastic cuts in greenhouse gas emissions. The smallest temperature increase in this range is likely only if global greenhouse gas emissions fall by 50–85% by 2050.

These models, like all scientific models, are not perfect, because scientists can never prove anything absolutely (p. 27). The goal of any scientific model is to establish a high degree of certainty (at least 90%) about its usefulness. But in any scientific model, there is always some degree of uncertainty, as indicated by the range of projected temperature changes in climate models. Climate experts are working hard to improve these models and to narrow the projected range of temperature increases. Also, current climate models are better at projecting likely 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.

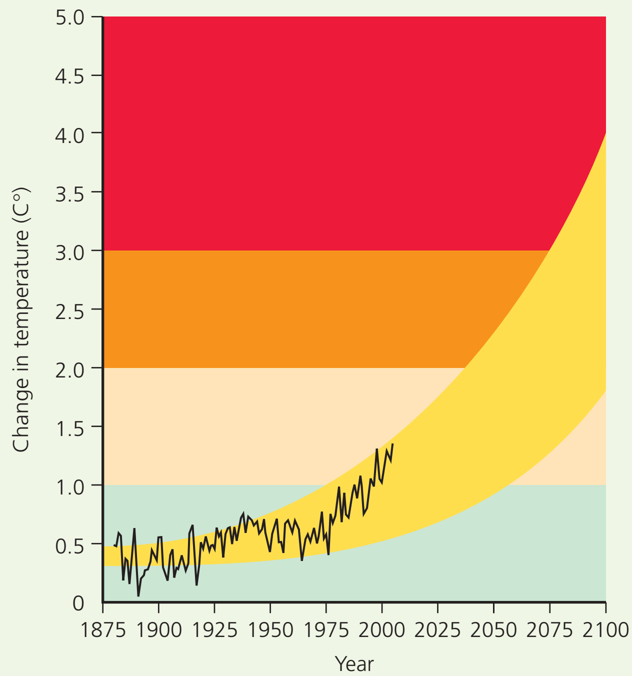


Figure 15-B **Science:** comparison of measured changes in the average temperature of the atmosphere at the earth's surface between 1860 and 2007 and the projected range of temperature increase during the rest of this century (**Concept 15-4**). The projected range of temperature changes is large because of uncertainties in climate models. But according to the IPCC, the difference in the low and high range is between bad and catastrophic. (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, 2007)

Critical Thinking

If projected temperature increases shown in Figure 15-B take place during this century, what are three major ways in which this will likely affect your lifestyle and that of any children or grandchildren you might have?

In 2008, the largest CO_2 emitters were, in order, China, the United States, the European Union (with 27 countries), Indonesia, Russia, Japan, and India. Over time, the United States has been responsible for 25% of the world's cumulative CO_2 emissions, compared to China's 5% contribution. Although China's total CO_2 emissions are high and growing rapidly, 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.

What Role Do Oceans Play in Climate Change?

Scientists have identified a number of natural and human-influenced factors that might *amplify* or *dampen* projected changes in the average temperature of the atmosphere (red and blue arrows in Figure 15-A). The world's oceans, for example, help to moderate the earth's average surface temperature and thus its climate by removing about 25–30% of the CO_2 pumped into the lower atmosphere by human activities. The oceans also absorb heat from the lower atmosphere and use currents to slowly transfer some CO_2 to the deep ocean (Figure 7-5, p. 125), where it is buried in bottom sediments for several hundred million years.

The solubility of CO_2 in ocean water decreases with increasing temperature. Thus, 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. This could speed up projected changes in the average temperature of the atmosphere and the resulting climate change.

According to a 2007 study, scientific measurements show that the upper portion of the ocean warmed by 0.32–0.67 C° (0.6–1.2 F°) during the last century—an astounding increase considering the huge volume of water involved. And a 2007 study, led by researcher Corinne Le Quere, cites evidence that the ability of the oceans to absorb more CO_2 from the atmosphere is weakening.

In 2005, the U.K. Royal Society reported that higher levels of CO_2 in the ocean have increased the acidity of the ocean surface by 30% from preindustrial times, 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). While the oceans help to regulate atmospheric warming by removing CO_2 from the lower atmosphere and storing it in bottom sediments, the increased acidity is reducing this effect and thus can accelerate atmospheric warming and the resulting climate change.

There Is Uncertainty about the Effects of Cloud Cover on Projected Atmospheric Temperatures

Warmer temperatures increase evaporation of surface water and create more clouds. Depending on their content and reflectivity, these additional clouds can cool or warm the atmosphere.

An increase in thick and continuous light-colored clouds at low altitudes could *decrease* surface warming by reflecting more sunlight back into space. But an increase in thin and discontinuous cirrus clouds at high altitudes could increase the warming of the lower atmosphere by preventing more heat from escaping into space. Currently, there is not enough evidence to indicate which of these effects is the most important. This is one reason for the wide range of projected temperature increases shown by the yellow-shaded curved area in Figure 15-B.

In addition, infrared satellite images indicate that wispy condensation trails (contrails) left behind by jet planes expand and turn into large cirrus clouds that tend to heat the atmosphere.

15-5 What Are Some Possible Effects of Projected Climate Change?

CONCEPT 15-5 The projected change in the earth's climate during this century could have severe and long-lasting consequences, including increased drought and flooding, rising sea levels, and shifts in locations of agriculture and wildlife habitats.

Projected Climate Change Could Have Severe Consequences

Most historic changes in the temperature of the lower atmosphere took place over thousands of years (Figure 15-16, 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 15-B). This gives us little time to deal with the projected effects of such a major change in the earth's climate (**Concept 15-5**).

Figure 15-20 summarizes some of the projected effects of a warmer atmosphere and the projected resulting changes in global climate. If these changes occur, they will affect parts of the world differently (Figure 12, p. S45, in Supplement 9).

According to the IPCC, a warming of 2 C° (3.6 F°) and its effects on global climate appears to be inevitable because we have waited too long to prevent some degree of change, having ignored the warnings of the world's leading climate scientists for more than 25 years. A 2009 U.S. government study warned that even if greenhouse gas emissions are stopped now, some effects such as increased drought and a sea level rise will be felt for at least 1,000 years.

A temperature increase of 2 C° (3.6 F°) is probably manageable. But as temperatures increase beyond this level, the harmful effects and costs of the resulting irreversible climate change will very likely escalate rapidly (Figure 15-20, middle and right). Climate scientists warn that a 4 C° (7.2 F°) warming will threaten human civilization as we know it and much of the earth's biodiversity.

The good news is that we can limit the extent of these projected harmful effects if the world takes strong global action *now* to sharply reduce greenhouse gas emissions. Let us look more closely at some of the projected effects of projected climate change.

Severe Drought Will Increase

A 2005 study by Aiguo Dai and his colleagues, estimated that severe and prolonged drought affects at least 30% of the earth's land (excluding Antarctica). According to a 2007 study by climate researchers at the NASA Goddard Institute for Space Studies, by 2059, up to 45% of the world's land area could experience extreme drought.

Southern Australia has been in the grips of a severe drought for a decade. The western United States is experiencing its worst drought in 500 years, and according to 2008 projections by climate scientists, there appears to be no relief in sight for the remainder of this century, perhaps longer. Other areas likely to become drier are Mexico, northern Africa, and southern Europe.

Drought based on decreased rainfall is related to changes in weather patterns such as high pressure systems and jet streams (see Figure 2, p. S33, in Supplement 8). Drought in parts of the world is also related to

2 °C (3.6 °F) Warming with 450 ppm CO_2 (now unavoidable effects)

- Forest fires worsen
- Prolonged droughts intensify
- Deserts spread
- Major heat waves more common
- Fewer winter deaths in higher latitudes
- Conflicts over water supplies increase
- Modest increases in crop production in temperate regions
- Crop yields fall by 5–10% in tropical Africa
- Coral reefs affected by bleaching
- Many glaciers melt faster and threaten water supplies for up to 100 million people
- Sea levels rise enough to flood low-lying coastal areas such as Bangladesh
- More people exposed to malaria
- High risk of extinction for Arctic species such as the polar bear and several penguin species in Antarctica

3 °C (5.4 °F) Warming with 550 ppm CO_2 (potentially avoidable effects)

- Forest fires get much worse
- Prolonged droughts get much worse
- Deserts spread more
- Major heat waves and deaths from heat increase
- Irrigation and hydropower decline
- 1.4 billion people suffer water shortages
- Water wars, environmental refugees, and terrorism increase
- Malaria and several other tropical diseases spread faster and further
- Crop pests multiply and spread
- Crop yields fall sharply in many areas, especially Africa
- Coral reefs are severely threatened
- Amazon rainforest may begin collapsing
- Up to half of Arctic tundra melts
- Sea levels continue to rise
- 20–30% of plant and animal species face premature extinction

4 °C (7.2 °F) Warming with 650 ppm CO_2 (potentially avoidable effects)

- Forest fires and drought increase sharply
- Water shortages affect almost all people
- Crop yields fall sharply in all regions and cease in some regions
- Tropical diseases spread even faster and further
- Water wars, environmental refugees, terrorism, and economic collapse increase sharply
- Methane emissions from melting permafrost accelerate and cause more warming
- Ecosystems such as coral reefs, tropical forests, alpine and Arctic tundra, polar seas, coastal wetlands, and high-elevation mountaintops begin collapsing
- Glaciers and ice sheets melt faster
- Sea levels rise faster and flood many low-lying cities and agricultural areas
- At least half of plant and animal species face premature extinction

Figure 15-20 Some projected effects of atmospheric warming and the resulting changes in global climate, based on the extent of warming and the total atmospheric concentrations of the greenhouse gas CO_2 in parts per million. According to the IPCC, a warming of 2 C° (3.6 F°) over 2005 levels is unavoidable, and an increase of at least 3 C° (5.4 F°) is likely sometime during this century (Figure 15-B). (Data from 2007 Intergovernmental Panel on Climate Change Report and Nicolas Stern, *The Economics of Climate Change: The Stern Report,* Cambridge University Press, 2006)

shifts every few years in trade winds known as *El Niño–Southern Oscillation (ENSO)* that alter water currents in the Pacific Ocean (see Figure 4, p. S34, in Supplement 8) This temporarily increases drought and alters other weather conditions over much of the globe (Figure 5, p. S35, in Supplement 8).

Long-term climate change can also contribute to prolonged drought. Australian climate scientist Peter Bains has analyzed global rainfall and sea surface temperature data over the past 50 years. In 2009, he reported that during the past 15 years or so, average rainfall in Australia and in the western United States has been decreasing, with a warmer atmosphere being responsible for 37% of the drop. If the atmosphere continues to warm as projected (Figure 15-B), he expects its influence on prolonged drought to increase.

As drought increases and spreads, the growth of trees and other plants declines, which reduces the removal of CO_2 from the atmosphere. And forest and grassland fires increase, which adds CO_2 to the atmosphere. Climate scientists project that these combined effects from increased drought will speed up the warming of the atmosphere.

More Ice and Snow Will Melt

Climate models predict that atmospheric warming will be the most severe in the world's polar regions. 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 absorb more solar energy. This causes polar regions to warm faster than lower latitudes, and it accelerates atmospheric warming because less solar energy is reflected away from the earth's surface. This melts more snow and ice and causes further warming in an escalating spiral of change.

According to the 2007 IPCC report, arctic atmospheric 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 Russian industries is darkening arctic ice and lessening its ability to reflect sunlight. As a result, summer sea ice in the Arctic is disappearing faster than scientists thought only a few years ago (Figure 15-19). 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 average coverage to decrease.

Loss of arctic sea ice affects global air and water circulation patterns. Thus it could reduce long term average rainfall and snowfall in the already arid American West (Figure 11-5, p. 242) and affect food production in several areas by reducing the availability of irrigation water. It could also lead to increased precipitation and flooding in western and southern Europe.

Mountain glaciers play a vital role by storing water as ice during cold wet seasons and releasing it slowly to streams during warmer dry seasons. Such glaciers are a major source of water for large rivers (Figure 7-32, p. 148). Mountain glaciers can shrink or expand depending on short-term weather conditions. But during the past 25 years, many of the world's mountain glaciers have been melting and shrinking at accelerating rates (Figure 15-18). The U.S. Geological Survey, for example, reported in 2009 that 99% of Alaska's glaciers are shrinking.

In 2007, scientists estimated that 80% of the mountain glaciers in South America will be gone by 2025. As this occurs, 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. Similar shortages could threaten billions of people in Asia—4 of every 10 people in the world—if mountain glaciers in the Himalaya and Tibetan Plateau melt as projected in a 2009 Worldwatch Institute report. Himalayan glaciers also receive soot from the Asian Brown Cloud (**Core Case Study**), which settles on the ice, absorbs sunlight, and hastens its melting. CORE CASE STUDY

CONNECTIONS

Melting Permafrost and Atmospheric Warming

Ice within soils and ocean bottom sediments, or *permafrost*, is also melting. According to the 2004 Arctic Climate Impact Assessment, 10–20% of the Arctic's current permafrost soils might thaw during this century. And recent research indicated that the amount of carbon stored as methane (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. Some scientists refer to these sources as "methane time bombs." They could eventually release amounts of methane and CO_2 that would be many times the current levels in the atmosphere, resulting in rapid and catastrophic climate change.

Sea Levels Will Rise

Rising sea levels resulting from a warmer atmosphere pose a far bigger threat 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 is most likely to rise 0.8–2 meters (2.6–6.5 feet) during this century—3 to 5 times the increase estimated in the 2007 IPCC report—and to keep rising for centuries. This rise is due to the expansion of seawater as it warms, and to the melting of land-based ice, especially mountaintop glaciers.

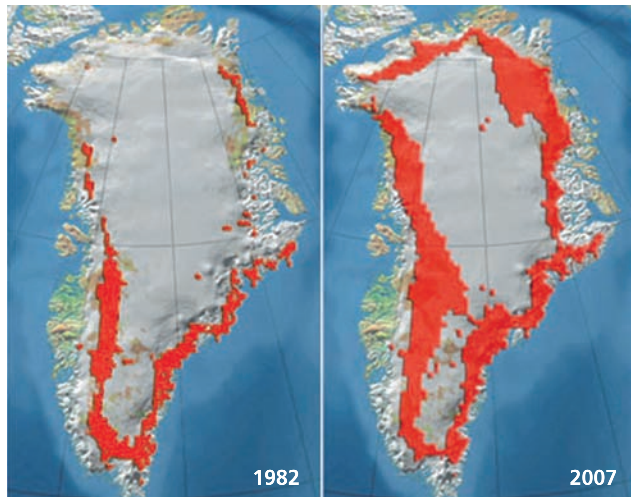


Figure 15-21 Glaciers covering about 80% of Greenland, the world's largest island, contain about 10% of the world's freshwater. This is enough water to raise the global sea level by as much as 7 meters (23 feet) if they all melt. Complete melting of Greenland's land-based glaciers is highly unlikely. But partial summer melting of some of its glacial ice increased dramatically between 1982 and 2007. (Data from Konrad Steffen and Russell Huff, University of Colorado, Boulder, 2007).

Such a rise in sea level would be more dramatic if land-based glaciers in Greenland (Figure 15-21) and western Antarctica (covering an area the size of the U.S. states of Oklahoma and Texas, combined) 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 would cause a devastating 1-meter (3.3-foot) rise in sea level that would threaten millions of people and cause trillions of dollars of damage to many of the world's major coastal cities (Figure 6-11, p. 108).

Severe reductions in greenhouse gas emissions might prevent such a catastrophic rise in sea level, but even then, most scientists are projecting a minimum rise of 1 meter (3.3 feet) by 2100. According to the IPCC, this projected change could threaten at least one-third of the world's coastal estuaries, wetlands, and coral reefs. It would also contaminate freshwater coastal aquifers with saltwater, disrupt many of the world's coastal fisheries, flood low-lying barrier islands, and cause gently sloping coastlines to erode and retreat inland. For example, Figure 15-22 shows areas of the U.S. state of Florida that would be flooded with an average sea level rise of 1 meter (3.3 feet).

Projected sea level rises would also submerge low-lying islands around the world, flooding out a total population greater than that of the United States. Flooding in some of the world's largest cities located on coasts would displace at least 150 million people. It would also threaten trillions of dollars worth of buildings, roads, and other forms of infrastructure. (See *The Habitable Planet*, Video 5 at **www.learner.org/resources/series209.html**.) U.N. officials and a 2008 U.S. National

Figure 15-22 Areas of the U.S. state of Florida that will be flooded (red) if the average sea level rises by 1 meter (3.3 feet). (Data from Jonathan Overpeck and Jeremy Weiss based on U.S. Geological Service Data, 2007)

Intelligence Assessment warned that such displacement and other climate-driven changes such as water and food scarcity could lead to massive forced migration of desperate environmental refugees on a scale never seen before, making climate change a serious threat to international and national security.

Extreme Weather Will Increase in Some Areas

According to the IPCC, projected climate change will increase the incidence of extreme weather such as heat waves and severe droughts 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 precipitation. (See Figure 12, p. S45, in Supplement 9.)

At least six peer-reviewed studies published in 2006 indicated that a warmer atmosphere could, on average, increase the size and strength of tropical storms in the Atlantic by warming the ocean's surface water. But some climate scientists hypothesize that atmospheric warming might lead to fewer hurricanes in the Atlantic Ocean. More research is needed to evaluate the effects of atmospheric warming on hurricane frequency and intensity.

Climate Change Will Threaten Biodiversity

According to the 2007 IPCC report, changes in climate are already affecting physical and biological systems on every continent and are altering ecosystem services in some areas. An even warmer climate could expand ranges and populations of some organisms that can adapt to the change. However, some adaptive organisms—such as weeds, fire ants, beetles that kill trees, and disease-carrying organisms—will likely threaten many other species as they expand.

According to the IPCC, approximately 30% of the land-based plant and animal species assessed so far could disappear if the average global temperature change exceeds 1.5–2.5 C° (2.7–4.5 F°). This percentage could grow to 70% if the temperature change exceeds 3.5 C° (6.3 F°) (**Concept 15-5**). 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 at higher elevations; plant and animal species with limited ranges such as some amphibians (Figure 4-1, p. 59); and those with limited tolerance for temperature change. The ecosystems *most likely* to suffer disruption and species loss from climate change are coral reefs (Figure 7-26, p. 143, and Figure 7-27, p. 144), polar seas, coastal wetlands, high-elevation mountaintops, and alpine and arctic tundra.

As conditions become warmer and drier, the frequency of forest fires could increase in some areas such as the southeastern and western United States, which would decrease forest biodiversity and accelerate climate change by adding more CO_2 to the atmosphere. A warmer climate would also greatly increase populations of insects and fungi that damage trees. Tree losses due to global warming in Brazil's Amazon basin could be as high as 85%, according to a 2009 British study.

CONNECTIONS

CO_2 Emissions and Polar Ecosystems

As oceans have absorbed huge amounts of CO_2 since preindustrial times, their waters have become more acidic. According to a 2008 report by a panel of marine scientists, ocean acidity now threatens the survival of tiny sea snails, because the acidic water tends to dissolve their shells. These snails form part of the base of the food web that supports entire polar ecosystems, including salmon, seals, whales, and people. Pink salmon, for example, rely on these snails for nearly half of their food supply in these regions. This ecosystem could collapse if there is a sharp drop in the snail population.

Food Production May Decline

According to the 2007 IPCC report, crop productivity is projected to increase slightly at middle to high latitudes with moderate atmospheric warming, but decrease if warming goes too far. For example, moderately warmer atmospheric temperatures and increased precipitation at northern latitudes may lead to a northward shift of some agricultural production to parts of midwestern Canada, Russia, and Ukraine. But overall food production could decrease because of unsuitable soils in these northern regions.

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 malnutrition and starvation due to the effects of climate change on agricultural systems.

Climate Change Will Threaten the Health of Many People

In 2009, the U.S. Environmental Protection Agency found that carbon dioxide and other greenhouse gases are a significant threat to human health and thus will be classified as air pollutants under the Clean Air Act. Also, in 2009, a report by doctors, led by Anthony Costello, warned that climate change will be the biggest threat to human health during the 21st century.

According to the IPCC and other reports, more frequent and prolonged heat waves in some areas will increase deaths and illnesses, especially among older people, those with poor health, and the urban poor who cannot afford air conditioning. In a warmer world, fewer people will die from cold weather. But a 2007 study by Mercedes Medina-Ramon of the Harvard University School of Public Health and her colleagues suggests that increased numbers of heat-related deaths will be greater than the projected drop in cold-related deaths.

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. Microbes that cause tropical infectious diseases such as dengue fever, yellow fever, and malaria (Figure 14-6, p. 350) are likely to expand their ranges and numbers if mosquitoes that carry them spread to warmer temperate and higher elevation areas. Higher atmospheric temperatures will also increase air pollution by increasing the rate of chemical reactions that produce photochemical smog.

A 2005 WHO study estimated that climate change already affects more than 250 million people and contributes to the premature deaths of more than 150,000 people a year—an average of 411 people a day—and that this number could double by 2030. Most of these deaths are caused by increases in malaria, diarrhea, malnutrition, and flooding that can be traced to climate change. By the end of this century, the annual death toll from climate change could be in the millions.

15-6 What Can We Do to Slow Projected Climate Change?

CONCEPT 15-6 To slow the rate of projected climate change, we can increase energy efficiency, sharply reduce greenhouse gas emissions, rely more on renewable energy resources, and slow population growth.

What Are Our Options?

There are two basic approaches to dealing with the projected harmful effects of global climate change. One is to drastically reduce greenhouse gas emissions to slow down the rate of temperature increase and to shift to a mix of noncarbon-based energy options (Figure 13-41, p. 340) in time to prevent major climate changes. The other is to recognize that some climate change is unavoidable and to devise strategies to reduce its harmful effects. Most analysts believe we need a mix of both approaches.

In 2008, more than 1,700 of the most prominent U.S. scientists and economists (including six Nobel Prize winners) issued a first-ever joint statement calling on U.S. policymakers to make immediate deep reductions in greenhouse gas emissions. They called for the United States to lead the world in meeting the climate change challenge by reducing greenhouse gas emissions to at least 15–20% below 2000 levels by 2020 and to 80% below 2000 levels by 2050.

HOW WOULD YOU VOTE?

Should we take serious action now to help slow climate change as a result of human actions? Cast your vote online at **www.cengage.com/biology/miller**.

We Can Reduce the Threat of Climate Change

GOOD NEWS

We know a number of ways to slow the rate and degree of atmospheric warming and the resulting climate change caused by our activities, as summarized in Figure 15-23.

The solutions on the left side of Figure 15-23 come down to three major *input* or *prevention* strategies (**Concept 15-6**):

- improve energy efficiency to reduce fossil fuel use and waste
- shift from nonrenewable carbon-based fossil fuels to a mix of carbon-free renewable energy resources based on local and regional availability
- stop cutting down tropical forests

Slowing population growth, which would slow the increase in the number of fossil fuel consumers and CO_2 emitters, would enhance the effectiveness of these strategies. Reducing poverty would also help, because it would decrease the need for poor people to clear more land for crops and fuelwood.

The solutions listed on the right side of Figure 15-23 are *output*, or *cleanup*, strategies, which focus on deal-

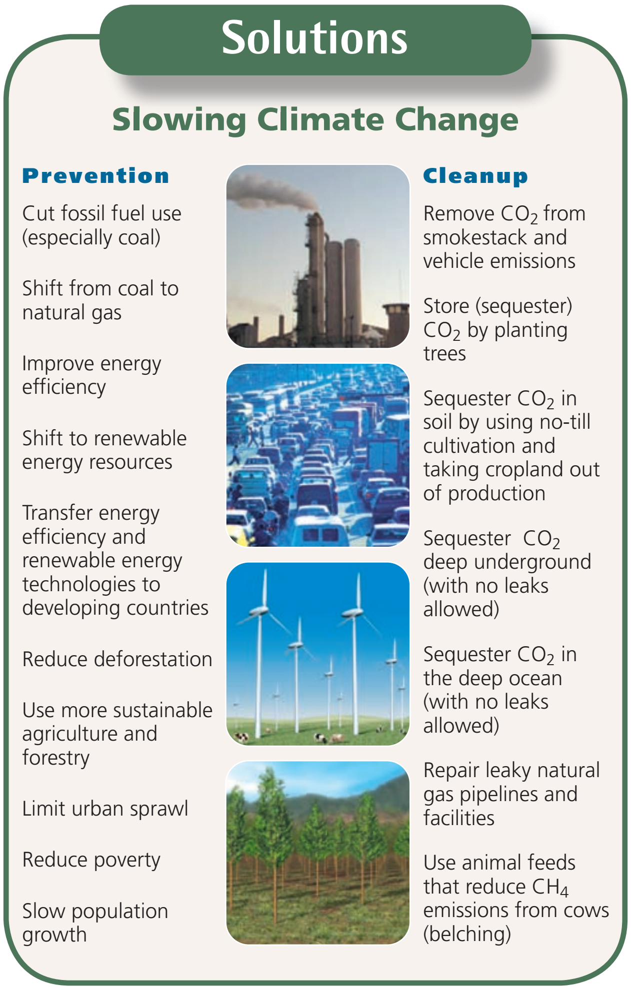


Figure 15-23 Methods for slowing projected climate change during this century (**Concept 15-6**). **Questions**: Which five of these solutions do you think are the most important? Why?

ing with CO_2 after it has been emitted (Science Focus, p. 394).

Some scientists and entrepreneurs are promoting other prevention strategies that fall under the umbrella of *geo-engineering*, or trying to manipulate natural conditions to counter an enhanced greenhouse effect.

For example, some scientists argue for injecting sulfate particles into the stratosphere to reflect some of the incoming sunlight into space and cool the troposphere. Other scientists have called for placing a series of giant mirrors in orbit above the earth for the same purpose. Another scheme is to wrap large areas of glaciers with insulating blankets to slow down their melting. Some agricultural researchers are promoting crop varieties that reflect more sunlight. Other scientists call for painting all roofs and roads white to reflect more sunlight and help cool the planet's surface.

The major problem with most of these technological fixes and with some carbon capture and storage schemes (Science Focus, p. 394) is that they require huge investments of energy and materials, and there is no guarantee that they will work. If we continue emitting greenhouse gases and these systems fail, atmospheric temperatures will likely soar at a rapid rate and speed up climate change.

Governments Can Help to Reduce the Threat of Climate Change

Governments can use four major methods to promote the solutions listed in Figures 15-23 and 15-C (**Concept 15-6**). They can:

- Strictly regulate carbon dioxide (CO_2) and methane (CH_4) as climate-changing pollutants
- Put a price on carbon emissions by phasing in taxes on each unit of CO_2 or CH_4 emitted by fossil fuel use or phasing in energy taxes on each unit of fossil fuel that is burned and offsetting these tax increases by reducing taxes on income, wages, and profits
- Use a cap-and-trade system (p. 379), which uses the marketplace to help reduce emissions of CO_2 and CH_4
- Phase out government subsidies and tax breaks for environmentally harmful fossil fuels, and phase in government subsidies and tax breaks for energy-efficiency technologies, carbon-free renewable energy sources, and more sustainable agriculture

The basic problem is that carbon emissions have essentially been free, and this has led to a tragedy of the commons (p. 9) in terms of atmospheric warming and climate change. Unless we use taxes or cap-and-trade to put a price on carbon emissions and gradually increase this price, carbon emissions will not be reduced enough to help slow the rate of projected climate change.

There is much debate within governments about which is better: direct taxes on CO_2 or a cap-and-trade approach. Critics of cap-and-trade argue that directly taxing greenhouse gas emissions or fossil fuel use would work much better and more quickly than cap-and-trade. Political opposition to such taxes could be reduced by decreasing taxes on income and wealth and using some of the tax revenues to provide an economic safety net for low and low-middle income individuals.

Governments Can Enter into International Climate Negotiations: The Kyoto Protocol

In December 1997, more than 2,200 delegates from 161 nations met in Kyoto, Japan, to negotiate a treaty to cut greenhouse gas emissions and slow projected climate change. The first phase of the resulting *Kyoto Protocol* went into effect in February 2005, and 183 of the world's 194 countries (not including the United States) ratified the agreement by early 2009.

This agreement requires 36 participating 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

SCIENCE FOCUS

Is Capturing and Storing CO_2 the Answer?

Output strategies for dealing with CO_2 (Figure 15-23, right) would allow us to keep burning fossils fuels. But they would require us to capture and store as much CO_2 as possible in soil, in vegetation, underground, and in the deep ocean, and to hope that it would never leak out.

Figure 15-C 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.

One way to increase the uptake of CO_2 is by implementing an emergency global tree-planting program, especially on degraded land in the tropics. Such tree planting would have to continue indefinitely, because trees decrease their CO_2 uptake as they mature and release their stored CO_2 back into the atmosphere when they die and decompose or when they are burned.

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.

A third cleanup approach is to plant large areas of degraded land with fast-growing perennial plants, which can remove CO_2 from the air and store it in the soil and be harvested to produce biofuels such as ethanol. But warmer temperatures can increase decomposition in soils and return some of this CO_2 to the atmosphere. (See *The Habitable Planet*, Video 10 at **www.learner.org/resources/series209.html**.)

Fourth, we could help the natural uptake and storage of carbon by preserving natural forests. A 2008 study by Australian scientists found that such forests store three times more CO_2 than was previously estimated and 60% more than tree plantations store. In addition, they reported that natural forests are more resilient to climate change and other disturbances than tree plantations are.

Fifth, some scientists call for 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. For example, 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 off the coast of Argentina with iron. If this were to happen regularly, it would defeat the purpose of seeding oceans with iron.

Sixth, remove some of the CO_2 from smokestacks and 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 15-C). 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 the 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 storage sites around the world, could dramatically increase atmospheric temperatures and climate change in a very short time. Some scientists doubt that we can develop the technology to guarantee that such stored CO_2 would never be released.

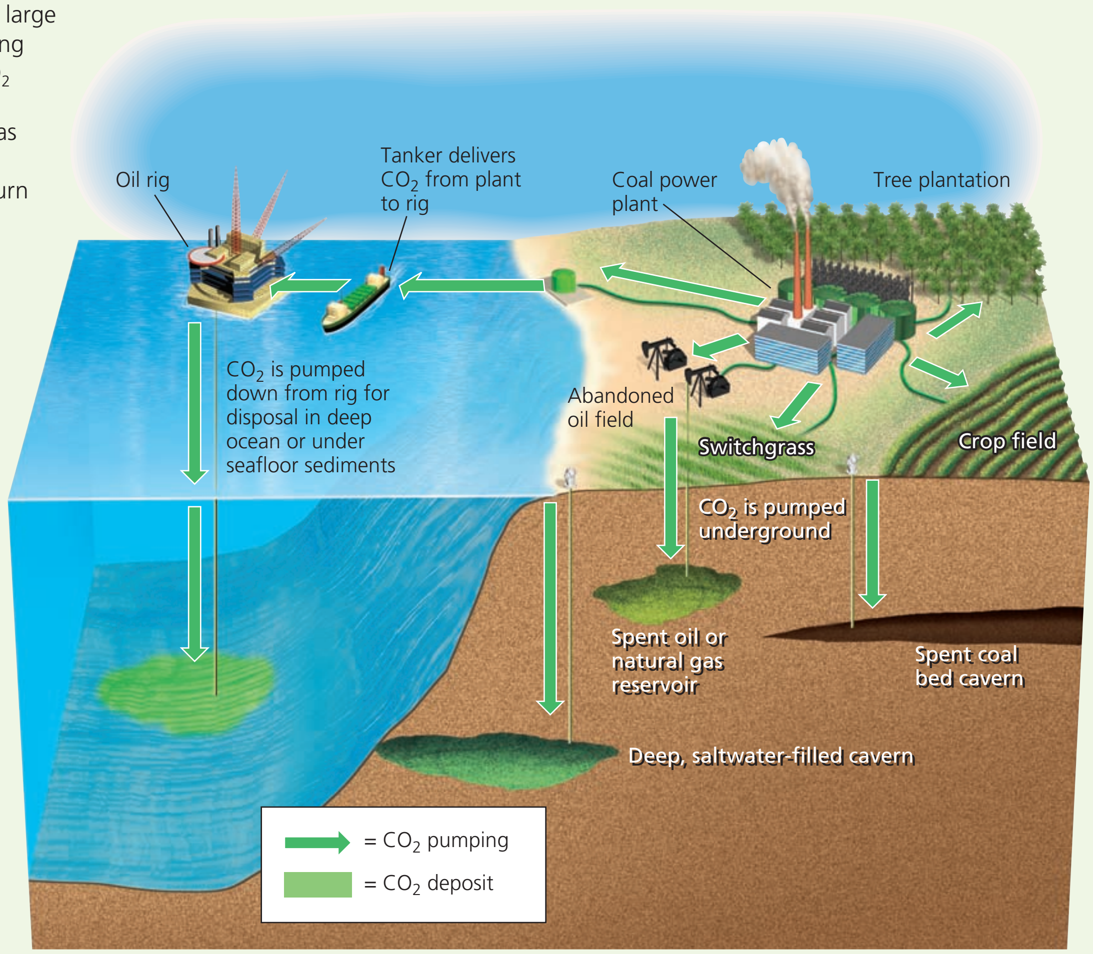


Figure 15-C Solutions: some *output* methods for removing carbon dioxide from the atmosphere or from smokestacks and storing it in plants, soil, deep underground reservoirs, and the deep ocean. **Questions**: Which two of these solutions do you think are the most important? Why?

There are other problems. CCS power plants will be very expensive to build and run and thus would greatly increase the price of electricity for consumers. In addition, current technologies would remove only part (perhaps 25–35%) of the CO_2 from smokestack emissions and would do nothing to reduce the massive amounts of CO_2 emitted by motor vehicles. They would also promote increased use of coal, the world's most environmentally harmful fuel to dig up and burn (Figure 13-12, right, p. 307).

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 15-23, left). To these scientists, when we face a problem such as CO_2 coming out of a smokestack or exhaust pipe, the key 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 favor developing a government-supported crash program to build coal-burning power plants with CCS components? Explain.

by 2012. Developing countries were excluded from this requirement in this first phase, because such reductions would curb their economic growth. In 2005, countries began negotiating a second phase, which is supposed to go into effect after 2012.

Some analysts praise the Kyoto agreement as a small but important step in attempting to slow projected climate change. Others see the agreement as a weak and slow response to an urgent global problem.

In 2001, the U.S. government withdrew from the Kyoto agreement, arguing that it did not require greenhouse gas emissions reductions for rapidly developing countries such as China and India and that it would harm the U.S. economy. In 2009, President Barack Obama indicated that he wanted the United States to lead the way in creating a new international agreement on climate change. He said he would set annual targets for reducing U.S. carbon emissions to their 1990 levels by 2020 and for reducing them another 80% by 2050. Some European Union countries hope to set even more ambitious goals.

Some Governments, Corporations, and Schools Are Leading the Way

Some nations are leading others in facing the challenges of climate change. Costa Rica aims to be the first country to become *carbon neutral* by cutting its net carbon emissions to zero by 2030. Norway aims to become carbon neutral by 2050.

By 2009, some 30 U.S. states had greenhouse gas emission reduction programs. California planned to get 33% of its electricity from noncarbon renewable energy sources by 2030. Local governments in more than 650 cities around the world (including 453 U.S. cities) have established programs to reduce their greenhouse gas emissions.

A 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. 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.

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 mostly carbon-free renewable energy. See **http://www.nwf.org/campusecology/BusinessCase/index.cfm** for a 2008 report by the National Wildlife Federation that includes information on how your school can cut its CO_2 emissions.

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?

GOOD NEWS

Figure 15-24 (p. 396) summarizes ways in which you can make a difference by cutting your CO_2 emissions (see **http://worldwildlife.org/carbon-calculator** for tips on reducing your carbon footprint).

We Can Prepare for Climate Change

According to recent global climate models, the world needs to make a 50–85% cut in emissions of greenhouse gases by 2050 (some say by 2020) to stabilize concentrations of these gases in the atmosphere and to help prevent the atmosphere from heating up by more than 2 C° (3.6 F°) (Figure 15-23). Scientists from the Worldwatch Institute stated in 2009 that even this temperature rise would be too dangerous, and they call for dropping world carbon emissions to near zero by 2050.

However, because of the political and economic difficulty of making such large reductions, many analysts believe that, while we work to slash emissions, we should

What Can You Do?

Reducing CO_2 Emissions

- Drive a fuel-efficient car, walk, bike, carpool, and use mass transit
- Use energy-efficient windows
- Use energy-efficient appliances and lights
- Heavily insulate your house and seal all air leaks
- Reduce garbage by recycling and reusing more items
- Insulate your hot water heater
- Use compact fluorescent lightbulbs
- Plant trees to shade your house during summer
- Set your water heater no higher than 49 °C (120 °F)
- Wash laundry in warm or cold water
- Use a low-flow showerhead
- Buy products from, or invest in, companies that are trying to reduce their impact on climate

Figure 15-24 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?

also begin to prepare for the projected harmful effects of some essentially irreversible climate change. China, for example, plans to build 59 reservoirs to collect water from its shrinking glaciers. Figure 15-25 shows some other ways to prepare for projected climate change.

A No Regrets Strategy

The threat of projected climate change pushes us to make changes such as those listed in Figure 15-23. But suppose we find out that the climate models are wrong and that atmospheric warming is not a serious threat. Should we then abandon the strategies listed in Figure 15-23?

A number of climate and environmental scientists say *absolutely not*, 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 15-23 lead to other very important environmental, health, and economic benefits.

For example, burning fossil fuels, especially coal, is the biggest cause of outdoor air pollution. Thus, a sharp decrease in the use of fossil fuels will sharply reduce air pollution that harms or kills large numbers of people. Cutting coal use will also greatly reduce land disruptions resulting from surface mining. Reducing oil use will decrease dependence on imported oil, which threatens the economic and military security of oil-dependent nations. And improving energy efficiency has numerous economic and environmental benefits (Figure 13-20, p. 318).

In addition, sharply decreasing or halting tropical forest destruction would help to preserve the earth's increasingly threatened biodiversity. So even if atmospheric warming and the resulting climate change were not an issue, there are still plenty of important reasons for implementing these strategies on an urgent basis.

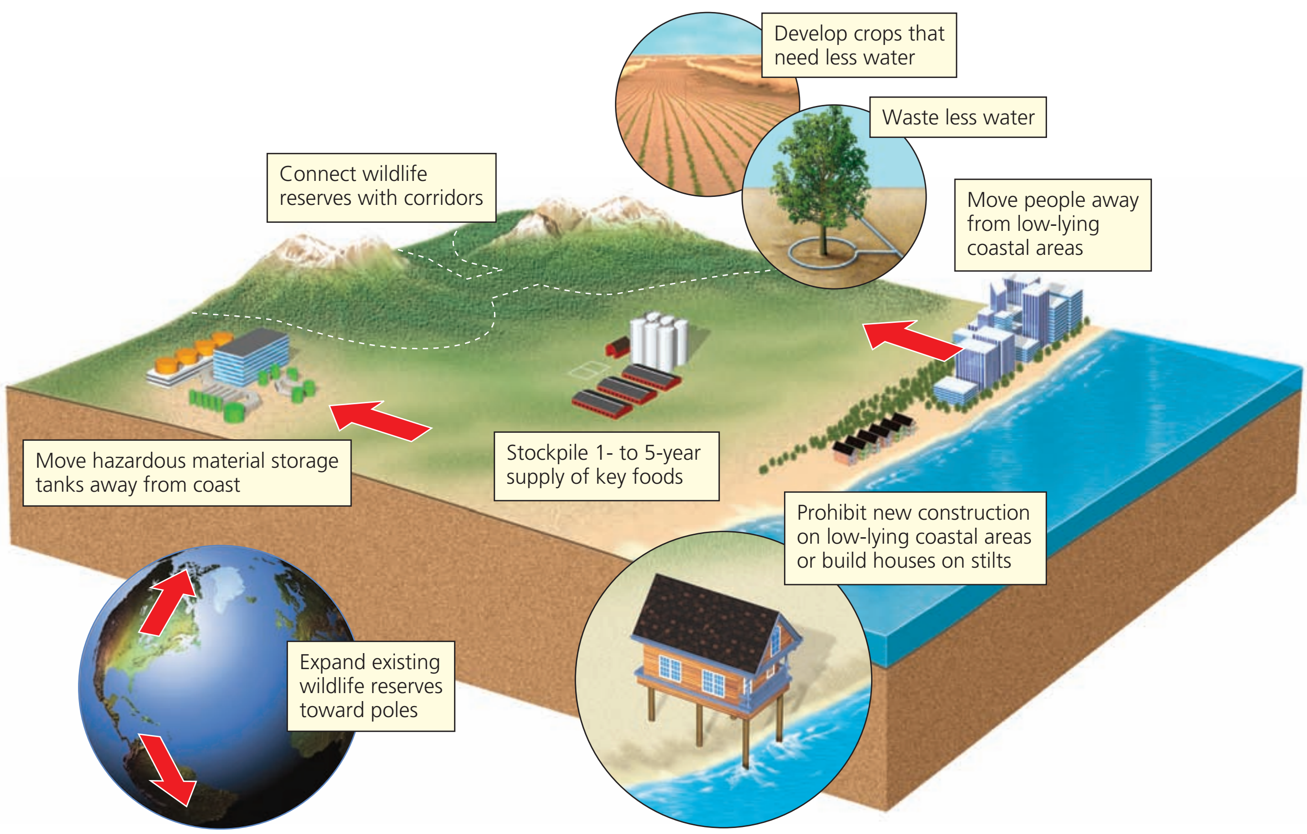


Figure 15-25 Solutions: ways to prepare for the possible long-term harmful effects of climate change. **Questions**: Which three of these adaptation solutions do you think are the most important? Why?

15-7 How Have We Depleted Ozone in the Stratosphere and What Can We Do about It?

▶ **CONCEPT 15-7A Widespread use of certain chemicals has reduced ozone levels in the stratosphere and allowed more harmful ultraviolet radiation to reach the earth's surface.**

▶ **CONCEPT 15-7B To reverse ozone depletion, we need to 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 (Figure 15-2). But measurements taken by meteorologists show 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.

Based on these measurements and 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 15-7A**).

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 as 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 (Individuals Matter, p. 360), fumigants for granaries and ship cargo holds, and 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, below), 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-depleting chemicals into the atmosphere, beginning in the 1950s.

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 at the University of California–Irvine indicated that chlorofluorocarbons (CFCs) were lowering the average concentration of ozone in the stratosphere. 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 of 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), a powerful, well-funded adversary with a lot of profits and jobs at stake, attacked Rowland's and Molina's calculations and conclusions. 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."

Natural Capital Degradation

Effects of Ozone Depletion

Human Health

- Worse sunburns
- More eye cataracts
- More 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

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

Climate Change

- While in troposphere, CFCs act as greenhouse gases

Figure 15-26 Expected effects of decreased levels of ozone in the stratosphere (**Concept 15-7A**). **Questions**: Which three of these effects do you think are the most threatening? Why?

Why Should We Worry about Ozone Depletion?

Why should we care about ozone loss? Figure 15-26 lists some of the expected effects of decreased levels of ozone in the stratosphere. One effect is that more biologically damaging UV-A and UV-B radiation will reach the earth's surface (**Concept 15-7A**). This will give people more eye cataracts, worse sunburns, and more skin cancers.

Figure 15-27 lists ways in which you can protect yourself from harmful UV radiation. GOOD NEWS

We Can Reverse Stratospheric Ozone Depletion

The problem of ozone depletion has been tackled quite impressively by almost all the world's nations. But in 2008, the area of ozone thinning was still near its record high of 29 million square kilometers (11 million square miles), set in 2006. U.N. scientists reported that this area had shrunk by 14% in 2007, but then increased by nearly the same amount in 2008.

According to researchers in this field, we should immediately stop producing all ozone depleting chemicals (**Concept 15-7B**). 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.

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 keep oozing, bleeding, and crusting over. If you observe any of these signs, consult a doctor immediately.

Figure 15-27 **Individuals matter:** You can reduce your exposure to harmful UV radiation. **Question**: Which of these precautions do you take?

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 in some areas, with higher atmospheric temperature, 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 over Antarctica, 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.

These landmark international agreements, now signed by 195 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 15-7B**). However, hydrofluorocarbons (HFCs) developed to replace ozone-depleting CFCs are greenhouse gases with a warming effect that is up to 10,000 times as much per molecule as that of CO_2. In 2009, the U.S. government proposed expanding the global ozone protection agreement so that it would also help slow atmospheric warming by reducing HFC use by 85% by 2030.

GOOD NEWS

The ozone protocols set an important precedent by using *prevention* to solve a serious environmental problem. The certainty that CFC sales would decline over a period of years unleashed the economic and creative resources of the private sector to find even more profitable substitute chemicals. And nations and companies worked together and made real progress in solving this global problem.

Here are the *three big ideas* for this chapter:

- All countries need to step up efforts to control and prevent outdoor and indoor air pollution.
- Reducing the possible harmful effects of projected rapid climate change during this century requires emergency action to cut energy waste, sharply reduce greenhouse gas emissions, rely more on renewable energy resources, and slow population growth.
- We need to continue phasing out the use chemicals that have reduced ozone levels in the stratosphere and allowed more harmful ultraviolet radiation to reach the earth's surface.

REVISITING The Asian Brown Cloud, Climate Change, Ozone Depletion, and Sustainability

CORE CASE STUDY

SUSTAINABILITY

In this chapter we have seen that human activities such as the burning of fossil fuels (especially coal), widespread clearing and burning of forests for planting crops, and releasing certain chemicals into the atmosphere can create massive and severe air pollution, represented by the Asian Brown Cloud (**Core Case Study**). Some of these chemicals are playing a major role in changing the earth's climate by warming the troposphere, and some of them deplete ozone in the stratosphere.

The three **scientific principles of sustainability** (see back cover) can be applied to help reduce the harmful effects of air pollution, projected climate change, and stratospheric ozone depletion. We can reduce inputs of air pollutants, greenhouse gases, and ozone-depleting chemicals into the atmosphere by relying more on direct and indirect forms of solar energy than on fossil fuels; reducing the waste of matter and energy resources and recycling and reusing matter resources; and mimicking biodiversity by using a variety of carbon-free renewable energy resources, especially those that are available regionally and locally. We can enhance these strategies by finding substitutes for ozone-depleting chemicals, emphasizing pollution prevention, and reducing human population growth.

The scientific consensus of experts in these fields is that we need to implement known solutions to the problems of projected climate change and ozone depletion globally and on an emergency basis. Each of us has an important role to play in protecting the atmosphere—an irreplaceable resource that sustains all life on earth.

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. 369. Describe the nature and harmful effects of the massive Asian Brown Cloud. CORE CASE STUDY

2. Define **troposphere**, **stratosphere**, and **ozone layer**. Describe how the troposphere and stratosphere differ. 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.

3. Distinguish between **industrial smog** and **photochemical smog**. 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? What is **acid deposition**, how does it form, and what are its major environmental impacts on vegetation, lakes, human-built structures, and human health? List three major ways to reduce acid deposition.

4. What is the major indoor air pollutant in many developing countries? What are the top four indoor air pollutants in the United States? Briefly describe the human body's defenses against air pollution, how they can be overwhelmed, and illnesses that can result. About how many people die prematurely from air pollution each year in the world and in the United States?

5. Summarize the accomplishments of air pollution control laws in the United States and discuss how they can be improved. List the advantages and disadvantages of using an emissions trading program to reduce outdoor air pollution. Summarize the major ways to reduce emissions from power plants and motor vehicles. What are four ways to reduce indoor air pollution?

6. Describe the warming and cooling of the atmosphere that has occurred 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? What is the scientific consensus about global temperature change during the last half of the past century and about projected temperature changes during this century?

7. Describe how each of the following might affect average atmospheric temperatures and projected climate change during this century: **(a)** the oceans, **(b)** cloud cover, and **(c)** air pollution. Briefly describe the projections of scientists on how projected climate change is likely to affect drought, ice cover, sea levels, extreme weather events, biodiversity, crop yields, and human health during this century. What are four major strategies for slowing projected climate change? What is **carbon capture and storage (CCS)**? Describe five problems associated with capturing and storing carbon dioxide emissions.

8. List four things that governments could do to help slow projected climate change. What are the pros and cons of the Kyoto Protocol? Describe what some countries, cities, major corporations and 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 projected climate change. Explain the argument for doing these things even if projected climate change doesn't occur.

9. Describe how human activities have depleted ozone in the stratosphere and list five harmful effects of such depletion. Describe how scientists Sherwood Roland and Mario Molina helped to awaken the world to this threat. What has the world done to help reduce the threat of ozone depletion in the stratosphere?

10. What are the *three big ideas* for this chapter? Describe how the three **principles of sustainability** can be applied to deal with the problems of air pollution, climate change, and ozone depletion. SUSTAINABILITY

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

CRITICAL THINKING

1. China relies on coal for two-thirds of its commercial energy usage and 80% of its electricity, partly because the country has abundant supplies of this resource. Yet China's coal burning has caused innumerable and growing problems for China and neighboring countries, and now, because of the Asian Brown Cloud (**Core Case Study**), for the Pacific Ocean and the west coast of North America. 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

2. Photochemical smog is largely the result of motor vehicle emissions. Considering your use, now and in the future, of motor vehicles, what are some ways in which you could reduce your contribution to photochemical smog?

3. Explain how sulfur impurities in coal can increase the acidity of rainwater and deplete soil nutrients.

4. List three important ways in which your life would be different today if grassroots actions 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 grassroots actions now do not lead to strengthening of the U.S. Clean Air Act or to a similar law in the country where you live.

5. A top U.S. presidential economic adviser 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 global 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, D.C., to nearby Williamsburg. What was the flaw in his reasoning? Outline an argument you would use to counter his claim.

6. Explain why you agree or disagree with each of the proposals listed in Figure 15-23 for slowing projected climate change.

7. What changes might occur in **(a)** the global hydrologic cycle (Figure 3-12, p. 49) and **(b)** the global carbon cycle (Figure 3-13, p. 51) if the atmosphere experiences significant warming? 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 things would you be willing to give up to help slow projected climate change?

9. Congratulations! You are in charge of the world. List at least three points in your strategy for dealing with each of the following problems: **(a)** outdoor air pollution, **(b)** indoor air pollution, **(c)** climate change from human activities, and **(d)** ozone depletion.

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 U.S. are nearly five times the world average. According to a 2007 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 on p. 402 is designed to help you understand the sources of your personal inputs of CO_2 into the atmosphere and how you can reduce your inputs.

Some typical numbers are provided in the "Typical Quantity per Year" column of the table. However, the calculations will be more accurate if, in place of these 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 a household to determine your utility use, and you could analyze your driving habits to determine how much fuel you use in automobile transportation.

After completing the table, you can compare your emissions against the per capita U.S. average. 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.

Finally, you can check your result against the greenhouse gas calculator provided on the web by the EPA at **www.epa.gov/climatechange/emissions/ind_calculator.html**.

Now fill in the table with the help of the following instructions:

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" 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" 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 the per capita U.S. average of 19.6 metric tons (21.6 tons) of CO_2 per person per year and with those of your classmates.

3. List three important actions you might take to reduce your carbon footprint by 20%.

	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, Bowling Green State University, Bowling Green, Ohio (USA), developed this CO_2 calculator.

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Solid and Hazardous Waste

16

Drowning in E-waste

CORE CASE STUDY

Electronic waste or *e-waste* consists of discarded television sets, cell phones, computers, iPods, and other electronic devices (Figure 16-1). 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, 68 million television sets, 48 million personal computers, and many millions of iPods, Blackberries, 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, which can contaminate air, surface water, groundwater, and soil and cause serious health problems and even early death for e-waste workers.

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Figure 16-1 *Rapidly growing electronic waste* (e-waste) from discarded computers and other electronic devices wastes resources and pollutes the air, water, and land with harmful chemicals. **Questions**: Have you disposed of an electronic device lately? If so, how did you dispose of it?

Much of the remaining e-waste in the United States is shipped to Asia (mostly China and India) and poor African nations where labor is cheap and environmental regulations are weak. Workers there—many of them children—dismantle such products 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 coal fires, exposing many people to toxic dioxins.

Transfer of such hazardous waste from developed to developing countries is banned by the International Basel Convention. Despite such a ban, much e-waste is not officially classified as hazardous waste or is illegally smuggled into China and other countries. The United States can export this 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 for repair, remanufacture, or recycling, 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.

The United States produces roughly half of the world's e-waste and recycles only about 15% of it; but that is beginning to change. Thirty-five states have banned the disposal of computers and TV sets in landfills and incinerators and are setting the stage for an emerging highly profitable *e-recycling* industry. Some electronics manufacturers in the United States have free recycling programs for consumers, which are described on their websites. Some manufacturers will arrange to pick up discarded electronic products or will pay shipping costs to have them returned. And the U.S. Postal Service is developing a free national collection program for small electronic items. In addition, nonprofit groups, such as Free Geek in Portland, Oregon, are motivating many people to donate, recycle, and reuse old electronic devices.

But recycling and reuse probably will not keep up with the explosive growth of e-waste. According to Jim Puckett, coordinator of the Basel Action Network, the only real long-term solution is a *prevention* approach through which electrical and electronic products are designed for easy recycling and manufactured without the use of toxic materials. Electronic waste is just one of many types of solid and hazardous waste discussed in this chapter.

Key Questions and Concepts

16-1 What are solid waste and hazardous waste, and why are they problems?

CONCEPT 16-1 Solid waste represents pollution and unnecessary waste of resources, and hazardous waste contributes to pollution, natural capital degradation, health problems, and premature deaths.

16-2 How should we deal with solid waste?

CONCEPT 16-2 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.

16-3 Why is reusing and recycling materials so important?

CONCEPT 16-3 Reusing items decreases the use of matter and energy resources and reduces pollution and natural capital degradation; recycling does so to a lesser degree.

16-4 What are the advantages and disadvantages of burning or burying solid waste?

CONCEPT 16-4 Technologies for burning and burying solid wastes are well developed, but burning contributes to pollution and greenhouse gas emissions, and buried wastes can eventually contribute to air and water pollution and land degradation.

16-5 How should we deal with hazardous waste?

CONCEPT 16-5 A more 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.

16-6 How can we make the transition to a more sustainable low-waste society?

CONCEPT 16-6 Shifting to a low-waste society requires individuals and organizations to reduce resource use and to reuse and recycle wastes at local, national, and global levels.

Note: Supplements 3 (p. S6) and 6 (p. S26) can be used with this chapter.

Solid wastes are only raw materials we're too stupid to use.

ARTHUR C. CLARKE

16-1 What Are Solid Waste and Hazardous Waste, and Why Are They Problems?

▶ **CONCEPT 16-1 Solid waste represents pollution and unnecessary waste of resources, and hazardous waste contributes to pollution, 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 (Figure 3-9, p. 46). This natural recycling of nutrients follows one of the three **principles of sustainability**. SUSTAINABILITY

Humans, on the other hand, produce huge amounts of wastes that go unused and pollute the environment. Because of the law of conservation of matter (**Concept 2-2B**, p. 28) and the nature of human CONCEPT LINK lifestyles, we will always produce some waste, but the amount can be drastically reduced.

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, agriculture, 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. Examples include paper and cardboard, food wastes, cans, bottles, yard wastes, furniture, plastics, metals, glass, wood, and e-waste (**Core Case Study**). CORE CASE STUDY

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. CONCEPT LINK indicates links to key concepts in earlier chapters. GOOD NEWS refers to good news about the environmental challenges we face.

In developed countries, most MSW is buried in landfills or burned in incinerators. In many developing countries, much of it ends up in open dumps, where some poor people eke out a living finding items they can sell for recycling or reuse (Figure 1-6, p. 12). In 2008, the Organization for Economic Cooperation and Development projected that between 2005 and 2030, the world's output of MSW will almost double.

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 ash from incinerators and coal-burning power plants (Case Study, p. 307). Figure 16-2 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 (p. 314). Such wastes must be stored safely for 10,000–240,000 years, depending on what radioactive isotopes are present. (Case Study, p. 315).

According to the U.N. Environment Programme (UNEP), 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 waste of the earth's resources. Studies show that we could copy nature by reducing resource use and reusing or recycling up to 90% of the MSW we produce. A second reason is that the production of the products we use and often discard creates huge amounts of air pollution, greenhouse gases, water pollution (Figure 16-3), land degradation, and ocean pollution. 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 16-1**).

CASE STUDY

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.

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 16-2 Harmful chemicals found in many homes. The U.S. Congress has exempted disposal of these materials from government regulation. **Question**: Which of these chemicals are in your home?

Lineair Fotochief/Peter Arnold, Inc.

Figure 16-3 **Natural capital degradation:** solid wastes polluting a river in Jakarta, Indonesia, a city of more than 18 million people. The man in the boat is looking for items to salvage or sell.

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%).

The remaining 1.5% of U.S. solid waste is municipal solid waste (MSW), the largest categories of which are paper and cardboard (33% of total U.S. MSW), 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 12, p. S13, in Supplement 3 shows the total and per capita production of MSW in the United States between 1960 and 2007.) Each 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 or incinerated, but much of it ends up as litter (Figure 14-2, p. 344).

Consider some of the solid wastes that consumers throw away in the high-waste economy of the United States (see Science Focus, p. 408):

- Enough tires each year to encircle the planet almost three times
- An amount of disposable diapers each 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 2.5 million nonreturnable plastic bottles *every hour*
- About 274 million plastic shopping bags per day, an average of nearly 3,200 every second
- About 25 million metric tons (27 million tons) of edible food per year
- 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 612 pieces per American) each year, about 45% of which are thrown in the trash unopened
- Around 131,500 personal computers and 425,000 cell phones each day (**Core Case Study**). CORE CASE STUDY

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; a plastic six-pack holder, 100 years; and plastic bags, 10–20 years.

Some encouraging news is that since 1990, the average weight of MSW per American has leveled off (Figure 12, p. S13, Supplement 3), mostly because of increased recycling (Figure 13, p. S13, in Supplement 3) and the use of lighter products. GOOD NEWS

16-2 How Should We Deal with Solid Waste?

CONCEPT 16-2 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 is **waste management** in which we attempt to manage wastes in ways that reduce their environmental harm without seriously trying to reduce the amount of waste produced. 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 can be reused, recycled, or composted (**Concept 16-2**). With this prevention approach (**Concept 1-3**, p. 14), we should think of trash cans and garbage trucks as *resource containers* that are on their way to recycling or composting facilities. CONCEPT LINK

There is no single solution to the solid waste problem. Most analysts call for using **integrated waste management**—a variety of strategies for both waste reduction and waste management (Figure 16-4). Scientists call for much greater emphasis on waste reduction (Figure 16-5) than what they have found in the United States (and in most industrialized countries). In 2007, the EPA reported that 54% of the MSW produced in the United States was buried in landfills and 13% was incinerated. Only 25% was recycled and 8% was composted. (This was the latest available data as the book went to press.)

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 16-5. Let us look more closely at these options in the order of the priorities suggested by scientists.

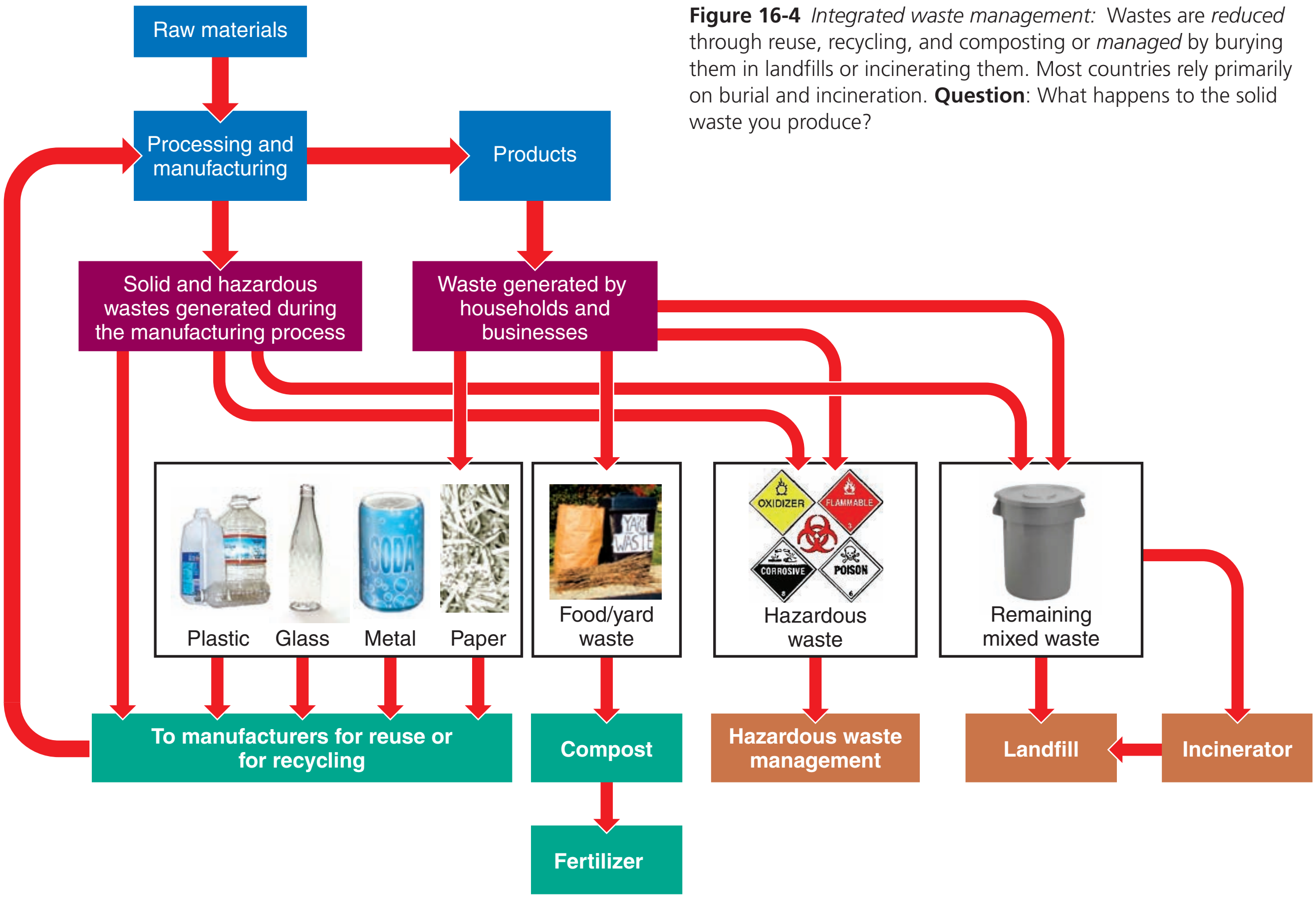


Figure 16-4 *Integrated waste management:* Wastes are *reduced* through reuse, recycling, and composting or *managed* by burying them in landfills or incinerating them. Most countries rely primarily on burial and incineration. **Question**: What happens to the solid waste you produce?

We Can Cut Solid Wastes by Reducing, Reusing, and Recycling

Waste reduction (**Concept 16-2**) is based on three Rs:

- **Reduce**: consume less and live a simpler lifestyle.
- **Reuse**: rely more on items that can be used repeatedly instead of on throwaway items, and buy necessary items secondhand or borrow or rent them.
- **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. By reducing and reusing, we also save matter and energy resources,

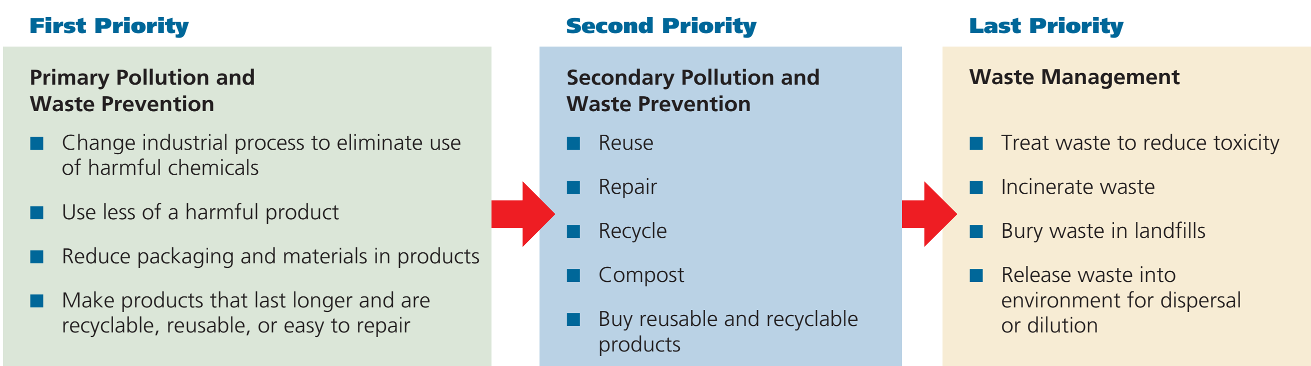


Figure 16-5 **Science:** *Integrated waste management:* priorities suggested by the U.S. National Academy of Sciences for dealing with solid waste. To date, these waste-reduction priorities have not been followed in the United States or in most other countries. Instead, most efforts are devoted to waste management (bury it or burn it). **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)

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, and 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
- Buy products in bulk or concentrated form whenever possible

Figure 16-6 **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?

reduce pollution (including greenhouse gas emissions), help protect biodiversity, and save money. Recycling is important, but it deals with wastes after they have been produced.

Figure 16-6 lists some ways in which you can use the 3Rs to reduce your output of solid waste. GOOD NEWS

Here are seven strategies that industries and governments 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.

Second, *redesign manufacturing processes to produce less waste and pollution*. Manufacturing plants can be upgraded to recover and use wastewater, for example, thereby reducing their pollution outputs.

Third, *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/biology/miller**.

Fourth, *eliminate or reduce unnecessary packaging*. Use the following hierarchy for packaging: no packaging, minimal packaging, reusable packaging, and recyclable packaging. The 37 European Union countries require recycling 55–80% of all packaging waste.

Fifth, *use fee-per-bag waste collection systems* that charge consumers for the amount of waste they throw away but provide free pickup of recyclable and reusable items.

Sixth, *establish cradle-to-grave responsibility laws* that require companies to take back various discarded consumer products such as electronic equipment (**Core Case Study**), appliances, and motor vehicles, as Japan and many European countries do. CORE CASE STUDY

Seventh, *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. And using a bicycle represents a small fraction of the resource use and solid waste involved with the manufacture and use of a motor vehicle.

CONNECTIONS

Reducing Waste and Pollution by Exchanging Wastes

In the *ecoindustrial revolution* (Case Study, p. 291), manufacturing processes are redesigned to mimic the way nature reduces and recycles wastes. This includes designing industrial ecosystems in which the wastes of some businesses are used as raw materials by other businesses (Figure 12-21, p. 292). This is, in effect, an industrial resource web that mimics a natural food web (Figure 3-9, p. 46). In addition to reducing waste production and pollution, industrial ecosystems also save energy and reduce resource use.

SCIENCE FOCUS

Garbology

How do we know the composition of trash in landfills? Much of this knowledge comes from research by *garbologists* such as William Rathje, who pioneered this field in the 1970s at the University of Arizona. 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.

Critical Thinking

Should landfills be exposed to more air and water to hasten decomposition of their wastes? Explain.

16-3 Why Is Reusing and Recycling Materials So Important?

▶ **CONCEPT 16-3 Reusing items decreases the use 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 those who bring their own refillable coffee mugs would help to reduce this waste.

Reuse involves cleaning and using materials over and over and thus increasing the typical life span of a product. This form of waste reduction decreases the use of matter and energy resources, cuts pollution and waste, creates local jobs, and saves money (**Concept 16-3**).

Reuse is alive and well in most developing countries (Figure 1-6, p. 12), but it has a downside for some people. The poor who scavenge in open dumps (Figure 1-11, p. 16) for food scraps and items they can reuse or sell are often exposed to toxins and infectious diseases.

Reuse strategies in developed countries include yard sales, flea markets, secondhand stores, and online sites such as e-bay 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.

Technology allows for reuse of many items such as 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 as few as 15 minutes, and greatly reduce toxic waste when used in place of discarded conventional batteries.

GOOD NEWS

Reuse is on the rise. Denmark, Finland, and Canada's 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.

Should we use paper or plastic bags to carry groceries and other items? Because both are environmentally harmful, the answer is to use *neither*. Instead, we can carry our own reusable cloth bags. There is a growing backlash against plastic shopping bags. Worldwide, about 1 million of these bags are used each minute. About 99% of these bags are thrown away and end up in landfills or as litter on the land and on the oceans They also block street drains and kill wildlife.

To encourage people to carry reusable bags, the governments of Ireland, Taiwan, Bangladesh, and the Netherlands tax plastic shopping bags (see **www.plasticbag.com**). In Ireland, a tax of about 25¢ per bag cut litter from plastic bags by 90% as people switched to reusable bags. The use of all or most types of plastic shopping bags has been banned in several countries, including China and Bangladesh, and in cities such as New Delhi, India, (where anyone found using a plastic bag can be fined $2,000 or spend 5 years in jail) and the U.S. cities of San Francisco and Los Angeles, California. Some efforts to ban such bags in other U.S. cities have been squelched by ad campaigns and political pressure from the plastics industry.

HOW WOULD YOU VOTE?

Should consumers have to pay for plastic or paper shopping bags at grocery stores and other stores? Cast your vote online at **www.cengage.com/biology/miller**.

GOOD NEWS

There are many other ways to reuse various items, some of which are listed in Figure 16-7.

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 food in the refrigerator 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
- Carry groceries and other items in a reusable basket, a canvas or string bag, or a small cart
- Buy used furniture, computers, cars, and other items instead of buying new
- Give away or sell items you no longer use

Figure 16-7 Individuals matter: There are many ways to reuse some of the items you buy. **Question**: Which of these suggestions have you tried and how did they work for you?

There Are Two Types of Recycling

Recycling involves reprocessing discarded solid materials into new, useful products. Households and workplaces produce five major types of materials that can be recycled: paper products, glass, aluminum, steel, and some plastics.

Such materials can be reprocessed in two ways. In **primary**, or **closed-loop**, **recycling**, materials are recycled into new products of the same type. For example, used aluminum cans are turned into new aluminum cans. In **secondary recycling**, waste materials are converted into different products. For example, used tires can be shredded and turned into rubberized road surfacing and newspapers can be reprocessed into cellulose insulation.

Scientists distinguish between two types of wastes that can be recycled: *preconsumer*, or *internal waste*, generated in a manufacturing process and *postconsumer*, or *external waste*, generated by consumer use of products. Preconsumer waste makes up more than three-fourths of the total.

Just about anything is recyclable, but there are two key questions. *First*, do the items that get 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?

While Switzerland recycles about 53% of its MSW, the United States recycles about 25%—up from 6.4% in 1960. This increase has gotten a boost by almost 9,000 curbside pickup recycling programs that serve about half of the U.S. population. Experts say that with education and proper incentives, the United States could recycle 60–75% of its MSW, more in keeping with the recycling **principle of sustainability**.

SUSTAINABILITY

We Can Mix or Separate Household Solid Wastes for Recycling

One way to recycle is to send mixed urban wastes to centralized **materials recovery facilities** (**MRFs** or "murfs"). There, machines or workers separate the mixed wastes to recover valuable materials for sale to manufacturers as raw materials (Figure 16-4). 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 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 16-5).

To some 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 MRFs cost. It also saves more energy, provides more jobs per unit of material, and yields cleaner and usually more valuable recyclables.

CONNECTIONS

Recycling and the Pocketbook

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. It charges households and businesses for the amount of mixed waste picked up, but does 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%. And 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. Using a similar program, the U.S. city of San Francisco, California, reuses or recycles 70% of its MSW and has plans to increase that amount to 75%.

HOW WOULD YOU VOTE?

Should households and businesses be charged for the amount of mixed waste picked up but not for pickup of materials separated for recycling? Cast your vote online at **www.cengage.com/biology/miller**.

We Can Copy Nature and Recycle Biodegradable Solid Wastes

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, 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 metal drums that can be rotated to mix the wastes to speed up the decomposition process. (For details on composting, see the website for this chapter.)

SUSTAINABILITY

Some cities in Canada and many European Union countries collect and compost more than 85% of their biodegradable wastes in centralized community facilities. The United States has about 3,300 municipal composting programs that recycle about 37% of the country's yard wastes.

GOOD NEWS

To be successful, a large-scale composting program must be located carefully and odors must be controlled, especially near residential areas. Composting programs must also exclude toxic materials that can contaminate the compost and make it unsafe for fertilizing crops and lawns.

Recycling Has Advantages and Disadvantages

Figure 16-8 lists the advantages and disadvantages of recycling (**Concept 16-3**). Whether recycling makes economic sense depends on how you look at its economic and environmental benefits and costs.

Critics say that recycling may make economic sense for valuable and easy-to-recycle materials such as aluminum, paper, and steel, but probably not for cheap or plentiful resources such as glass made from silica. Currently, only about 4% by weight of all plastic wastes in the United States is recycled because there are many different types of plastic resins, which are difficult to separate from products. The two most widely recycled plastics are polyethylene terephthalate (PET, labeled with the number 1), mostly used to make bottles, and high-density polyethylene (HDPE, labeled with the number 2), used to make food containers, pipes, carpet backing, vinyl siding, and other products. But progress is being made in the recycling of plastics (Individuals Matter, at right) and in the development of more degradable bioplastics (Science Focus, p. 412).

Critics argue that recycling should pay for itself. But proponents of recycling point out that conventional garbage disposal systems are funded by charges to households and businesses. So why should recycling be held to a different standard and forced to compete on

INDIVIDUALS MATTER

GOOD NEWS

Mike Biddle's Contribution to Recycling Plastics

In 1994, Mike Biddle, a former PhD engineer with Dow Chemical, and a partner, Trip Allen, founded MBA Polymers, Inc. Their goal was to develop a commercial process for recycling high-value plastics from complex streams of 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 and 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 cheap or free junk. The environment also wins because greenhouse gas emissions from this process are much lower than those from making virgin plastics. Also, recycling waste plastics reduces the need to incinerate them or bury them in landfills.

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, and recently opened the world's two most advanced plastics recycling plants in China and Austria. MBA Polymers has won many awards, including the 2002 Thomas Alva Edison Award for Innovation, and it was selected by *Inc.* magazine as one of "America's most innovative companies."

Maybe you can be an environmental entrepreneur by using your brain power to develop an environmentally beneficial and financially profitable process or business.

Figure 16-8 Advantages and disadvantages of recycling solid waste (**Concept 16-3**). **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

SCIENCE FOCUS

Bioplastics

Most of today's plastics are made from organic polymers produced from petroleum-based chemicals (petrochemicals). 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 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 bioplastic made from soybeans. A 1914 photograph showed him using an ax to strike the body of a car made from soy bioplastic to demonstrate its strength.

But as oil became widely available, petrochemical plastics took over the market. Now with projected 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. Such *bioplastics* can be made from corn, soybeans, sugarcane, switchgrass (Figure 13-36, p. 334), chicken feathers, and some components of garbage. And 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 accelerate reactions that chemists can use to form polymers from biologically based chemicals without having to use high temperatures. With proper design and mass production, such bioplastics could be lighter, stronger, and cheaper, and the process of making them could require less energy and produce less pollution per unit of weight than is involved in the making of conventional petroleum-based plastics.

Instead of being sent to landfills, packaging made from such bioplastics could be composted to produce a soil conditioner, in keeping with the nutrient recycling **principle of sustainability**.

Toyota is investing $38 billion in a process that makes plastics from plants. By 2020, it expects to control two-thirds of the world's supply of such bioplastics.

Critical Thinking

What might be some disadvantages of more rapidly degradable bioplastics? Do you think they outweigh the advantages?

an uneven playing field? Proponents also point to studies showing that the net economic, health, and environmental benefits of recycling (Figure 16-8, left) far outweigh the costs. They argue that the U.S. recycling industry employs about 1.1 million people and that its annual revenues are much larger than those of the waste management industry.

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 (the carrot) and *decrease* subsidies and tax breaks for making items from virgin resources (the stick).

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 reuse or recycle packaging and electronic waste discarded by consumers (**Core Case Study**), as is done in Japan and most European Union countries.

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/biology/miller**.

Citizens can pressure governments to require product labeling that lists recycled content of products and 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.

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 16-3**).

16-4 What Are the Advantages and Disadvantages of Burning or Burying Solid Waste?

CONCEPT 16-4 **Technologies for burning and burying solid wastes are well developed, but burning contributes to pollution and greenhouse gas emissions, and buried wastes can eventually contribute to air and water pollution and land degradation.**

Burning Solid Waste Has Advantages and Disadvantages

Globally, MSW is burned in more than 600 large *waste-to-energy incinerators* (89 in the United States), which burn MSW to boil water to make steam for heating water or space or for producing electricity. Trace the flow of materials through this process, as diagrammed in Figure 16-9.

Figure 16-10 (p. 414) lists the advantages and disadvantages of using incinerators to burn solid waste.

HOW WOULD YOU VOTE?

Do the advantages of incinerating solid waste outweigh the disadvantages? Cast your vote online at **www.cengage.com/biology/miller**.

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, and 12% in Switzerland.

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 developed countries, but are widely used near major cities in many developing countries (Figure 1-11, p. 16)

In newer landfills, called **sanitary landfills** (Figure 16-11, p. 414), 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

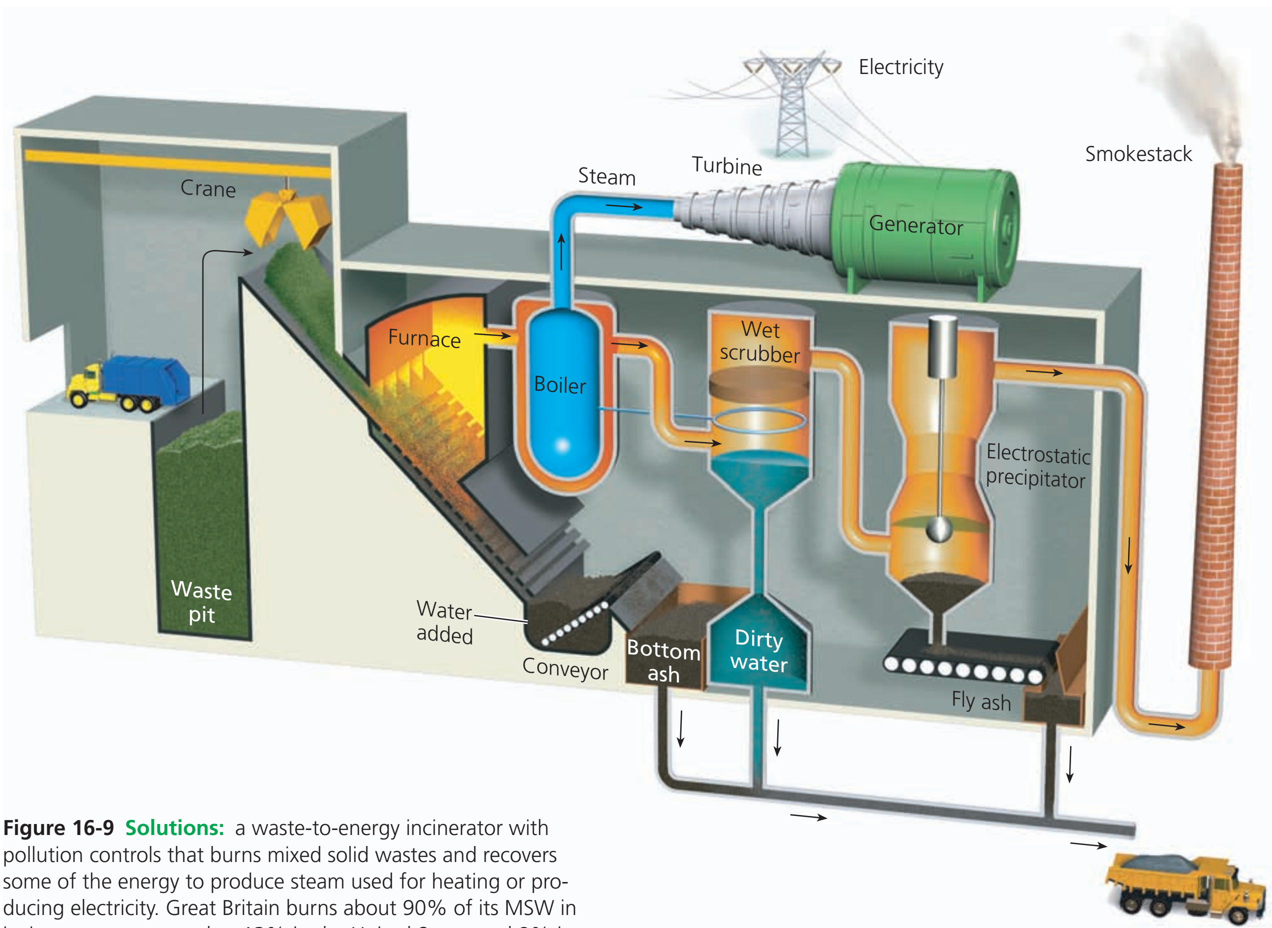


Figure 16-9 **Solutions:** a waste-to-energy incinerator with pollution controls that burns mixed solid wastes and recovers some of the energy to produce steam used for heating or producing electricity. Great Britain burns about 90% of its MSW in incinerators, compared to 13% in the United States and 8% in Canada. **Questions**: Would you invest in such a project? Why or why not?

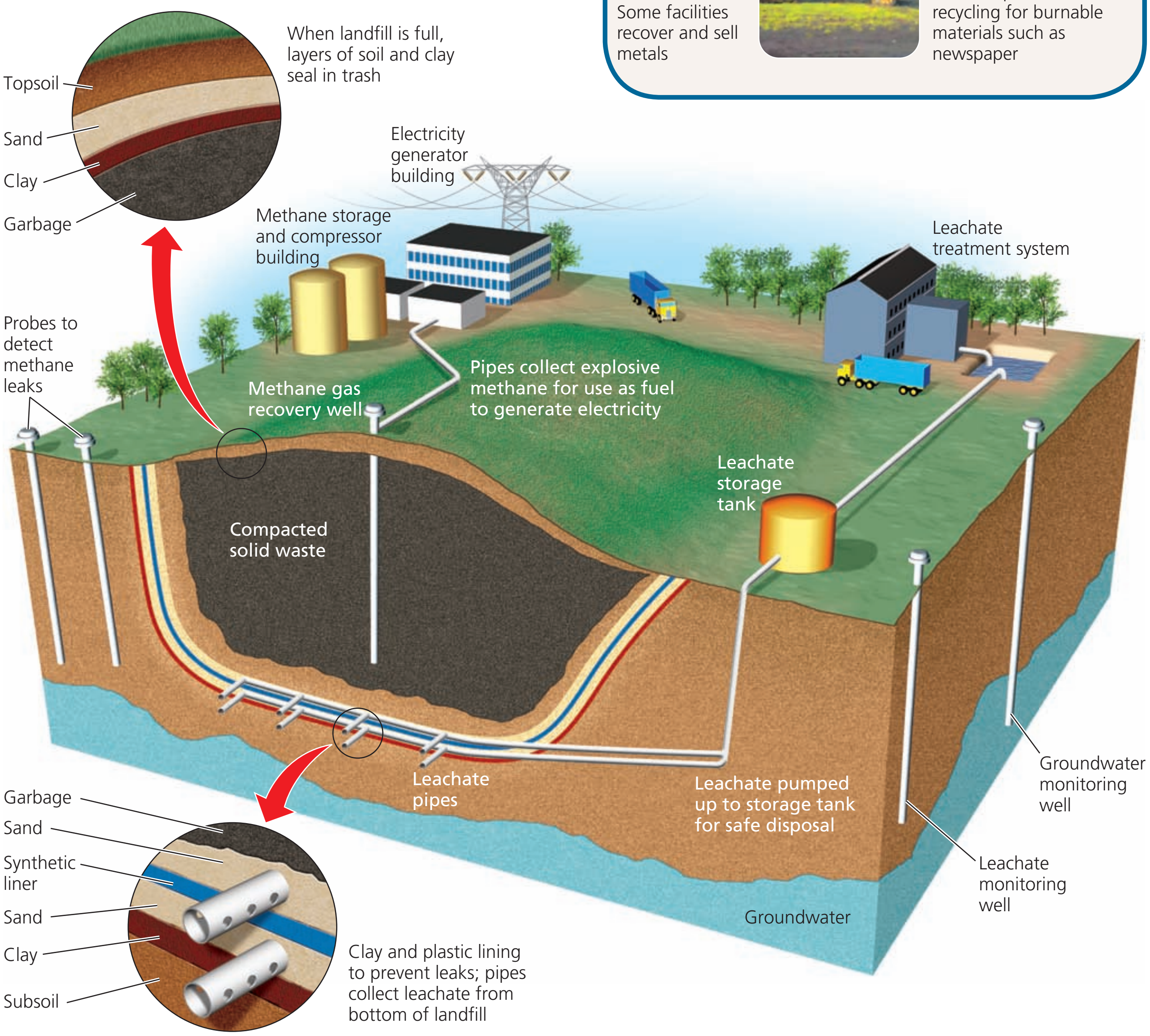
Figure 16-10 Advantages and disadvantages of incinerating solid waste (**Concept 16-4**). These trade-offs also apply to the incineration of hazardous waste. Since 1985, more than 280 new incinerator projects have been delayed or canceled in the United States because of high costs, concern over air pollution, and intense citizen opposition. **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

Trade-Offs

Incineration

Advantages	Disadvantages
Reduces trash volume	Expensive to build
Less need for landfills	Costs more than short-distance hauling to landfills
Low water pollution	Difficult to site because of citizen opposition
Concentrates hazardous substances into ash for burial	Some air pollution and CO_2 emissions
Sale of energy reduces cost	Older or poorly managed facilities can release large amounts of air pollution
Modern controls reduce air pollution	Output approach that encourages waste production
Some facilities recover and sell metals	Can compete with recycling for burnable materials such as newspaper

Figure 16-11 **Solutions:** state-of-the-art *sanitary landfill,* which is designed to eliminate or minimize environmental problems that plague older landfills. Since 1997, only modern sanitary landfills are allowed in the United States. As a result, many small, older landfills have been closed and replaced by larger and more regional landfills. **Question**: Some experts say that these landfills will eventually develop leaks, which could emit toxic liquids. How do you think this could happen?



(leachate) from the landfill. This covering also lessens the risk of fire, decreases odor, and reduces accessibility to vermin. As underground wastes decay in a nonoxygen environment, they produce methane—the main component in natural gas. In large landfills, it is profitable to collect and use or sell the methane. This also helps reduce the emission of this potent greenhouse gas into the atmosphere.

Figure 16-12 lists the advantages and disadvantages of using sanitary landfills to dispose of solid waste. According to the EPA, all landfills eventually leak and thus pass on both the effects of contamination and cleanup costs to future generations.

A 2007 report by the nonprofit Nuclear Information and Resource Service reported that radioactive materials from nuclear weapons facilities run by the U.S. Department of Energy were being dumped into regular landfills with little tracking of their dispersal, despite intense public opposition.

HOW WOULD YOU VOTE?

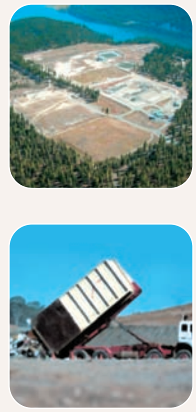
Do the advantages of burying solid waste in sanitary landfills outweigh the disadvantages? Cast your vote online at **www.cengage.com/biology/miller**.

Trade-Offs

Sanitary Landfills

Advantages

- No open burning
- Little odor
- Low groundwater pollution if sited properly
- Can be built quickly
- Low operating costs
- Can handle large amounts of waste
- Filled land can be used for other purposes
- No shortage of landfill space in many areas



Disadvantages

- Noise and traffic
- Dust
- Air pollution from toxic gases and trucks
- Releases greenhouse gases (methane and CO_2) unless they are collected
- Slow decomposition of wastes
- Output approach that encourages waste production
- Eventually leaks and can contaminate groundwater

Figure 16-12 Advantages and disadvantages of using sanitary landfills to dispose of solid waste (**Concept 16-4**). **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

16-5 How Should We Deal with Hazardous Waste?

CONCEPT 16-5 A more 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 16-13 shows an integrated waste management approach suggested by the U.S. National Academy of Sciences that establishes three levels of priority 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 16-5**). 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 them within industrial processes, or use them as raw materials for making other products (Figure 12-21, p. 292). (See Case

Produce Less Hazardous Waste

- Change industrial processes to reduce or eliminate hazardous waste production
- Recycle and reuse hazardous waste

Convert to Less Hazardous or Nonhazardous Substances

- Natural decomposition
- Incineration
- Thermal treatment
- Chemical, physical, and biological treatment
- Dilution in air or water

Put in Perpetual Storage

- Landfill
- Underground injection wells
- Surface impoundments
- Underground salt formations

Figure 16-13 Science: *Integrated hazardous waste management:* priorities suggested by the U.S. National Academy of Sciences for dealing with hazardous waste (**Concept 16-5**). **Question**: Why do you think that most countries do not follow these priorities? (Data from U.S. National Academy of Sciences)

Study, p. 291 and the Guest Essays on this subject by Lois Gibbs and Peter Montague at CengageNOW™.)

However, most e-waste recycling efforts (**Core Case Study**) create further hazards, especially for workers—many of them children. According to the United Nations, more than 70% of the world's e-waste ends up in China. In 2008, only about 15% of the e-waste in the United States was recycled and up to 80% of that was shipped overseas to dismantling shops. These shops employ thousands of adults and children who work under dangerous conditions and often are exposed to a cocktail of toxic chemicals and fumes.

Sarah Westervelt of the Basal Action Network (BAN) warns that "most of those businesses calling themselves recyclers take your old equipment for free, or pocket your recycling fee, and then simply load it into a sea-going container and ship it to China, India, or Nigeria." (See **www.eiae.org** to find out where to recycle electronic devices in your area of the United States and **www.recycle.org** to find out how to donate your used computer.)

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 21 transfer stations throughout the country. From there it is taken to a large treatment 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.

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. 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. Various plants have 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.

Hazardous wastes can be incinerated to break them down and convert them to harmless or less harmful chemicals such as carbon dioxide and water. This has the same advantages and disadvantages as those of burning solid wastes (Figure 16-10). In addition, incinerating hazardous waste can release air pollutants such as toxic dioxins, and it produces a highly toxic ash that must be safely and permanently stored in a landfill or vault especially designed for hazardous waste.

RESEARCH FRONTIER

Improving current methods and finding new ways to detoxify wastes. See **www.cengage.com/biology/miller**.

We can also detoxify hazardous wastes by using a *plasma arc torch*, somewhat similar to a welding torch, to incinerate them at very high temperatures. This process decomposes liquid or solid hazardous organic waste into ions and atoms that can be converted into simple molecules, cleaned up, and released as a gas. The high temperatures can also convert hazardous inorganic matter into a molten glassy material that can be used to encapsulate toxic metals and keep them from leaching into groundwater. However, this process is expensive, produces CO and CO_2, and can vaporize and release toxic metals and radioactive elements into the atmosphere.

We Can Store Some Forms of Hazardous Waste

According to scientists, burial on land or long-term storage of hazardous and toxic wastes should be used only as the third and last resort after the first two priorities have been exhausted (Figure 16-13 and **Concept 16-5**). But currently, burial on land is the most widely used method for dealing with such wastes in the United States and most other countries, largely because it is the least expensive of all methods. This is primarily because the environmentally harmful costs of producing and discarding products that contain hazardous materials are not included in their market prices.

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 sometimes located far beneath aquifers that are tapped for drinking and irrigation water. Theoretically, these liquids soak into the porous rock material and are isolated from overlying groundwater by essentially impermeable layers of clay and rock. The cost is low and the wastes can often be retrieved if problems develop.

However, 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. Also, this is an output approach that encourages the production of hazardous wastes. 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.

Surface impoundments are ponds, pits, or lagoons in which wastes are stored (Figure 16-14). Sometimes they include liners to help contain the waste. As the water evaporates, the waste settles and becomes more concentrated. Surface impoundments are widely used for storage of hazardous ash produced by the burning of coal in power plants (Case Study, p. 307).

Ken Sherman/Bruce Coleman USA, Inc.

Figure 16-14 *Surface impoundment* in Niagara Falls, New York (USA). Such sites can pollute the air and nearby groundwater and surface water.

Figure 16-15 lists the advantages and disadvantages of this method.

U.S. Environmental Protection Agency (EPA) studies found that 70% of these storage basins in the United States have no liners, and up to 90% of them may threaten groundwater. According to the EPA, all liners are likely to leak, eventually.

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/biology/miller**.

Trade-Offs

Surface Impoundments

Advantages	Disadvantages
Low construction costs	Groundwater contamination from leaking liners (or no lining)
Low operating costs	Air pollution from volatile organic compounds
Can be built quickly	Overflow from flooding
Wastes can often be retrieved if necessary	Disruption and leakage from earthquakes
Can store wastes indefinitely with secure double liners	Output approach that encourages waste production

Figure 16-15 Advantages and disadvantages of storing liquid hazardous wastes in surface impoundments. **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

There are some highly toxic materials such as mercury (Science Focus, p. 354) 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 safe containers and place them 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. Carefully designed aboveground storage buildings are a good option in areas where the water table is close to the surface and in areas that lie over aquifers used for drinking water. Such storage structures should be built to withstand storms and to prevent the release of toxic gases. Leaks should be monitored and any leakage collected and treated.

Sometimes, liquid and solid hazardous wastes are put into drums or other containers and buried in carefully designed and monitored *secure hazardous waste landfills* (Figure 16-16, p. 418). This is the least used method because of the expense involved.

Figure 16-17 (p. 418) lists some ways in which you can reduce your output of hazardous waste.

GOOD NEWS

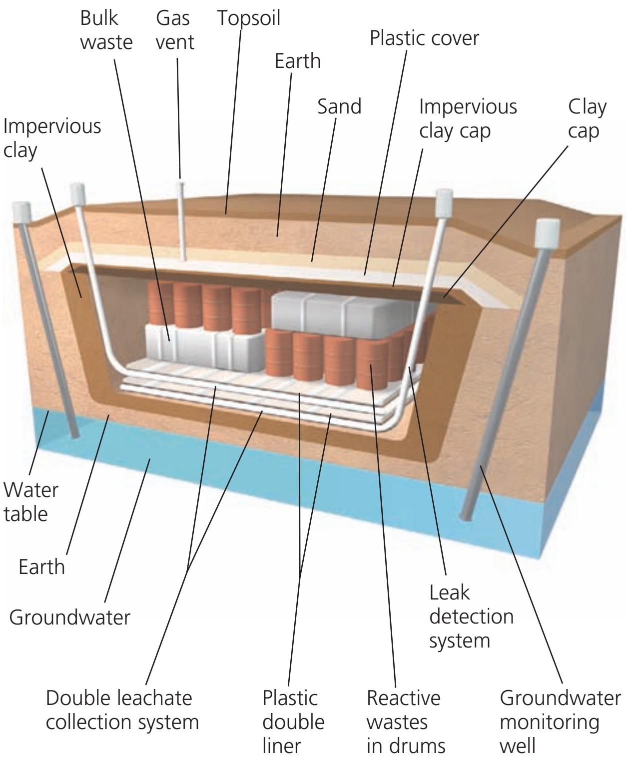


Figure 16-16 **Solutions:** secure hazardous waste landfill.

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 in 1976 and amended in 1984. The EPA sets standards for management of several types of hazardous waste and issues permits to companies allowing them to produce and dispose of a certain amount of wastes in acceptable ways. 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 it and other laws regulate only about 5% of the hazardous and toxic wastes, including e-waste, produced in the United States. In most other countries, especially developing countries, even less 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 might be the economic consequences of doing this? How would this change the way waste producers deal with the hazardous wastes they produce?

In 1980, the U.S. Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act, commonly known as the CERCLA, or Superfund, program. Its goals are to identify sites where hazardous wastes have contaminated the environment and to clean them up on a priority basis. The worst sites that represent an immediate and severe threat to human health are put on a *National Priorities List* and scheduled for total cleanup using the most cost-effective method. In June 2009, there were 1,264 sites on this list, and 332 previously listed sites had been cleaned up and removed from the list. (To view some of these sites see **http://superfund365.org**.) 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.

The Superfund law, designed to have polluters pay for cleaning up abandoned hazardous waste sites, greatly reduced the number of illegal dumpsites. It has also forced waste producers, fearful of future liability claims, to reduce their production of such waste and to reuse or recycle much more of it. However, facing pressure from oil and chemical companies, the U.S. Congress refused to renew the tax on these companies, which had financed the Superfund 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.

HOW WOULD YOU VOTE?

Should the U.S. Congress reinstate the polluter-pays principle by using 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/biology/miller**.

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 16-17 **Individuals matter:** ways to reduce your output of hazardous waste (**Concept 16-5**). **Question**: Which measures on this list, if any, have you tried?

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 (Figure 12-21, p. 292), and neighborhoods. By 2009, more than 42,000 former brownfield sites had been redeveloped in the United States.

Various 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 in the United States (see the following Case Study).

CASE STUDY

Lead Is a Highly Toxic Pollutant

Because it is a chemical element, lead (Pb) does not break down in the environment. This potent neurotoxin can harm the human nervous system, especially in young children. Each year, 12,000–16,000 American children younger than 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 younger than age 6 and unborn fetuses, even with quite 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, and various behavior disorders. A 1993 study by the U.S. National Academy of Sciences and numerous other studies indicate there is no safe level of lead in children's blood.

Between 1976 and 2004, the percentage of U.S. children ages 1 to 5 years with blood lead levels above the safety standard dropped from 85% to just 1.4%, which prevented at least 9 million childhood lead poisonings. The primary reason for this drop was that government regulations banned leaded gasoline in 1976 (ordering a complete phase-out by 1986) and lead-based paints in 1970 (but 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 estimates that at least 310,000 U.S. children still have unsafe blood levels of lead caused by exposure from a number of sources. One major source is peeling lead-based paint found in about 38 million houses built before 1960 and lead-contaminated dust in deteriorating buildings. Lead can also leach from water pipes and faucets containing lead parts or lead solder. And in 2007, major U.S. toy companies had to recall millions of toys made in China that contained lead paint. Another potential source of lead for urban gardeners is soil contaminated by decades of lead particles falling from the atmosphere when leaded gasoline was still in use.

Solutions

Lead Poisoning

Prevention

- Phase out leaded gasoline worldwide
- Phase out waste incineration
- Ban use of lead solder
- Ban use of lead in computer and TV monitors
- Ban lead glazing for ceramicware used to serve food
- Ban candles with lead cores
- Test blood for lead by age 1

Control

- Replace lead pipes and plumbing fixtures containing lead solder
- Remove leaded paint and lead dust from older houses and apartments
- Sharply reduce lead emissions from incinerators
- Remove lead from TV sets and computer monitors before incineration or land disposal
- Test for lead in existing ceramicware used to serve food
- Test existing candles for lead
- Wash fresh fruits and vegetables

Figure 16-18 **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?

Health scientists have proposed a number of ways to help protect children from lead poisoning, as listed in Figure 16-18. Although the threat from lead has been greatly reduced in the United States, this is not the case in many developing countries. About 80% of the gasoline sold in the world today is unleaded, but about 100 countries still use leaded gasoline. The WHO estimates that 130 million to 200 million children around the world are at risk from lead poisoning, and that 15 million to 18 million children in developing countries have permanent brain damage from lead poisoning—mostly because of the use of leaded gasoline in their countries.

Environmental and health scientists call for global bans on leaded gasoline and lead-based paints. China recently phased out leaded gasoline in less than 3 years.

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?

16-6 How Can We Make the Transition to a More Sustainable Low-Waste Society?

CONCEPT 16-6 **Shifting to a low-waste society requires individuals and organizations 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 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.

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 16-13). They call for drastically reducing production of such wastes by emphasizing pollution prevention and using the precautionary principle (**Concept 14-4B,** p. 356). CONCEPT LINK

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 larger share of polluting factories, hazardous waste dumps, incinerators, and landfills in the United States are located in or near 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 such 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 movement known as the *environmental justice movement*. Supporters of this movement have pressured governments, businesses, and environmental groups to become aware of environmental injustice and to act to prevent it. They have made some progress toward their goals, but there is 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, describe 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 developed countries had been shipping hazardous wastes to developing countries. In 1989, the UNEP developed an international treaty known as the Basel Convention. It banned 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 industrial countries to developing countries. By 2009, this agreement had been ratified by 152 countries, but not by the United States. GOOD NEWS

This ban will help, but it will not wipe out the very profitable illegal waste trade. Smugglers evade the laws by using an array of tactics, including bribes, false permits, and mislabeling of hazardous wastes as materials to be recycled.

In 2000, delegates from 122 countries completed a global treaty to control 12 *persistent organic pollutants (POPs).* These widely used toxic chemicals can accumulate in the fatty tissues of humans and other organisms at high trophic levels in food webs. There they can reach levels hundreds of thousands of times higher than levels in the general environment (Figure 8-15, p. 166). POPs can also be transported long distances by wind and water. In 2009, nine more chemicals widely used in pesticides and flame retardants were added to the list of controlled POPs.

The original list of 12 chemicals, called the *dirty dozen*, includes DDT and 8 other chlorine-containing persistent pesticides, PCBs, dioxins, and furans. Using blood tests, medical researchers at New York City's Mount Sinai School of Medicine estimated that nearly every person on earth has detectable levels of POPs. The long-term health effects of this involuntary global chemical experiment are largely unknown.

The treaty seeks to ban or phase out use of POPs and to detoxify or isolate stockpiles of them. It allows 25 countries to continue using DDT to combat malaria until safer alternatives are available. As of 2009, the United States had not ratified this treaty. Environmental scientists consider the treaty to be an important milestone in international environmental law and pollution prevention because it uses the *precautionary principle* (p. 174) to reduce the risks from toxic chemicals.

In 2000, the Swedish Parliament enacted a law that, by 2020, will ban all POPs. 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 presumed 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 such regulation in the United States, especially from most industries producing potentially dangerous chemicals.

THINKING ABOUT
Hazardous Chemicals

Should we assume that all chemicals are potentially harmful until shown otherwise? Explain.

We Can Make the Transition to Low-Waste Societies

Many environmental scientists argue that we can make a transition to a low-waste society by understanding and following key principles:

GOOD NEWS

- 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.
- Different categories of hazardous waste and recyclable waste should not be mixed.
- We can mimic nature by reusing, recycling, or composting most of the municipal solid wastes we produce.

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.

Here are the *three big ideas* for this chapter:

- The order of priorities for dealing with solid waste should be to reduce, reuse, recycle as much of it as possible and to 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.

REVISITING E-Waste and Sustainability

CORE CASE STUDY

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 waste discussed in this chapter. The challenge is to make the transition from a high-waste, throwaway economy to a 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) and 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. Integrated waste management, which uses a diversity of approaches and emphasizes waste reduction and pollution prevention, is another useful way to mimic nature. 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. 404. Describe the problems associated with electronic waste (e-waste) (**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 wastes we produce. Describe the production of solid waste in the United States and what happens to such waste.

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. Distinguish among the three Rs: **reduce**, **reuse**, and **recycle**. Describe seven 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. What are the major advantages and disadvantages of recycling? Describe progress in recycling plastics. What are bioplastics? What are three factors that discourage recycling? Describe three ways to encourage recycling and reuse.

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?

7. What are the priorities that scientists believe we should use in dealing with hazardous waste? What is phytoremediation? What is a plasma torch?

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? 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? Describe the effects of lead as a pollutant and how we can reduce our exposure to this chemical. Why is the reduction of lead pollution in the United States a good example of successful use of laws to prevent pollution?

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 to 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.

10. What are this chapter's *three big ideas*? Describe connections between dealing with the growing problem of e-waste (**Core Case Study**) and the three **principles of sustainability**.

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

CRITICAL THINKING

1. Do you think that manufacturers of computers and television sets and other forms of e-waste (**Core Case Study**) should be required to take them back at the ends of their useful lives for repair, remanufacture, or recycling? Explain. Would you be willing to pay more for these products to cover the costs of such take-back programs? If so, what percent more per purchase would you be willing to pay?

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 (p. 35) to explain why **(a)** dilution is not always the solution to pollution from hazardous wastes and **(b)** different categories of hazardous waste and recyclable waste should not be mixed.

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 lead to increased waste production.

5. Would you oppose having a hazardous waste landfill, waste treatment plant, deep-injection well, or incinerator in your community? For each of these facilities, explain your answer. If you oppose these disposal facilities, 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 waste? Does it have a recycling program? How well does it work? Does it have a hazardous waste collection system? If so, what does it do with these wastes? Write a report based on these questions and 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.

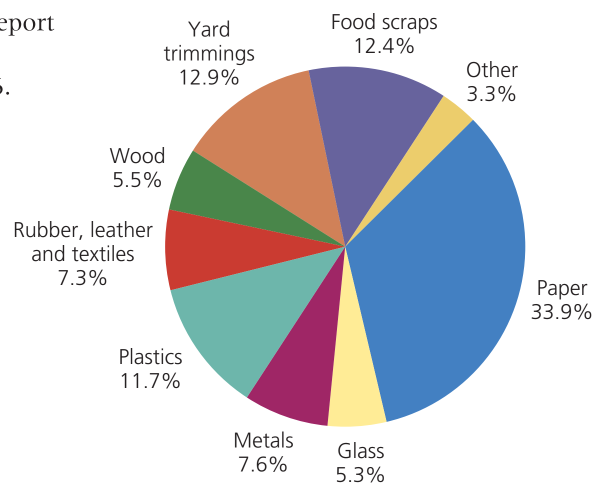
8. List three ways in which you could apply **Concept 16-6** to making your lifestyle more environmentally sustainable.

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

This pie chart diagram from an EPA report shows the typical composition of U.S. municipal solid waste (MSW) in 2006.



Source: U.S. Environmental Protection Agency, 2008. **www.epa.gov/epaoswer/non-hw/muncpl/pubs/msw06.pdf**

1. The average daily MSW production per person in the United States in 2006 was 2.1 kilograms (4.6 pounds). Use the data in the figure above to understand what makes up the annual MSW ecological footprint of a typical American. For each category in the pie chart, calculate the total weight in kilograms (and pounds) generated in 2006 by the average American. (*Note:* 1 kilogram = 2.20 pounds)

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengage.com/biology/miller** and choose Chapter 16 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, web links, information on Green Careers, and InfoTrac® College Edition articles.

CENGAGENOW™ For students with access, log on at **www.cengage.com/login** for the animations, active figures, activities, and readings indicated within the text by the CengageNOW logo. If your textbook did not come with access, visit **www.iChapters.com** to purchase.

17 Environmental Economics, Politics, and Worldviews

CORE CASE STUDY The Chattanooga, Tennessee, Story

Local officials, business leaders, and citizens have worked together to transform the city of Chattanooga, Tennessee, from a highly polluted city to one of the most sustainable cities in the United States (Figure 17-1).

During the 1960s, U.S. government officials rated Chattanooga as having the dirtiest air in the United States. Its air was so polluted by smoke from its coke ovens and steel mills that people sometimes had to turn on their vehicle headlights in the middle of the day. The Tennessee River, which flows 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.

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 the Vision 2000 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 those 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, which draws more than 1 million visitors per year to the downtown area. As property values and living conditions have improved, people and businesses have moved back downtown.

Chattanooga's environmental success story, a result of people working together to produce a more livable and sustainable city, is a shining example of how people can use economic and political tools, while motivated by ethical concerns, to solve serious environmental problems. Such use of economics, politics, and ethics to address environmental problems is the subject of this chapter.

Chattanooga Area Convention and Visitors Bureau

Figure 17-1 Since 1984, citizens have worked together to make the U.S. city of Chattanooga, Tennessee, a more sustainable and livable city.

Key Questions and Concepts

17-1 How are economic systems related to the biosphere?

CONCEPT 17-1 Ecological economists regard human economic systems as subsystems of the biosphere.

17-2 How can we use economic tools to deal with environmental problems?

CONCEPT 17-2 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*), subsidizing environmentally beneficial goods and services, taxing pollution and waste instead of wages and profits, and reducing poverty.

17-3 How can we implement more sustainable and just environmental policies?

CONCEPT 17-3 Individuals can work together to become part of political processes that influence how environmental policies are made and implemented. (*Individuals matter.*)

17-4 What are some major environmental worldviews?

CONCEPT 17-4 Major environmental worldviews differ on which is more important: human needs and wants, or the overall health of ecosystems and the biosphere.

17-5 How can we live more sustainably?

CONCEPT 17-5 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 2 (p. S3), 3 (p. S6), and 5 (p. S21) can be used with this chapter.

We did not weave the web of life; we are merely strands within it.
Whatever we do to the web, we do to ourselves.

CHIEF SEATTLE

17-1 How Are Economic Systems Related to the Biosphere?

▶ **CONCEPT 17-1 Ecological economists regard human economic systems as subsystems of the biosphere.**

Economic Systems Are Supported by Three Types of Resources

Economics is a social science that deals with the production, distribution, and consumption of goods and services to satisfy people's needs and wants. In a market-based economic system, buyers and sellers interact in markets to make economic decisions about how goods and services are produced, distributed, and consumed. In a *free-market* economic system, the prices of goods and services are determined by supply and demand with little or no government control or interference. If the demand for a good or service is greater than the supply, its price rises, and when supply exceeds demand, the price falls.

Three types of capital, or resources, are used to produce goods and services (Figure 17-2, p. 426). **Natural capital** (**Concept 1-1A**, p. 6 and Figure 1-2, p. 7) CONCEPT LINK 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, innovation, culture, and organization. **Manufactured capital**, or **manufactured resources**, are items such as machinery, equipment, and factories made from natural resources with the help of human resources.

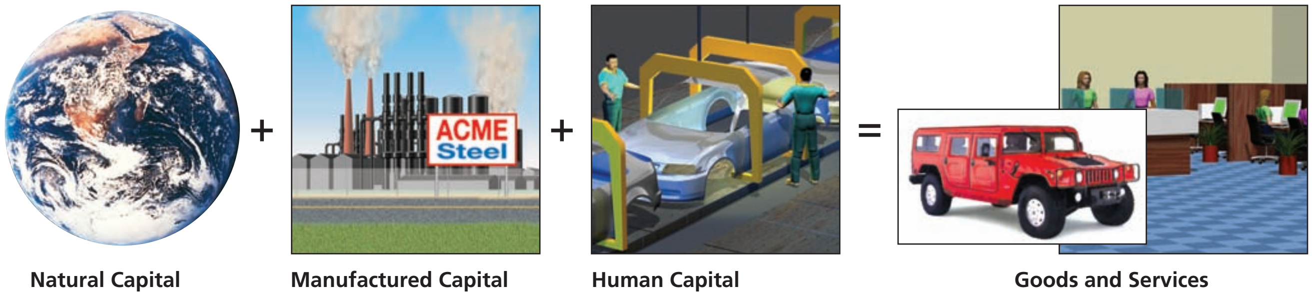
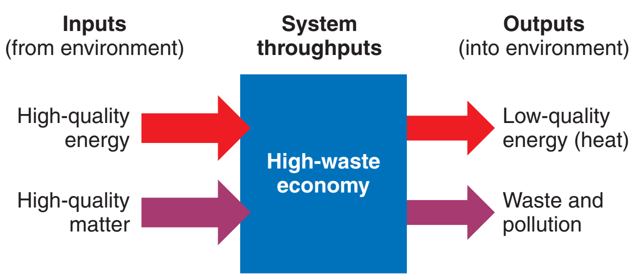


Figure 17-2 Three types of capital, or resources, are used to produce goods and services in an economic system.

Economists Disagree over whether Ever-Increasing Economic Growth Is Sustainable

Economic growth is an increase in a nation's capacity to provide goods and services to people, and *economic development* is the improvement of human living standards made possible by economic growth. Most of today's advanced industrialized countries have **high-throughput economies**, which attempt to boost economic growth by increasing the flow of natural matter and energy resources through their economic systems to produce more goods and services (Figure 17-3).

Neoclassical economists such as Robert Samuelson and the late Milton Friedman view the earth's natural capital as a subset, or part, of a human economic system and assume that the potential for economic growth is essentially unlimited. They also consider natural capital as important but not indispensible because they believe we can find substitutes for essentially any resource. They argue that we can maintain an ever-increasing throughput of matter and energy resources through economic systems (Figure 17-3) and thus increase economic growth indefinitely.



CENGAGENOW™ **Active Figure 17-3** The *high-throughput economies* of most developed countries rely on continually increasing the rates of energy and matter flow 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 that you regularly do that add to this throughput of matter and energy?

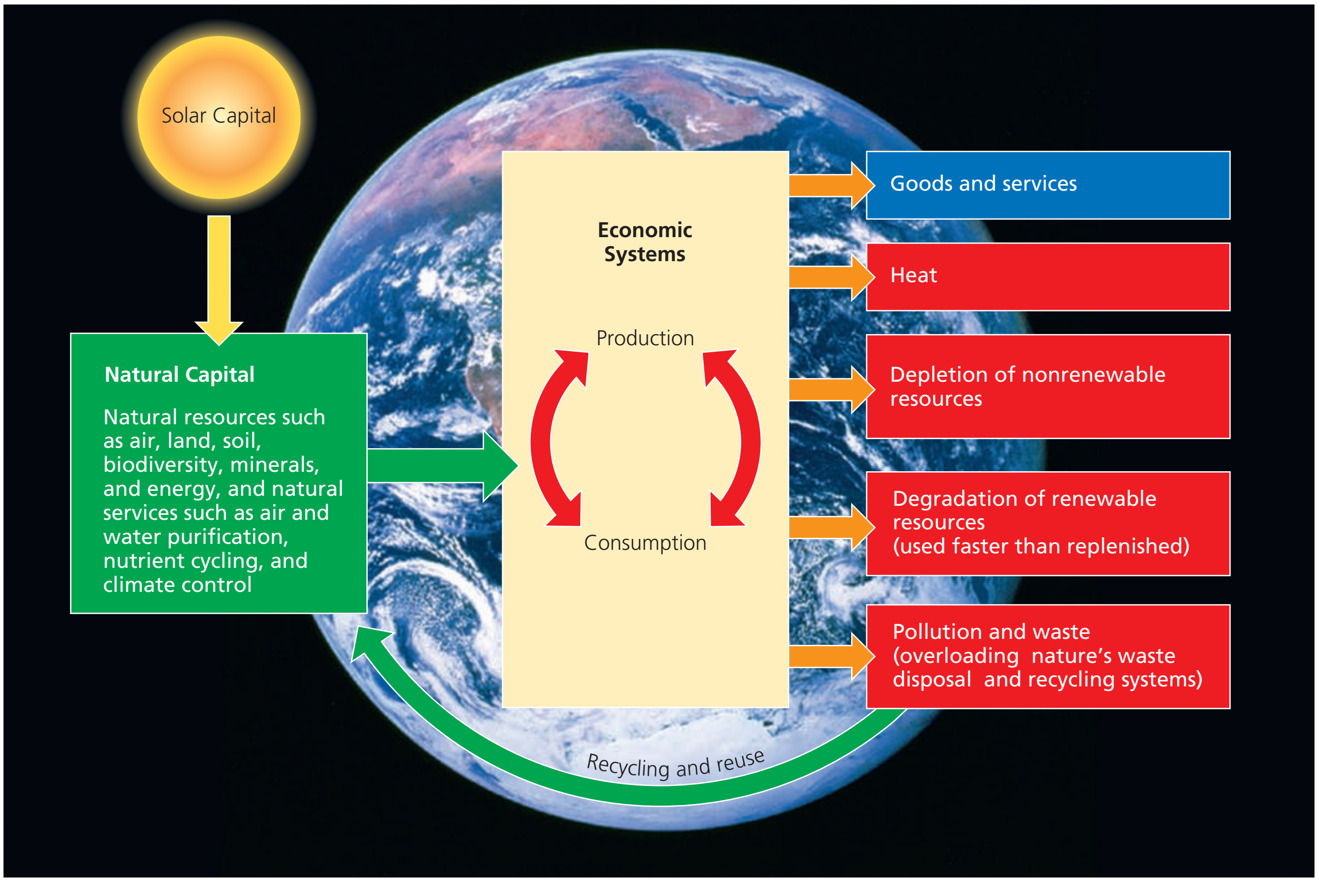
Ecological economists such as Herman Daly and Robert Costanza disagree. (See Daly's Guest Essay on the steady state economy at CengageNOW.) They point out that there are no substitutes for many vital natural resources such as air, water, fertile soil, and biodiversity, or for nature's free ecological services such as climate control, air and water purification, pest control, and nutrient recycling. They also believe that conventional economic growth eventually will become unsustainable. Their reasoning is that such growth will lead us to deplete or degrade much of the natural capital (Figure 1-2, p. 7) on which all economic systems depend and to exceed the capacity of the environment to handle the pollutants and wastes we produce.

Ecological economists view economic systems as subsystems of the biosphere that depend heavily on the earth's irreplaceable natural resources and services (**Concept 17-1**) (Figure 17-4). As a result, they urge us to shift from our current high-throughput economies to more *economically sustainable economies*, or *eco-economies*. They urge us to redesign our political and economic systems to encourage environmentally beneficial and more sustainable forms of economic development and to discourage environmentally harmful forms of economic growth. In 2008, Achim Steiner, head of the U.N. 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."

Taking the middle in this debate are *environmental economists*. Many generally agree with the model proposed by ecological economists in Figure 17-4, 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.

CENGAGENOW™ Learn more about how ecological economists view market-based systems, and contrast their views with those of conventional economists at CengageNOW.

We will now look at several strategies suggested by some ecological and environmental economists for making the transition to more sustainable eco-economies over the next several decades.



CENGAGENOW™ **Active Figure 17-4** *Ecological economists* see all economies as human 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.

17-2 How Can We Use Economic Tools to Deal with Environmental Problems?

▶ **CONCEPT 17-2 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*), subsidizing environmentally beneficial goods and services, taxing pollution and waste instead of wages and profits, and reducing poverty.**

Most Things Cost 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, shipping, and a markup for dealer profit. In using the car, we pay additional direct costs for gasoline, maintenance, repairs, 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 costs of health care and insurance, higher taxes for pollution control, traffic congestion, and environmental degradation such as destruction of ecosystems to build highways and parking lots. Many economists and environmental experts cite the 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 (Figure 1-9, p. 15).

CONNECTIONS

Environmental Costs, Consumer Demands, and Environmental Problems

Excluding the harmful environmental costs from the market prices of goods and services hides these harmful costs from consumers. Many consumers therefore do not learn about these harmful costs and are less likely to demand more environmentally beneficial goods and services. Thus, hiding these costs promotes pollution, resource waste, and environmental degradation.

Environmental Economic Indicators Could Help Us Reduce Our Environmental Impact

Economic growth 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 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 the 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 *green indicators*—to help monitor environmental quality and human well-being. One such indicator is the **genuine progress indicator** (**GPI**)—the 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 midyear. 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 1-5, p. 11.)

Examples of beneficial transactions included in the GPI include unpaid volunteer work and health care, child care, and housework provided by family members. Harmful costs that are subtracted to arrive at the GPI include pollution, resource depletion and degradation, poor health due to environmental degradation, and crime. The GPI is calculated as follows:

$$\text{Genuine progress indicator} = \text{GDP} + \text{benefits not included in market transactions} - \text{harmful environmental and social costs}$$

Figure 17-5 compares the per capita GDP with the per capita 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.

The genuine progress indicator and other green indicators under development are far from perfect, which is true of the GDP as well. But without green 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 work best in improving environmental quality and life satisfaction.

RESEARCH FRONTIER

Developing and refining environmental and social quality of life indicators. See **www.cengage.com/biology/miller**.

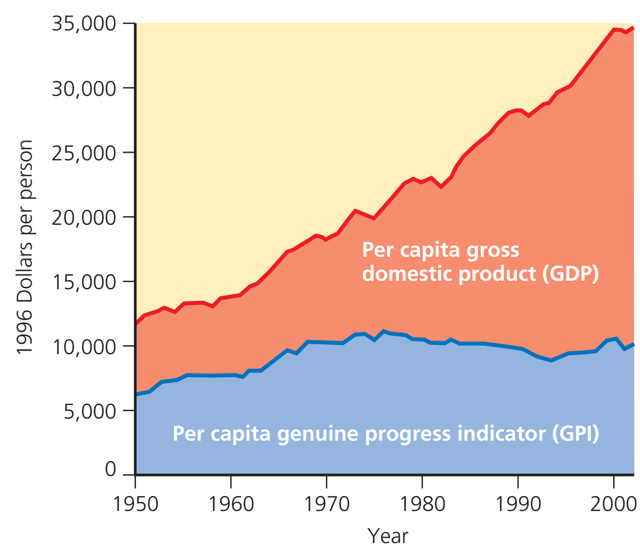


Figure 17-5 *Monitoring environmental progress:* Comparison of the per capita gross domestic product (GDP) and the per capita genuine progress indicator (GPI) in the United States between 1950 and 2004. **Questions**: Would you favor making widespread use of this or similar green economic indicators? Why have we not done this? (Data from Redefining Progress, 2006)

Include the Harmful Environmental Costs in the Prices of Goods and Services

Most environmental and ecological economists argue for an *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 plus external costs (**Concept 17-2**). This is also a 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 enable consumers to make more informed choices. Jobs and profits would be lost in environmentally harmful businesses as consumers would more often choose green products, 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.

If a shift to full-cost pricing were phased in over 2 decades, many environmentally harmful businesses would have time to transform themselves into environmentally beneficial businesses. And consumers would 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. So why is it not used more widely? *First*, most producers of harmful and wasteful products and services would have to charge more, 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 essentially excludes such costs.

RESEARCH FRONTIER

Refining methods for estimating and implementing full-cost pricing. See **www.cengage.com/biology/miller**.

HOW WOULD YOU VOTE?

Should full-cost pricing be used in setting market prices for goods and services? Cast your vote online at **www.cengage.com/biology/miller**.

Governments can use several strategies to encourage or force producers to work toward full-cost pricing. Here, we take a look at some of them.

Reward Environmentally Sustainable Businesses

One way to encourage a shift to full-cost pricing is to *phase out* environmentally harmful (*perverse*) subsidies and tax breaks, which, according to environmental scientist Norman Myers, 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.) Such subsidies distort the economic playing field and create huge economic incentives for unsustainable resource waste, depletion, and degradation. Examples include depletion subsidies and tax breaks for extracting minerals and oil, cutting timber on public lands, and irrigating with low-cost water.

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 *lobbying*, or trying to influence governments, to keep and even increase these subsidies. They also lobby against subsidies and tax breaks for more environmentally beneficial competitors. Perverse subsidies and tax breaks will continue until enough individuals work together to counteract such lobbying by electing and then influencing officials who support phasing out environmentally harmful subsidies and tax breaks.

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. GOOD NEWS

At the same time, governments could phase in environmentally beneficial subsidies and tax breaks for pollution prevention, ecocities, sustainable forestry, sustainable agriculture, sustainable water use, energy efficiency and renewable energy use, and actions to slow projected climate change (**Concept 17-2**). Making such subsidy shifts would encourage the rise of new environmentally beneficial businesses. The U.S. city of Chattanooga, Tennessee, (**Core Case Study**) used such subsidies and tax breaks for exactly that purpose and succeeded. CORE CASE STUDY

THINKING ABOUT
Subsidies

Do you favor phasing out environmentally harmful government subsidies and tax breaks and phasing in environmentally beneficial ones? If so, what 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

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 Fairly easy to detect cheaters		Governments may use money as general revenue instead of improving environmental quality and reducing taxes on income, payroll, and profits

Figure 17-6 Advantages and disadvantages of using green taxes to help reduce pollution and resource waste. **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

environmental and health costs of production and consumption in market prices (**Concept 17-2**). Taxes can be levied on a per-unit basis on the amount of pollution and hazardous waste produced and on the use of fossil fuels, nitrogen fertilizer, timber, minerals, and other resources. Figure 17-6 lists 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/biology/miller**.

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 turn this around. 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*, they 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 or replaced so that there is no net increase in taxes. And *third*, the poor and middle class would need a safety net to help provide them with essentials such as fuel and food.

In Europe and the United States, polls indicate that, once such tax shifting is explained to them, 70% of voters support the idea. In Europe, green taxes on activities such as waste disposal, air and water pollution, CO_2 emissions, energy consumption, and vehicles entering congested cities account for more than 7% of total tax revenues. Germany's green tax on fossil fuels, introduced in 1999, has reduced pollution and greenhouse gas emissions, created up to 250,000 new jobs, lowered taxes on wages, and greatly increased dependence on renewable energy resources.

The U.S. Congress has not enacted green taxes, mostly because politically powerful automobile, oil, coal, and other industries claim that such taxes will reduce their competitiveness and harm the economy. 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/biology/miller**.

Environmental Laws and Regulations Can Discourage or Encourage Innovation

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 developed countries has involved passing laws that are enforced through a *command and control* approach. Critics say that this approach can unnecessarily increase costs and discourage innovation, because many of these regulations concentrate on cleanup instead of prevention. Some regulations also set compliance deadlines that are too short to allow companies to find innovative solutions. Or they require use of specific technologies where less costly but equal or better alternatives might be available.

A different approach favored by many economists and environmental and business leaders, is to use *incentive-based regulations*. Rather than requiring all companies to follow the same fixed procedures, this approach uses the economic forces of the marketplace to encourage businesses to be innovative in reducing pollution and resource waste. Experience in several European nations shows that *innovation-friendly 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 can create jobs, increase company profits, and make the companies more competitive in national and international markets. The U.S. city of Chattanooga, Tennessee, (**Core Case Study**) used this approach to help it become a more environmentally sustainable and livable city.

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.

The United States has used this *cap-and-trade* approach to reduce the emissions of sulfur dioxide (p. 379) and several other air pollutants. Tradable rights can also be established among countries to help to preserve biodiversity and to reduce emissions of greenhouse gases and other regional and global pollutants.

Figure 17-7 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.

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/biology/miller**.

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, pollution, and waste for a number of goods. Their idea for more sustainable economies focuses on shifting from the current *material-flow economy* (Figure 17-3) to a *service-flow economy*. Instead of buying many goods outright, customers *eco-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) as possible in its production and use, and is easy to maintain, repair, reuse, or recycle.

Such an economic shift based on eco-leasing 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 its machines to have few parts, 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 customers with the indoor temperatures they want. It makes higher profits by 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 and tile company, plans to lease rather than sell carpet (Individuals Matter, p. 432). This will reduce his company's resource use and harmful environmental impacts and could increase profits for stockholders.

THINKING ABOUT
Selling Services

Do you favor a shift from selling goods to selling the services that the goods provide? List some services that you would be willing to lease.

Trade-Offs

Tradable Environmental Permits

Advantages

- Flexible
- Easy to administer
- Encourage pollution prevention and waste reduction
- Permit prices determined by market transactions
- Confront ethical problem of how much pollution or resource waste is acceptable

Disadvantages

- Big polluters and resource wasters can buy their way out
- May not reduce pollution at dirtiest plants
- Can exclude small companies from buying permits
- Caps can be too high and not regularly reduced to promote progress
- Self-monitoring of emissions can promote cheating

Figure 17-7 Advantages and disadvantages of using tradable pollution and resource-use permits to reduce pollution and resource waste. **Questions**: Which two advantages and which two disadvantages do you think are the most important? Why?

INDIVIDUALS MATTER

GOOD NEWS

Ray Anderson

Ray Anderson (Figure 17-A) founded Interface, a company based in Atlanta, Georgia (USA). The company is the world's largest manufacturer of commercial carpet tiles, with 26 factories in 6 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, by 2020, the nation's first totally sustainable green corporation with a zero-waste environmental footprint. Since then, he has implemented hundreds of projects with goals of greatly reducing energy use, reducing fossil fuel use, relying more on solar energy, and copying nature.

By 2008, Interface had cut water usage by 77%, reduced solid waste by 75%, cut greenhouse gas emissions by 82%, lowered energy use by 27%, and was getting 88% of its electricity from renewable sources. These efforts have saved the company $393 million. Interface invented a variety of recyclable and compostable carpet fabrics that have diverted enough carpet from landfills to carpet New York City's Empire State Building 45 times. One of Interface's factories in California runs on solar cells and produced the world's first solar-made carpet.


Interface

Figure 17-A Ray Anderson.

The company is applying the three **principles of sustainability** to its carpet business. It employed the biodiversity principle by creating a line of carpet tiles that mimic the way nature covers a forest floor. No two tiles from this line have the same design. Buyers like it because it seems to bring nature indoors. Similar product lines now make up more than half of the company's sales.

Also, the tiles are made from recycled fibers, and the tile factory runs partly on solar energy. Thus, the company is applying the recycling and solar energy sustainability principles.

To help achieve the goal of zero waste by 2020, 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's long-term goals for his company are to have it put back more than it takes from nature; to do good, not just to do no harm; and to influence other businesses to do the same while still increasing profits. In 2009, Anderson said that the company had achieved about half of its sustainability goals. And he hopes to live long enough to finish climbing his sustainability mountain. He hopes his efforts will serve as an example for other companies and as a gift for his five grandchildren and for the earth.

Reducing Poverty Can Help Us to Deal with Environmental Problems

Poverty is defined as the inability to meet one's basic economic needs. According to the World Bank and the United Nations, 1.1 billion people—a number equal to the entire population of China and almost four times the size of the U.S. population—struggle to survive on an income equivalent to less than $1.25 a day.

Poverty has numerous harmful health and environmental effects (Figure 1-12, p. 17, and Figure 14-14, p. 362) and has been identified as one of the four major causes of the environmental problems we face. Reducing poverty benefits individuals, economies, and the environment (**Concept 17-2**) and helps to slow population growth.

Some nations have climbed out of serious poverty in a short time. For example, South Korea and Singapore made the journey from being poor developing nations to becoming world-class industrial powers in only 2 decades, mostly by focusing on education, hard work, and discipline, all of which attracted investment capital. China and India are on a similar path. GOOD NEWS

To reduce poverty and its harmful effects, governments, businesses, international lending agencies, and wealthy individuals in developed countries could:

- Mount a massive global effort to combat malnutrition and the infectious diseases that kill millions of people prematurely (Figure 14-5, p. 347 and Figure 14-13, p. 361)
- Provide primary school education for all children and for the world's nearly 800 million illiterate adults (a number that is almost three times the size of the U.S. population)
- Stabilize population growth in developing countries as soon as possible, mostly by investing in family planning, reducing poverty, and elevating the social and economic status of women
- Sharply reduce the total and per capita ecological footprints of developed countries and rapidly developing countries such as China and India (Figure 1-5, p. 11) because of the threat from these growing footprints to the world's environmental and economic security

- Make large investments in small-scale infrastructure such as solar-cell power facilities for rural villages (Figure 13-30, p. 328) and sustainable agriculture projects to help developing nations develop more energy-efficient eco-economies
- Encourage lending agencies to make small loans to poor people who want to increase their income (see Individuals Matter, p. 434)

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. Developed countries agreed to devote 0.7% of their annual national income toward achieving the goals. But by 2008, only five countries—Denmark, Luxembourg, Sweden, Norway, and the Netherlands—had achieved this goal.

In fact, the average amount donated in 2008 was 0.28% of national income. The United States—the world's richest country—gave only 0.18% of its national income to help poor countries in 2008. 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 involves evaluating individual and national priorities (Figure 17-8).

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.

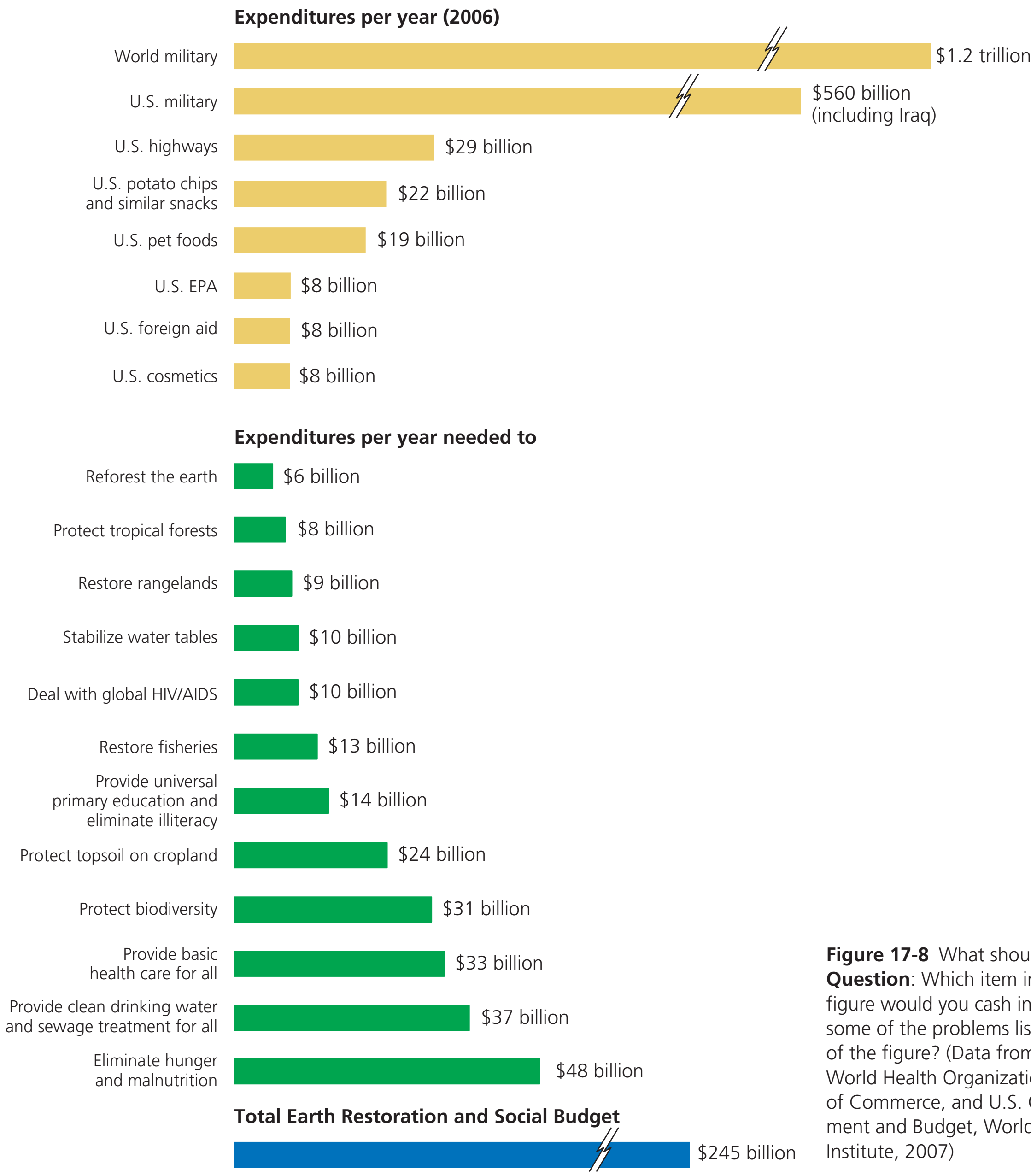


Figure 17-8 What should our priorities be? **Question**: Which item in the top part of the figure would you cash in to pay for solving some of the problems listed in the lower part of the figure? (Data from United Nations, World Health Organization, U.S. Department of Commerce, and U.S. Office of Management and Budget, World Bank, Earth Policy Institute, 2007)

INDIVIDUALS MATTER

GOOD NEWS

Muhammad Yunus—a Pioneer in Microlending

Most of the world's poor people want to work and to earn enough to climb out of poverty. But few of them have credit records or assets that they could use for collateral to secure loans. With loans, they could buy whatever they would need to start farming or to start small businesses.

For almost 3 decades, an innovation called *microlending,* or *microfinance,* has helped a number of people to deal with this problem. For example, since economist Muhammad Yunus started it in 1983, the Grameen (Village) Bank in Bangladesh has provided microloans ranging from $50 to $500 to more than 7 million Bangladeshi villagers. About 97% of the loans are used by women to start small businesses, to plant crops, or to buy cows and chickens for producing and selling milk and eggs.

To stimulate repayment and provide support, the Grameen Bank organizes microborrowers into five-member groups. If a member of the group misses a weekly payment or defaults on the loan, the other members of the group must make the payments. The repayment rate on these microloans is an astounding 95% compared to 45–50% for loans made by traditional banks in Bangladesh. And about half of Grameen's borrowers move above the poverty line within 5 years.

Grameen Bank microloans are also being used to develop daycare centers, health care clinics, reforestation projects, drinking water supply projects, literacy programs, and sma scale solar and wind power systems in rural villages. The Grameen model has inspired the development of microcredit projects that have helped some 50 million people in more than 58 countries, and the numbers are growing rapidly. Grameen Bank of Bangladesh now has over 2,500 branch offices and loans about $1 billion a year. And in 2008, Grameen America opened an office i Queens, New York.

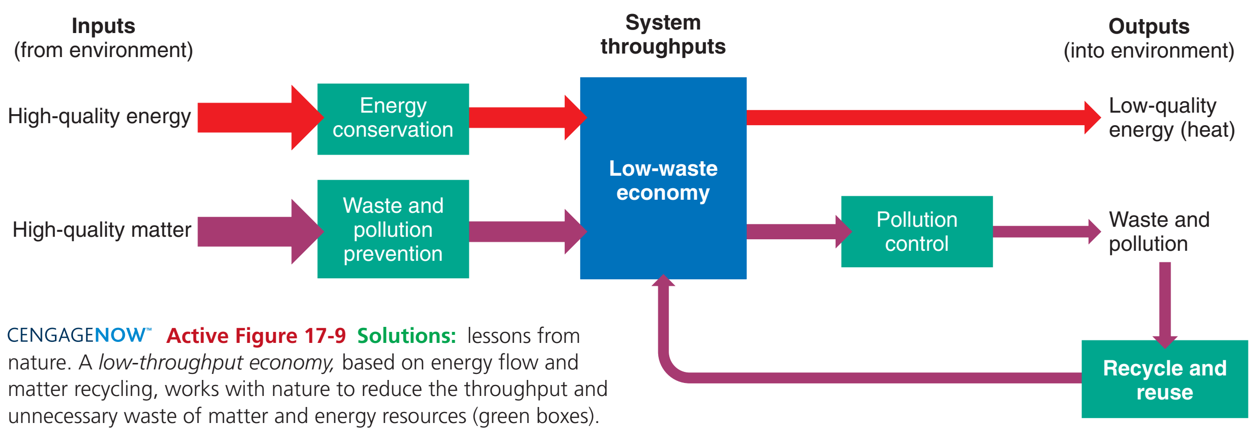
In 2006, Muhammad Yunus and his Grameen Bank were joint winners of the Nobel Peace Prize for their pioneering use o microcredit to assist millions of people in lift ing themselves out of poverty.

We Can Use Lessons from Nature to Shift to More Environmentally Sustainable Economies

The three scientific laws governing matter and energy changes (pp. 32 and 35) 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 17-3) to a more sustainable **low-throughput** (**low-waste**) **economy**, as summarized in Figure 17-9. In other words, we can live more sustainably by controlling human population growth, using and wasting less matter and energy resources, and reusing, recycling, or composting most matter resources.

CENGAGENOW™ Compare how energy is used in high- and low-throughput economies at CengageNOW.

Figure 17-10 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*



CENGAGENOW™ **Active Figure 17-9** **Solutions:** lessons from nature. A *low-throughput economy,* based on energy flow and matter recycling, works with nature to reduce the throughput and 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 reduce 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 or community could operate more like a low-throughput economy?

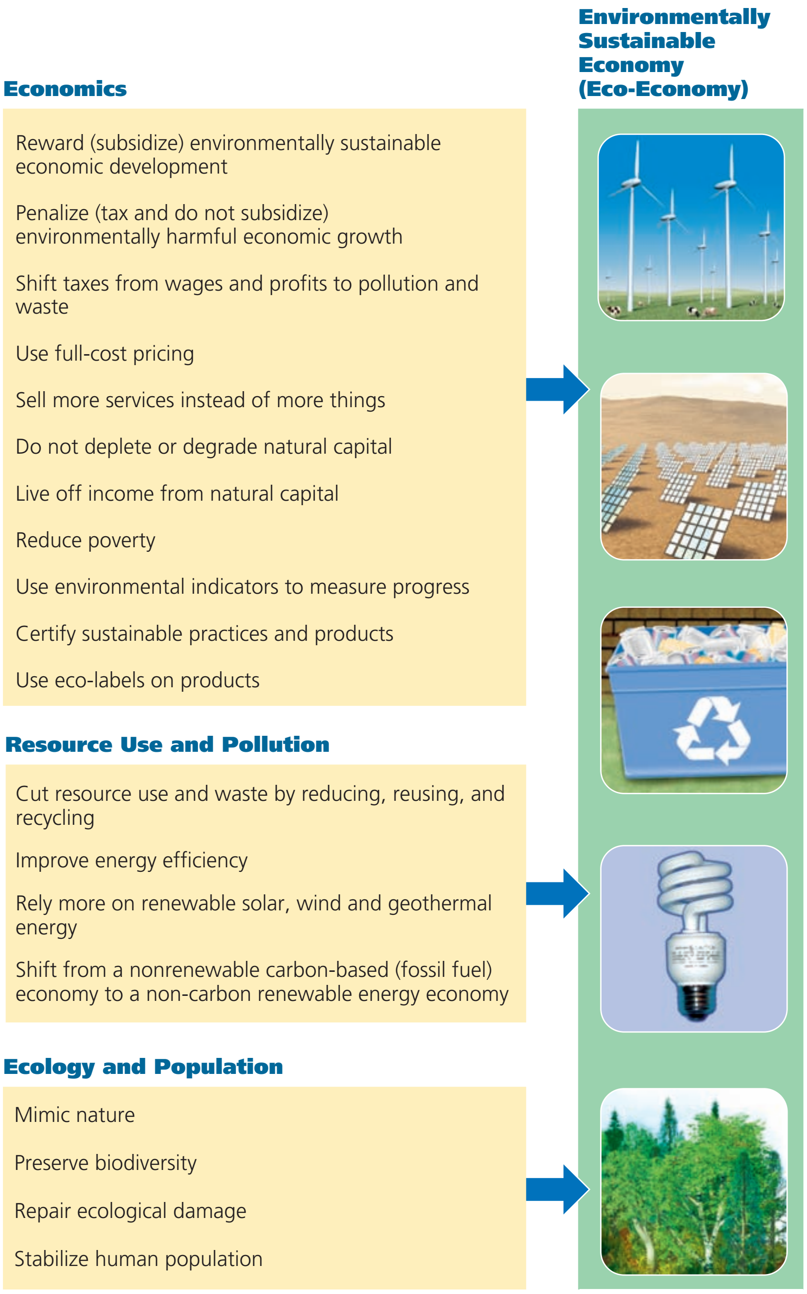


Figure 17-10 **Solutions:** principles for shifting to more environmentally sustainable economies, or *eco-economies*, during this century. **Question**: Which three of these solutions do you think are the most important?

it, take no more than you need, try not to harm life or the environment, and make amends if you do."

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. This is based on the ideas of Austrian economist Joseph Schumpeter (1883–1950) who suggested that the lifeblood of capitalism and entrepreneurship is "creative destruction" as failing companies are replaced by more innovative ones. *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 (Figure 5-11, p. 90). 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.

GOOD NEWS

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*, which are devoted to improving environmental quality, developing cleaner, carbon-free energy resources, and promoting environmental sustainability. An increasing number of economists and business leaders say that *making the shift to an eco-economy could be the greatest investment opportunity of this century*.

One way to encourage such a shift and create millions of jobs in the United States (and in other countries) might be to establish a Green Earth Corps where people get green-collar job training while providing community service devoted to promoting environmental sustainability. Participants could restore degraded ecosystems, learn how to weatherize new and existing buildings, install panels of solar cells, do green construction, and establish examples of more sustainable agriculture throughout the nation—an exciting example of sustainability-driven economic succession.

Another way is to invest in green infrastructure such as mass transit, more sustainable eco-cities (Case Study, p. 118), sustainable agriculture, wind turbines, solar cells, solar water heaters, and an updated, super-efficient electrical grid. Figure 17-11 might give you some ideas for a green career choice in the rapidly emerging eco-economy. Some analysts believe that the current global financial crisis creates a unique opening for a shift to such an economy over the next few decades.

GOOD NEWS

Environmentally Sustainable Businesses and Careers

- Aquaculture
- Biodiversity protection
- Biofuels
- Climate change research
- Conservation biology
- Eco-industrial design
- Ecotourism management
- Energy efficient product design
- Environmental chemistry
- Environmental (green) design
- Environmental economics
- Environmental education
- Environmental engineering
- Environmental health

- Environmental law
- Environmental nanotechnology
- Fuel cell technology
- Geographic information systems (GIS)
- Geothermal geologist
- Hydrogen energy
- Marine science
- Pollution prevention
- Reconciliation ecology
- Selling services in place of products
- Solar cell technology
- Sustainable agriculture
- Sustainable forestry
- Waste reduction
- Watershed hydrologist
- Water conservation
- Wind energy

Figure 17-11 **Green careers:** some key environmentally sustainable, or eco-friendly, businesses and careers. These businesses 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.)

17-3 How Can We Implement More Sustainable and Just Environmental Policies?

CONCEPT 17-3 **Individuals can work together to become part of political processes that influence how environmental policies are made and implemented. (*Individuals matter.*)**

Dealing with Environmental Problems in Democracies Is Not Easy

The role played by a government is determined largely by its **policies**—the set of laws and regulations it enforces and the programs it funds. **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. **Democracy** is government by the people through elected officials and representatives. In a *constitutional democracy*, a constitution provides the basis of government authority, and, in most cases, limits government power by mandating free elections and guaranteeing free speech.

Political institutions in most constitutional democracies are designed to allow gradual change to ensure 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.

The major function of government in democratic countries is to develop and implement policies for dealing with various issues. The first step is the complex process is to develop a policy and enact it into a law. The next step involves getting enough funds set aside by an elected legislative body to implement and enforce the new law. Developing and adopting a budget is the most important and controversial activity of the executive and legislative branches of democratic governments. Once a law has been passed and funded, the appropriate government department or agency must draw up regulations or rules for implementing it.

In passing laws, developing budgets, and formulating regulations, elected and appointed government officials must deal with pressure from many competing *special-interest groups*. Each group advocates passing laws, providing subsidies or tax breaks, or establishing regulations favorable to its cause, and weakening or repealing laws, subsidies, tax breaks, and regulations favorable to its opposition. Some special-interest groups such as corporations are *profit-making organizations*. Others special interests are represented by *nongovernmental organizations (NGOs)*, most of which are nonprofit such as labor unions and environmental organizations.

Certain Principles Can Guide Us in Making Environmental Policy

Analysts suggest that legislators and individuals evaluating existing or proposed environmental policies should be guided by several 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, three essentially irreversible actions affecting the environment are production of indestructible hazardous and toxic waste in coal-burning power plants (Case Study, p. 307), which we must try to store safely, essentially forever; production of deadly radioactive wastes through the nuclear power fuel cycle, which must be store safely for 10,000 – 240,000 years (p. 314); and capturing and storing 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 (Science Focus, p. 394).
- *The net energy principle:* Do not encourage the widespread use of energy alternatives or technologies with low net energy yields (Science Focus, p. 299, 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, tar sands, shale oil, coal gasification, ethanol from corn, biodiesel from soybeans, and hydrogen, as discussed in Chapter 13.
- *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 public access and participation principle:* Citizens should have open access to environmental data and information and the right to participate in developing, criticizing, and modifying environmental policies.
- *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.)

CASE STUDY

Managing Public Lands in the United States—Politics in Action

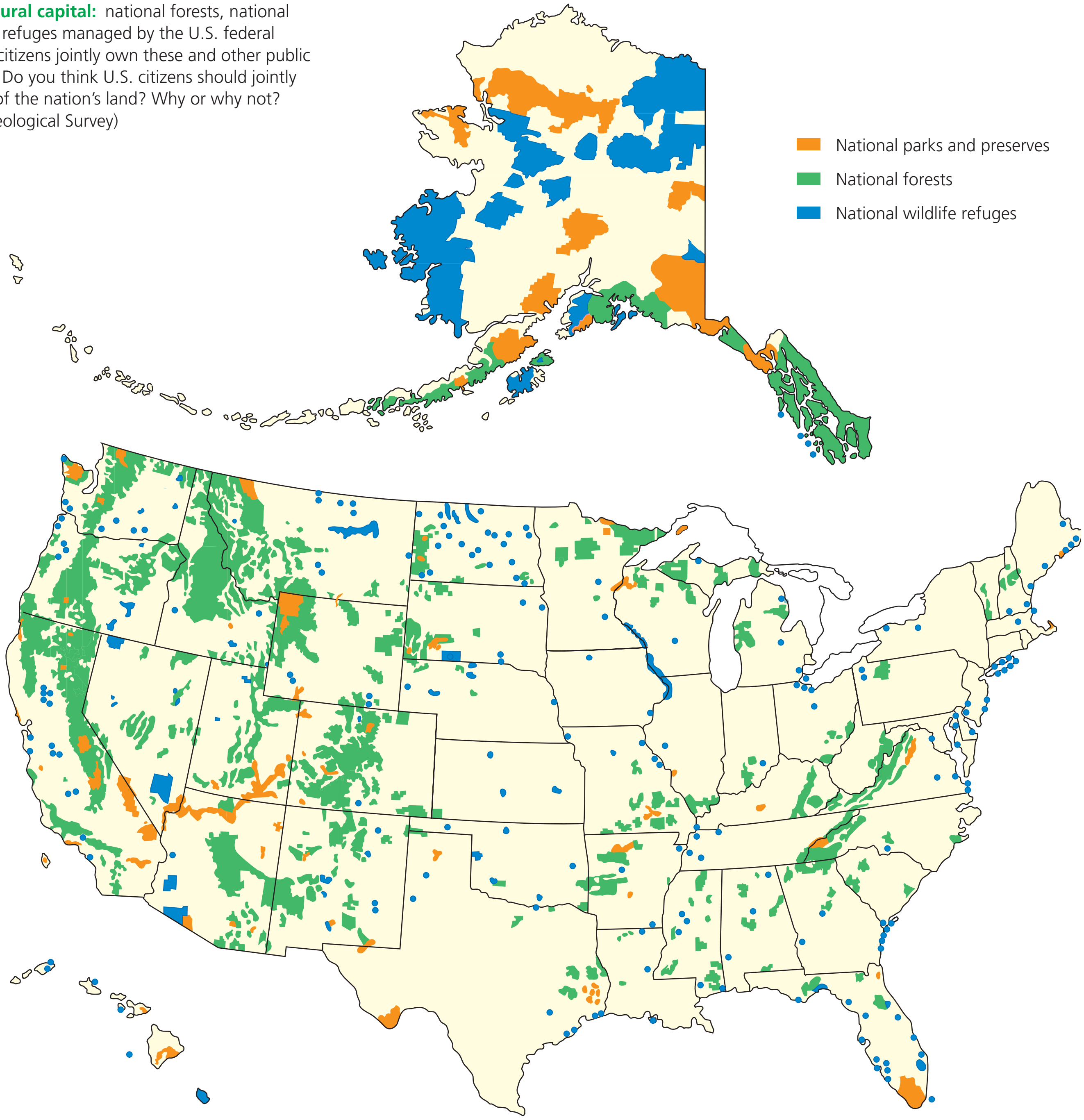
No nation has set aside as much of its land for public use, resource extraction, enjoyment, or wildlife habitat as has the United States. The federal government manages roughly 35% of the country's land, which belongs to every American. About three-fourths of this federal public land is in Alaska and another fifth is in the western states (Figure 17-12, p. 438).

Some federal public lands are used for many 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, and livestock grazing.

The U.S. Fish and Wildlife Service (USFWS) manages 549 *National Wildlife Refuges*. Most refuges protect habitats and breeding areas for waterfowl and big game to provide a harvestable supply for hunters. Permitted activities in most refuges include hunting, trapping, fishing, oil and gas development, mining, logging, grazing, some military activities, and farming.

Figure 17-12 **Natural capital:** national forests, national parks, and wildlife refuges managed by the U.S. federal government. U.S. citizens jointly own these and other public lands. **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)



Uses of some other public lands are more restricted. The *National Park System*, managed by the National Park Service (NPS), includes 66 major parks and 331 national recreation areas, monuments, memorials, battlefields, historic sites, parkways, trails, rivers, 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 756 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 2, p. S39, in Supplement 9). The use and management of the resources on these lands has been debated since the 1800s.

Most conservation biologists, environmental economists, and many free-market economists believe that four principles should govern use of public lands:

- They should be used primarily for protecting biodiversity, wildlife habitats, and ecosystems.

- No one should receive government subsidies or tax breaks for using or extracting resources on public lands.
- The American people deserve fair compensation for the use of their property.
- 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, resource extractors, many economists, and many citizens tend to view public lands in terms of their usefulness in providing mineral, timber, and other resources and increasing short-term economic growth. They have succeeded in blocking implementation of the four principles listed above. For example, in recent years, analyses of budgets and appropriations reveal that the government has given an average of $1 billion a year—an average of $2.7 million a day—in subsidies and tax breaks to privately owned interests that use U.S. public lands for mining, fossil fuel extraction, logging, and grazing.

Some developers and resource extractors have sought to go further. Here are some of the proposals such interests have made to get the U.S. Congress to open up more federal lands for development:

- 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.
- Slash federal funding for administration of regulations over public lands.
- Cut old-growth forests in the national forests and replace them with tree plantations.
- Open national parks, national wildlife refuges, and wilderness areas to oil drilling, mining, off-road vehicles, and commercial development.
- Eliminate or take power away from the National Park Service and launch a 20-year construction program of new concessions and theme parks to be run by private firms in the national parks.

Between 2002 and 2009, the U.S. Congress and executive branch have expanded the extraction of mineral, timber, and fossil fuel resources on U.S. public lands and weakened environmental laws and regulations protecting such lands from abuse and exploitation.

Although this case study has focused on the debate over the use of public lands in the United States, the same issues apply to the use of government or publicly owned lands in other countries.

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/biology/miller**.

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 together to bring about change. Without grassroots political action by millions of individual citizens and organized citizen groups, the air you breathe and the water you drink today would be much more polluted, and much more of the earth's biodiversity would already have disappeared (**Concept 17-3**).

Figure 17-13 lists ways in which you can influence and change local, state, and national government policies in constitutional democracies. This is how the citizens and elected officials of the U.S. city of Chattanooga, Tennessee, (**Core Case Study**) made their city more sustainable, beginning in 1984.

GOOD NEWS

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 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. As Indian political and spiritual leader

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 for office
- 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 17-13 **Individuals matter:** You can influence environmental policy (**Concept 17-3**). **Questions**: Which three of these actions do you think are the most important? Which ones, if any, have you taken?

Mahatma Gandhi (1869–1948) observed: "An ounce of practice is worth more than tons of preaching." For example, we can use fewer disposable products, eat food that has been sustainably produced (Figure 10-25, p. 234), reuse and recycle many items, and walk, bike, or take mass transit to work or school. We can also think more about whether we should acquire everything we want instead of limiting our purchases more to things we really need.

Second, we can *work within existing economic and political systems to bring about environmental improvement* by campaigning and voting for well-informed, pro-environmental sustainability 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 (Figure 17-11) and described 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 office holder.

Fourth, we can *propose and work for better solutions to environmental problems*. Leadership is more than being 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.

U.S. Environmental Laws and Regulations Have Been under Attack

Concerned citizens have persuaded the U.S. Congress to enact a number of important federal environmental and resource protection laws, most of them in the 1970s (Figure 17-14 and Supplement 5, p. S21).

U.S. environmental laws 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 and to change the ways in which public lands (Figure 17-12) 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. Since 2000, most major U.S. federal environmental laws and regulatory agencies have been weakened by a combination of executive orders and congressional actions.

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 17-14 Some major environmental laws and their amended versions enacted in the United States since 1969. (Supplement 5, p. S21, contains information on these laws, as does the website for this chapter.) **Question**: Why do you think so few new U.S. environmental laws have been enacted and existing environmental laws have been under attack since 1980?

On the other hand some concerned citizens have worked together to improve environmental quality in their local communities. The story of Chattanooga, Tennessee, (**Core Case Study**) shows how people on all sides of important environmental issues can listen to one another's concerns, try to find areas of agreement, and work together to find solutions to environmental problems.

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 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.

Citizen Environmental Groups Play Important Roles

The spearheads of the global conservation, environmental, and environmental justice movements are the tens of thousands of nonprofit NGOs working at the international, national, state, and local levels (**Concept 17-3**). 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 (Individuals Matter, p. 434).

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.

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 17-14 and Supplement 5, p. S21) and they fight attempts to weaken or repeal such laws.

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. 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*.

Some 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 sway members of the public to oppose various environmentally harmful activities. Much more controversial are militant environmental groups that use violent means such as destroying 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/biology/miller**.

INDIVIDUALS MATTER

Butterfly in a Redwood Tree

"Butterfly" is the nickname given to Julia Hill. This young woman spent 2 years of her life on a small platform near the top of a giant redwood tree in the U.S. state of California to protest the clear-cutting of a forest of these ancient trees, some of them more than 1,000 years old. She and other protesters were illegally occupying these trees as a form of *nonviolent civil disobedience*.

Butterfly 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 to cut down these ancient giants for short-term economic gain on the part of the land owners. 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 try to 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 try to develop public support for saving the trees.

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, and enduring high winds, intense rainstorms, snow, and ice? All around her was noise from trucks, chainsaws, and helicopters.

Although Butterfly lost her courageous battle to save the surrounding forest, she persuaded Pacific Lumber MAXXAM to save her tree (called 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 Butterfly 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.

Butterfly led others by following in the tradition of Mahatma Gandhi, an Indian political and spiritual leader who said, "My life is my message." Would you spend a day or a week or 2 years of your life protesting something that you believed to be wrong?

SCIENCE FOCUS

Greening American Campuses

Environmental audits by students at American colleges and universities have focused on implementing or improving recycling programs (now found at almost 80% of U.S. colleges and universities). They have also aimed for getting university food services to buy more food from local organic farms, shifting from fossil fuels to renewable energy, improving energy efficiency, reducing dependence on cars, cutting water waste, and retrofitting campus buildings to make them more energy efficient.

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 (Science Focus, p. 269) 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. A wind turbine at Minnesota's Carleton College generates 40% of the school's electricity. 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. And in 2009, Middlebury College opened a biomass gasification plant that will reduce its carbon footprint by 40%.

Many of these improvements started with an environmental audit. 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**.

Critical Thinking

What major steps is your school taking to increase its own environmental sustainability and to educate its students about environmental sustainability?

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 across the United States. Most student environmental groups work with members of the 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 it to propose changes that will make their campuses or schools more environmentally sustainable and usually save money in the process. Any school without a serious sustainability program is now viewed as outdated. Campus audits have resulted in numerous environmental improvements (Science Focus, above).

Environmental Security Is as Important as Military and Economic Security

Countries are legitimately concerned with *military security* and *economic security*. However, ecologists and many economists point out that all economies are supported by the earth's natural capital (Figure 1-2, p. 7, and Figure 17-4).

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.) Some analysts call for all countries to make environmental security a major focus of diplomacy and government policy at all levels.

HOW WOULD YOU VOTE?

Is environmental security just as important as economic and military security? Cast your vote online at **www.cengage.com/biology/miller**.

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 U.N. Environment Programme (UNEP), the World Health Organization (WHO), the U.N. 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:

- 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
- 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, on the order of the World Health Organization and the World Trade Organization, to help deal with global environmental challenges.

17-4 What Are Some Major Environmental Worldviews?

▶ **CONCEPT 17-4 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 various 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 that perceived role 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. According to environmental ethicist Robert Cahn:

> *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.*

People with widely differing environmental worldviews can take the same data, be logically consistent, and arrive at quite different conclusions, because they start with different assumptions and values. Figure 17-15 (p. 444) summarizes the four major beliefs of each of three different major environmental worldviews.

Most People Have Human-Centered Environmental Worldviews

One human-centered worldview held by many people is the **planetary management worldview**. Figure 17-15 (left) summarizes the major beliefs of this worldview.

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. Other species and parts of nature are seen as having *instrumental value* based 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, and, as the world's most important and intelligent species, we can redesign the planet and its life-support systems to support us and our ever-growing economies.

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 17-15 (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. Thus, 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.

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. Critics of human-centered worldviews point out that we do not even know how many species live on the earth, much less what their roles are and how they interact with one another and their nonliving environment. 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 illustrated by the failure of the Biosphere 2 project (Science Focus, p. 444).

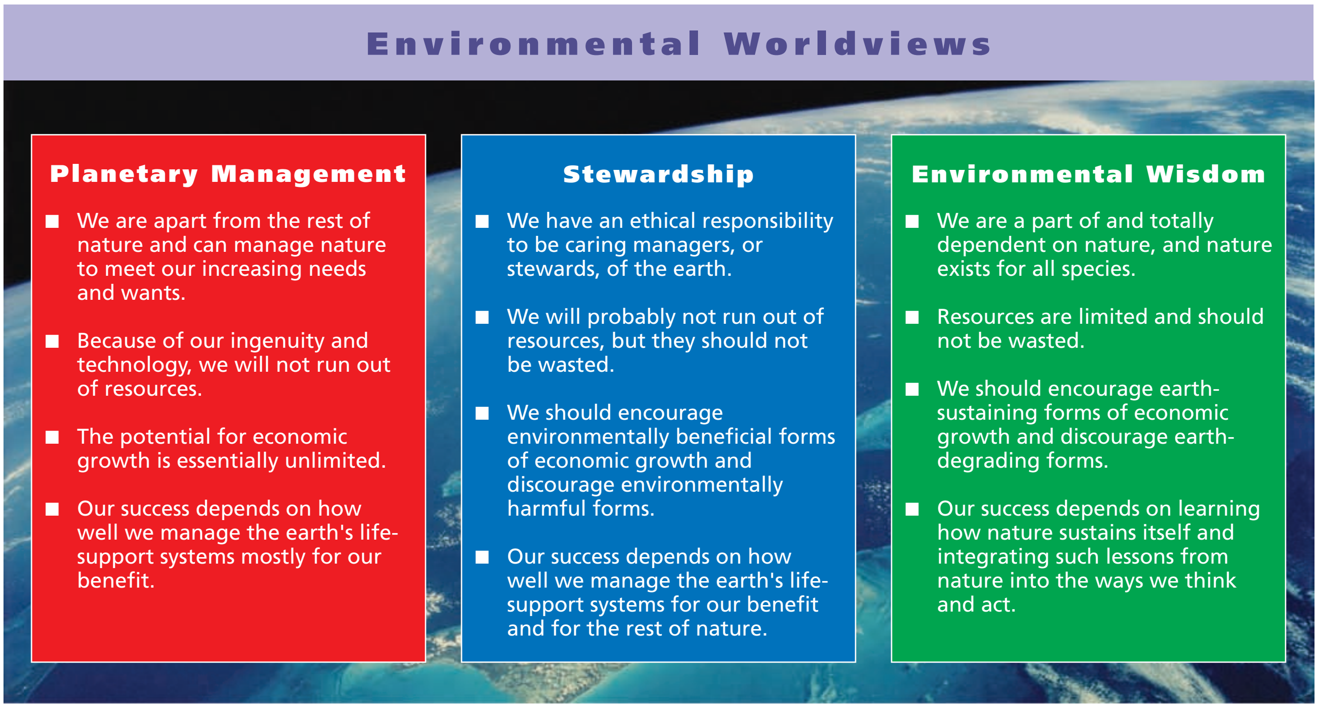


Figure 17-15 Comparison of three major environmental worldviews (**Concept 17-4**). **Questions**: Which of these descriptions most closely fits your worldview? Which of them most closely fits the worldviews of your parents?

Some People Have Life-Centered and Earth-Centered Environmental Worldviews

Critics of human-centered environmental views argue that they should be expanded to recognize the *inherent* or *intrinsic value* of all forms of life, regardless of their potential or actual use to humans. Most people with a life-centered worldview believe we have an ethical responsibility to avoid causing the premature extinction of species through 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 (*intrinsic value*). *Second,* each species is

SCIENCE FOCUS

Biosphere 2—A Lesson in Humility

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 that would increase 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, desert, 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. 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.

Sunlight and external natural gas–powered generators provided energy. The Biospherians were to be isolated for 2 years and to raise their own food using intensive organic agriculture. They were to breathe air recirculated by plants and to drink water cleansed by natural recycling processes.

From the beginning, many unexpected problems cropped up and the life-support system began unraveling. The level of oxygen in the air declined when soil organisms converted it to carbon dioxide. Additional oxygen had to be pumped in from the outside to keep the Biospherians from suffocating.

Tropical birds died after the first freeze. An ant species got into the enclosure, proliferated, and killed off most of the system's original insect species. In total, 19 of the Biosphere's 25 small animal species became extinct. Before the 2-year period was up, all plant-pollinating insects became 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. However, they suffered from persistent hunger and weight loss.

Scientists Joel 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."

Critical Thinking

Some analysts argue that the problems with Biosphere 2 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.

a potential economic good for human use (*instrumental value*), which is also an important part of the human-centered stewardship environmental worldview.

Some people think we should go beyond focusing mostly on species. They believe we have an ethical responsibility to prevent degradation of the earth's ecosystems, biodiversity, and the biosphere. This *earth-centered* environmental worldview is devoted to preserving the earth's biodiversity and the functioning of its life-support systems for us and other 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 biosphere (Figure 17-4). They understand that the earth's natural capital keeps us and other species alive and supports our economies. They argue that preserving the earth's natural capital requires mimicking nature by applying the three **principles of sustainability** (see back cover) to human economies and lifestyles.

One earth-centered worldview is called the **environmental wisdom worldview**. Figure 17-15 (right) summarizes its major beliefs. According to this view, we are part of—not apart from—the community of life and the ecological processes that sustain all life. Therefore, we should work with the earth to promote environmental sustainability instead of trying to conquer and manage it mostly for our own benefit. In many respects, it is the opposite of the planetary management worldview (Figure 17-15, left).

Chief Seattle (1786–1866), leader of the Suquamish and Duwamish Native American tribes in what is now the U.S. state of Washington, summarized an ethical belief included in the environmental wisdom worldview: "The earth does not belong to us. We belong to the earth." (Another part of this statement by Chief Seattle is this chapter's opening quotation.)

This worldview suggests that the earth does not need us managing it in order to go on, whereas we need the earth in order to survive. *Talk about saving the earth is nonsense, because it does not need saving.* What we need to save is the existence of our own species and cultures—which have been around for less than an eyeblink of the earth's 4.5-billion-year history—and 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.)

THINKING ABOUT
Environmental Worldviews and Biosphere 2

CORE CASE STUDY

What environmental worldview would best explain 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/biology/miller**.

17-5 How Can We Live More Sustainably?

CONCEPT 17-5 **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.**

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 and that, during this century, this behavior will threaten human civilization and the existence of up to half of the world's species. Part of the problem stems from ignorance about how the earth works, how our actions affect its life-sustaining systems, and how we can change our behavior toward the earth. Correcting this begins by understanding three important ideas:

- *Natural capital matters* because it supports the earth's life and our economies.
- *Our ecological footprints are immense and are expanding rapidly*; in fact, they already exceed the earth's ecological capacity (Figure 1-5, p. 11).
- *Ecological and climate change tipping points are irreversible and should never be crossed*. Once we cross such a point, neither money nor technology will save us from harmful consequences that could last for thousands of years.

Learning how to live more sustainably requires a foundation of environmental education aimed at producing environmentally literate citizens. Here are some key goals for each person seeking *environmental literacy*:

- Understand as much as we can about how the earth works and sustains itself, and use such knowledge to guide our lives, communities, and societies.

- Understand the relationships between the economy and the earth's natural support systems (Figure 17-4) and the role of economics in making the transition to more sustainable economies (Figure 17-10) and societies.
- Use critical thinking skills (p. 2) to become seekers of environmental wisdom instead of overfilled vessels of environmental information and misinformation.
- Understand and evaluate our environmental worldviews and continue this as a lifelong process.

Specifically, an environmentally literate person should have a basic comprehension of the items listed in Figure 17-16.

Major Components of Environmental Literacy

- Concepts such as environmental sustainability, natural capital, exponential growth, carrying capacity, risk, and risk analysis
- Three scientific principles of sustainablility
- Environmental history (to help us to keep from repeating past mistakes)
- The two laws of thermodynamics and the law of conservation of matter
- Basic principles of ecology, such as food webs, nutrient cycling, biodiversity, ecological succession, and population dynamics
- Human population dynamics
- Ways to sustain biodiversity
- Sustainable agriculture
- Sustainable forestry
- Soil conservation
- Sustainable water use
- Nonrenewable mineral resources
- Nonrenewable and renewable energy resources
- Climate change and ozone depletion
- Pollution prevention and waste reduction
- Sustainable cities
- Environmentally sustainable economic and political systems
- Environmental worldviews and ethics

Figure 17-16 Major components of environmental literacy (**Concept 17-5**). **Question**: After taking this course do you feel that you have a basic understanding of each of these items?

We Can Learn from the Earth

Formal environmental education is important, but is it enough? Many analysts say no. They call for us to appreciate not only the economic value of nature, but also its ecological, aesthetic, and spiritual values. To these analysts, the problem is not simply a lack of environmental literacy but also too little intimacy with nature and a limited understanding of how it sustains us.

We face a dangerous paradox. At a time when humans have more power than ever before to disrupt nature, more people than ever before know little about, and have little direct contact with, nature. A growing chorus of analysts urge us to experience and learn directly from nature as an important way to help us act to sustain the earth's precious biodiversity and our own species and cultures.

They suggest we kindle a sense of awe, wonder, mystery, excitement, and humility by standing under the stars, sitting in a forest, or taking in the majesty and power of the sea. 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 they are a part of us and how we are a part of them, as interdependent participants in the earth's life-sustaining recycling and energy-flow processes.

Such direct experiences with nature reveal parts of the complex web of life that cannot be built with technology or in a chemical lab, bought with money, or reproduced with genetic engineering. Understanding and directly experiencing the precious gifts we receive from nature can help us to fulfill our ethical commitment to living more sustainably.

This might lead us to recognize that the healing of the earth and the healing of the human spirit are one and the same. We might discover and tap into what conservationist Aldo Leopold calls "the green fire that burns in our hearts" and use this as a force for respecting and working with the earth and with one another.

We Can Live More Simply and Lightly on the Earth

Sustainability is not only about sustaining resources for our use. It is about sustaining the entire web of life, because all past, present, and future forms of life are connected. Figure 17-17 summarizes some guidelines for achieving more sustainable and compassionate societies, which have been discussed throughout this book. They represent ways to convert environmental literacy, wisdom, and concerns into environmentally responsible actions.

GOOD NEWS

Let us look at some ways in which individuals can put such guidelines into action in their lives.

Solutions

Some Guidelines for Living More Sustainably

- Learn about, respect, and mimic how nature sustains itself
- Do not degrade or deplete the earth's natural capital
- Take no more from nature than what nature can replenish
- Do not waste matter and energy resources
- Protect biodiversity
- Avoid climate-changing activities
- Help maintain the earth's capacity for self-repair
- Repair ecological damage that we have caused
- Leave the world in as good a condition as we found or better
- Cultivate a passion for sustaining all life and let this passion energize your actions

Figure 17-17 Some guidelines for achieving more environmentally sustainable and compassionate societies. **Questions**: Which three guidelines do you think are the most important? Why?

Many 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, modern advertising persistently encourages people to buy more and more things to fill a growing list of wants as a way to achieve happiness. As American humorist and writer Mark Twain put it: "Civilization is the limitless multiplication of unnecessary necessities."

According to 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, and neighbors and more opportunities to express their creativity and to have more fun.

Some affluent people in 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. They are living with fewer material possessions and using products and services that have a smaller environmental impact (**Concept 17-5**). Instead of working longer to pay for bigger vehicles and houses, they are spending more time with their loved ones, friends, and neighbors. 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.

Living more lightly starts with asking the question: How much is enough? Similarly, one can ask: What do I really need? These are not easy questions to answer, because people in affluent societies are conditioned to want more and more material possessions. And as a result of a lifetime of exposure to commercial advertising, they often think of such wants as needs.

Throughout this text, you have encountered lists of things you can do to live more lightly by reducing the *size* and *impact* of your 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? To decide, consider the fact that the human activities that have the greatest harmful impacts on the environment are *agriculture*, *transportation*, *home energy use*, *water use*, and our *overall resource consumption and waste*. Based on this fact, Figure 17-18 (p. 448) lists the *sustainability dozen*—12 key ways in which some people are choosing to walk more lightly on the earth.

In the end, it comes down to what each of us does to make the earth a better place to live for current and future generations, for other species, and for the ecosystems that support us. However, because we do not want to feel guilty about the environmental harm we cause, we try not to think about it too much—taking a path that can lead to denial and inaction.

Some suggest that we move beyond blame, guilt, fear, and apathy by recognizing and avoiding common mental traps that lead to denial, indifference, and inaction. These traps include:

- *gloom-and-doom pessimism* (it is hopeless)
- *blind technological optimism* (science and technofixes will save us)
- *paralysis by analysis* (searching for the perfect worldview, scientific information, or solutions before doing anything)
- *faith in simple, easy answers to complex problems* (which some political and organizational leaders tend to offer)

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.

THINKING ABOUT
Mental Traps

Which of these traps, if any, have you fallen into? Were you aware you had done so? How do you think you could free yourself from these traps?

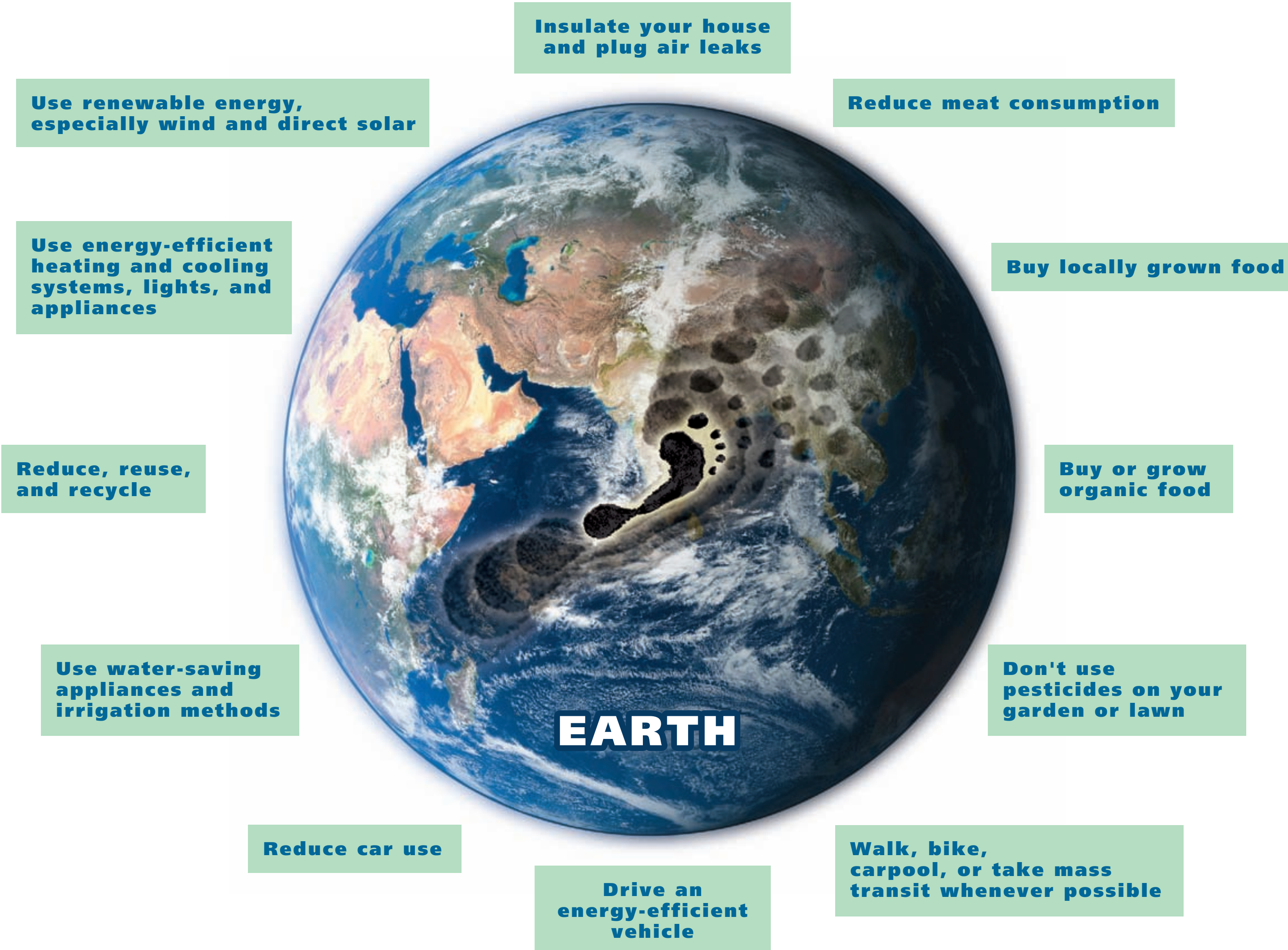


Figure 17-18 *The sustainability dozen*—12 ways in which people can live more lightly on the earth (**Concept 17-5**).
Questions: Which of these things do you already do? Which, if any, do you hope to do?

Some people are ethically driven to improve environmental quality by following principles such as the three **principles of sustainability** promoted in this book. Others want to improve the environment for more practical reasons arising out of self-interest. They promote environmental sustainability because they enjoy living on this wonderful planet and want to keep it that way for themselves and their children. Thus it is possible for a more self-centered worldview to be compatible with a more earth-centered worldview.

It is also important to recognize that there is no single correct or best solution to any of the environmental problems we face. Indeed, one of nature's 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 environmental 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 dedicated earth citizens who practice *good earthkeeping*.

We Can Bring about a Sustainability Revolution during Your Lifetime

The industrial revolution took place during the past 275 years. Now in this century, environmental leaders say it is time for an *environmental* or *sustainability revolution*. Many analysts argue that this would raise the world's standard of living. Figure 17-19 lists some of the major shifts involved in bringing about such a revolution, as discussed throughout this book.

Current Emphasis	Sustainability Emphasis
Pollution cleanup	Pollution prevention
Waste disposal (bury or burn)	Waste prevention
Protecting species	Protecting habitat
Environmental degradation	Environmental restoration
Increasing resource use	Less resource waste
Population growth	Population stabilization
Depleting and degrading natural capital	Protecting natural capital

Figure 17-19 **Solutions:** some shifts involved in bringing about the *environmental* or *sustainability revolution*. **Questions**: Which three of these shifts do you think are most important? Why?

This cultural shift would have several interrelated components:

- *Biodiversity protection*—dedication to protecting and sustaining the genes, species, natural systems, and chemical and biological processes that make up the earth's biodiversity
- A *commitment to eco-efficiency*, based on sharply reducing our waste of matter and energy resources
- An *energy transformation* devoted to shifting from reliance on carbon-based, nonrenewable, climate-changing fossil fuels to reliance on renewable energy from the sun, wind, flowing water, biomass, and geothermal sources
- *Pollution prevention* based on a commitment to reducing pollution and environmental degradation by applying the precautionary principle (p. 359)
- An *emphasis on sufficiency*, dedicated to meeting the basic needs of all people on the planet while affluent societies learn to live more sustainably by living well with less
- *Demographic equilibrium* based on bringing the size and growth rate of the human population into balance with the earth's ability to support humans and other species sustainably
- *Economic and political transformations* through which we use economic and political systems to reward environmentally beneficial behavior and to discourage environmentally harmful behavior

We know what needs to be done and we can change. According to social science research, 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. We may be close to this critical mass, or *positive tipping point*, in terms of political awareness of major environmental issues.

History also 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. As the Canadian writer Ronald Wright put it in his 2004 book *A Short History of Progress*, "The future of everything we have accomplished since our intelligence evolved will depend on the wisdom of our actions over the next few years. . . . The world has grown too small to forgive us any big mistakes."

We can use the incredible power of exponential growth to help us bring about a sustainability revolution. Recall from Chapter 1 (p. 15) that if you could fold a piece of paper in half 50 times, you would wind up with a stack of paper high enough to reach the sun—some 149 million kilometers (93 million miles) away. Exponential growth starts off slowly but at some point takes off dramatically.

The same model can be applied to environmental and social changes (Figure 17-20, p. 450). A number of environmental concerns and social trends are driving the development of technologies and economic tools (discussed in earlier chapters of this book) that could help us to round the bend on an exponential curve of beneficial change. We can tap into this power of exponential growth to help us avoid environmentally harmful tipping points and, instead, enjoy the effects of going beyond environmentally beneficial tipping points.

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. As Irish playwright George Bernard Shaw (1856–1950) put it: "I dream of things that never were; and I say 'Why not?'"

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

- A more sustainable economic system would include the harmful environmental and health costs of producing and using goods and services in their market prices, subsidize environmentally beneficial goods and services, tax pollution and waste instead of wages and profits, and reduce poverty.
- Individuals can work together to become part of the political processes that influence how environmental policies are made and implemented.
- Living more sustainably means becoming environmentally literate, learning from nature, living more simply, and becoming active environmental citizens.

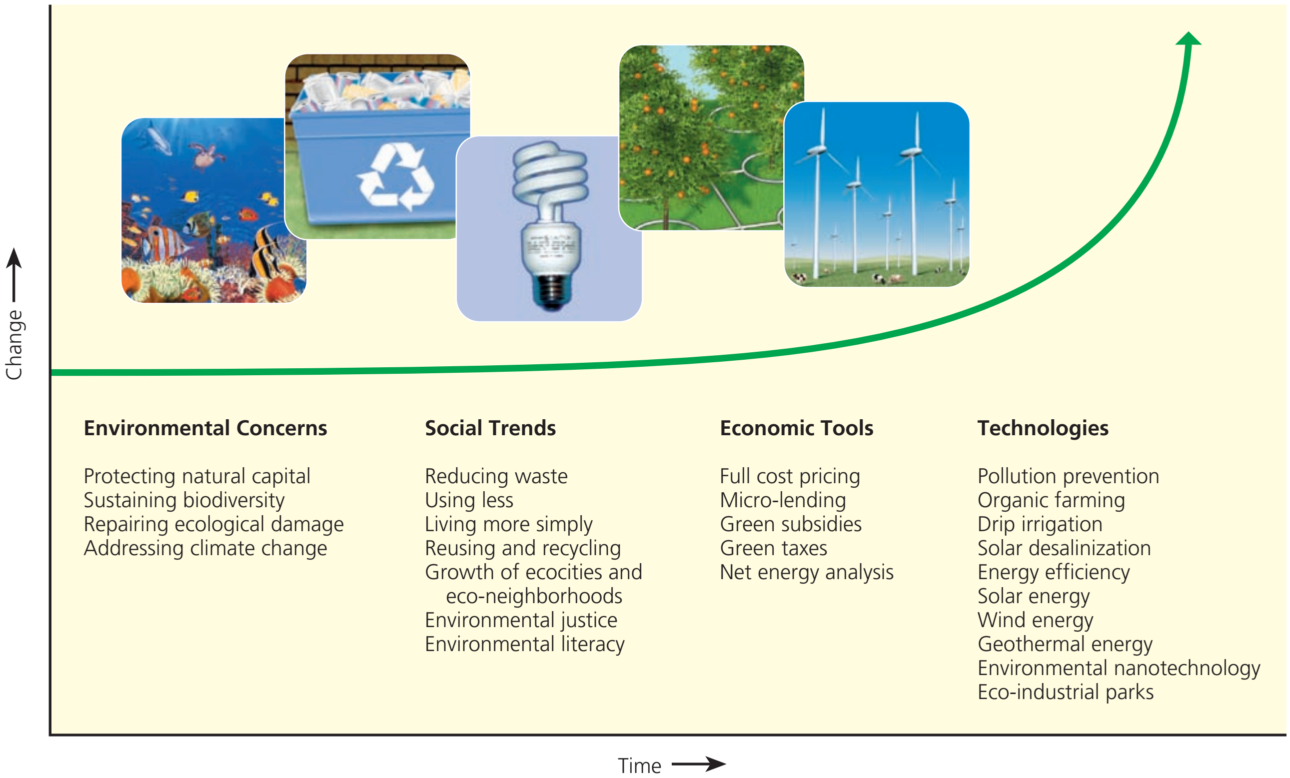


Figure 17-20 Change can occur very rapidly. Using the astonishing power of exponential growth, we could bring about a sustainability revolution in a very short time. Exponential growth starts off slowly. But it takes off at a very rapid rate, once it rounds the bend on the J-curve and heads sharply upward. Below the curve are listed some concerns, trends, tools, and technologies that could all be part of this change within your lifetime. **Question**: Where on the curve would you place each of these items?

REVISITING Chattanooga, Tennessee, and Sustainability

Citizens and elected officials of Chattanooga, Tennessee (USA), have worked together for more than 25 years to make their city more sustainable. They have shown that, by using economics, politics, and ethical concerns, committed people can work together to improve the environmental quality of the place where they live.

Looking for ways to develop more sustainable lifestyles, cities, and societies begins by understanding that our lives, economies, 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 begin the search for *solutions* to difficult environmental problems. Competing interests working together to find the solutions must make *trade-offs*; this is the essence of the political process.

We must also recognize that *individuals matter.* Virtually all of the environmental progress made during the last few decades occurred because individuals banded together to insist that we can do better. This means that the journey begins in your own community and with your own lifestyle, because in the final analysis, *all sustainability is local,* as the citizens of Chattanooga demonstrated. This is the meaning of the motto, "Think globally; act locally."

In working to make the earth a better and more sustainable place to live, we should be guided by historian Arnold Toynbee's observation: "If you make the world ever so little better, you will have done splendidly, and your life will have been worthwhile." Each of us has to decide whether we want to be part of the problem or part of the solution to the environmental challenges we face. What an incredible and exciting time to be alive!

When there is no dream, the people perish.

PROVERBS 29:18

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 425. Describe the efforts of citizens in the U.S. city of Chattanooga, Tennessee, to make their city more sustainable and livable (**Core Case Study**) and the major lessons learned from this successful effort.

2. What is **economics**? Distinguish among **natural capital**, **human capital** (**human resources**), and **manufactured capital** (**manufactured resources**). What is a **high-throughput economy**? Compare how neoclassical economists and ecological and environmental economists view economic systems. List eight principles that ecological and environmental economists would use to make the transition to more sustainable eco-economies.

3. Why do products and services actually cost more than most people think? Define and distinguish between **gross domestic product** (**GDP**) and **per capita GDP**. What is the **genuine progress indicator** (**GPI**) and how does it differ from the GDP economic indicator? 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. Describe the benefits of shifting from environmentally unsustainable to more environmentally sustainable government subsidies and tax breaks. Discuss whether we should tax pollution and wastes instead of wages and profits?

4. Distinguish between command-and-control and incentive-based government regulations and describe the advantages of the second approach. What are the major advantages and disadvantages of using the cap-and-trade approach to implementing environmental regulations for controlling pollution and resource use? 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. What is **poverty** and how is it 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?

5. What is a **low-throughput** (**low-waste**) **economy**? List six ways to shift to more environmentally sustainable economies. Name five new green businesses or careers that would be important in such eco-economies.

6. Define **politics**, **policies**, and **democracy**. Describe eight principles that decision makers can use in making environmental policy. What are four major types of public lands in the United States? Describe the political controversy over managing these lands.

7. Describe four ways in which individuals in democracies can help to develop or to change environmental policy. What does it mean to say that we should *think globally and act locally*? What are four ways to provide environmental leadership? Describe Julia "Butterfly" Hill's efforts to save giant redwood trees in California from being cut down. Describe the roles of grassroots and mainstream environmental organizations and give an example of each type of organization. Give two examples of successful roles that students have played in improving environmental quality. Explain the importance of environmental security, relative to economic and military security.

8. What is an **environmental worldview**? What are **environmental ethics**? Distinguish among the following environmental worldviews: **planetary management**, **stewardship**, and **environmental wisdom**. Discuss the debate over whether we can effectively manage the earth. Describe the ecological lessons learned from the failure of the Biosphere 2 project. List eight goals for a person seeking environmental literacy. Describe three ways in which we can learn from the earth.

9. List six guidelines for achieving more sustainable and compassionate societies. What is *voluntary simplicity*? List a dozen important steps that individuals can take to help make the transition to more sustainable societies. Describe three traps that lead to denial, indifference, and inaction concerning the environmental problems we face.

10. What are this chapter's *three big ideas*? Describe how the citizens of Chattanooga, Tennessee, have developed a more environmentally sustainable city by applying the three **principles of sustainability**.

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

CRITICAL THINKING

1. Use the model of the U.S. city of Chattanooga, Tennessee, (**Core Case Study**) to develop three ways to make the area where you live more sustainable.

2. Is environmental regulation bad for the economy? Explain. Describe harmful and beneficial forms of environmental regulation.

3. Suppose that over the next 20 years, the environmental and health costs of goods and services will be gradually 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?

4. Explain why you agree or disagree with each of the major principles for shifting to a more environmentally sustainable economy listed in Figure 17-10.

5. Explain why you agree or disagree with each of the eight principles listed on p. 437, which some analysts have proposed for use in making environmental policy decisions.

6. 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. 438–439), and **(b)** each of the five suggestions made by developers and resource extractors for managing and using U.S. public lands (p. 439).

7. 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, if any, of your beliefs were added or modified as a result of taking this course? Compare your answer with those of your classmates.

8. 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 an intrinsic value and therefore have a right to exist. Are your answers to each of these items consistent with the beliefs making up your environmental worldview, which you described in answering question 7?

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

Working with classmates, conduct an ecological footprint analysis of your campus. Work with a partner, or in small groups, to research and investigate an aspect of your school such as recycling and/or composting; water use; food service practices; energy use; building management and energy conservation; transportation, both on- and off-campus trips; grounds maintenance; and institutional environmental awareness and education. 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, classrooms and 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 to determine the ecological impact related to your chosen topic. Each question item in this questionnaire could have a range of responses on a scale of 1 (poor) to 10 (excellent).

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.cengage.com/biology/miller** and choose Chapter 17 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, web links, information on Green Careers, and InfoTrac® College Edition articles.

CENGAGENOW™ For students with access, log on at **www.cengage.com/login** for the animations, active figures, activities, and readings indicated within the text by the CengageNOW logo. If your textbook did not come with access, visit **www.iChapters.com** to purchase.

Supplements

1 **Measurement Units** **S2**
Chapter 2

2 **Reading Graphs and Maps** **S3**
Chapters 2, 4–10, 13, 15, 17

3 **Maps and Data: Economics, Population, Hunger, Health, and Waste Production** **S6**
Chapters 1, 6, 10, 11, 14, 16, 17

4 **Maps: Biodiversity, Ecological Footprints, and Environmental Performance** **S14**
Chapters 1, 3–11, 15

5 **An Overview of U.S. Environmental History** **S21**
Chapters 1–3, 5, 6, 9–11, 17

6 **Some Basic Chemistry** **S26**
Chapters 2–5, 10–12, 14–16

7 **Classifying and Naming Species** **S32**
Chapters 3, 4, 8

8 **Weather Basics: El Niño, Tornadoes, and Tropical Cyclones** **S33**
Chapters 7, 15

9 **Maps and Data: Energy and Climate** **S38**
Chapters 9, 13, 15

SUPPLEMENT

1

Measurement Units (Chapter 2)

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):
$°C = (°F - 32.0) \div 1.80$
Celsius (°C) to Fahrenheit (°F):
$°F = (°C \times 1.80) + 32.0$

Reading Graphs and Maps (Chapters 2, 4–10, 13, 15, 17)

SUPPLEMENT 2

Graphs and Maps Are Important Visual Tools

A **graph** is a tool for conveying information that can be summarized numerically by illustrating 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 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 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 2008. 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 2008? Roughly how many times more oil was consumed in 2008 than in 1970? How many times more oil was consumed in 2008 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 differ from what it is now? (See Figure 7-15, p. 135.) 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 data set 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 impressions of the same phenomenon. For example, we must be careful when talking about any type

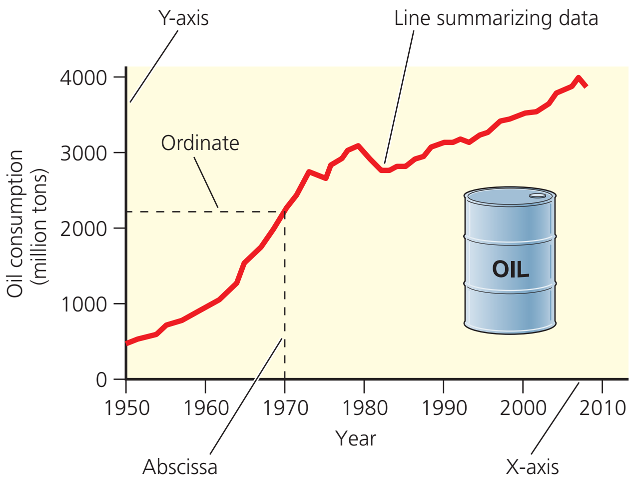


Figure 1 World oil consumption, 1950–2008. (Data from U.S. Energy Information Administration, British Petroleum, International Energy Agency, and United Nations)

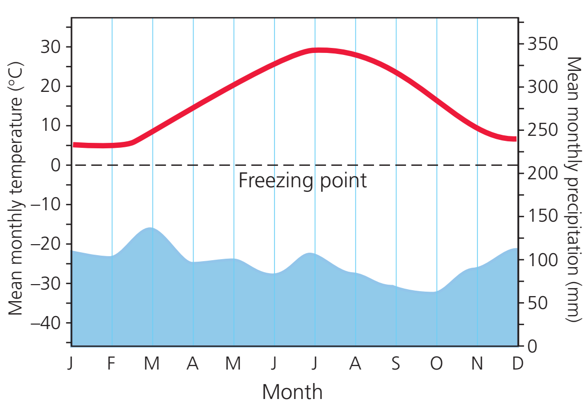


Figure 2 Climate graph showing typical variations in annual temperature (red) and precipitation (blue) in a temperate deciduous forest.

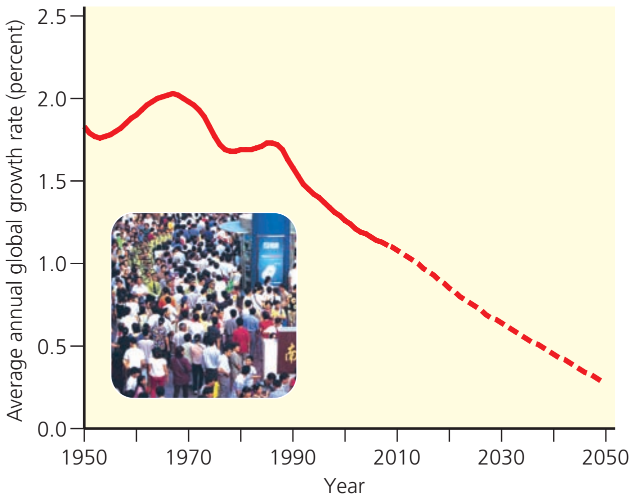


Figure 3 Annual growth rate in world population, 1950–2009. (Data from U.N. Population Division and U.S. Census Bureau)

of growth 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. Look at Figure 1-10 (p. 16). The graph in this figure gives you the impression that human population growth has been continuous and uninterrupted, for the most part. 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.

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/m^2/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?

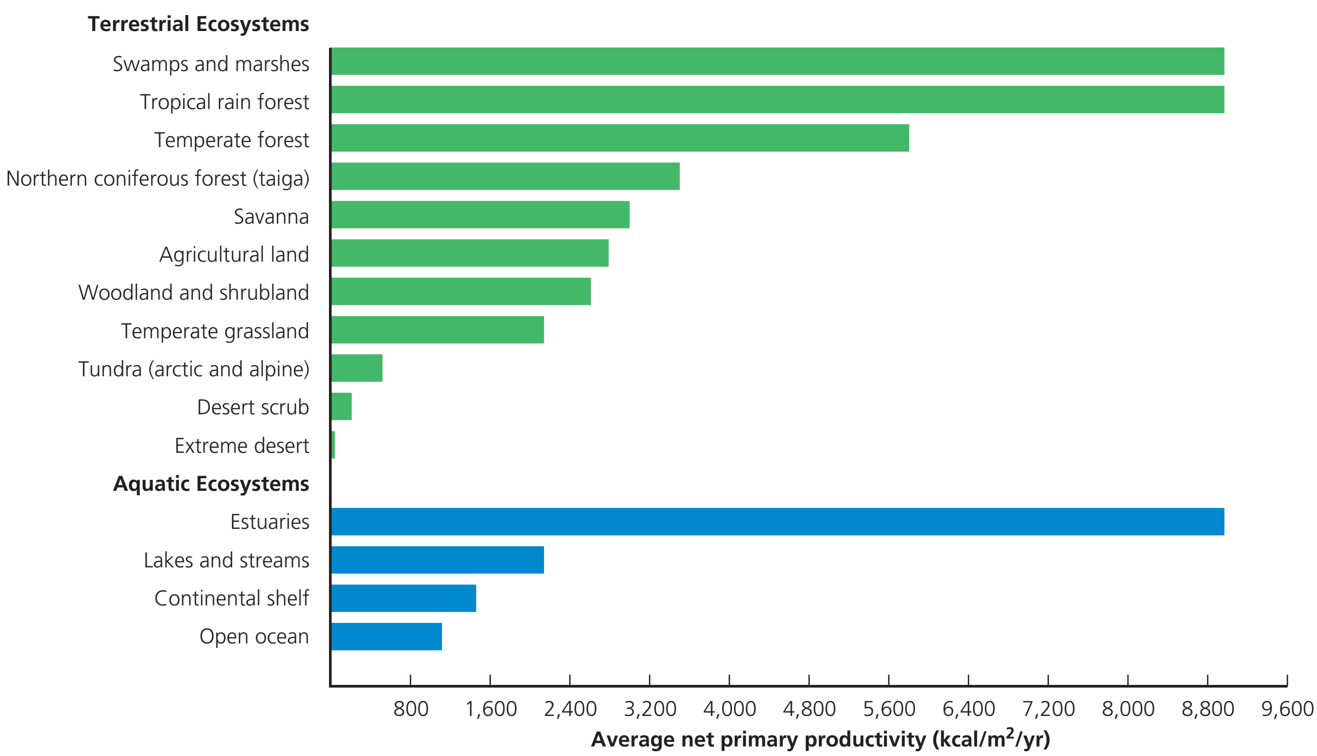


Figure 4 Estimated annual average net primary productivity (NPP) in major life zones and ecosystems, expressed as kilocalories of energy produced per square meter per year (kcal/m^2/yr). (Data from R. H. Whittaker, *Communities and Ecosystems*, 2nd ed., New York: Macmillan, 1975)

An important application of the bar graph used in this book is the *age structure diagram* (Figure 6-6, p. 102), which describes a population by showing the numbers of males and females in certain age groups (see pp. 101–104).

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. Usually, the categories are 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 set of data 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 contributed to the world's total amount of energy used in 2007. This graph includes the numerical data used to construct it: the percentages of the total taken up by each part of the pie. But pie graphs can be used without the numerical data included and such percentages can be estimated roughly. The pie graph thereby provides a generalized picture of the composition of a set of data.

Figure 13-2 (p. 298) shows this and other data in more detail, and illustrates how pie graphs can be used to compare different groups of categories and different data sets. Also, see the Active Graphing exercise for Chapter 13 on the website for this book.

Questions

1. Suppose the use of oil shrunk by 20% and the other four categories all grew by an equal amount to fill up the pie graph. What would be the resulting new percentages for each category?
2. About how many times bigger than renewable energy use is use of (a) oil, (b) coal, (c) natural gas?

Reading Maps

Maps can be used for considerably more than showing where places are, relative to one another. For example, in environmental science, maps can be used to compare 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. Generally, what part of the country has the lowest level of premature deaths due to air pollution?
2. What 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 the website for this textbook will help you to apply this information. 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.

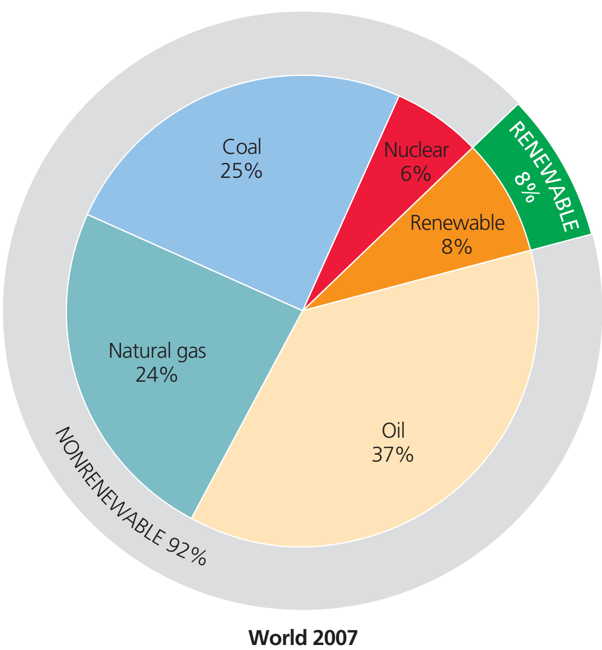


Figure 5 World energy use by source in 2007. (Data from U.S. Department of Energy, British Petroleum, Worldwatch Institute, and International Energy Agency)

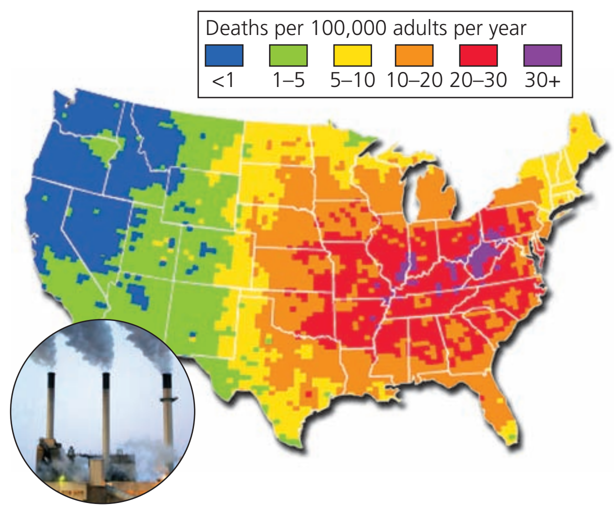


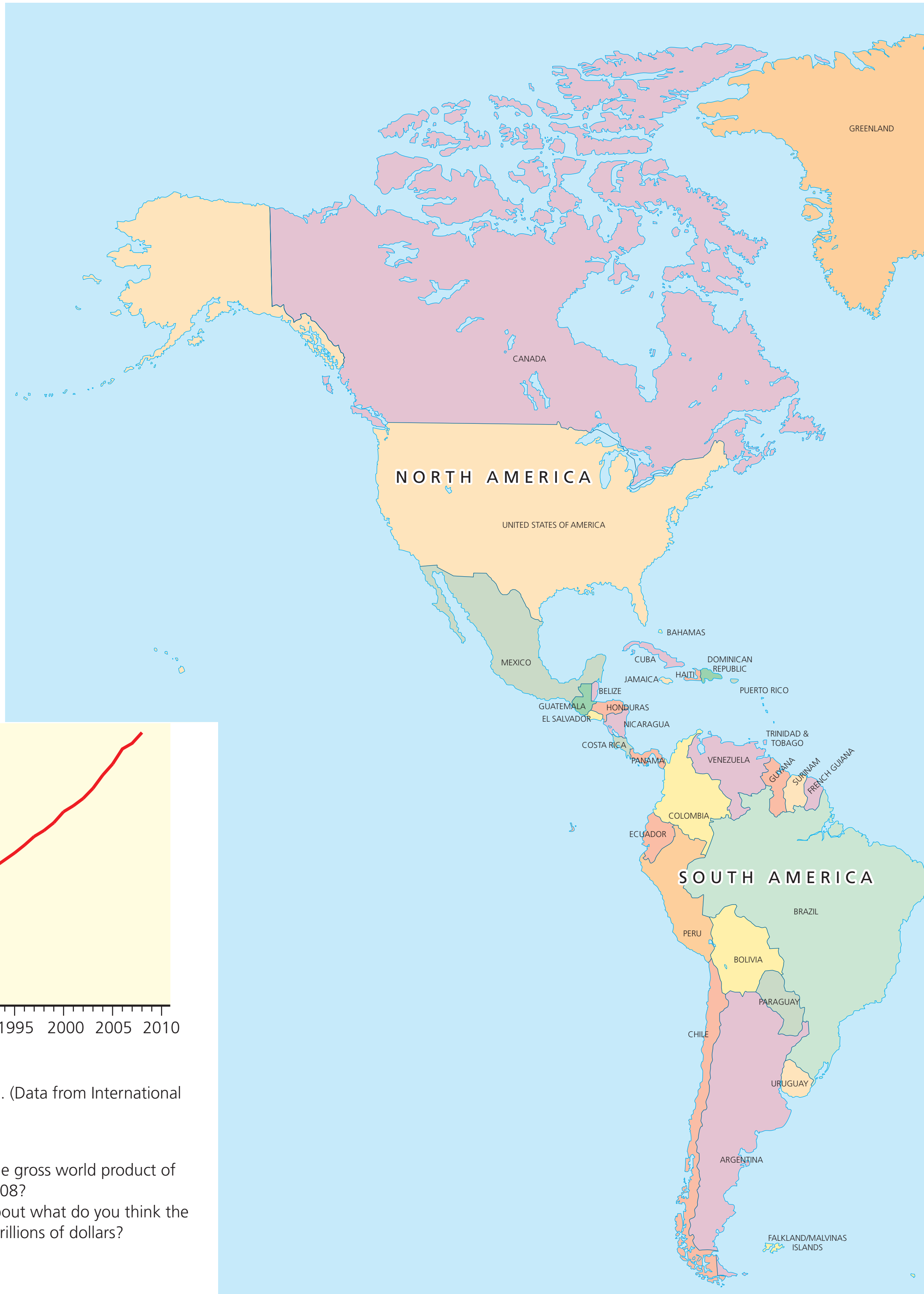
Figure 6 Premature deaths from air pollution in the United States, mostly from very small particles added to the atmosphere by coal-burning power plants. (Data from U.S. Environmental Protection Agency)

SUPPLEMENT 3 Maps and Data: Economics, Population, Hunger, Health, and Waste Production

Figure 1 Countries of the world.

Map Analysis

1. What is the largest country in **(a)** North America, **(b)** Central America, **(c)** South America, **(d)** Europe, and **(e)** Asia?
2. What countries surround **(a)** China, **(b)** Mexico, **(c)** Germany, and **(d)** Sudan?



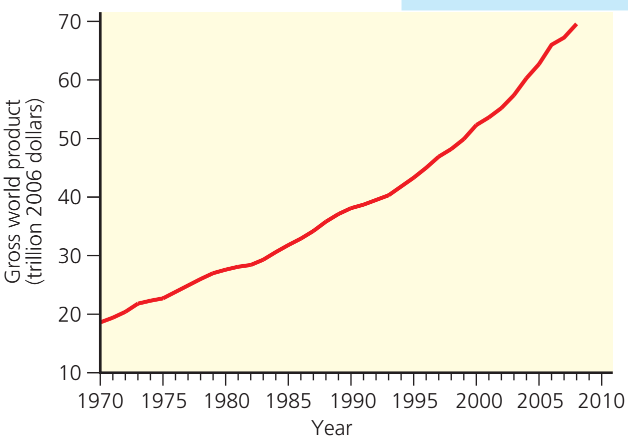


Figure 2 Gross world product, 1950–2008. (Data from International Monetary Fund and the World Bank)

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 overall growth trend continues, about what do you think the gross world product will be in 2010, in trillions of dollars?

(Chapters 1, 6, 10, 11, 14, 16, 17)

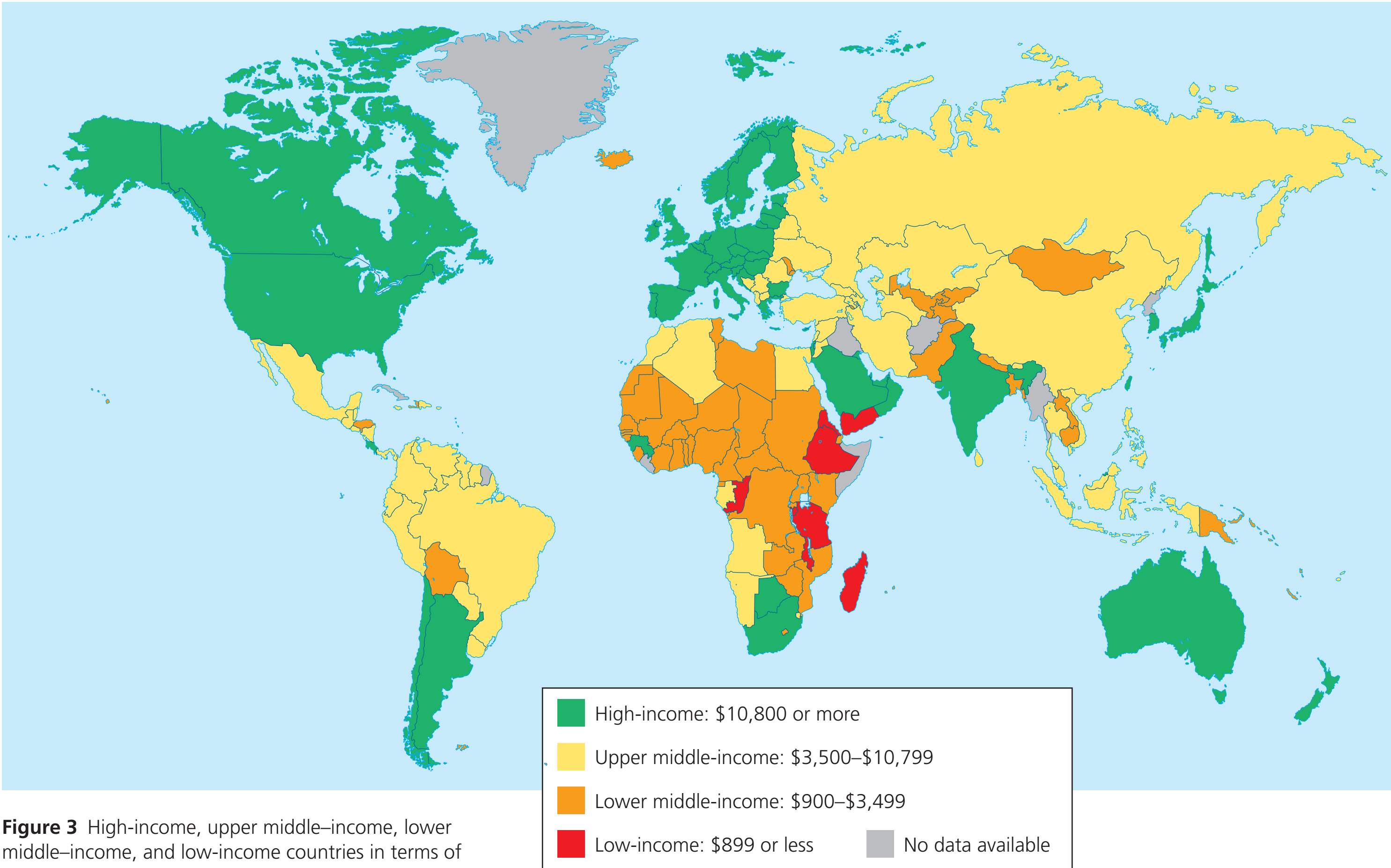


Figure 3 High-income, upper middle–income, lower middle–income, and low-income countries in terms of gross national income (GNI) PPP per capita (U.S. dollars) in 2006. (Data from World Bank and International Monetary Fund)

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 involved in three of these instances.

Year	Event	Human population
50,000 B.C.	Hunter-gatherer societies	1.2 million
10,000 B.C.	End of last Ice Age	4 million
8,000 B.C.	Agricultural Revolution	5 million
2,000 B.C.	Contraceptives in use in Egypt	
500 B.C.		100 million
1,000 A.D.		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	
1952	Contraceptive pill introduced	
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 Population timeline, 10,000 B.C.–2008.

Data Analysis

1. About how many years did it take the human population to reach 1 billion? How long after that did it take to reach 2 billion?
2. In about what year was the population half of what it is projected to be in 2011?

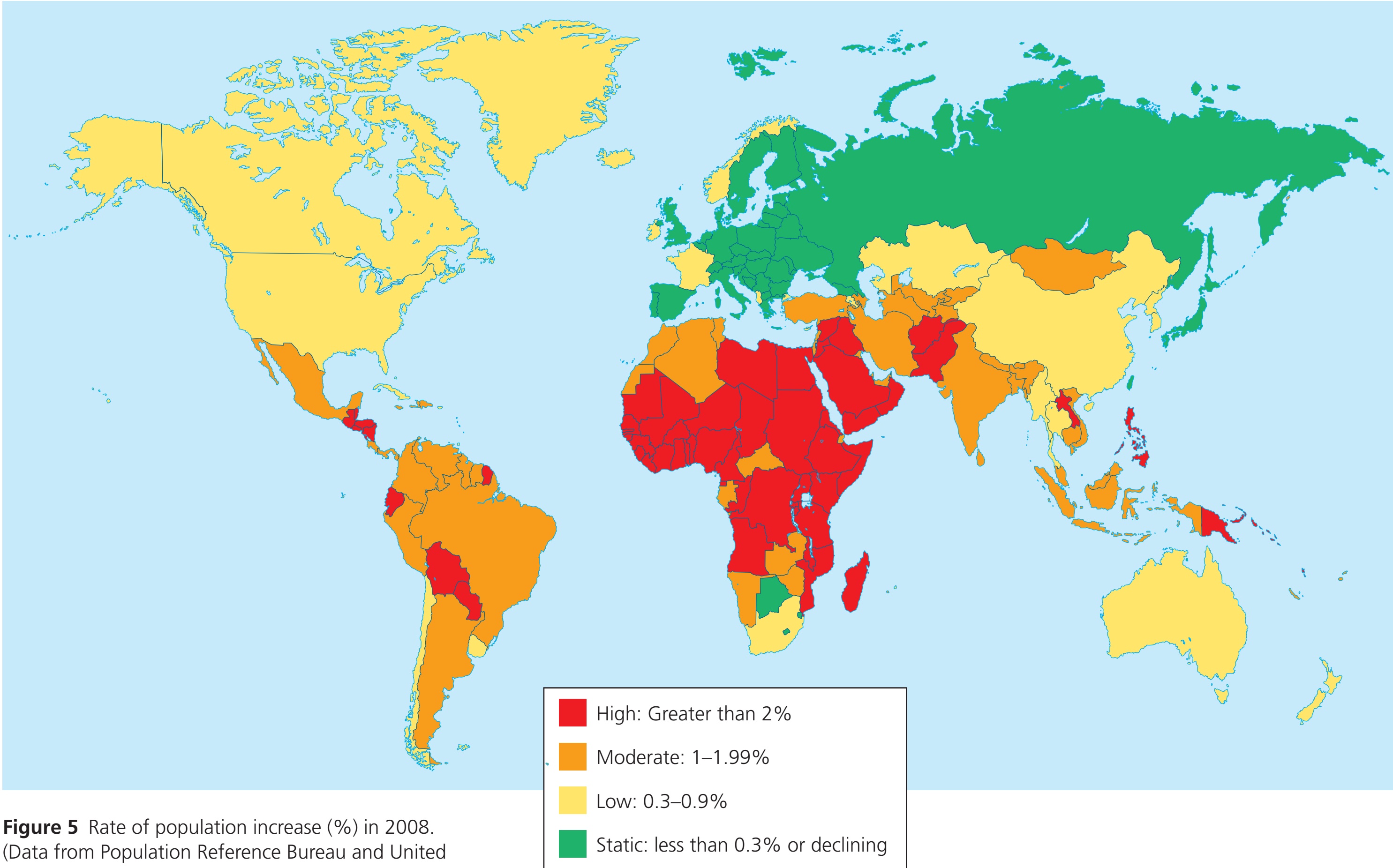


Figure 5 Rate of population increase (%) in 2008. (Data from Population Reference Bureau and United Nations Population Division)

Data and Map Analysis

1. What continent holds the highest number of countries with high rates of population increase? What continent has the highest number of countries with static rates? (See Figure 1 for country and continent names.)
2. For each category on this map, name the two countries that you think are largest in terms of total area?

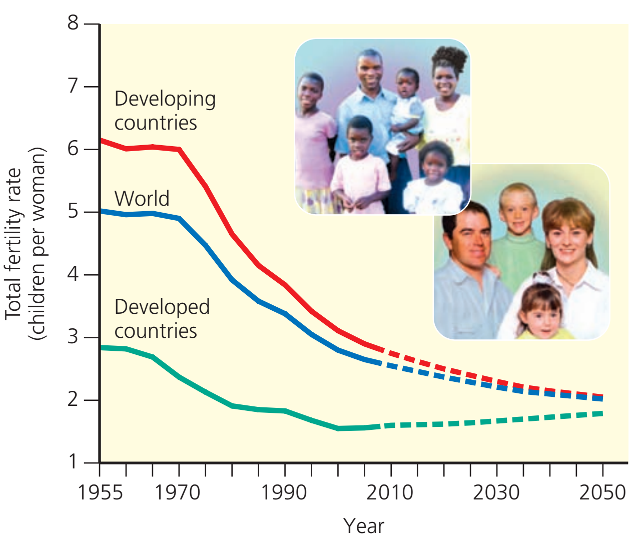


Figure 6 Total fertility rate for the world, developed regions, and less developed regions, 1950–2008, with projection to 2050 (based on medium population projections). (Data from U.N. Population Division)

Data and Graph Analysis

1. What are two conclusions you can draw from comparing these curves?
2. In 2010, about how many more children will be born to each woman in the developing regions than will be born to each woman in the developed regions?

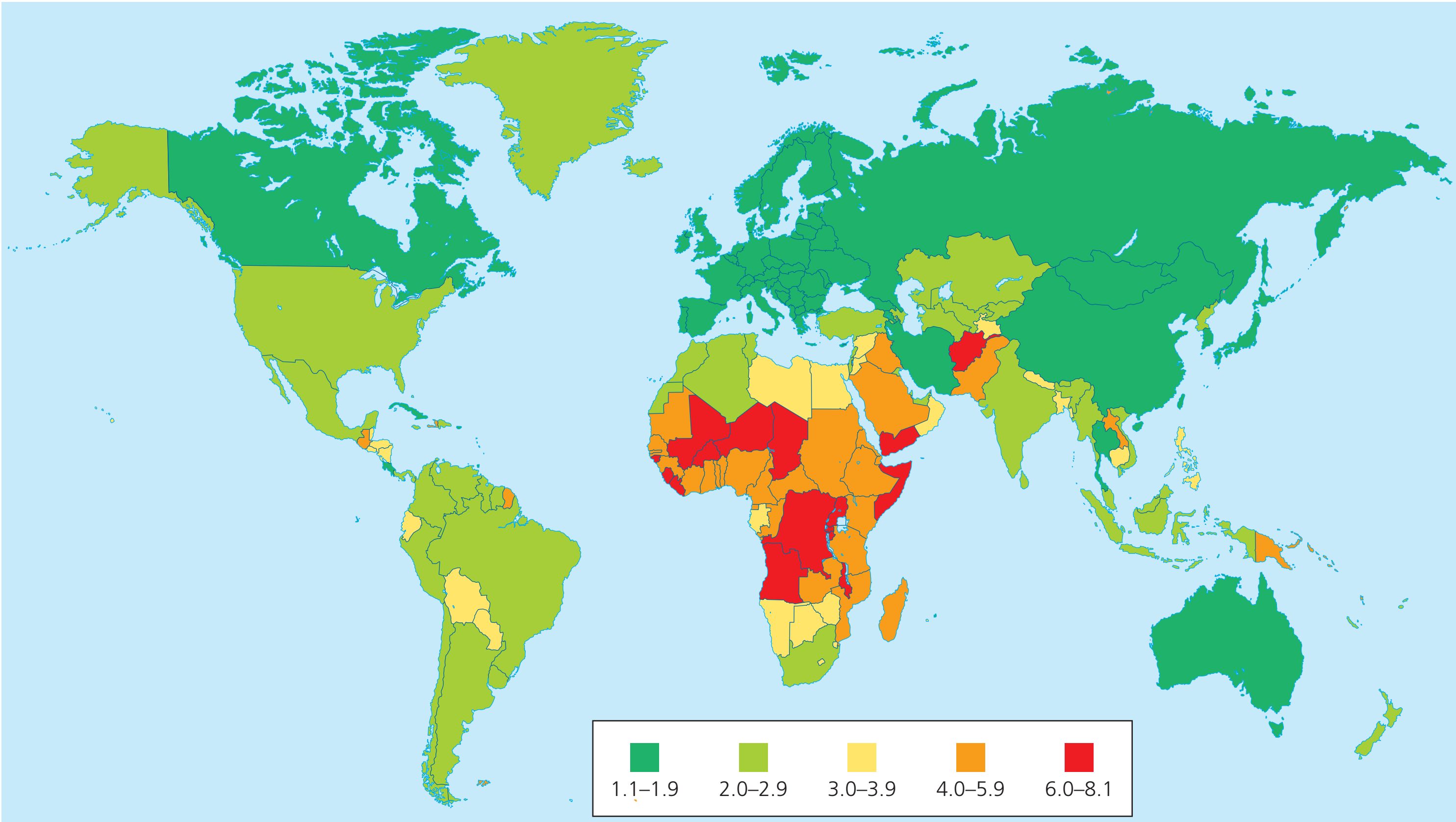


Figure 7 Total fertility rate (TFR), or average number of children born to the world's women throughout their lifetimes, as measured in 2008. (Data from Population Reference Bureau and United Nations Population Division)

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.)
2. Describe two geographic patterns that you see on this map.

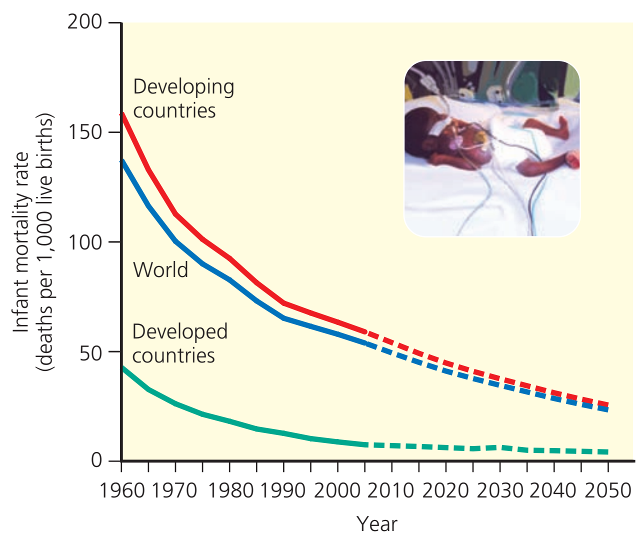


Figure 8 Infant mortality rate for the world, developed regions, and less developed regions, 1950–2008, with projection to 2050 (based on medium population projections). (Data from United Nations Population Division)

Data and Graph Analysis

1. What are two conclusions you can draw from comparing these curves?
2. When the world infant mortality was 100 deaths per 1,000 live births, what were the approximate infant mortality rates for developed and developing regions?

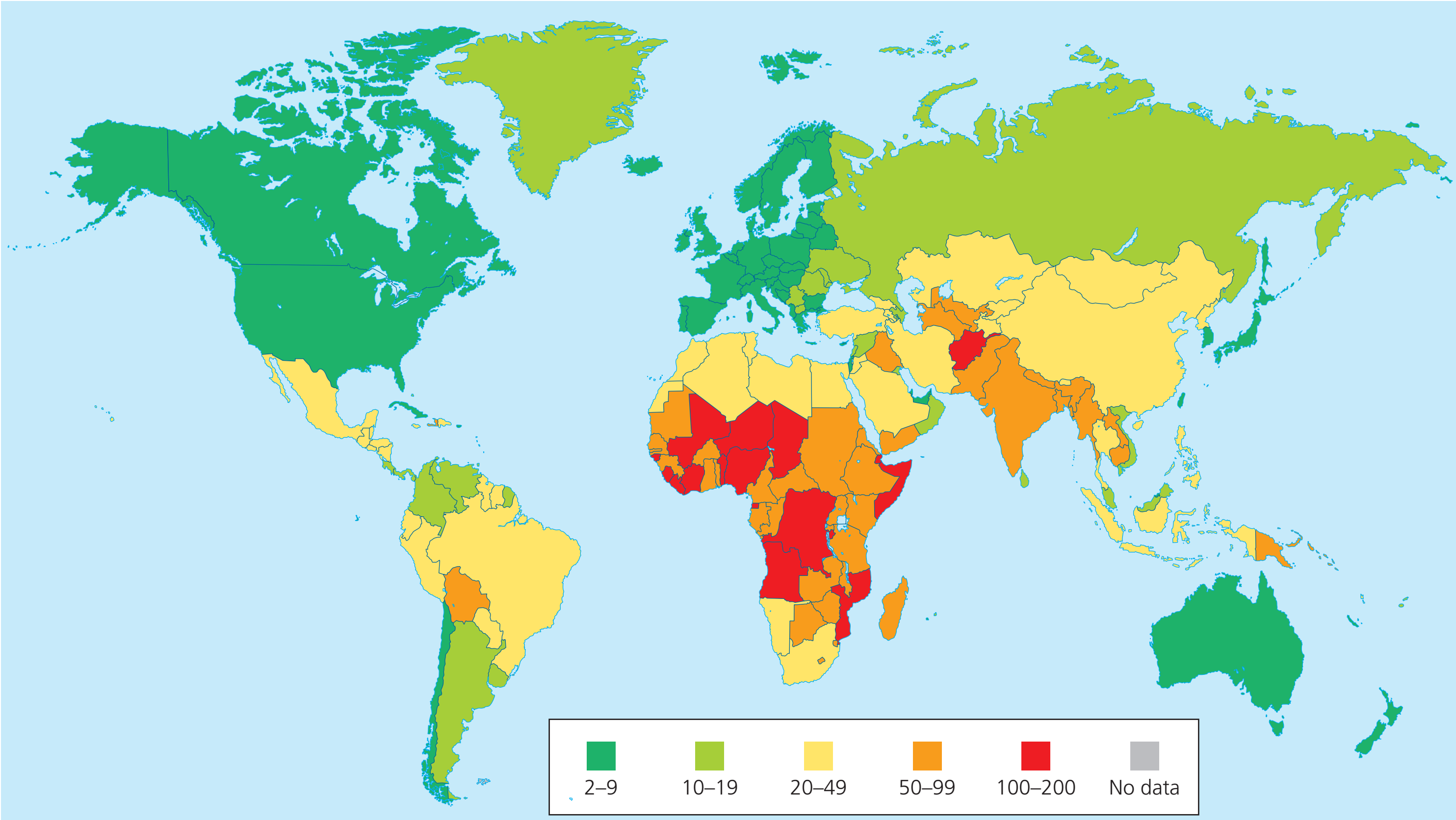


Figure 9 Infant mortality rate in 2008. (Data from Population Reference Bureau and United Nations Population Division)

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 7.

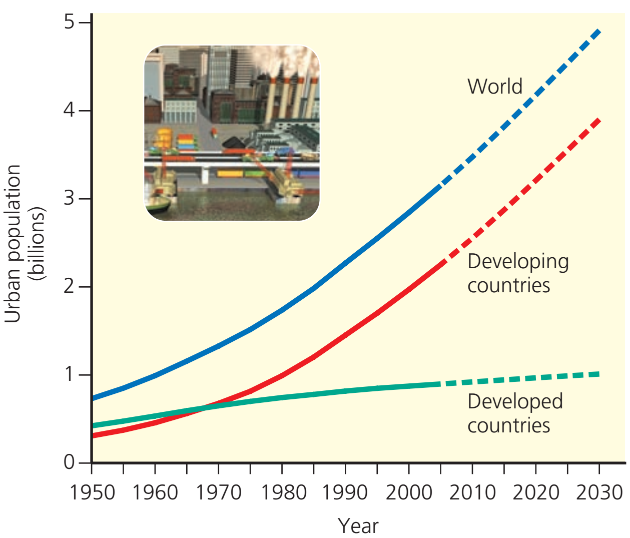
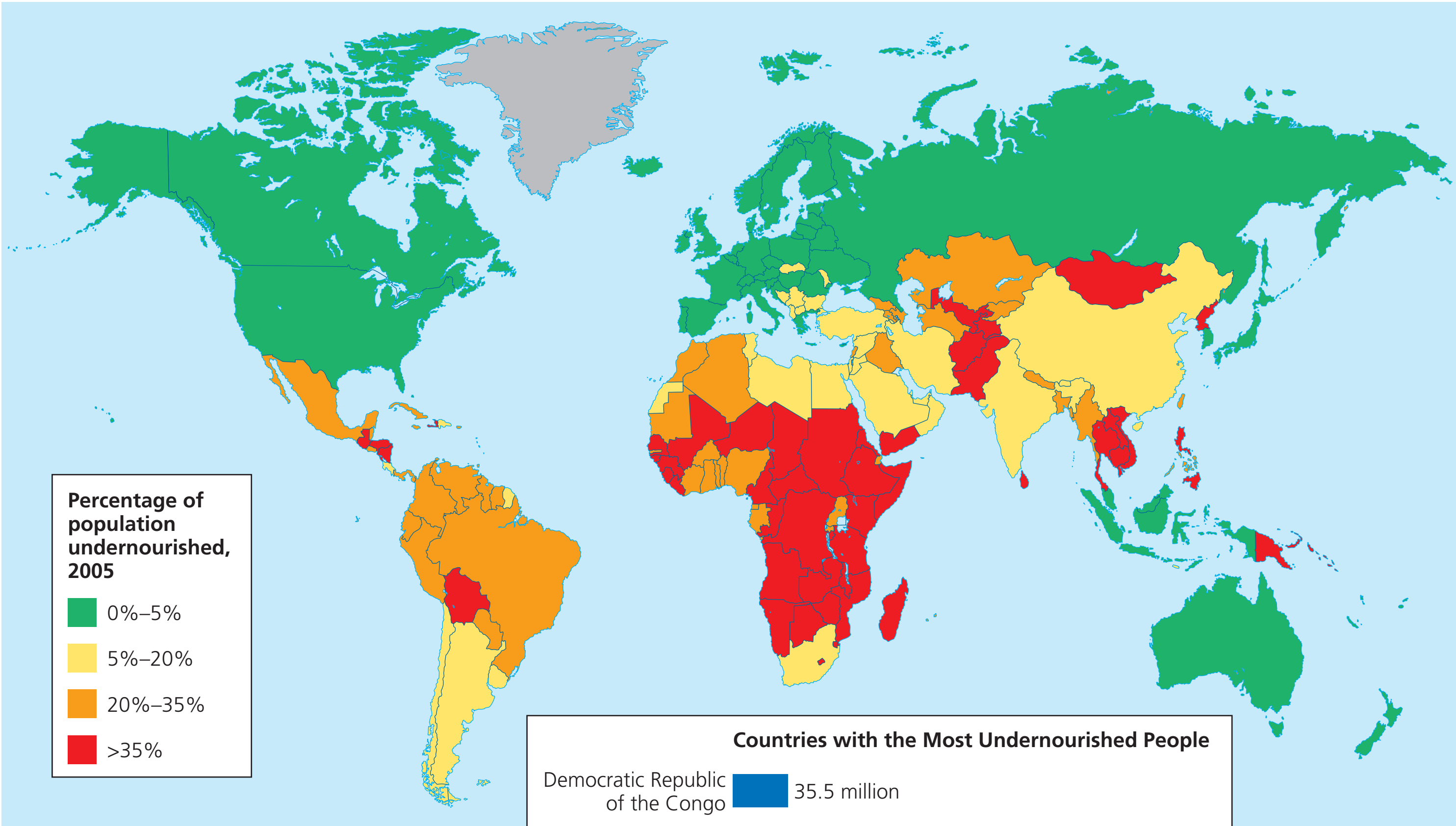


Figure 10 Urban population totals and projections for the world, for developing countries, and for developed countries, 1950–2030. (Data from United Nations Population Division)

Data and Graph Analysis

1. In about what year did the urban population in developing countries surpass the urban population in developed countries? In about what year was the former twice that of the latter?
2. About how many people will be living in urban areas in developing countries in 2030? In 2030, about how many people will be living in developing country urban areas for every person living in a developed country urban area?



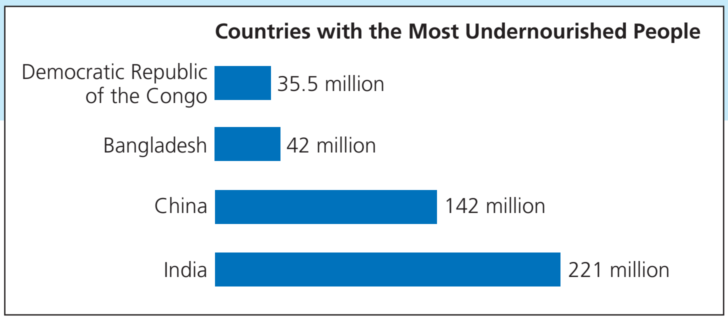


Figure 11 World hunger shown as a percentage of population suffering from chronic hunger and malnutrition in 2005. (Data from Food and Agriculture Organization, United Nations)

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.)
2. On which continent is the largest block of countries that suffer the highest levels of undernourishment? List five of these countries.

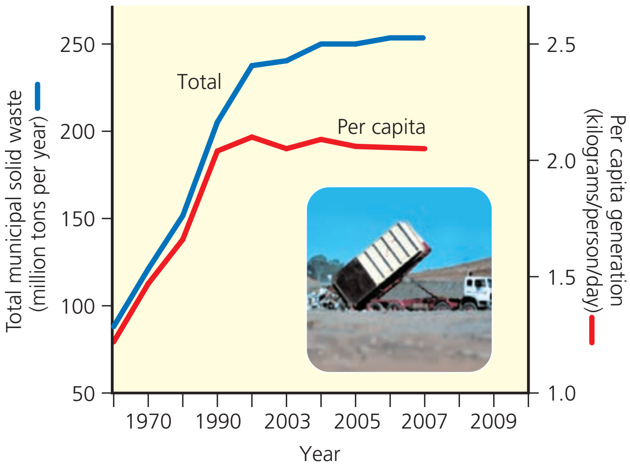


Figure 12 Total and per capita production of municipal solid waste in the United States, 1960–2007. (Data from the U.S. Environmental Protection Agency)

Data and Graph Analysis

1. How much more municipal solid waste was generated in 2007 than in 1960, in millions of tons?
2. In what year did per capita solid waste generation reach a level four times as high as it was in 1960?

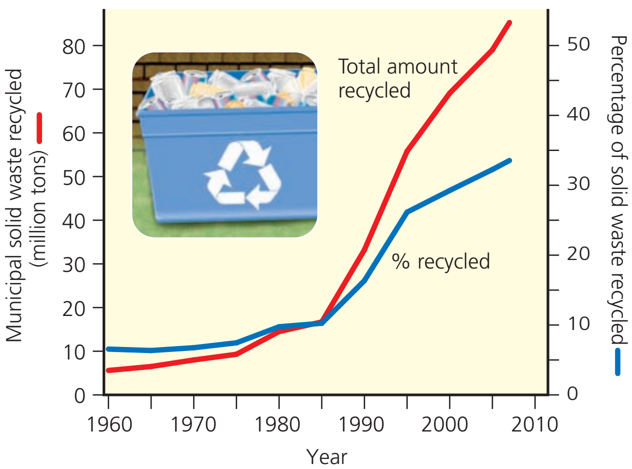


Figure 13 Total recycling and percent of municipal solid waste recycled (both including composted wastes) in the United States, 1960–2007. (Data from the U.S. Environmental Protection Agency)

Data and Graph Analysis

1. After 1980, how long did it take the United States to triple the total amount of materials recycled in 1980?
2. What 10-year period shows the sharpest increase in the percentage of solid waste recycled in the United States?

SUPPLEMENT

4

Maps: Biodiversity, Ecological Footprints, and Environmental Performance

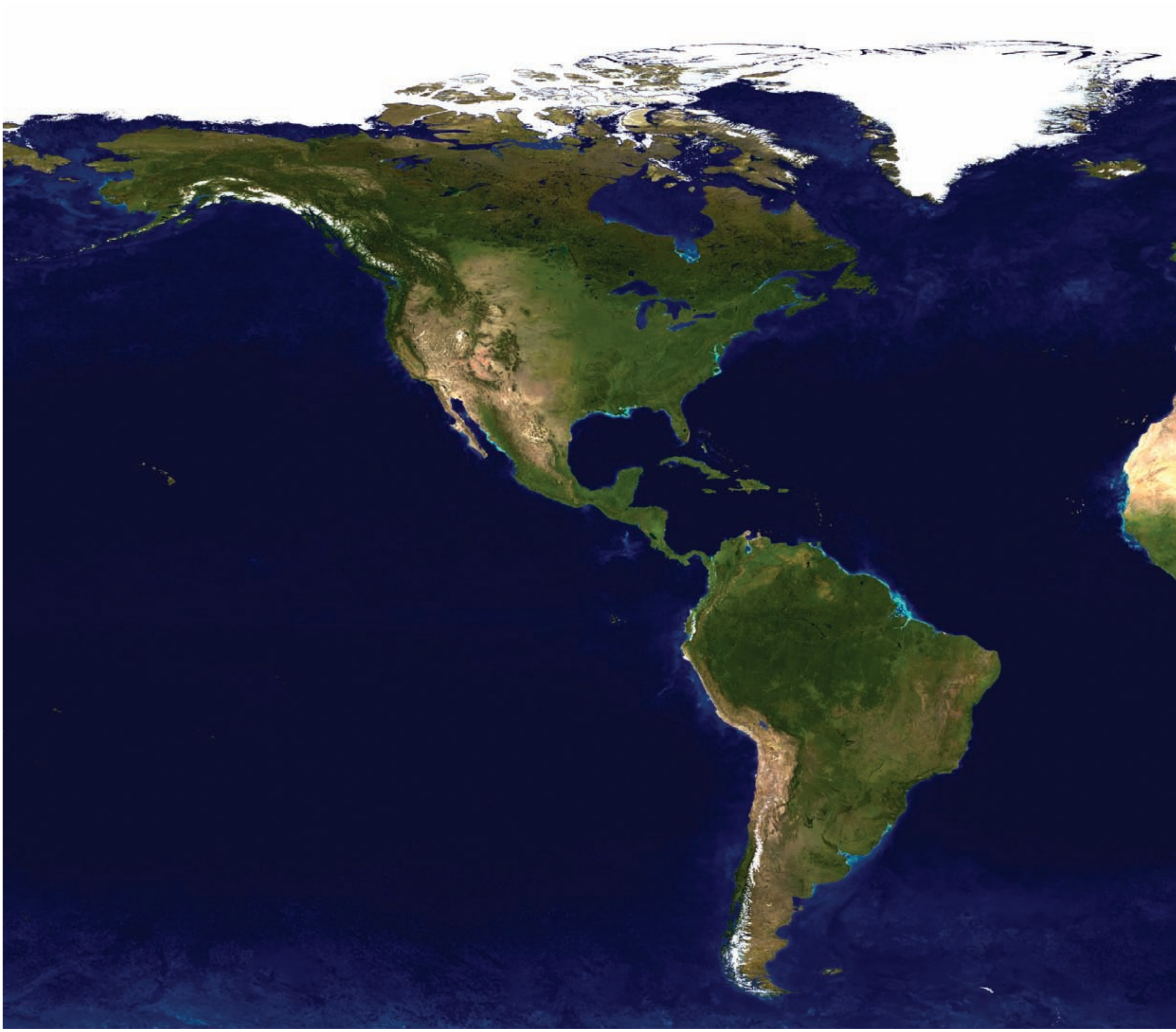
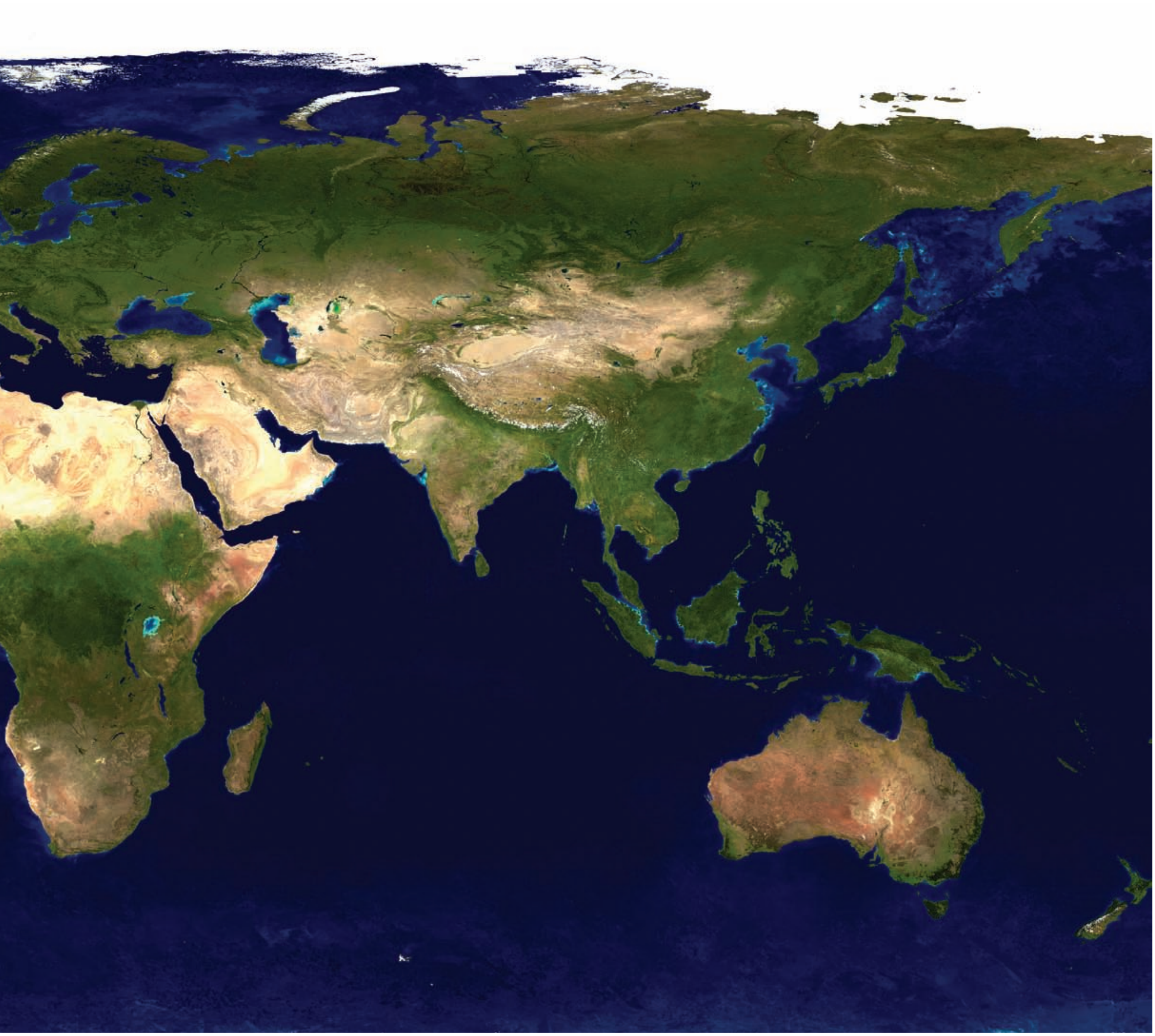


Figure 1 Composite satellite view of the earth showing its major terrestrial and aquatic features.

Data and Map Analysis

1. On what continent does desert make up the largest percentage of total land area? (See Figure 1 of Supplement 3, pp. S6–S7, for continent names.)
2. Which two continents contain large areas of polar ice?

(Chapters 1, 3–11, 15)

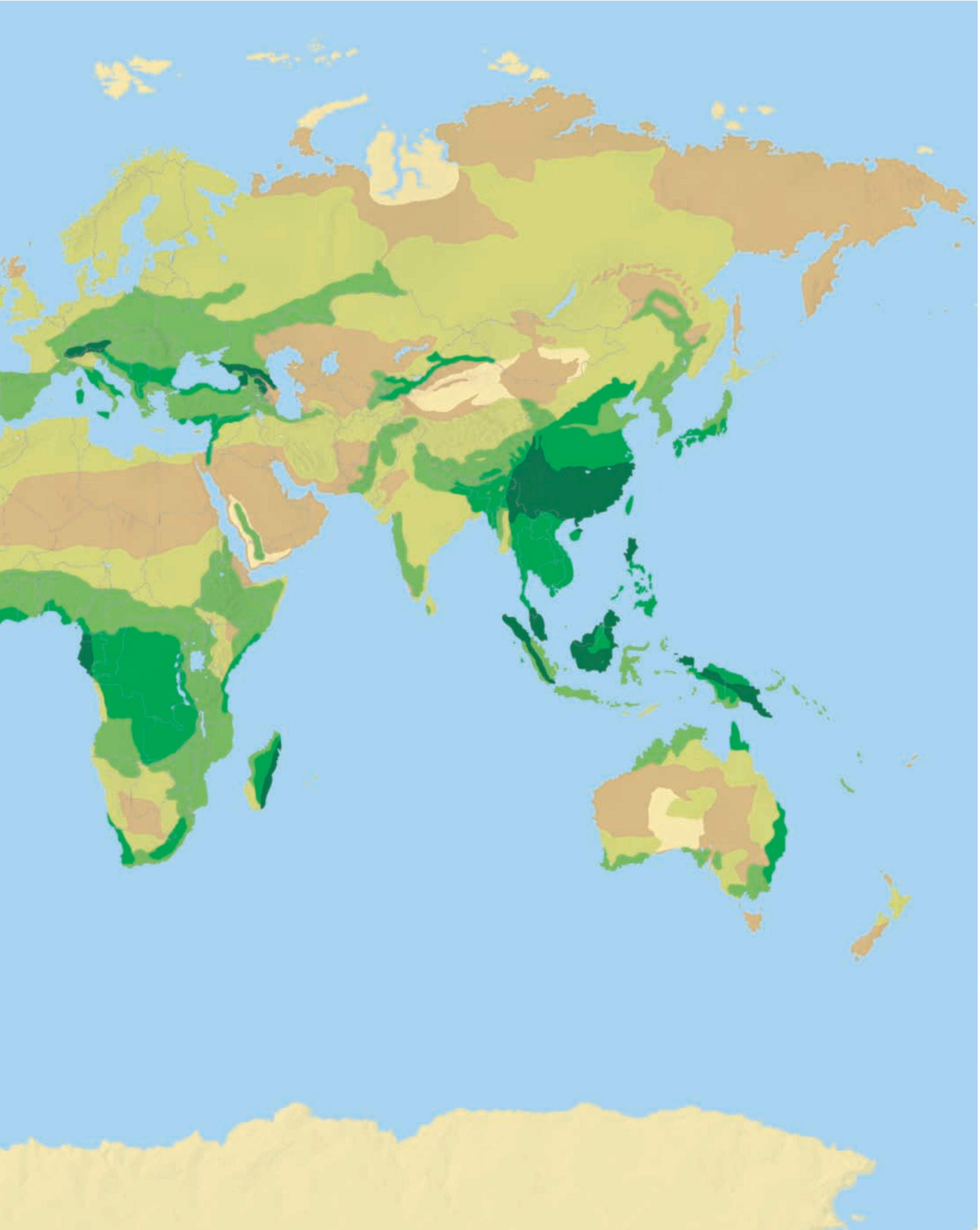


NASA Goddard Space Flight Center Image by Reto Stöckli (land surface, shallow water, clouds). Enhancements by Robert Simmon (ocean color, compositing, 3D globes, animation)

Figure 2 Global map of plant biodiversity. (Used by permission from Kier, et al. 2005. "Global Patterns of Plant Diversity and Floristic Knowledge." *Journal of Biogeography*, Vol. 32, Issue 6, pp. 921–1106, and Blackwell Publishing)

Data and Map Analysis

1. What continent holds the largest continuous area of land that hosts more than 5,000 species per eco-region? On what continent is the second largest area of such land? (See Figure 1, pp. S6–S7, in Supplement 3 for the names of continents.)
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)?



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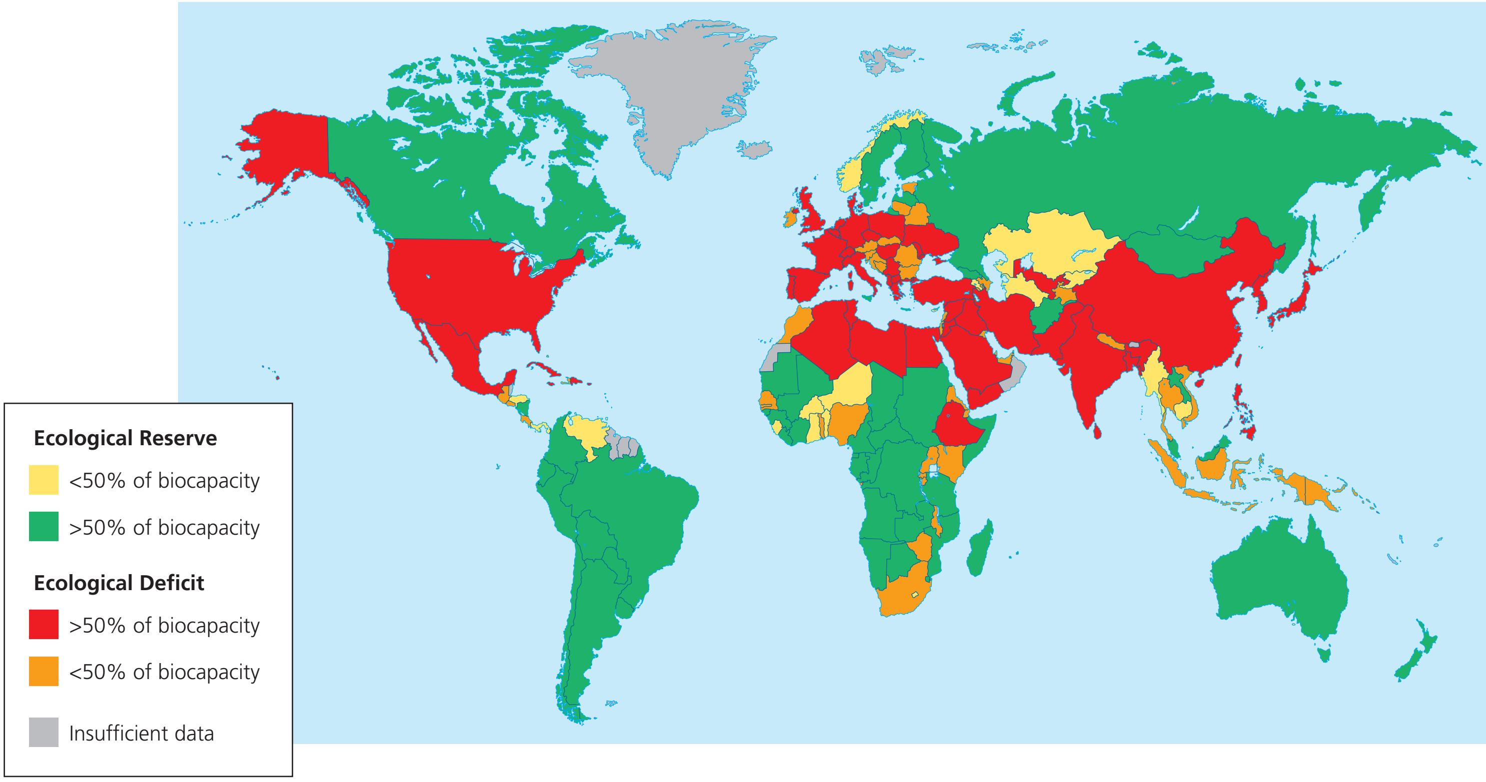


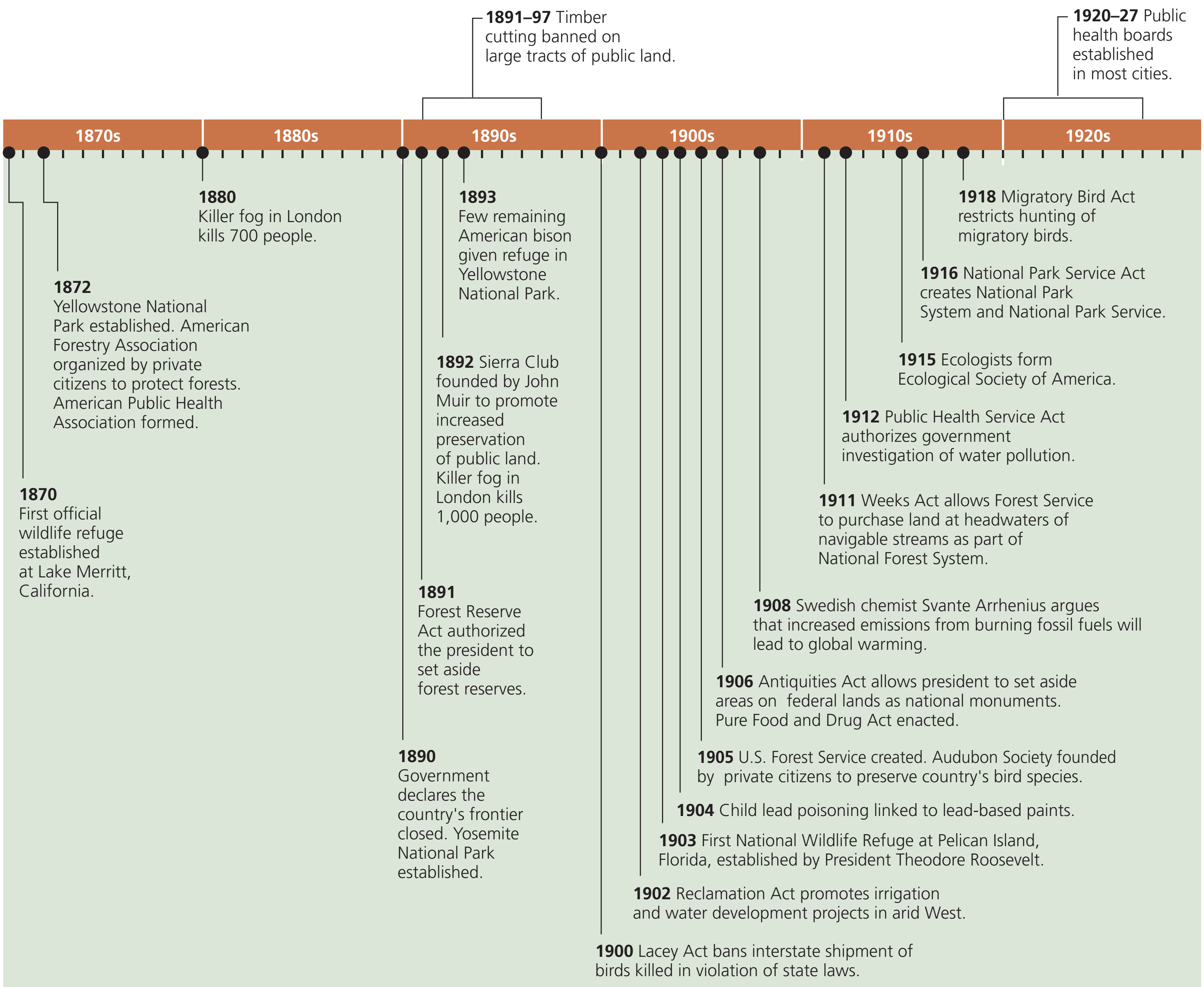
Figure 4 *Ecological Debtors and Creditors.* The ecological footprints of some countries exceed their biocapacity, while others still have ecological reserves. (Data from Global Footprint Network)

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 Supplement 3, pp. S6–S7, for country and continent 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? Look at Figure 3, and for each of these two continents, list the highest human footprint value that you see on the map.

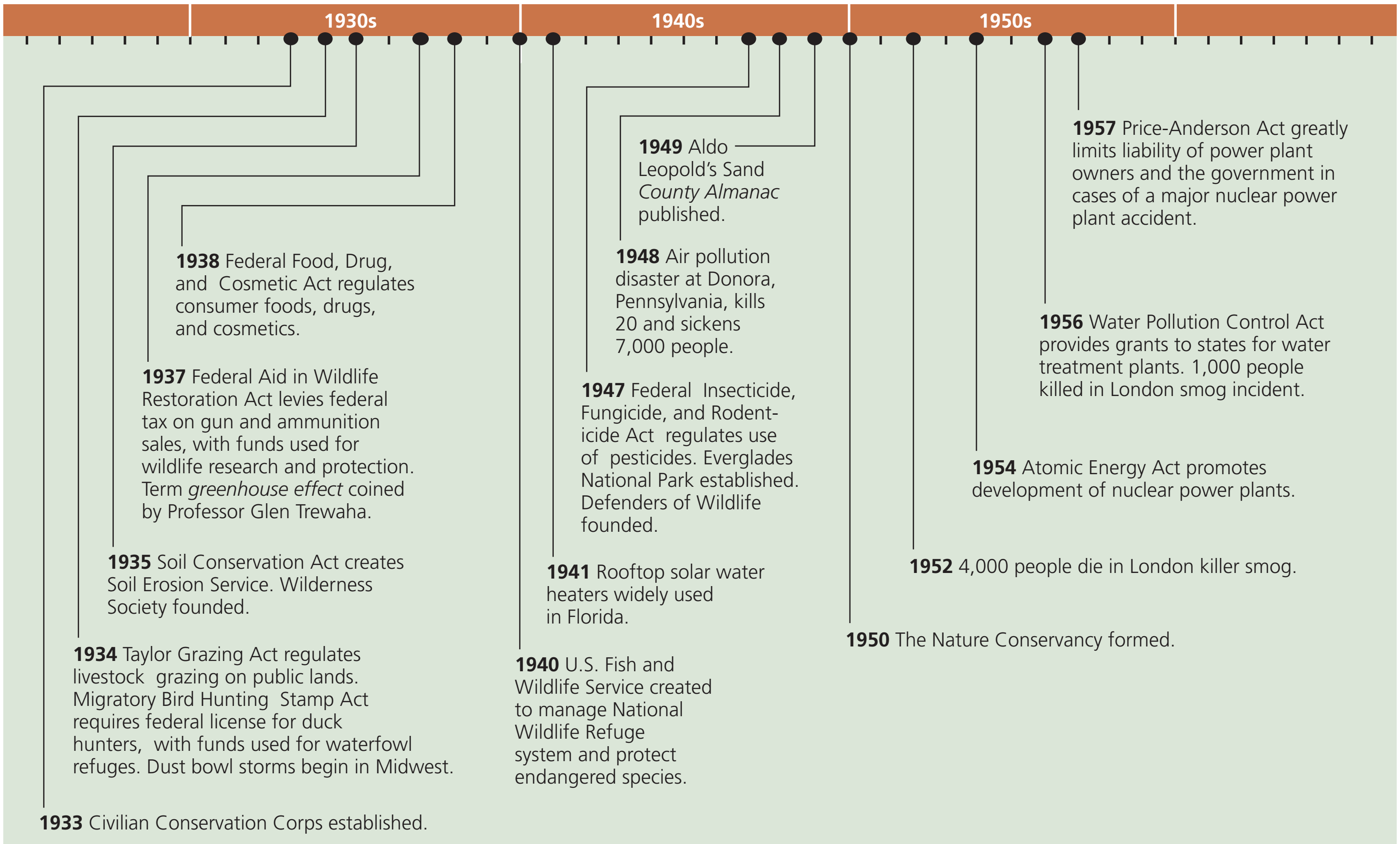
An Overview of U.S. Environmental History (Chapters 1–3, 5, 6, 9–11, 17)

SUPPLEMENT 5



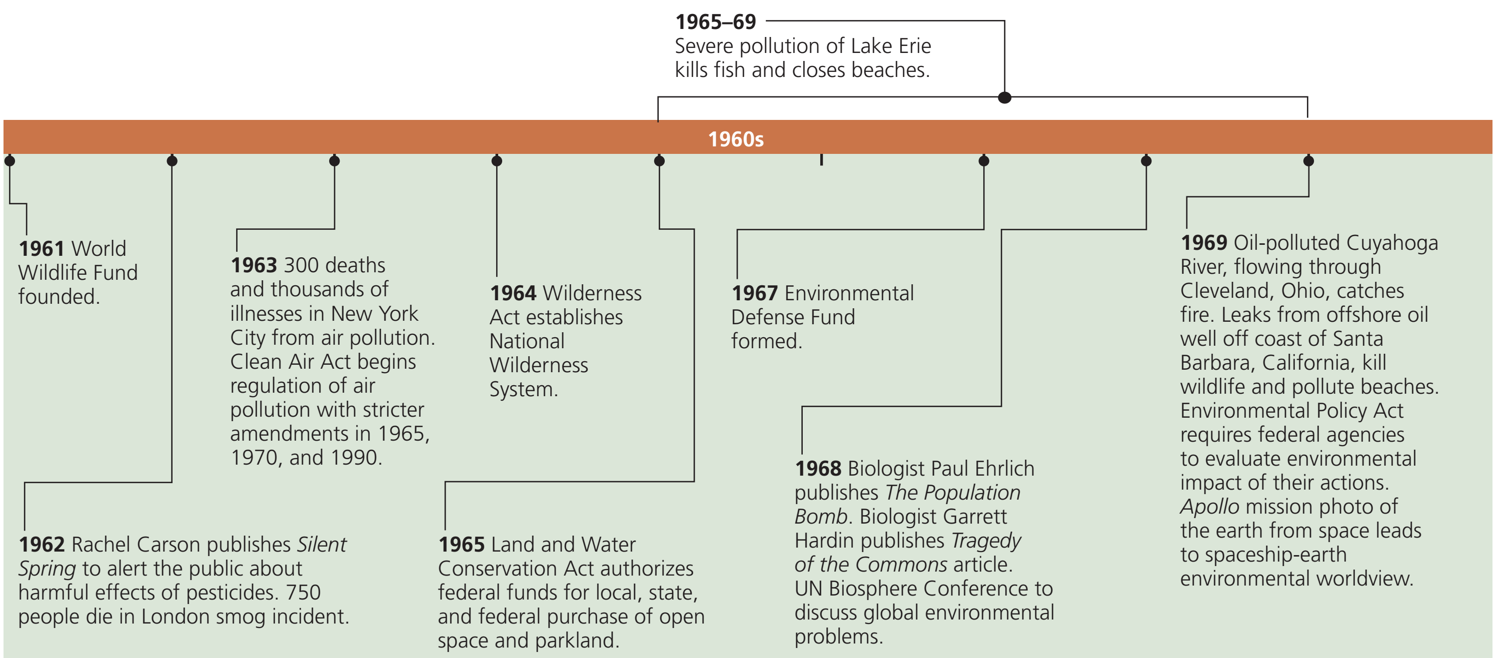
1870–1930

Figure 1 Examples of the increased role of the federal government in resource conservation and public health and the establishment of key private environmental groups, 1870–1930. **Question**: Which two of the events in each decade after the 1880s do you think were the most important for promoting environmental sustainability?



1930–1960

Figure 2 Some important conservation and environmental events, 1930–1960. **Question**: Which two of the events in each decade do you think were the most important for promoting environmental sustainability?



1960s

Figure 3 Some important environmental events during the 1960s. **Question**: Which two of these events do you think were the most important for promoting environmental sustainability?

1970s

1970
First Earth Day. EPA established by President Richard Nixon. Occupational Health and Safety Act promotes safe working conditions. Resource Conservation and Recovery Act regulates waste disposal and encourages recycling and waste reduction. National Environmental Policy Act passed. Clean Air Act passed. Natural Resources Defense Council created.

1971
Biologist Barry Commoner publishes *The Closing Circle* explaining ecological problems and calling for pollution prevention.

1972
Oregon passes first beverage bottle recycling law. Publication of *Limits to Growth*, which challenges idea of unlimited economic growth. David Brower founds Earth Island Institute. Federal Environmental Pesticide Control Act regulates registration of pesticides based on tests and degree of risk. Ocean Dumping Act; Marine Protection, Research, and Sanctuaries Act; and Coastal Zone Management Act help regulate and protect oceans and coastal areas. Marine Mammal Protection Act encourages protection and conservation of marine mammals. Consumer Product Safety Act helps protect consumers from hazardous products. UN conference on the Human Environment in Stockholm, Sweden.

1973
OPEC cuts off oil to the U.S. and other nations supporting Israel. Lead-Based Paint Poisoning Act regulates use of lead in toys and cooking and eating utensils. Convention on International Trade in Endangered Species (CITES) becomes international law.

1974
Chemists Sherwood Roland and Mario Molina suggest CFCs are depleting the ozone in stratosphere. Lester Brown founds the Worldwatch Institute. Safe Drinking Water Act sets standards for contaminants in public water supply.

1975
Energy Policy and Conservation Act promotes energy conservation.

1976
National Forest Management Act establishes guidelines for managing national forests.Toxic Substances Control Act regulates many toxic substances not regulated under other laws. Resource Conservation and Recovery Act requires tracking of hazardous waste and encourages recycling, resource recovery, and waste reduction. Noise Control Act regulates harmful noise levels. UN Conference on Human Settlements.

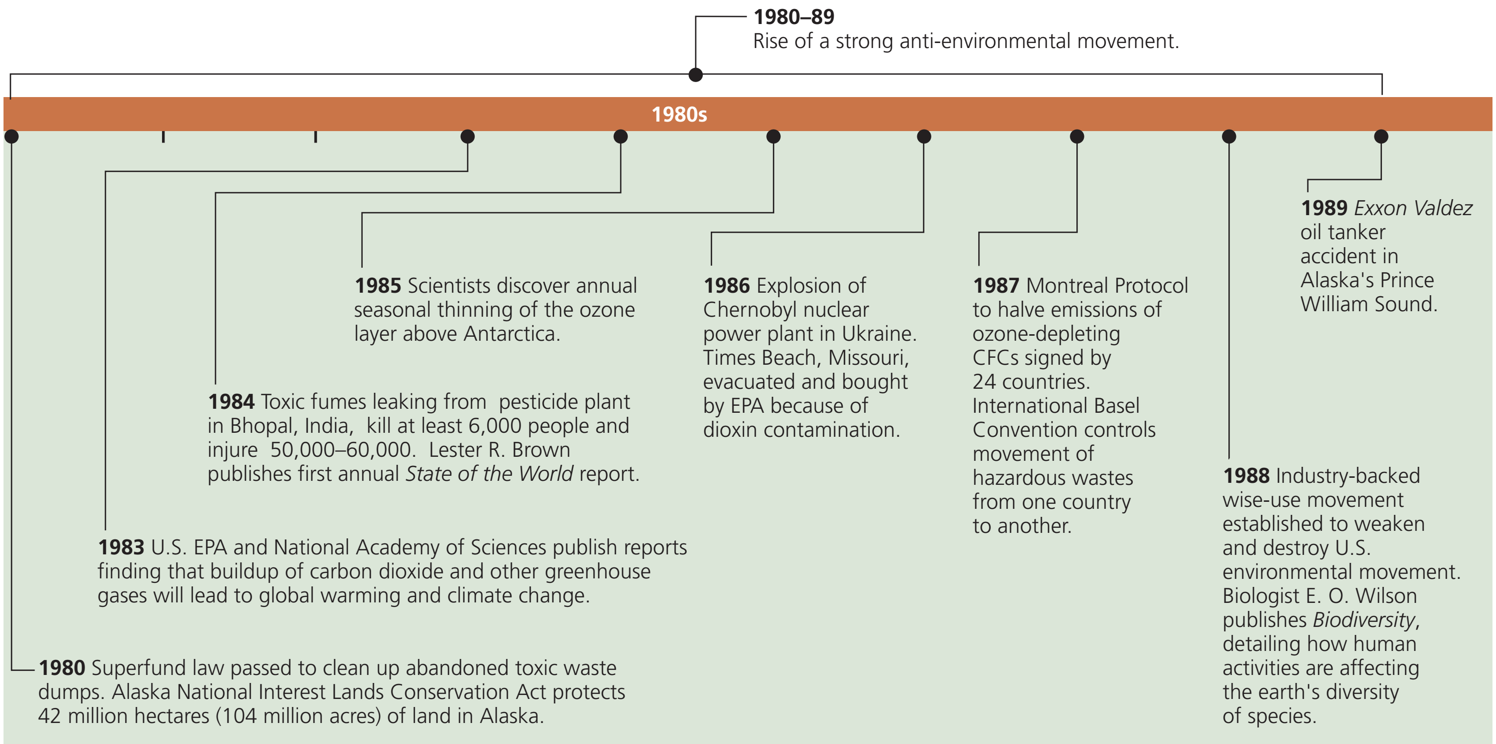
1977
Clean Water Act strengthens regulation of drinking water quality, with additional amendments in 1981 and 1987. Surface Mining Control and Reclamation Act regulates surface mining and encourages reclamation of mined land. Amory B. Lovins publishes *Soft Energy Paths* calling for switching from fossil fuels and nuclear power to solar energy. U.S. Department of Energy created.

1978
Love Canal, New York, housing development evacuated because of toxic wastes leaking from old dumpsite. Federal Land Policy and Management Act strengthens regulation of public lands by the Bureau of Land Management.

1979
Accident at Three Mile Island nuclear power plant in Pennsylvania. Oil shortage because of revolution in Iran.

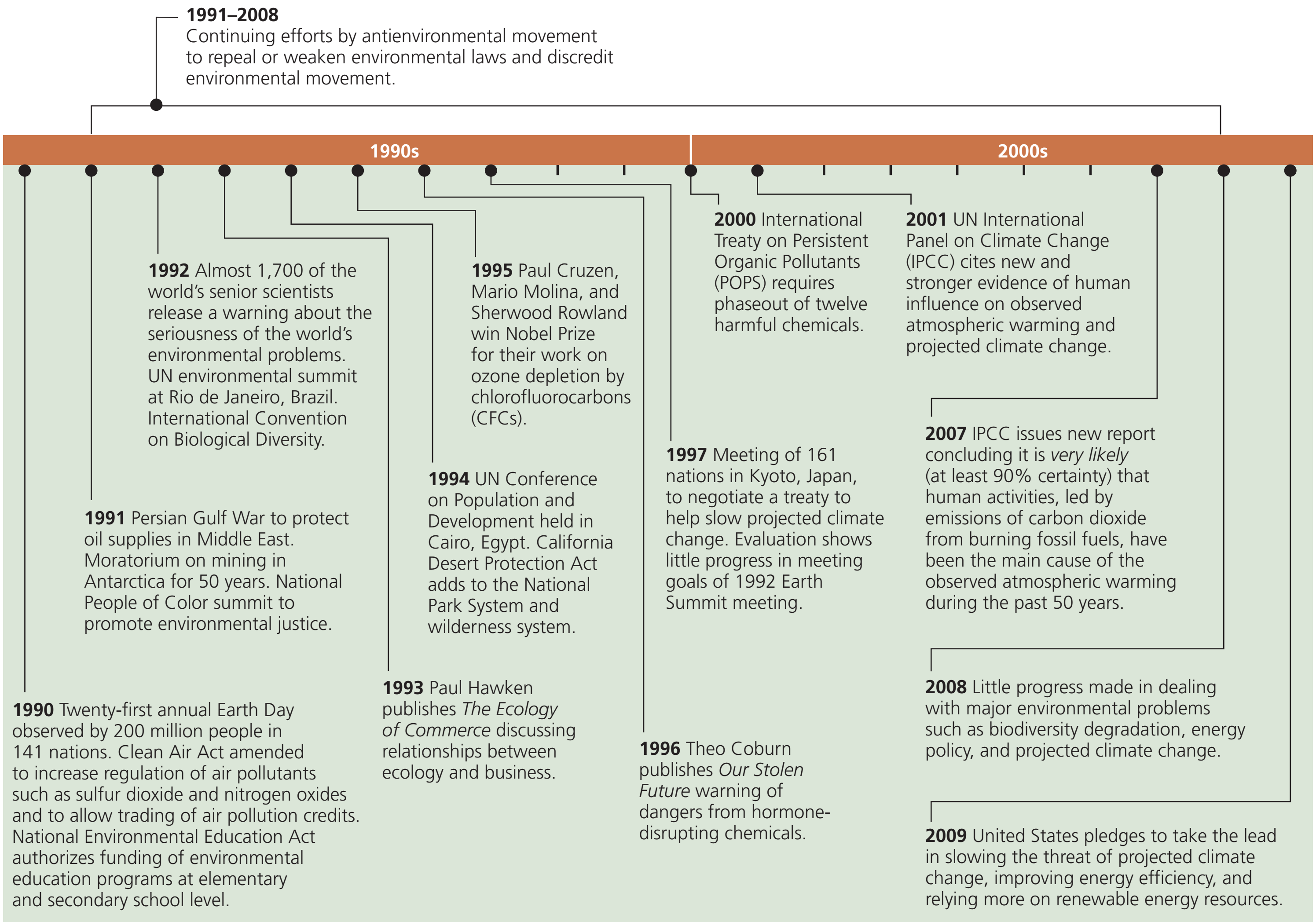
1970s

Figure 4 Some important environmental events during the 1970s, sometimes called the environmental decade. **Question**: Which two of these events do you think were the most important for promoting environmental sustainability?



1980s

Figure 5 Some important environmental events during the 1980s. **Question**: Which two of these events do you think were the most important for promoting environmental sustainability?



1990–2009

Figure 6 Some important environmental events, 1990–2009. **Question**: Which two of the events in each decade do you think were the most important for promoting environmental sustainability?

Some Basic Chemistry (Chapters 2–5, 10–12, 14–16)

Chemists Use the Periodic Table to Classify Elements on the Basis of Their Chemical Properties

The basic unit of each element is a unique *atom* that is different from the atoms of all other elements. Each atom consists of an extremely small and dense center called its *nucleus,* which contains one or more protons and, in most cases, one or more neutrons, and one or more electrons moving rapidly somewhere around the nucleus (Figure 1). 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*.

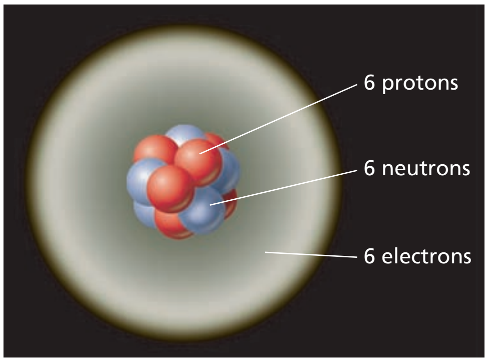


Figure 1 Greatly simplified model of a carbon-12 atom. It consists of a nucleus containing six positively charge protons and six neutral neutrons. There are six negatively charged electrons found outside its nucleus. We cannot determine the exact location of the electrons. Instead, we can estimate the *probability* that they will be found at various locations outside the nucleus in what is 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 where we can probably find them.

Chemists have developed a way to classify the elements according to their chemical behavior in what is called the *periodic table of elements* (Figure 2). 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 2 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 and 11 negatively charged electrons 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

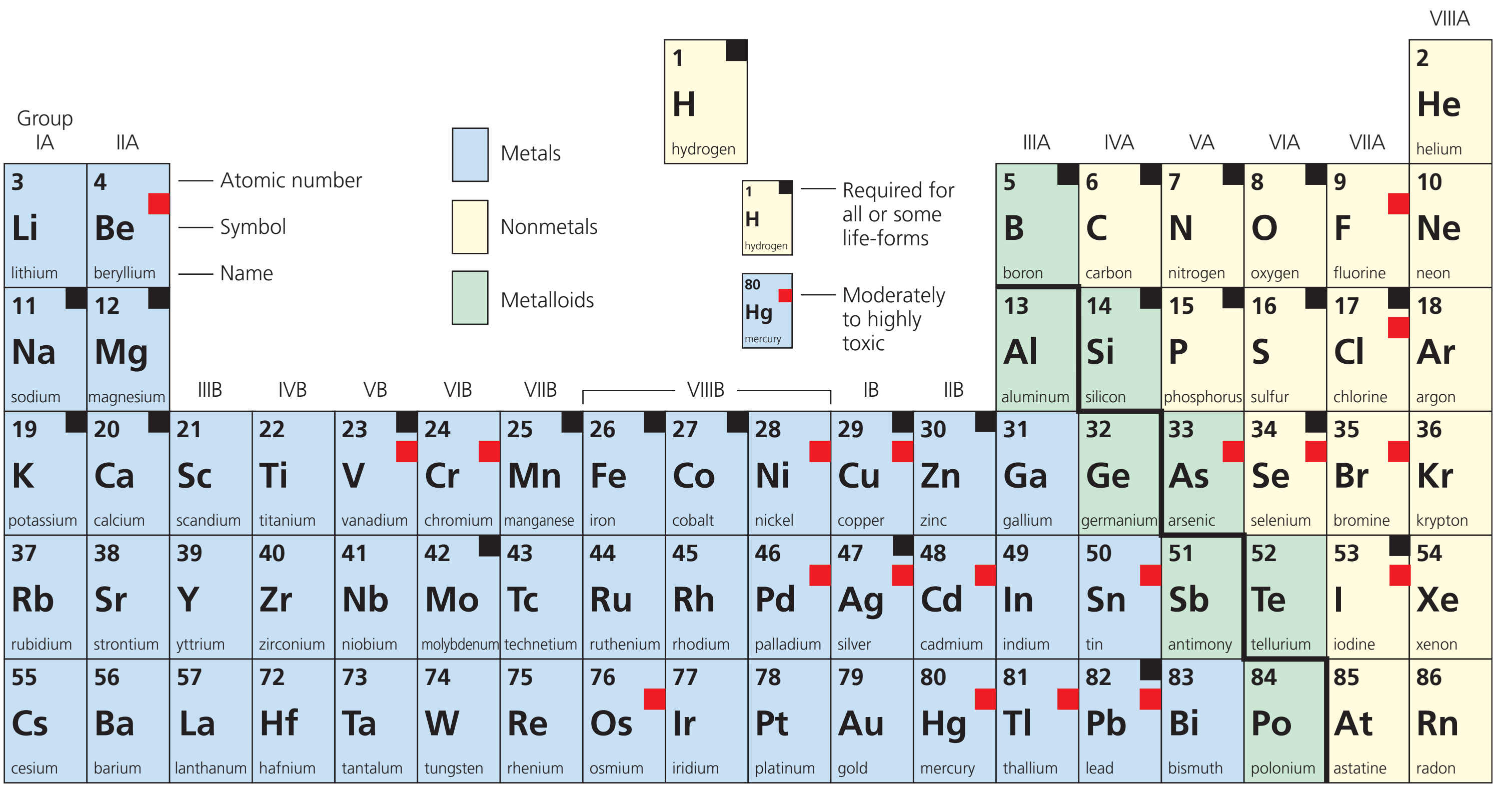


Figure 2 Abbreviated periodic table of elements. Elements in the same vertical column, called a *group*, have similar chemical properties. To simplify matters at this introductory level, only 72 of the 118 known elements are shown.

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 and 18 negatively charged electrons. 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 2 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, and **(d)** lead.

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 3). 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 2), they can be described as *metal–nonmetal compounds*.

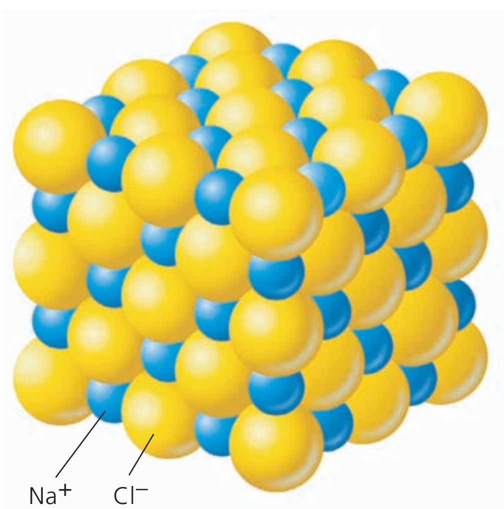


Figure 3 A solid crystal of an ionic compound such as sodium chloride consists of a three-dimensional array of oppositely charged ions held together by *ionic bonds* that result from the strong forces of attraction between opposite electrical charges. They are formed when an electron is transferred from a metallic atom such as sodium (Na) to a nonmetallic element such as chlorine (Cl).

Sodium chloride and many other ionic compounds tend to dissolve in water and break apart into their individual ions (Figure 4).

NaCl	→	Na^+ + Cl^-
sodium chloride (in water)		sodium ion + chloride ion

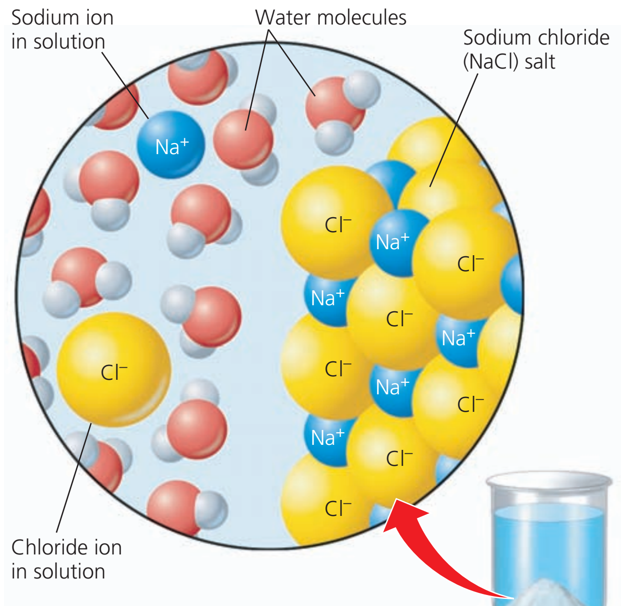


Figure 4 How a salt dissolves in water.

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 2), covalent compounds can be described as *nonmetal–nonmetal compounds*. Figure 5 shows the chemical formulas and shapes of the molecules that are the building blocks for several common *covalent compounds*.

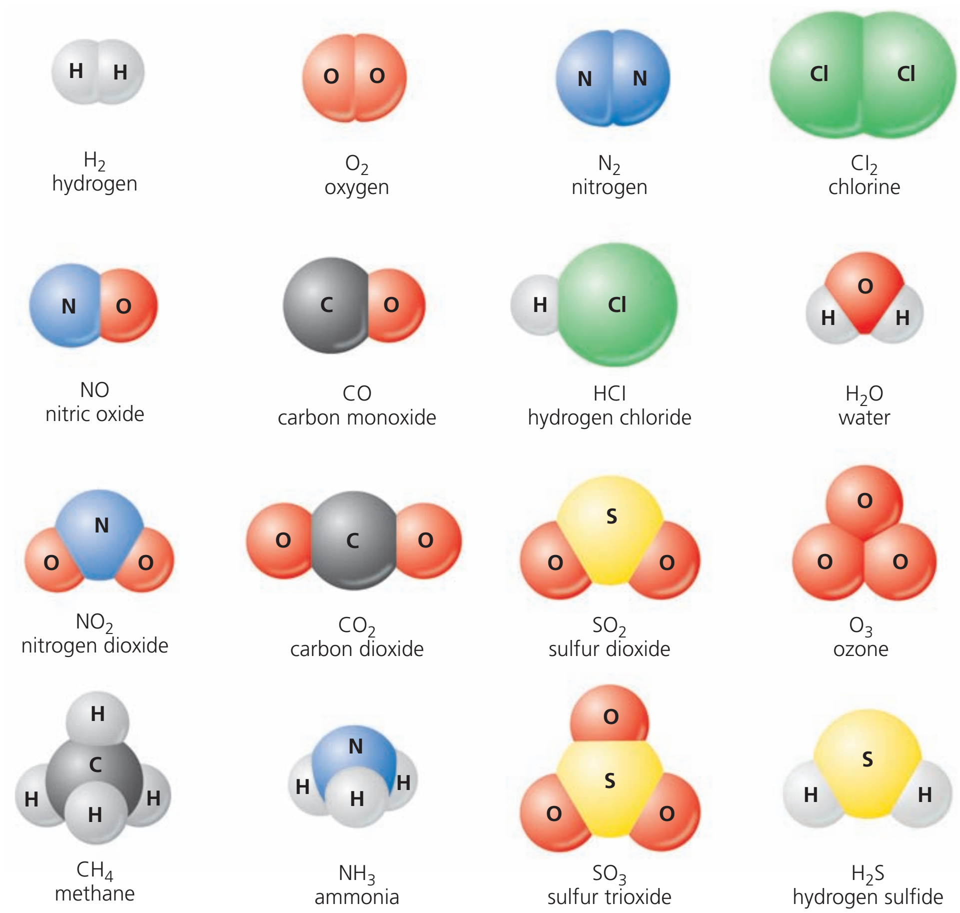


Figure 5 Chemical formulas and shapes for some *covalent compounds* formed when atoms of one or more nonmetallic elements combine with one another. The bonds between the atoms in such molecules are called *covalent bonds*.

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 acidic than a solution with a pH of 4. Figure 6 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?

When coal and oil are burned they give off acidic compounds that can return to the earth as *acid deposition* (Figure 15-5, p. 374 and Figure 15-6, p. 375).

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, in a water molecule the electrons shared between the oxygen atom and its two hydrogen atoms 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 7).

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 7). They account for many of water's unique properties (Science Focus, p. 50). Hydrogen bonds also form between other covalent molecules or 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 8) 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 9). 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.

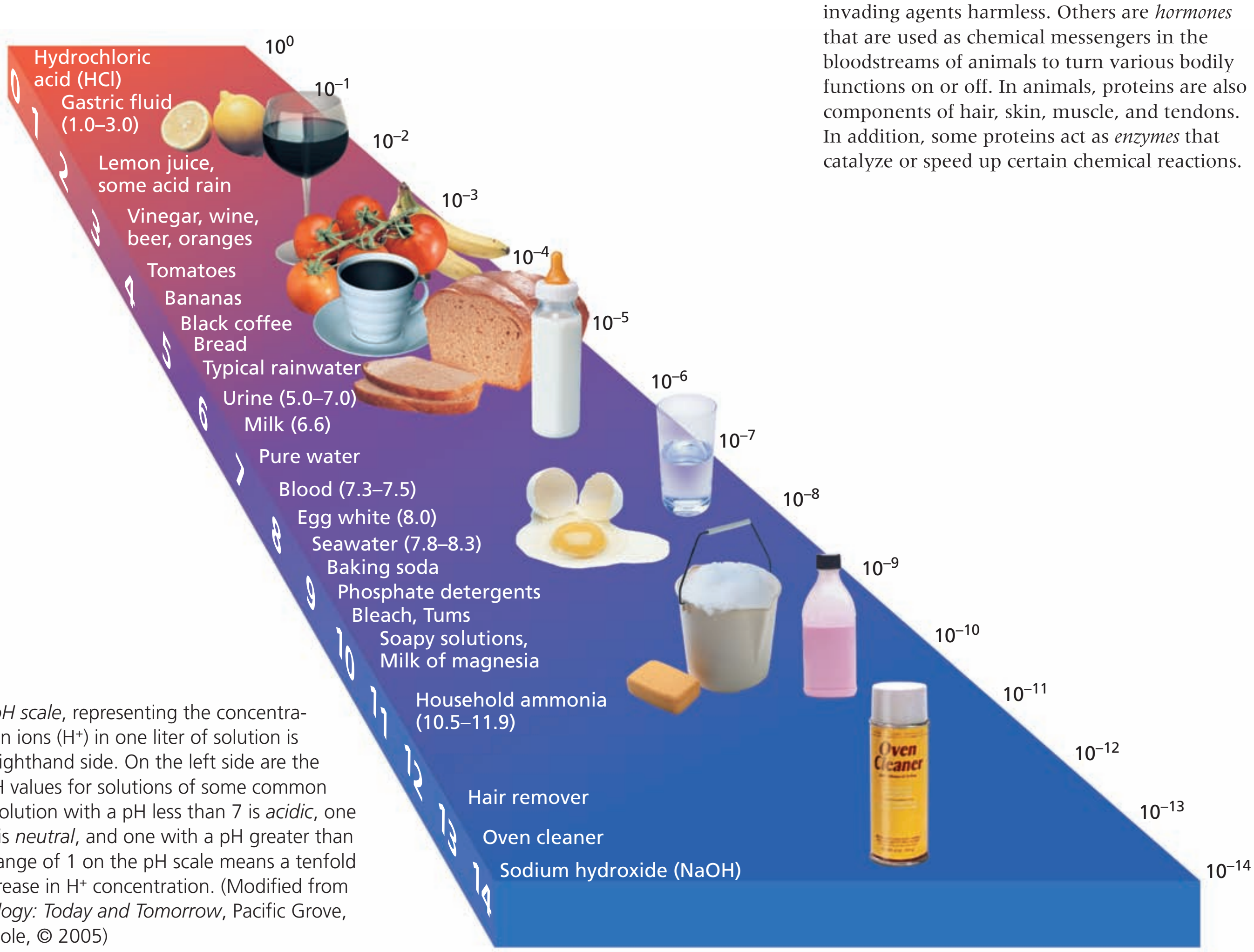


Figure 6 The *pH scale*, representing the concentration of hydrogen ions (H^+) in one liter of solution is shown on the righthand side. On the left side are the approximate pH values for solutions of some common substances. A solution with a pH less than 7 is *acidic*, one with a pH of 7 is *neutral*, 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, Calif.: Brooks/Cole, © 2005)

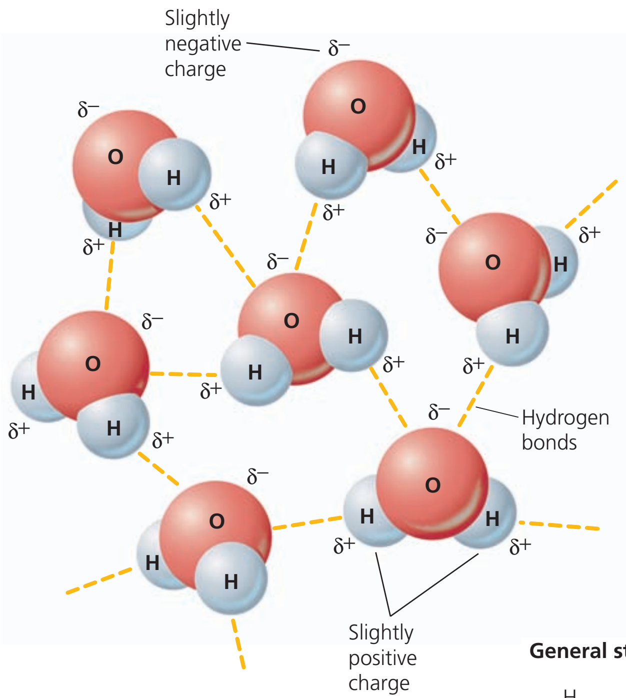


Figure 7 *Hydrogen bond:* slightly unequal sharing of electrons in the water molecule creates a molecule with a slightly negatively charged end and a slightly positively charged end. Because of this electrical polarity, the hydrogen atoms of one water molecule are attracted to the oxygen atoms in other water molecules. These fairly weak forces of attraction *between* molecules (represented by the dashed lines) are called *hydrogen bonds*.

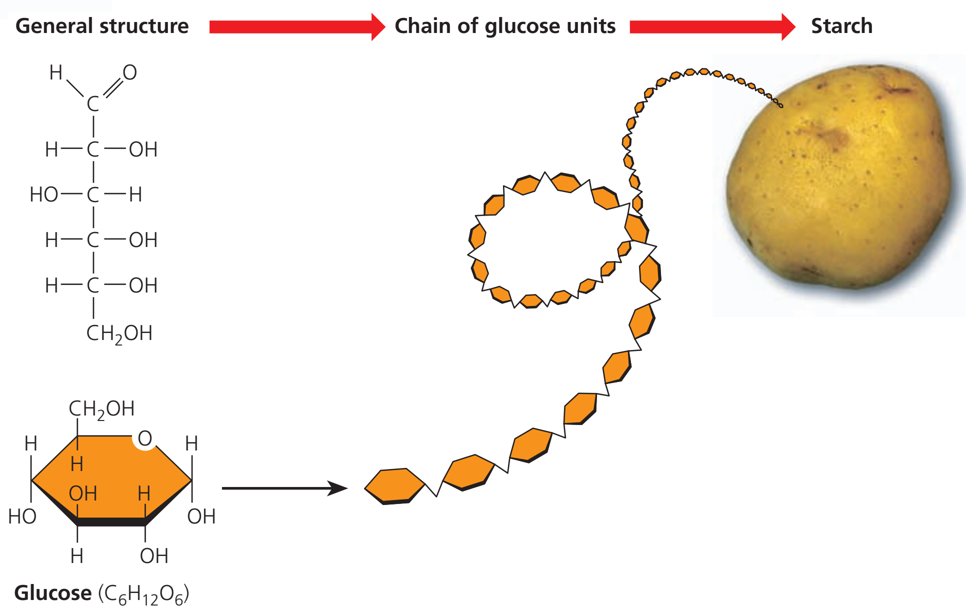


Figure 8 Straight-chain and ring structural formulas of glucose, a simple sugar that can be used to build long chains of complex carbohydrates such as starch and cellulose.

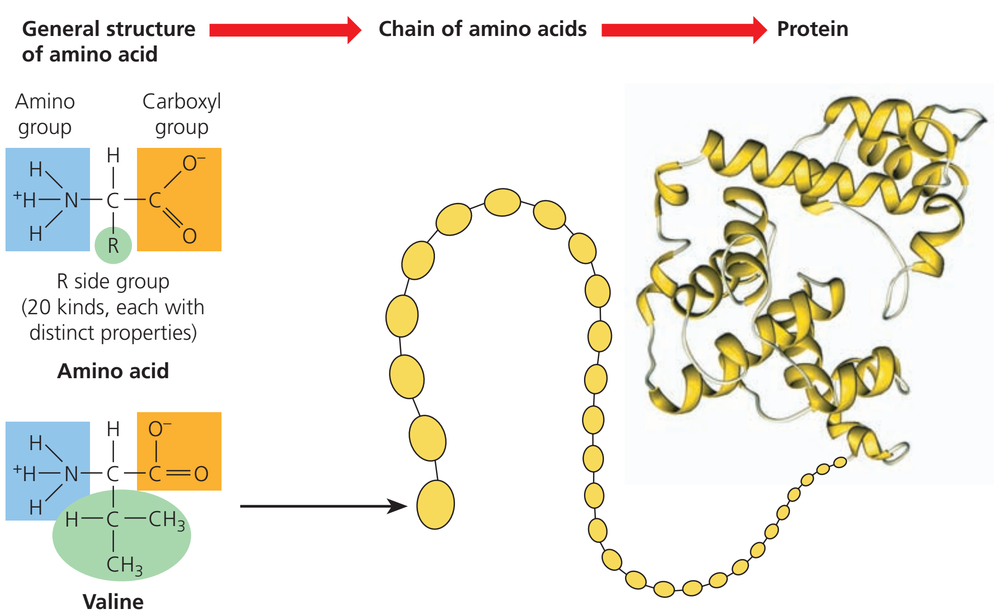


Figure 9 General structural formula of amino acids and a specific structural formula of one of the 20 different amino acid molecules that can be linked together in chains to form proteins that fold up into more complex shapes.

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 10). 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 11).

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 11). 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 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 12), *waxes* for structure, and *steroids* for producing hormones.

Figure 13 shows the relative sizes of simple and complex molecules, cells, and multicelled organisms.

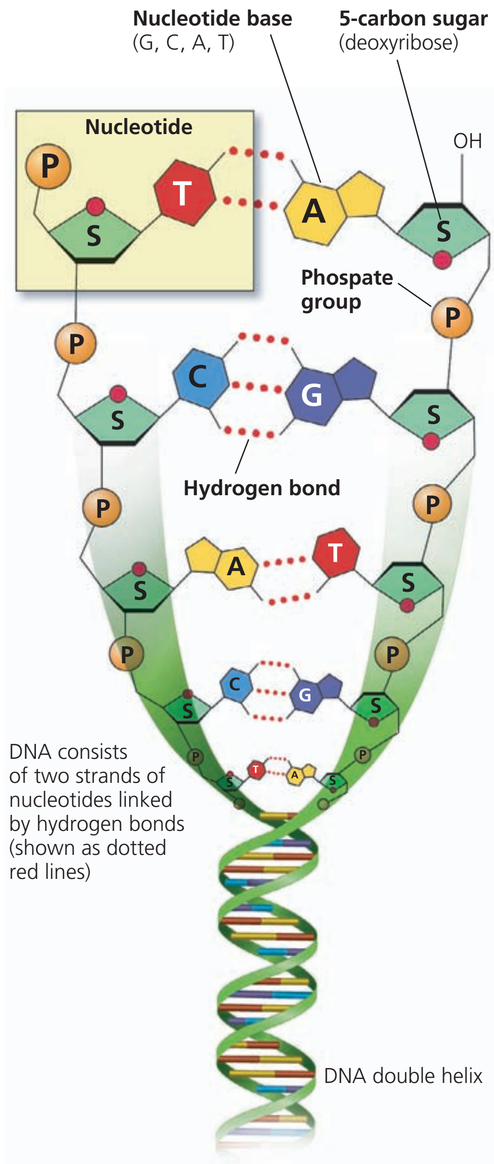


Figure 11 Portion of the double helix of a DNA molecule. The double helix is composed of two spiral (helical) strands of nucleotides. Each nucleotide contains a unit of phosphate (P), deoxyribose (S), and one of four nucleotide bases: guanine (G), cytosine (C), adenine (A), and thymine (T). The two strands 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).

Certain Molecules Store and Release Energy in Cells

Chemical reactions occurring in photosynthesis (p. 42) release energy that is absorbed by adenosine diphosphate (ADP) molecules and stored as chemical energy in adenosine triphosphate (ATP) molecules (Figure 14, left). When cellular processes require energy, ATP molecules release it to form ADP molecules (Figure 14, right).

Chemists Balance Chemical Equations to Keep Track of Atoms

Chemists use a shorthand system 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

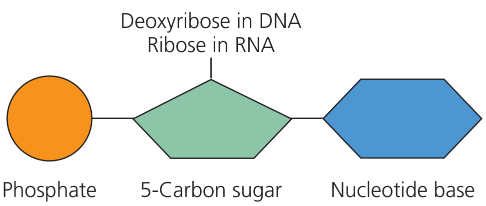


Figure 10 Generalized structures of the nucleotide molecules linked in various numbers and sequences to form large nucleic acid molecules such as various types of DNA (deoxyribonucleic acid) and RNA (ribonucleic acid). In DNA, the 5-carbon sugar in each nucleotide is deoxyribose; in RNA it is ribose. 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.)

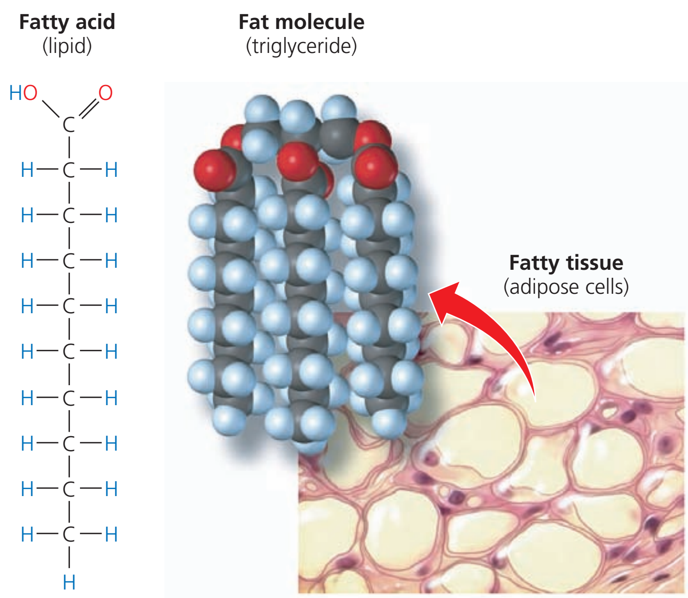


Figure 12 Structural formula of fatty acid that is one form of lipid (left). Fatty acids are converted into more complex fat molecules that are stored in adipose cells (right).

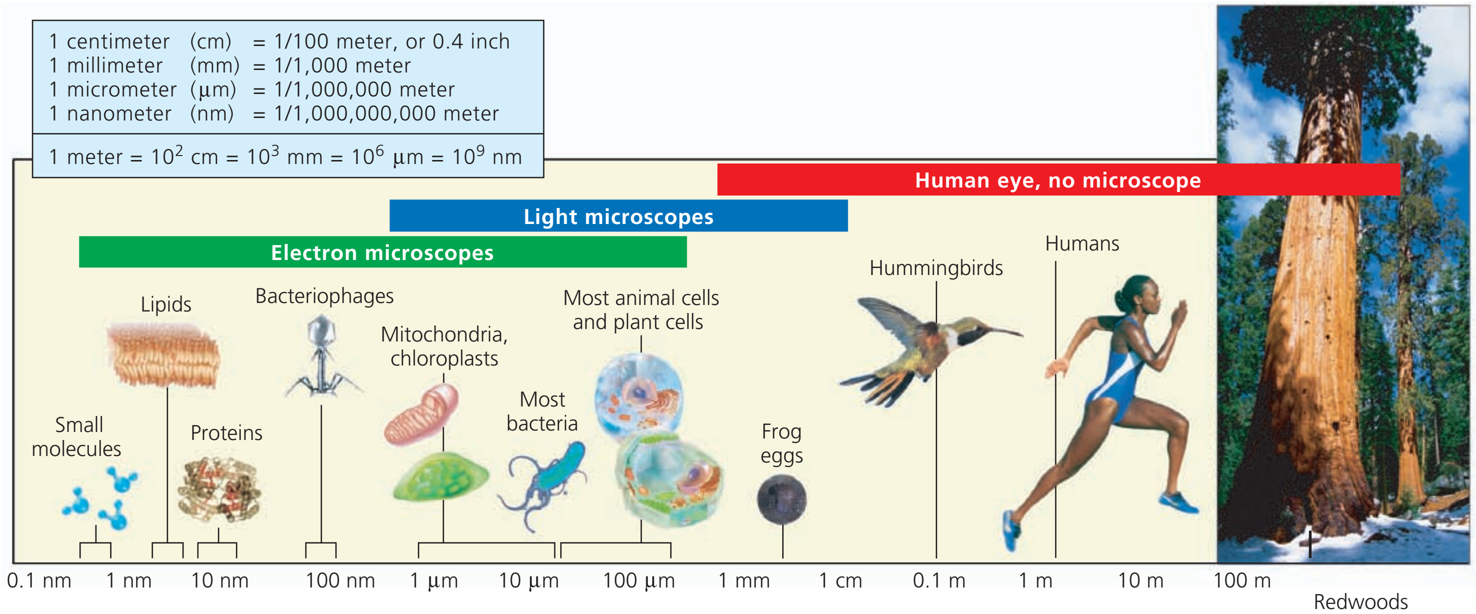


Figure 13 Relative size of simple molecules, complex molecules, cells, and multicellular organisms. This scale is exponential, not linear. Each unit of measure is ten times larger than the unit preceding it. (Used by permission from Cecie Starr and Ralph Taggart, *Biology*, 11th ed, Belmont, Calif.: Thomson Brooks/Cole, © 2006)

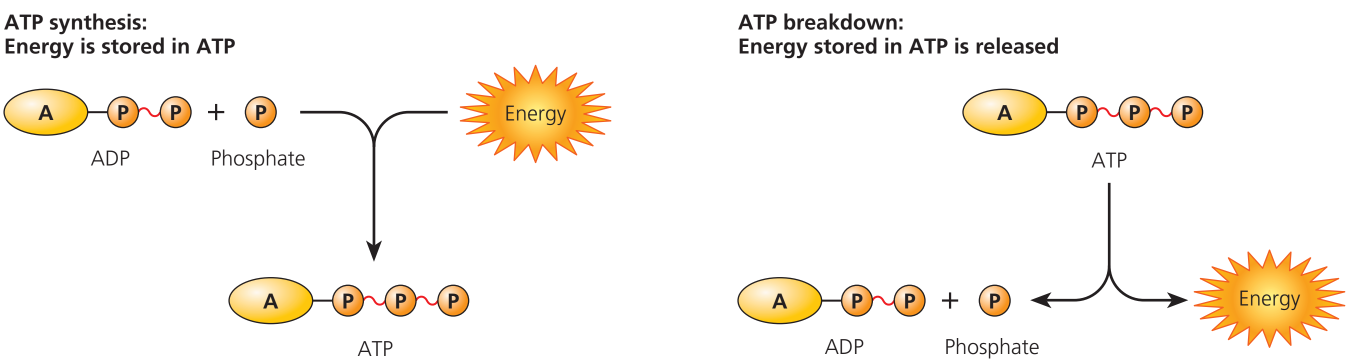


Figure 14 Energy storage and release in cells.

conservation of matter (p. 32 and **Concept 2-2B**, p. 28). 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.

CONCEPT LINK

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		2 H atoms		2 O atoms
1 O atom				

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 H atoms		2 O 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		4 H atoms		2 O 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).

SUPPLEMENT

7 Classifying and Naming Species (Chapters 3, 4, 8)

According to the scientific theory of evolution, 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*.

On the basis of their cell structure, organisms can be classified 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 of eukaryotic cells. A membrane also surrounds a **prokaryotic cell** 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. 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. These organisms live in extreme environments.

The remaining four kingdoms—protists, fungi, plants, and animals—are eukaryotes 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 (p. 350) and sleeping sickness.

Fungi are mostly many-celled, sometimes microscopic, eukaryotic organisms such as mushrooms, molds, mildews, and yeasts. Many fungi are decomposers (Figure 3-6, p. 44). 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 can live for more than 2 years.

Animals are also many-celled eukaryotic organisms. Most have no backbones and hence are called *invertebrates*. Invertebrates include sponges, jellyfish, worms, arthropods (e.g., insects, shrimp, 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 1 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").

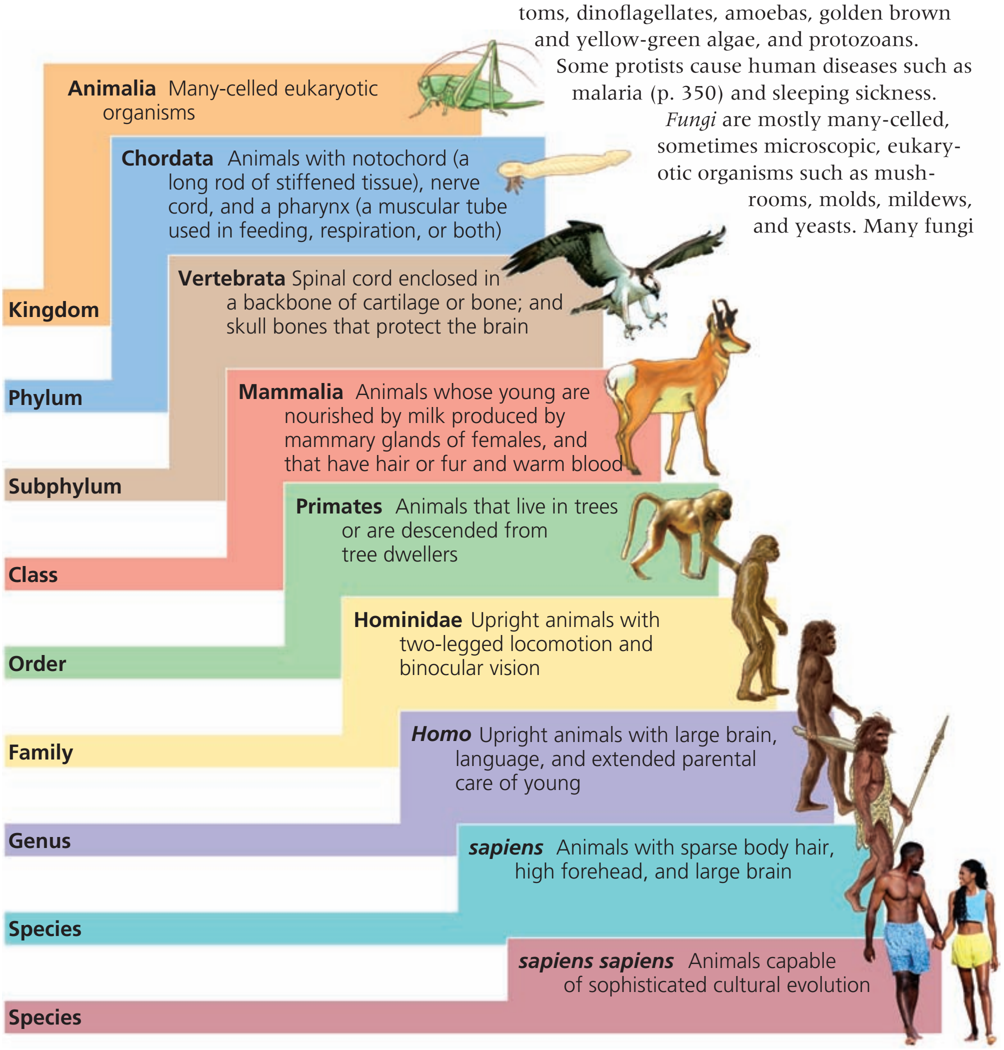


Figure 1 Taxonomic classification of the latest human species, *Homo sapiens sapiens*.

SUPPLEMENT

8

Weather Basics: El Niño, Tornadoes, and Tropical Cyclones (Chapters 7, 15)

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 or 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.

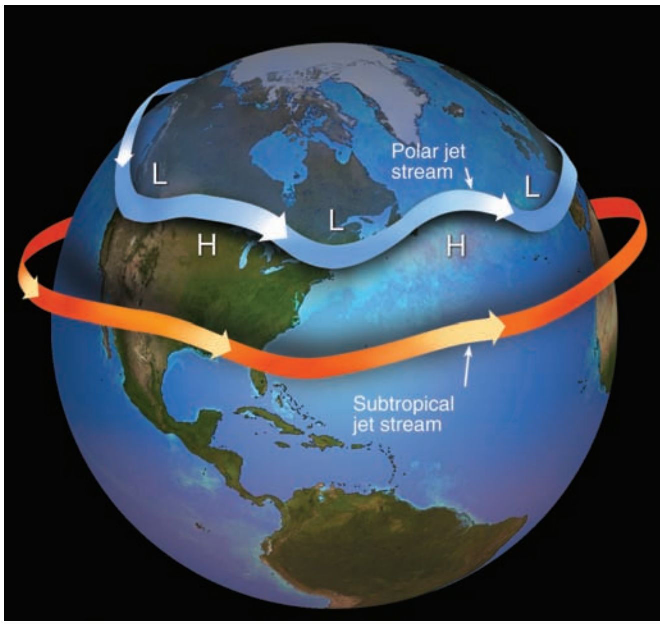


Figure 2 A *jet stream* is a rapidly flowing air current that moves west to east in a wavy pattern. This figure shows a polar jet stream and a subtropical jet stream in winter. In reality, jet streams are discontinuous and their positions vary from day to day. (Used by permission from C. Donald Ahrens, *Meteorology Today*, 8th ed. Belmont, Calif.: 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*.

As a cold front passes through, we may experience high surface winds and thunderstorms. After it leaves the area, we usually have 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.

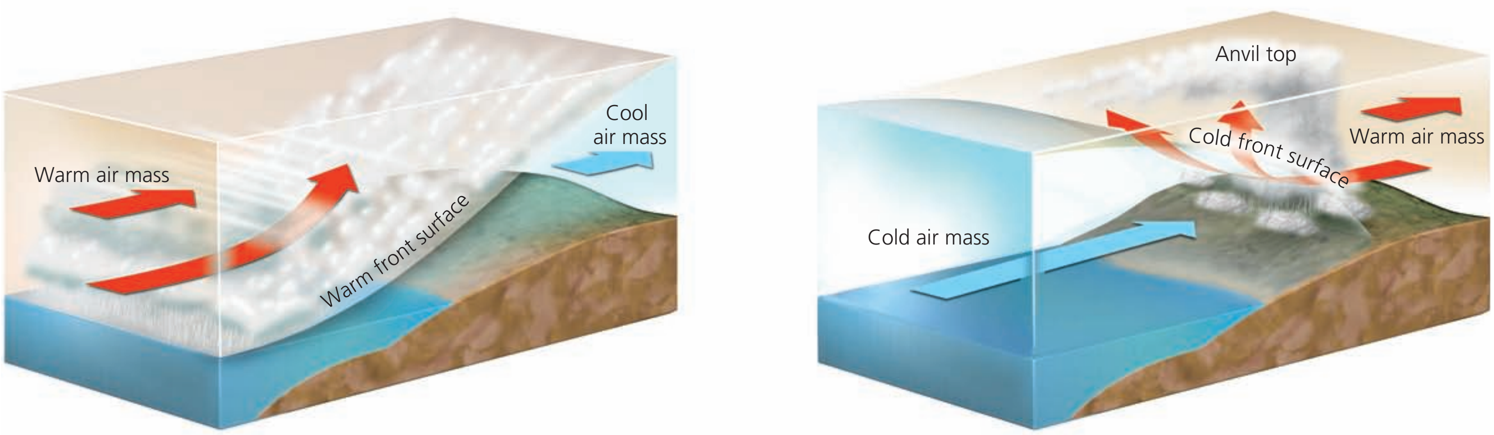


Figure 1 *Weather fronts.* A *warm front* (left) arises when an advancing mass of warm air meets and rises up over a mass of denser cool air. A *cold front* (right) forms when a moving mass of cold air wedges beneath a mass of less dense warm air.

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 the water, bringing cool and nutrient-rich water from the bottom of the ocean to the surface where it supports large populations of phytoplankton, zooplankton, fish, and fish-eating seabirds.

Figure 3 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.

Every few years in the Pacific Ocean, normal shore upwellings (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 tropical trade winds blowing east to west weaken or reverse direction. This allows the warmer waters of the western Pacific to

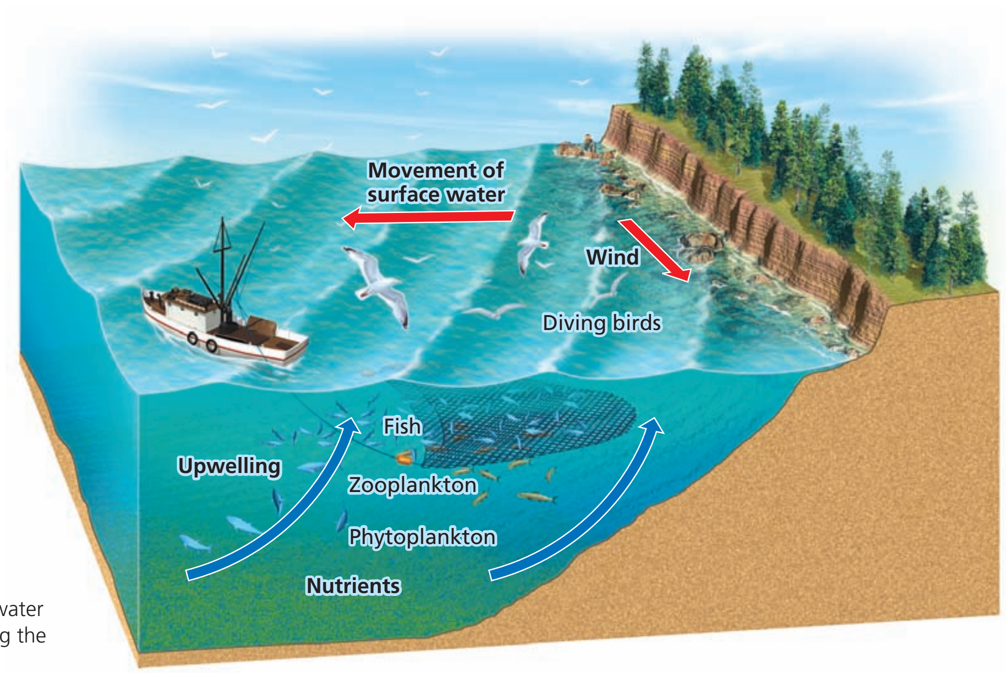


Figure 3 A *shore upwelling* occurs when deep, cool, nutrient-rich waters are drawn up to replace surface water moved away from a steep coast by wind flowing along the coast toward the equator.

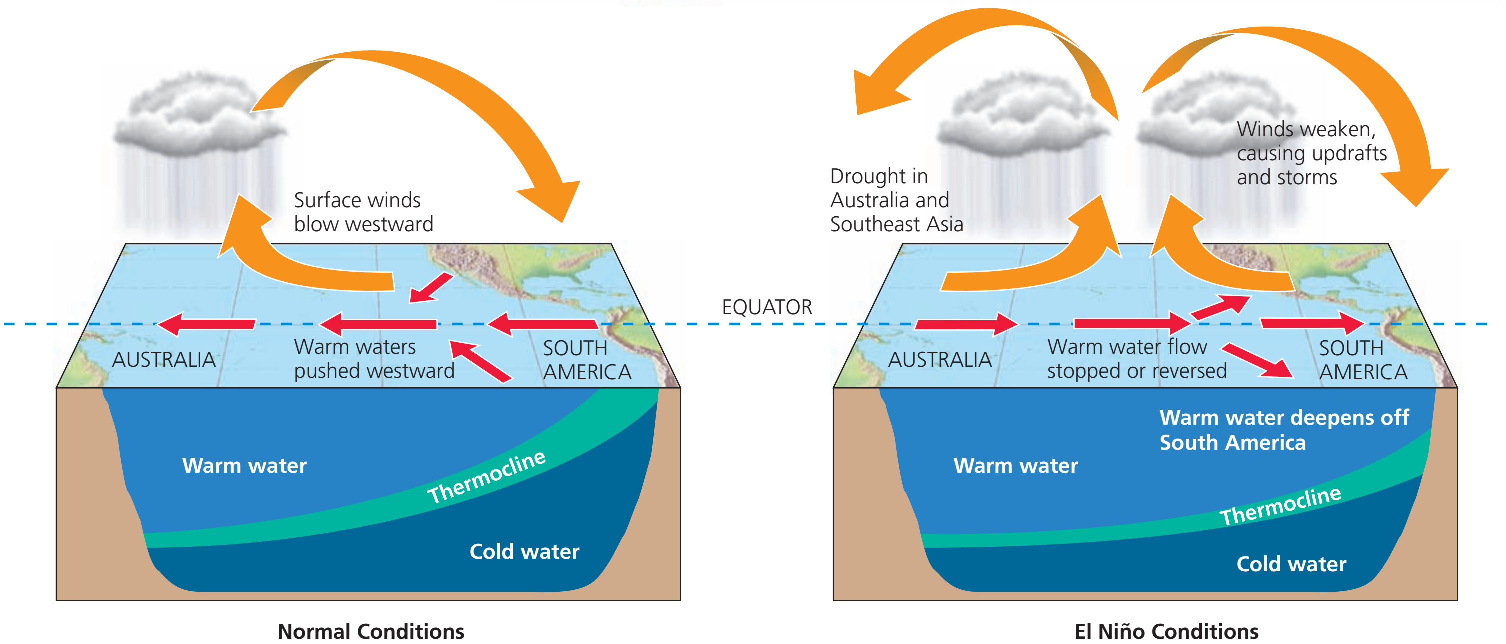


Figure 4 Normal trade winds blowing east to west cause shore upwellings of cold, nutrient-rich bottom water in the tropical Pacific Ocean near the coast of Peru (left). A zone of gradual temperature change called the *thermocline* separates the warm and cold water. Every few years a shift in trade winds 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).

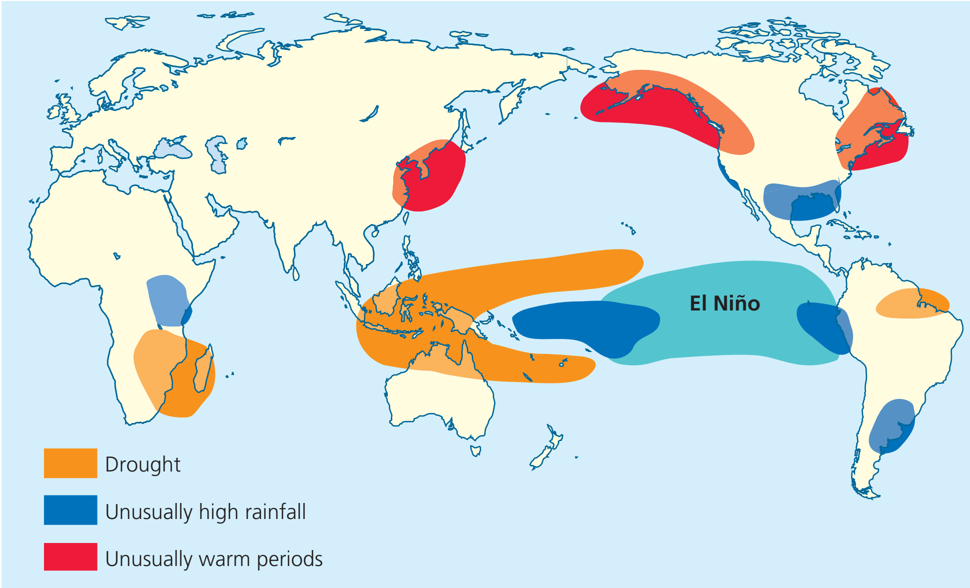


Figure 5 Typical global weather effects of an El Niño–Southern Oscillation. During the 1996–1998 ENSO, huge waves battered the coast in the U.S. state of California and torrential rains caused widespread flooding and mudslides. In Peru, floods and mudslides killed hundreds of people, left about 250,000 people homeless, and ruined harvests. Drought in Brazil, Indonesia, and Australia led to massive wildfires in tinder-dry forests. India and parts of Africa also experienced severe drought. A catastrophic ice storm hit Canada and the northeastern United States, but the southeastern United States had fewer hurricanes. **Question**: How might an ENSO affect the weather where you live or go to school? (Data from United Nations Food and Agriculture Organization)

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 land).

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 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 midwestern plains.

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 in such a rising column of air, the air near the ground is moving more slowly than the air above. This difference causes the air ahead of the advancing front to spin in the vertically rising air mass, or vortex.

Figure 7 (p. S36) 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 (p. S36) 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

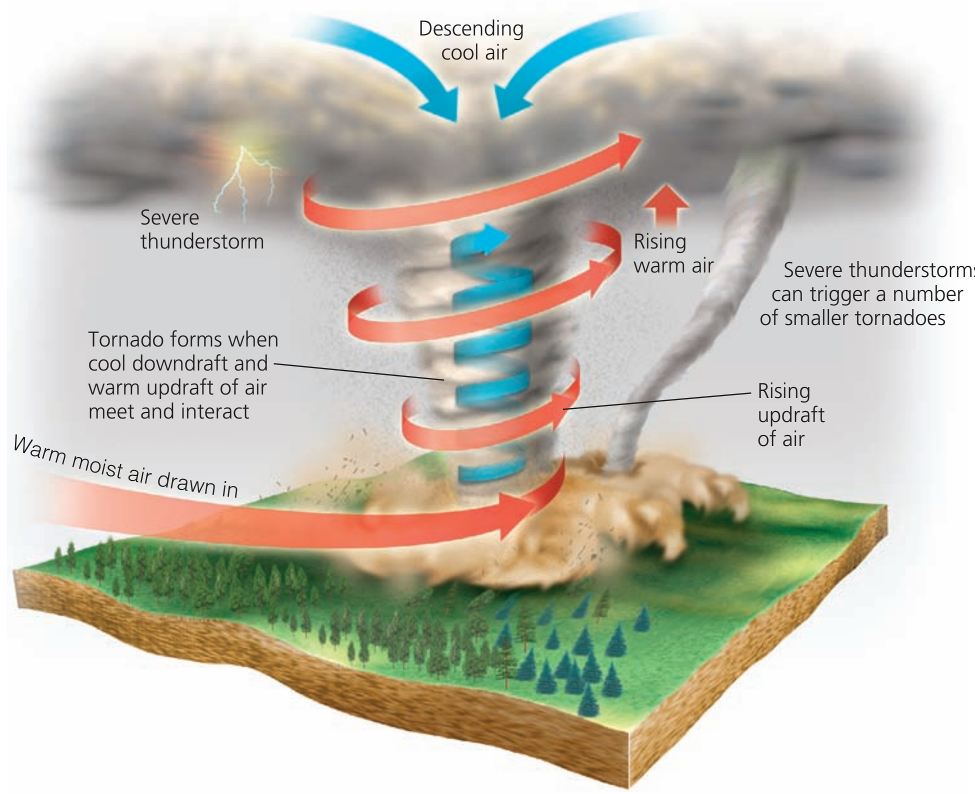
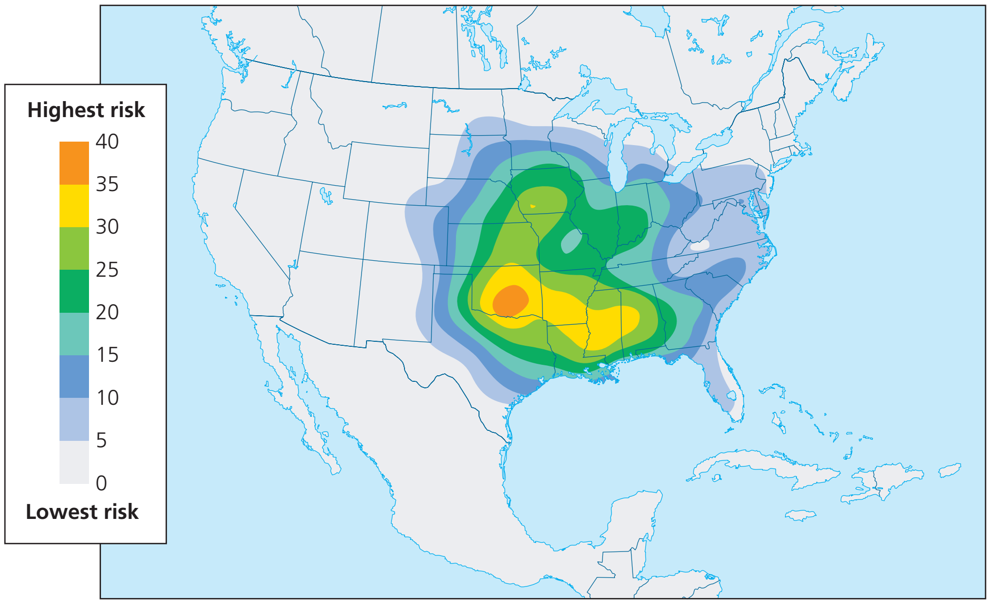


Figure 6 Formation of a *tornado*, or *twister*. Although twisters can form at any time of the year, the most active tornado season in the United States is usually March through August. Meteorologists cannot tell us with great accuracy when and where most tornadoes will form.

Figure 7 States with *very high* and *high* tornado risk in the continental United States. (Data from NOAA)



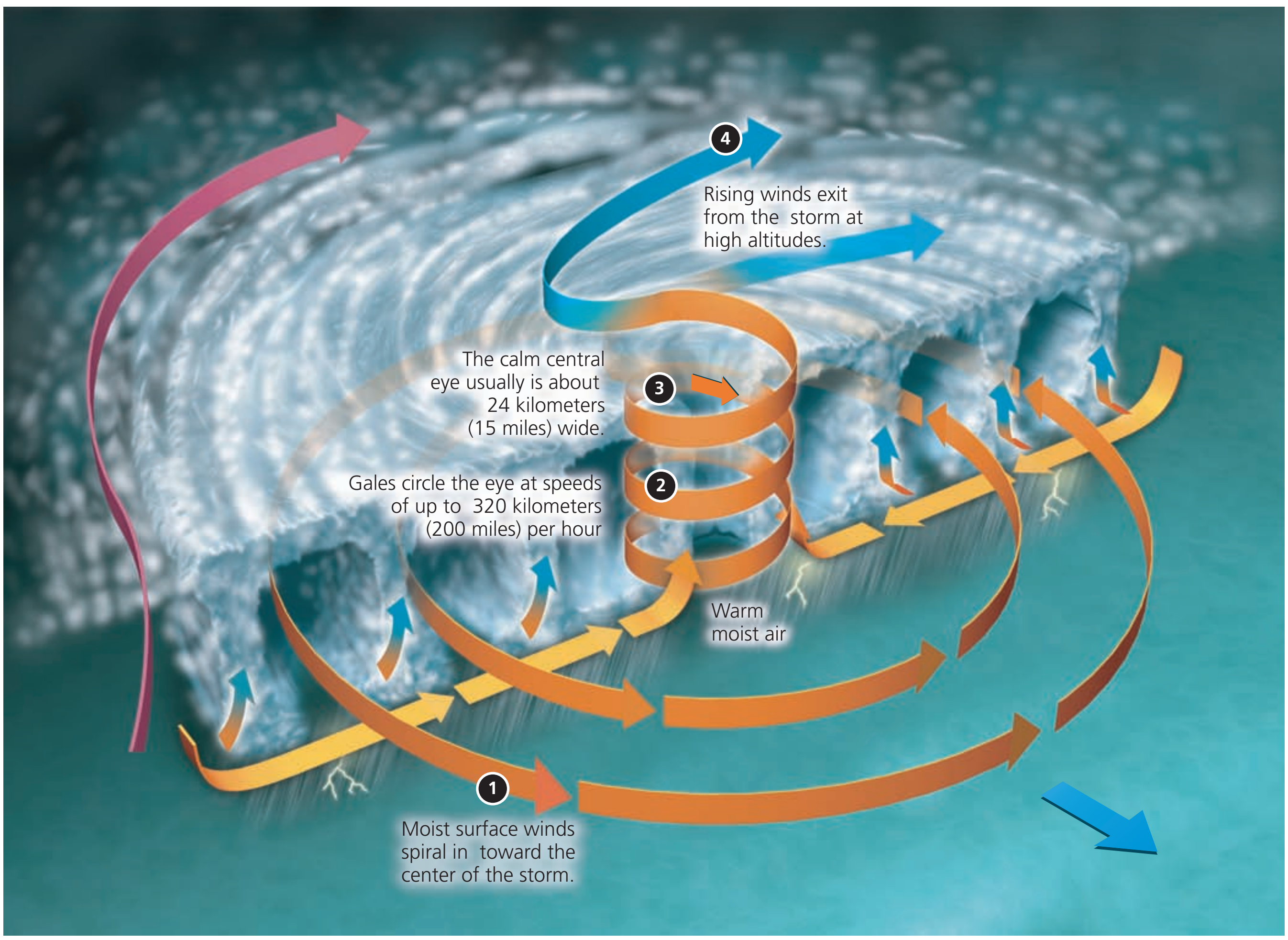


Figure 8 Formation of a *tropical cyclone*. Those forming in the Atlantic Ocean usually are called *hurricanes*; those forming in the Pacific Ocean usually are called *typhoons*.

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 27 °C (80 °F) 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 (Figure 7-3, p. 124). 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*: 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 normally are closed off from freshwater and saltwater inflows. In August 1999, Hurricane Brett struck this coastal area. According to marine biologists, it 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.

SUPPLEMENT

9

Maps and Data: Energy and Climate (Chapters 9, 13, 15)

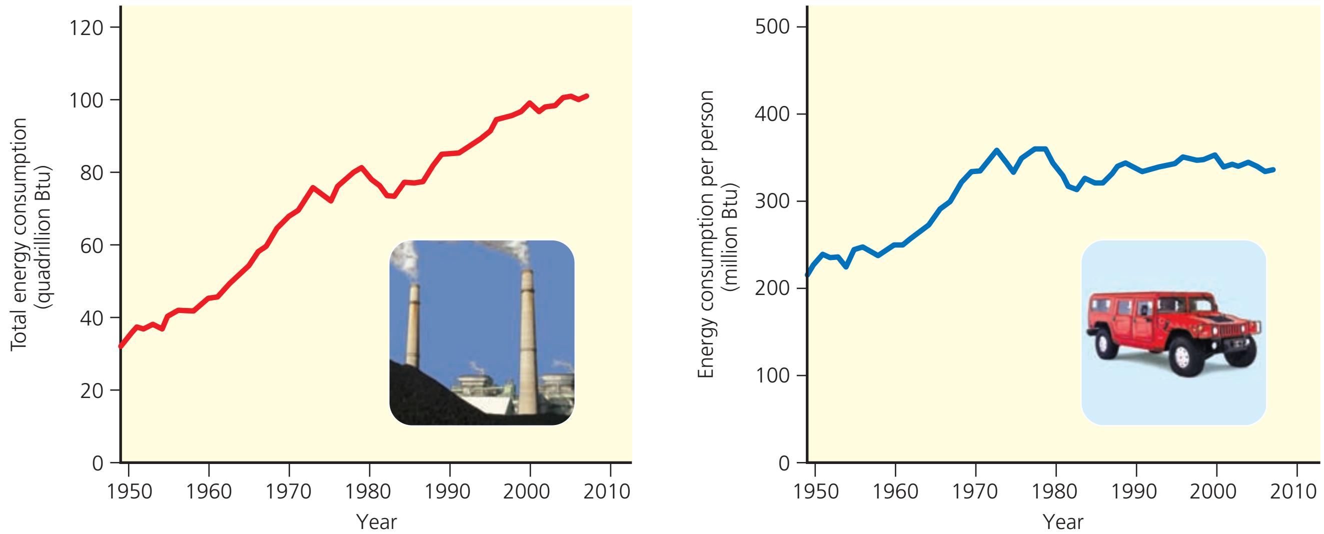
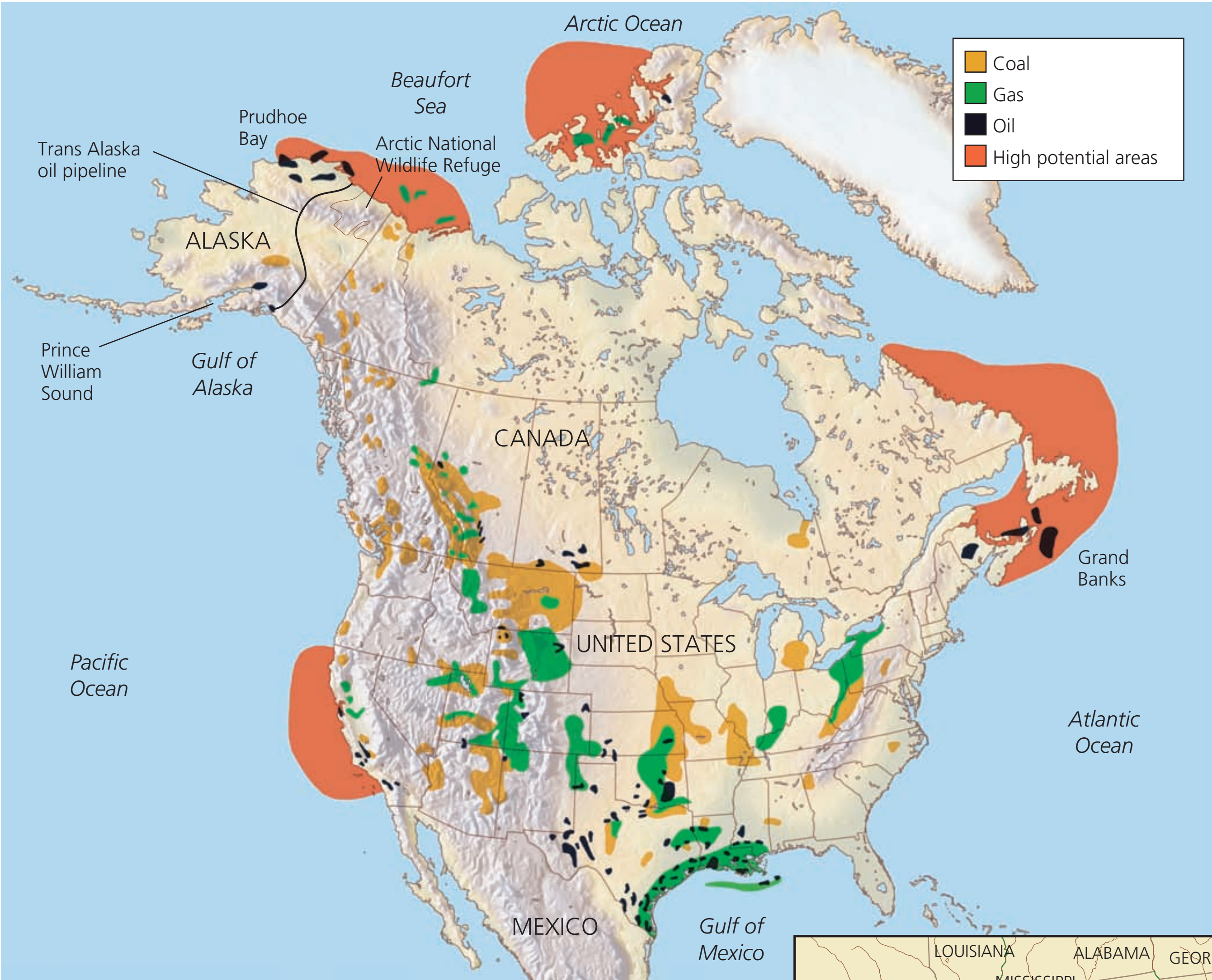


Figure 1 Total (left) and per capita (right) energy consumption in the United States, 1950–2007. (Data from U.S. Energy Information Administration/ Annual Energy Review 2008)

Data and Graph Analysis

1. In what year or years did the 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?



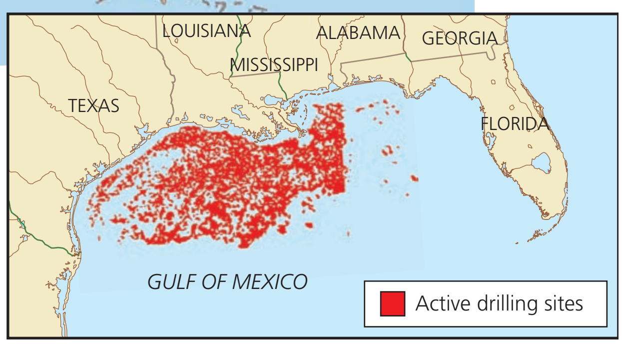


Figure 2 Locations of the major known deposits of oil, natural gas, and coal in North America, and offshore areas where more crude oil and natural gas might be found. Geologists do not expect to find very much new oil and natural gas in North America. Offshore drilling for oil accounts for about one-fourth of U.S. oil production. Nine of every ten barrels of this oil comes 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 Council on Environmental Quality and 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 has the longest total coastal area with high potential for oil and natural gas deposits?

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 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. oil reserves are projected to be 80% depleted.
2042–2083	A gradual decline in dependence on oil is expected.

Figure 3 Brief history of the Age of Oil.

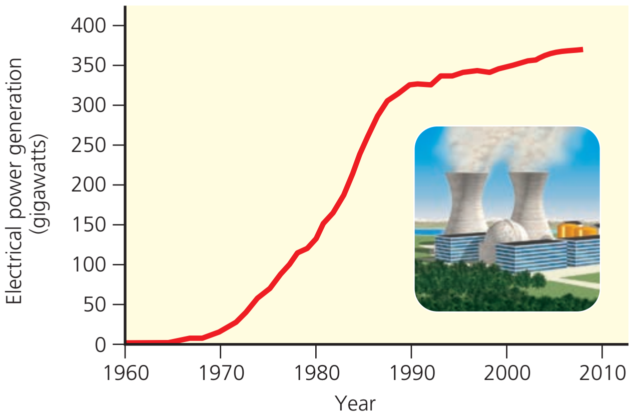


Figure 4 Electrical generating capacity of nuclear power plants, 1960–2008. (Data from International Energy Agency and Worldwatch Institute)

Data and Graph Analysis

1. After 1980, how long did it take to double the generating capacity that existed in 1980?
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?

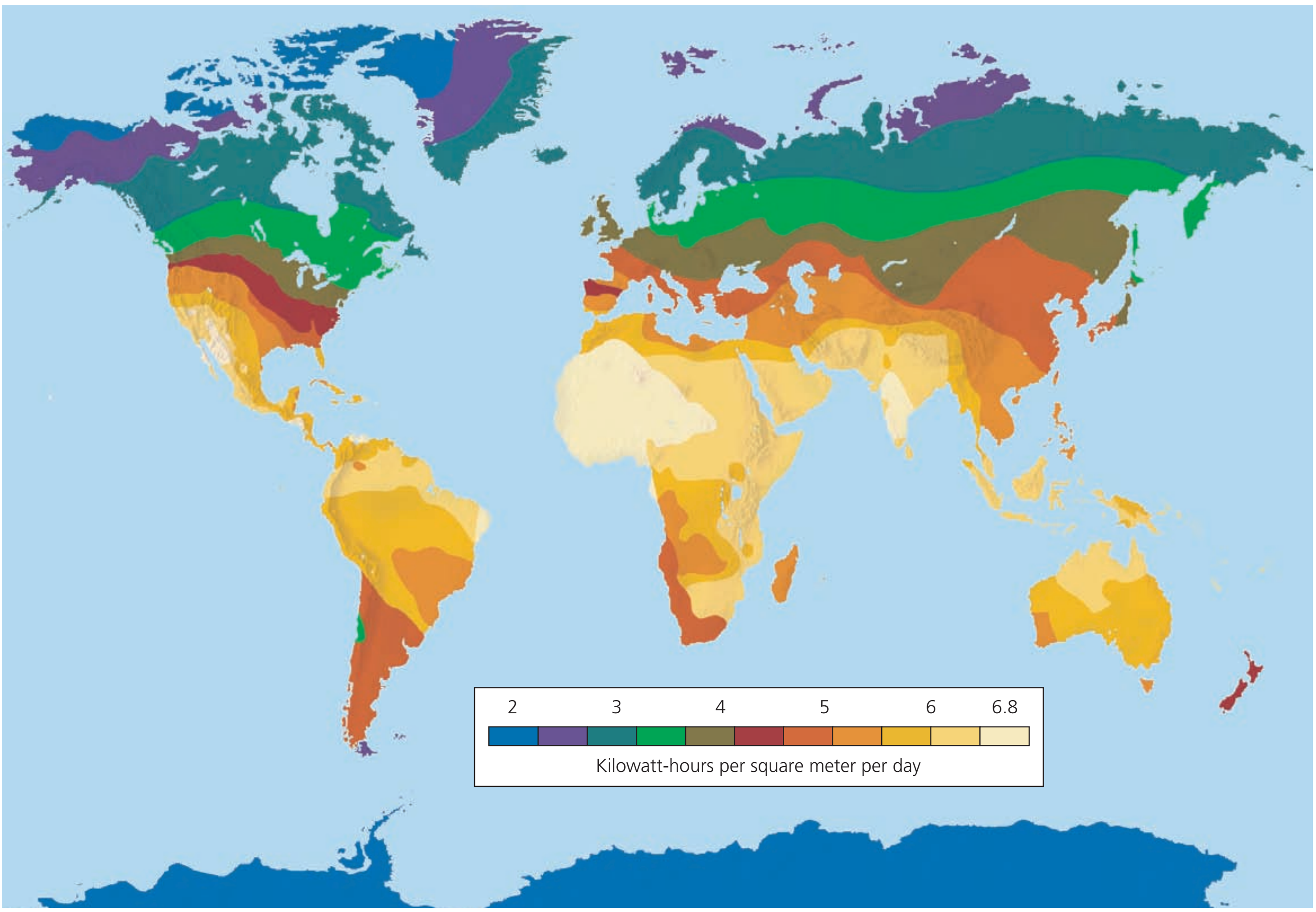


Figure 5 Global availability of direct solar energy. Areas with more than 3.5 kilowatt-hours per square meter per day (see scale) are good candidates for passive and active solar heating systems and use of solar cells to produce electricity. The United Nations is mapping the potential wind and solar 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 Supplement 3, pp. S6–S7, for continent names.)

Figure 6 Global cumulative production of electricity by solar (photovoltaic) cells, 1980–2008. (Data from PV News, Worldwatch Institute, and Global Data 2009)

Data and Graph Analysis

1. About how many times as much solar-cell production had occurred by 2008 as had occurred by 2000?
2. How long did it take the world to go from 0 to 6,000 in its cumulative production of electricity by solar cells?

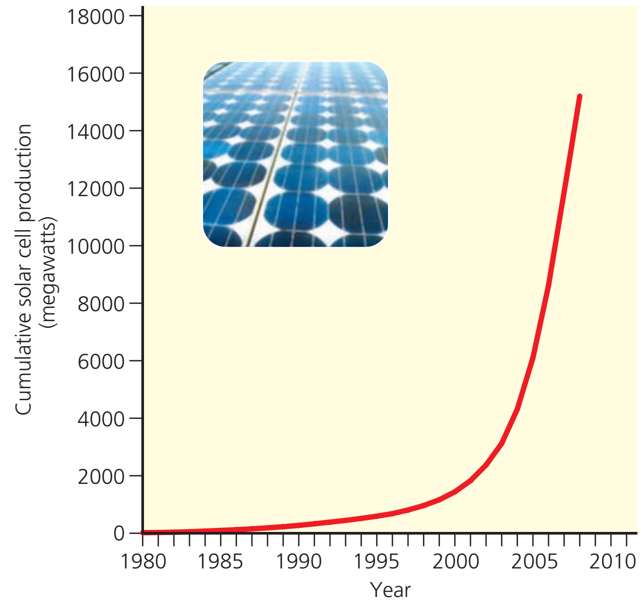
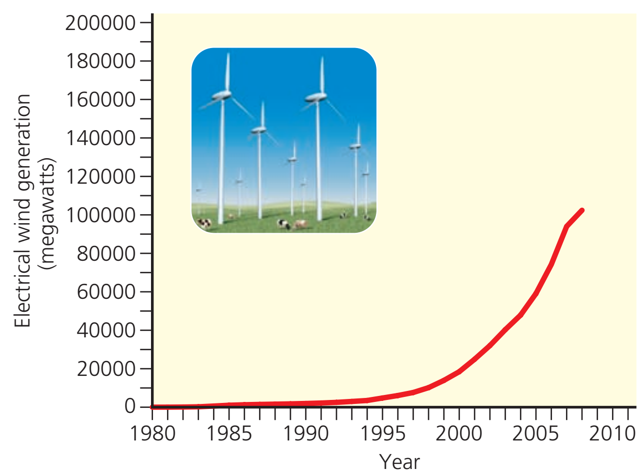


Figure 7 Global installed capacity for generation of electricity by wind energy, 1980–2008. (Data from Global Wind Energy Council, European Wind Energy Association, American Wind Energy Association, Worldwatch Institute, and World Wind Energy Association, 2009)

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 generation of electricity by wind energy?
2. In 2008, the world's installed capacity for generating electricity by wind power was about how many times as much as it was in 1995?



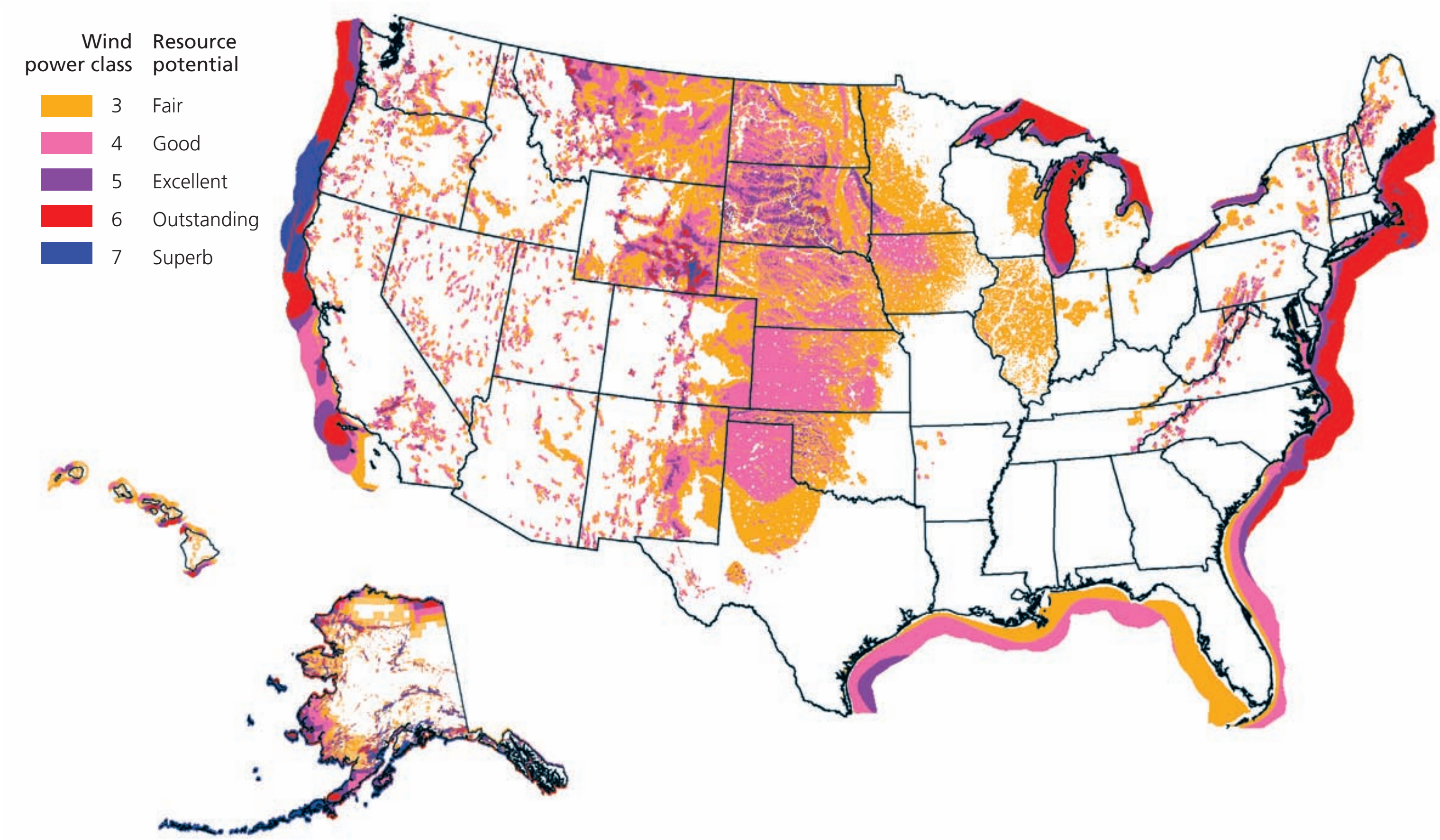


Figure 8 Potential supply of land-based wind energy (an indirect form of solar energy) in the United States. Locate the areas with the highest potential for wind power. Other excellent sites are found offshore along coasts in parts of the United States. Electricity produced by wind farms at such sites can be distributed through the country's electric power grid. 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?

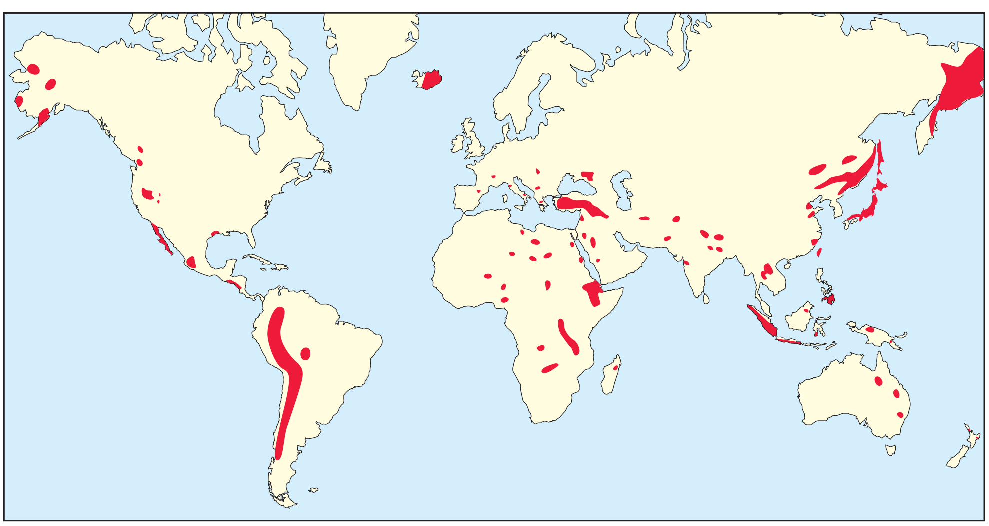


Figure 9 Known global reserves of moderate- to high-temperature geothermal energy. **Question**: What is the potential for tapping into geothermal energy as a source of heat or to produce electricity near where you live or go to school? (Data from Canadian Geothermal Resources Council)

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, pp. S6–S7, in Supplement 3 for country and continent names.)
2. What country in Asia has the greatest known reserves of geothermal energy?

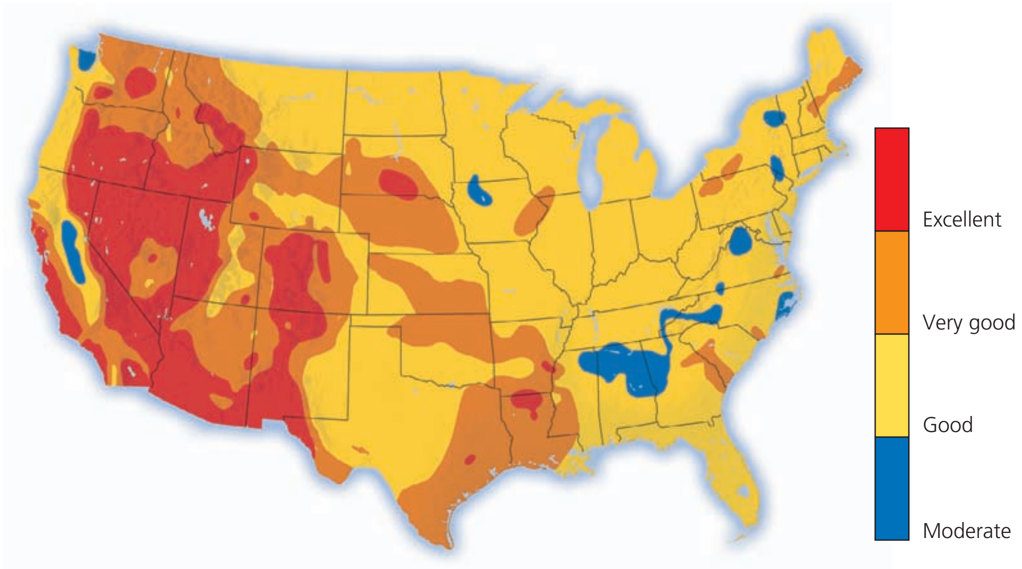


Figure 10 Potential geothermal energy resources in the continental United States. (Data from U.S. Department of Energy)

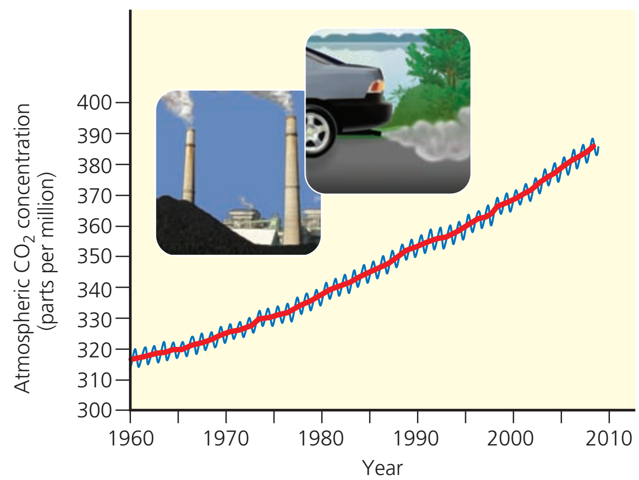
Data and Map Analysis

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 11 Average atmospheric concentration of carbon dioxide (CO_2) (red curve) measured at Mauna Loa, Hawaii, 1950–2008. The annual fluctuation in CO_2 values (blue jagged curve) occurs because land plants take up varying amounts of CO_2 in different seasons. (Data from Scripps Institute of Oceanography, 2009, and U.S. Energy Information Agency, 2009)

Data and Graph Analysis

1. How much did atmospheric CO_2 concentrations grow between 1960 and 2008 (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 400 parts per million.



North America

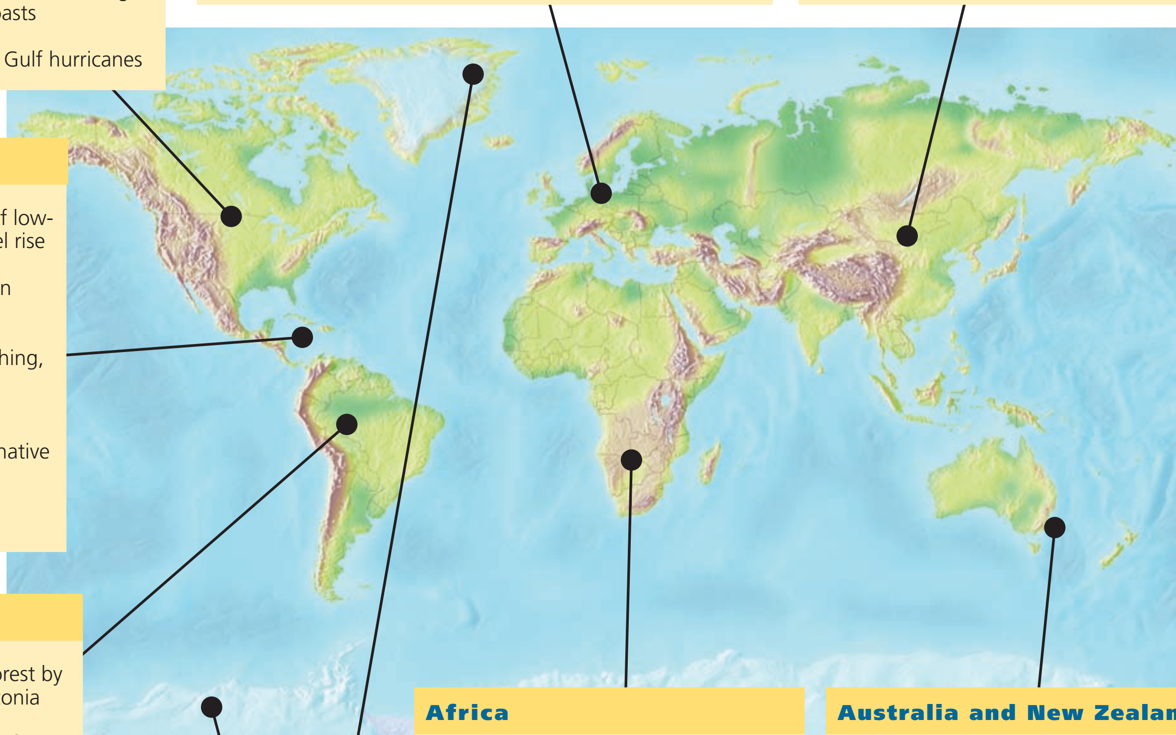
- In the western mountains, decreased snowpack, earlier snowmelt, more winter flooding, and reduced summer water flows
- Increased forest growth and increased forest fires
- Rapid melting of Alaska glaciers
- Increased intensity, duration and number of heat waves in many cities
- Sea-level rises, tidal surges, and flooding along Gulf and Atlantic coasts
- More intense Atlantic and Gulf hurricanes

Europe

- Increased risk of inland flash floods and coastal flooding
- Disappearance of alpine glaciers
- In the south, more health-threatening heat waves and wildfires, reduced forest area, reduced water availability and hydropower potential, reduced crop yields, and reduced summer tourism
- In the central and eastern areas, more heat waves and peatland fires and reduced summer rainfall and forest productivity
- In the north, negative impacts eventually outweigh such initial benefits as reduced heating demand, less severe winters, increased forest area, and increased crop yields and forest growth

Asia

- Increased flooding, rock avalanches and water resource disruptions from melting Himalayan glaciers
- Ongoing risk of hunger in several developing regions because of crop productivity declines combined with rapid population growth and urbanization
- Coastal flooding from rising sea levels



Small Islands

- Severe flooding and loss of low-lying islands from seal-level rise
- Reduced water resources in many places
- Beach erosion, coral bleaching, loss of mangroves, and declining fisheries
- Increased invasion by nonnative species
- Decreased tourism

Latin America

- Replacement of tropical forest by savannah in eastern Amazonia
- Desertification of farmland from increased drought in dry areas
- Melting of glaciers in tropical Andes with reduced water supplies and hydropower generation
- Rice yields may fall but soybean yields may increase

Polar Regions

- Thinning and shrinking of glaciers and ice sheets
- Decreased Arctic summer sea ice
- Decreased permafrost
- Increased agriculture and forest cover in Siberia
- Arctic tundra replaced by forest

Africa

- Decreased water availability by 2020 for 75 million–250 million people
- Loss of arable land, reduced growing seasons and reduced crop yields in some areas
- Decreased fish stocks in large lakes
- Coastal flooding from rising sea levels
- Flooding, drought, spread of disease

Australia and New Zealand

- Intensified water shortages in southern and eastern Australia and parts of New Zealand by 2030
- Increased loss of biodiversity by 2020
- Increased bush fires
- Increased storm severity and frequency in several places
- Coastal flooding from sea-level rise

Figure 12 Projected regional impacts of global warming during this century. (Data from Intergovernmental Panel on Climate Change, 4th Assessment, 2007)

Data and Map Analysis

1. In the area where you were born, what do you think will be the two most serious projected impacts of global warming?
2. Find three impacts listed on this map that you think may be happening already. Describe these effects and tell exactly where you think they are occurring.

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 will interact with and affect its environment.

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 radiation Process in which numerous new species evolve to fill vacant and new ecological niches in changed environments, usually after a mass extinction. Typically, this process takes millions of years.

adaptive trait See *adaptation*.

advanced sewage treatment Third level of sewage cleanup, which uses a series of specialized chemical and physical processes to remove specific pollutants left in the water after primary and secondary treatment. See *primary sewage treatment* and *secondary sewage treatment*.

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*.

age structure Percentage of the population (or number of people of each gender) at each age level in a population.

agricultural revolution Gradual shift from small, mobile hunting and gathering bands to settled agricultural communities in which people survived by breeding and raising wild animals and cultivating wild plants near where they lived. It began 10,000–12,000 years ago. Compare *environmental revolution*, *hunter–gatherers*, *industrial–medical revolution*, *information and globalization revolution*.

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 and noise are also considered forms 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.

altitude Height above sea level. Compare *latitude*.

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. 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 deep 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 that is made 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 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 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.

barrier islands Long, thin, low offshore islands of sediment that generally run parallel to the shore along some coasts.

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 *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 Composed of material that can be 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 *degradable pollutant*, *nondegradable pollutant*, *slowly degradable 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 hotspots Areas especially rich in plant species that are found nowhere else and are in great danger of extinction. These 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) 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 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 *adaptation*, *differential reproduction*, *natural selection*, *theory of evolution*.

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 characterized by certain types of vegetation and other forms of life. Examples include various types of deserts, grasslands, and forests.

biopharming Use of genetically engineered animals to produce drugs, vaccines, antibodies, hormones, industrial chemicals such as plastics and detergents, and human body organs.

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 potential Maximum rate at which the population of a given species can increase when there are no limits on its rate of growth. Compare *environmental resistance*.

birth rate See *crude birth rate*.

bitumen Gooey, black, high-sulfur, heavy oil extracted from oil sand and then upgraded to synthetic fuel oil. See *oil sand*.

breeder nuclear fission reactor Nuclear fission reactor that produces more nuclear fuel than it consumes by converting nonfissionable uranium-238 into fissionable plutonium-239.

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.

capital Money and other forms of wealth that can be used to support a lifestyle or economy.

carbon capture and storage (CCS) Process of removing carbon dioxide gas from coal-burning power and industrial plants and storing it permanently somewhere (usually underground or under the seabed) so that it is not released into the atmosphere.

carbon cycle Cyclical 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*) Capacity of a given habitat to support a given species, stated in terms of the maximum population of the species that the habitat can support over a given period.

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. See *DNA*.

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 plastic foam. 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.

chromosome A grouping of genes and associated proteins in plant and animal cells that carry certain types of genetic information. See *genes*.

chronic malnutrition See *malnutrition*.

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 *malnutrition*.

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 the *temperature*, with its seasonal variations, and the amount and distribution of *precipitation*. Compare *weather*.

climate change Broad term referring to changes in any aspects of the earth's climate, including long-term averages in temperature, precipitation, and storm activity. Compare *weather*.

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 saltwater 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 shelf-like 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 *biological 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) 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 forest See *tree plantation*.

commercial inorganic fertilizer Commercially prepared mixture of plant nutrients such as nitrates, phosphates, and potassium applied to the soil to restore fertility and increase crop yields. Compare *organic fertilizer*.

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*, *private property 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.

composting Form of recycling that mimics nature's recycling of nutrients; used to recycle organic materials into materials that can be used a nutrients for gardens or crops.

compound Combination of atoms, or oppositely charged ions, of two or more elements held together by attractive forces called chemical bonds. Compare *element*.

concentration Amount of a chemical in a particular volume or weight of air, water, soil, or other medium.

condensation nuclei Tiny particles on which droplets of water vapor can collect.

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*, *broadleaf evergreen plants*.

coniferous trees Cone-bearing trees, mostly evergreens, that have needle-shaped or scale-like leaves. They produce wood known commercially as softwood. Compare *deciduous plants*.

consensus science See *reliable science*.

conservation Sensible and careful use of natural resources by humans. People who advocate or practice it 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.

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*.

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*.

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*.

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 *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 Limit on population growth that would allow most people to live in reasonable comfort and freedom without impairing the ability of the planet to sustain future generations.

cultural eutrophication Overnourishment of aquatic ecosystems with plant nutrients (mostly nitrates and phosphates) resulting from human activities such as agriculture, urbanization, and discharges from industrial plants and sewage treatment plants. See *eutrophication*.

currents Mass movements of surface water produced by prevailing winds blowing over the oceans.

dam 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 harmful development.

deciduous plants Trees such as oaks and maples and other plants that survive during dry seasons 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. This process returns most of these chemicals to the soil and water for reuse. Decomposers consist of various bacteria and fungi. Compare *consumer*, *detritivore*, *producer*.

deforestation Removal of trees from a forested area without adequate replanting.

degradable pollutant Potentially polluting chemical that is broken down completely or reduced to acceptable levels by natural physical, chemical, and biological processes. Compare *biodegradable pollutant*, *nondegradable pollutant*, *slowly degradable pollutant*.

degree of urbanization Percentage of the population in the world or a country living in areas with a population of more than 2,500 people (higher by some other definitions). 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.

desalination Purification of saltwater 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, rainfed cropland, or irrigated cropland to desert-like 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. The two principal types are *detritus feeders* and *decomposers*.

detritus Parts of dead organisms and cast-off fragments and wastes of living organisms.

detritus feeder Organism that extracts nutrients from fragments of dead organisms and their cast-off parts and organic wastes. Examples include earthworms, termites, and crabs. Compare *decomposer*.

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 Country that is highly industrialized and has a high per capita GDP. Compare *developing country*.

developing 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 *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.

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.

distribution Area or volume over which a species is found.

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.

DNA (deoxyribonucleic acid) Large molecules in the cells of organisms that carry genetic information in living organisms.

domesticated species Wild species tamed or genetically altered by crossbreeding for use by humans for food (cattle, sheep, and food crops), pets (dogs and cats), or enjoyment (animals in zoos and plants in 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 rock, which produces a fault, or from subsequent movement along the fault.

ecological diversity 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 efficiency Percentage of energy transferred from one trophic level to another in a food chain or web.

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 measures 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.

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 succession*, *secondary succession*.

ecological tipping point Point in the development of an environmental problem where a threshold level is reached, causing an 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*.

economics Social science that deals with the production, distribution, and consumption of goods and services to satisfy people's needs and wants.

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 Community of different species interacting with one another and with the chemical and physical factors making up its 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. Compare *compound*.

elevation Distance above sea level.

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*.

enhanced greenhouse effect See *global warming*, *greenhouse effect*.

environment All external conditions and factors, living and nonliving (chemicals and energy), 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 people on environmental quality and believes that some human actions are degrading parts of the earth's life-support systems for humans and many other forms of life.

environmental justice Fair treatment and meaningful involvement of all people regardless of race, color, sex, national origin, or income with respect to resource development and use, waste disposal systems, and development, implementation, and enforcement of environmental laws, regulations, and policies.

environmentally sustainable economic development Development that *encourages* forms of economic growth that meet 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 and *discourages* environmentally harmful and unsustainable forms of economic growth. 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 basic 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 law Body of statements defining what is acceptable environmental behavior for individuals and groups, according to the larger community, and attempting to balance competing social and private interests.

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 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. See *environmental wisdom worldview*.

environmental science Interdisciplinary study that uses information and ideas from the physical sciences (such as biology, chemistry, and geology), the social sciences (such as economics and political science) and the humanities (such as history and ethics) to learn how nature works, how we interact with the environment, and how we can 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.

environmental wisdom worldview View holding that humans are part of, and totally dependent on, nature; that nature exists for all species, not just for us; that we should encourage earth-sustaining forms of economic growth and development and discourage earth-degrading forms; and that our success depends on learning how the earth sustains itself and integrating such environmental wisdom into the ways we think and act. Compare *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*, *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 toxic exposure 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 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.

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 ferns and 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*.

existence value See *intrinsic value*.

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. When the increase in quantity over time is plotted, this type of growth yields a curve shaped like the letter J. Compare *linear growth*.

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*.

extinction rate Percentage or number of species that go extinct within a certain 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. Compare *rangeland*.

fermentation See *anaerobic respiration*.

fertility rate Number of children born to a woman during her lifetime.

fertilizer Substance that adds inorganic or organic plant nutrients to soil and improves its ability to nourish crops, trees, or other vegetation. See *commercial inorganic fertilizer*, *organic fertilizer*.

first law of thermodynamics In any physical or chemical change, no detectable amount of 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 energy can be produced from small amounts of matter. See *second law of thermodynamics*.

fishery Concentrations of particular aquatic species suitable for commercial harvesting in a given ocean area or inland body of water.

fish farming Form of aquaculture in which fish are cultivated in a controlled pond or other environment and harvested when they reach the desired size. See also *fish ranching*.

fishprint Area of ocean needed to sustain the consumption of an average person, a nation, or the world. Compare *ecological footprint*.

fish ranching Form of aquaculture in which members of a fish species such as salmon are held in captivity for the first few years of their lives, released, and then harvested as adults when they return from the ocean to their freshwater birthplace to spawn. See also *fish farming*.

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 *throughput*.

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 that occur 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 communities 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 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.

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.

gamma ray Form of ionizing electromagnetic radiation with a high energy content emitted by some radioisotopes. It readily penetrates body tissues. See *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) Economic and environmental indicator that adds to the *GDP* estimated value of beneficial transactions in which no money changes hands and subtracts estimated harmful environmental, health, and social costs of all transactions. Compare *gross domestic product (GDP)*.

geographic isolation Separation of populations of a species for long times into different areas.

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.

globalization Broad process of global social, economic, and environmental change that leads to an increasingly integrated world.

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 irreversible 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 there is 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) reflected 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 gradually. Compare *global warming*. See also *natural greenhouse effect*.

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 (including rice, wheat, and corn) that, with adequate inputs of fertilizer and water, can greatly increase crop yields.

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*.

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 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.

half-life Time needed for one-half of the nuclei in a radioisotope to emit their radiation. Each radioisotope has a characteristic half-life, which may range from a few millionths of a second to several billion years. See *radioisotope*.

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. 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 cooler 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 the 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-and-reuse 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 fish.

hydrocarbon Organic compound 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.

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*.

immigrant species See *nonnative species*.

immigration Migration of people into a country or area to take up permanent residence.

indicator species Species that serve 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–medical revolution Use of new sources of energy from fossil fuels and later from nuclear fuels, and use of new technologies, to grow food and manufacture products. Compare *agricultural revolution*, *environmental revolution*, *hunter–gatherers*, *information and globalization revolution*.

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.

inertia Ability of a living system, such as a grassland or a forest, to survive moderate disturbances. Compare *resilience*.

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.

information and globalization revolution Use of new technologies such as the telephone, radio, television, computers, the Internet, automated databases, and remote sensing satellites to enable people to have increasingly rapid access to much more information on a global scale. Compare *agricultural revolution*, *environmental revolution*, *hunter–gatherers*, *industrial–medical revolution*.

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*.

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 size 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 *agroforestry, monoculture*, *polyculture*, *polyvarietal cultivation*.

interplanting See *intercropping*.

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. 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*.

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*.

K-selected species Species that produce a few, often fairly large offspring but invest a great deal of time and energy to ensure that most of those offspring reach reproductive age. Compare *r-selected species*.

K-strategists See *K-selected species*.

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 directly north or south 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*.

LD50 See *median lethal dose*.

leaching Process in which various chemicals in upper layers of soil are dissolved and carried to lower layers and, in some cases, to groundwater.

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 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 *liquified natural gas*.

loams Soils containing a mixture of clay, sand, silt, and humus. Good for growing most crops.

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; not degrading renewable resources; building things that are easy to recycle, reuse, and repair; not allowing population size to exceed the carrying capacity of the environment; and preserving biodiversity and ecological integrity. Compare *high-throughput economy*, *matter-recycling-and reuse economy*.

low-waste economy See *low-throughput economy*.

LPG See *liquefied petroleum gas*.

magma Molten rock below the earth's surface.

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*, *undernutrition*.

mangrove forest Swamp found on the coastlines in warm tropical climates. It is 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 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*.

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*.

materials recovery facility (MRF) Facility where machines or workers separate mixed wastes to recover valuable materials for sale to manufacturers as raw materials; the remaining paper, plastics, and other combustible wastes are recycled or burned to produce steam or electricity, which is used to run the facility, or sold to nearby industries or homes.

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*.

maximum sustainable yield See *sustainable yield*.

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 core of a nuclear reactor.

mesotrophic lake Lake with a moderate supply of plant nutrients. Compare *eutrophic lake*, *oligotrophic lake*.

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*.

micronutrients Chemical elements that organisms need in small or even trace amounts to live, grow, or reproduce. Examples include sodium, zinc, copper, chlorine, and iodine.

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, and household solar-cell panels and solar-cell roofs.

migration Movement of people into and out of specific geographic areas. Compare *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*, *polyvarietal cultivation*.

mountaintop removal Type of surface mining that uses explosives, massive shovels, and even larger machinery called draglines to remove the top of a mountain to expose seams of coal underneath a mountaintop. 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*.

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.

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 Heat buildup in the troposphere because of the presence of certain gases, called greenhouse gases. Without this effect, the earth would be nearly as cold as Mars and life as we know it could not exist. Compare *global warming*.

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 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, and 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 by lightning, bacteria, and cyanobacteria of atmospheric nitrogen gas into forms useful to plants; it is part of the nitrogen cycle.

nitrogen oxides (NO_x) See *nitric oxide, 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*, *degradable pollutant*, *slowly degradable 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*.

nonpersistent pollutant See *degradable pollutant*.

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*.

nuclear power fuel cycle Cycle required to produce nuclear power, which includes extracting and processing uranium ore, converting it into nuclear fuel, building and operating the nuclear power plant, safely storing the resulting highly radioactive wastes for thousands of years, dismantling the plant after its useful life (typically 40–60 years), and safely storing the highly radioactive parts for thousands of years.

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 element or compound 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 soil and water) through organisms and back to the environment.

ocean current Mass movements of surface water in oceans, driven by winds.

oil See *crude oil*.

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*, *private 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 and legally extracted at a given time. An ore typically contains 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 without or with limited use of synthetic pesticides and synthetic fertilizers and raising livestock without synthetic growth regulators and feed additives, and instead, using organic fertilizer (manure, legumes, compost) and natural pest control (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*, *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*.

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 fish, 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 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 deposited in bodies of water and can be 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.

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. Typically, about two-thirds of the SPM in outdoor air comes from natural sources such as dust, wild fires, and sea salt, and the remaining third 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 captures sunlight directly within a structure and converts it to low-temperature heat for space heating or for heating water for domestic use without the use of mechanical devices. 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*, *rangeland*.

pathogen Living organism that can cause disease in another organism. Examples include bacteria, viruses, and parasites.

PCBs See *polychlorinated biphenyls*.

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. Formerly called per capita gross national product (GNP). See *gross domestic product*.

per capita GDP PPP 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 Resource that is essentially inexhaustible on a human time scale because it is renewed continuously. Solar energy is an example. Compare *nonrenewable resource*, *renewable resource*.

persistence The ability of a living system such as a grassland or a forest to survive moderate disturbances. Also the tendency for a pollutant to stay in the air, water, soil, or body. Compare *resilience*.

persistent pollutant See *slowly degradable pollutant*.

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.

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*.

planetary management worldview View 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 meat-packing 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 Set of laws and regulations that a government enforces and the programs it 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 or process that prevents a potential pollutant from forming or entering the environment or sharply reduces 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*, *polyvarietal cultivation*.

polyvarietal cultivation Planting a plot of land with several varieties of the same crop. Compare *intercropping*, *monoculture*, *polyculture*.

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 Population dieback occurring when a population exceeds the carrying capacity of its environment for that species.

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 to meet basic needs for food, clothing, and shelter.

ppb See *parts per billion*.

ppm See *parts per million*.

ppt See *parts per trillion*.

prairie See *grasslands*.

precautionary principle When there is 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 Situation in which an organism of one species (the predator) captures and feeds on parts or all of an organism of another species (the prey).

predator Organism that captures and feeds on parts or all of an organism of another species (the prey).

predator–prey relationship Interaction between two organisms of different species in which one organism, called the *predator*, captures and feeds on parts or all of the other organism, called the *prey*.

prey Organism that is captured and serves as a source of food for an organism of another species (the predator).

primary consumer Organism that feeds on all or part of plants (herbivore) or on other producers. Compare *detritivore*, *omnivore*, *secondary consumer*.

primary ecological succession Ecological succession in a barren area that has never been occupied by a community of organisms or where all communities have been eliminated. See *ecological succession*. Compare *secondary ecological succession*.

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 *advanced sewage treatment*, *secondary sewage treatment*.

principles of sustainability Principles by which nature has sustained itself for billions of years by relying on solar energy, biodiversity, and nutrient recycling.

private property resource Land, mineral, or other resource owned by individuals or a firm. Compare *common property resource*, *open access renewable resource*.

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*.

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*.

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 *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 far side (leeward side) of a mountain resulting when prevailing winds flow up and over a high mountain or range of high mountains and drop most of the air's moisture as precipitation on the windward side of the mountain; this creates semiarid and arid conditions on the leeward side of a high mountain range.

range See *distribution*.

rangeland Land that supplies forage or vegetation (grasses, grass-like 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.

rare species Species that has naturally small numbers of individuals (often because of limited geographic ranges or low population densities) or that has been locally depleted by human activities.

recharge area Any area of land allowing water to pass through it and into an aquifer. See *aquifer*, *natural recharge*.

reconciliation ecology Science of inventing, establishing, and maintaining new habitats to conserve species diversity in places where people live, work, or play.

recycling Collecting and reprocessing a resource so that it can be made into new products. 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 *reuse*.

reduce First of the three Rs; choosing to consume a smaller amount of resources or products in order to lessen one's ecological footprint. Compare *recycling*, *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 people planting seeds or seedlings.

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*.

reliable surface runoff Surface runoff of water that generally can be counted on as a stable source of water from year to year. See *runoff*.

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. Compare *nonrenewable resource*, *perpetual resource*. See *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 technology.

reservoir Artificial lake created when a stream is dammed. See *dam*.

resilience Ability of a living system to be restored through secondary succession after a moderate disturbance.

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 Using a product over and over again in the same form. An example is collecting, washing, and refilling glass beverage bottles. Compare *recycling*.

riparian zones Thin strips and patches of vegetation that surround streams. They 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 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.

r-selected species Species that reproduce early in their life span and produce large numbers of usually small and short-lived offspring in a short period. Compare *K-selected species*.

r-strategists See *r-selected species*.

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.

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 Discipline that attempts to discover order in nature and use that knowledge to make predictions about what should happen in nature. See *frontier science*, *scientific hypothesis*, *scientific law*, *scientific methods*, *scientific model*, *scientific theory*, *sound science*.

scientific hypothesis An educated guess that attempts to explain a scientific law or certain scientific observations. Compare *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 hypothesis*, *scientific methods*, *scientific model*, *scientific theory*.

scientific methods Ways in which scientists gather data and formulate and test scientific hypotheses, models, theories, and laws. See *scientific hypothesis*, *scientific law*, *scientific model*, *scientific theory*.

scientific model Simulation of complex processes and systems. Many are mathematical models that are run and tested using computers.

scientific theory Well-tested and widely accepted scientific hypothesis. Compare *scientific hypothesis*, *scientific law*, *scientific methods*, *scientific model*.

secondary consumer Organism that feeds only on primary consumers. Compare *detritivore*, *omnivore*, *primary consumer*.

secondary ecological succession Ecological succession in an area in which natural vegetation has been removed or destroyed but the soil is not destroyed. See *ecological succession*. Compare *primary ecological succession*.

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. Compare *advanced sewage treatment*, *primary sewage treatment*.

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 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. 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*.

slowly degradable pollutant Material that is slowly broken down into simpler chemicals or reduced to acceptable levels by natural physical, chemical, and biological processes. Compare *biodegradable pollutant*, *degradable pollutant*, *nondegradable pollutant*.

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 which 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 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).

solid waste Any unwanted or discarded material that is not a liquid or a gas. See *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*.

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*. Compare *ecological diversity*, *genetic diversity*.

species equilibrium model See *theory of island biogeography*.

species evenness Relative abundance of individuals within each of the species in a community. See *species diversity*. Compare *species richness*.

species richness Number of different species contained in a community. See *species diversity*. Compare *species evenness*.

SPM See *particulates*.

spoils Unwanted rock and other waste materials produced when a material is removed from the earth's surface or subsurface by mining, dredging, quarrying, and excavation.

S-shaped curve Leveling off of an exponential J-shaped curve when a rapidly growing population exceeds the carrying capacity of its environment and ceases to grow.

statistics Mathematical tools used to collect, organize, and interpret numerical data.

stewardship worldview View that we can manage the earth for our benefit but 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 *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 (UV) 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 to 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 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.

subsidence Slow or rapid sinking of part of the earth's crust that is not slope-related.

subsistence farming Supplementing solar energy with energy from human labor and draft animals to produce enough food to feed oneself and family members; in good years enough food may be left over to sell or put aside for hard times. Compare *industrialized 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. 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 (and as much as 90% in urban areas) 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*.

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*.

suspended particulate matter (SPM) See *particulates*.

sustainability Ability of earth's various systems, including human cultural systems and economies, to survive and adapt to changing environmental conditions indefinitely.

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, usually hundreds to thousands of years. 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*.

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 tar-like heavy oil known as bitumen. Bitumen can be extracted from oil 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*.

TFR See *total fertility rate*.

theory of evolution Widely accepted scientific idea that all life forms developed from earlier life forms. Although this theory conflicts with the creation stories of many religions, it is the way biologists explain how life has changed over the past 3.5–3.8 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*.

third-level consumers See *tertiary consumers*.

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*.

throughput Rate of flow of matter, energy, or information through a system. Compare *input*, *output*.

throwaway society See *high-throughput economy*.

tipping point Threshold level at which an environmental problem causes a fundamental and irreversible shift in the behavior of a system.

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.

total fertility rate (TFR) Estimate of the average number of children per woman born to women of childbearing years (ages 15–44) in a given population in a year.

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 to survive and perhaps to sell surplus food for cash. 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 to survive and, in good years, to put a surplus aside for hard times. 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.

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, usually 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 clarity of water in lakes, streams, and other bodies of water.

undergrazing Absence of grazing for long periods (at least 5 years), which can reduce the net primary productivity of grassland vegetation and grass cover.

undernutrition Consuming insufficient food to meet one's minimum daily energy needs for a long enough time to cause harmful effects. Compare *malnutrition*, *overnutrition*.

unreliable science Scientific results or hypotheses presented as reliable science but not 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 surface layer of ocean water is pushed away from shore and replaced by cold, nutrient-rich bottom water.

urban area Geographic area 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 See *degree of urbanization*.

urban sprawl Growth of low-density development on the edges of cities and towns. See *smart growth*.

utilitarian value See *instrumental value*.

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 Way to deal with waste in which we attempt to manage wastes to reduce their environmental harm without seriously trying to reduce the amount of waste produced. See *integrated waste management*.

waste reduction Way to deal with waste in which we try to reduce the amount of waste produced and view wastes that are produced as potential resources that can be reused, recycled, or composted. See *integrated waste management*.

water cycle See *hydrologic cycle*.

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.

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 saltwater or freshwater, excluding streams, lakes, and the open ocean. See *coastal wetland*, *inland wetland*.

wilderness Area where the earth and its community of life 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 Area 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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