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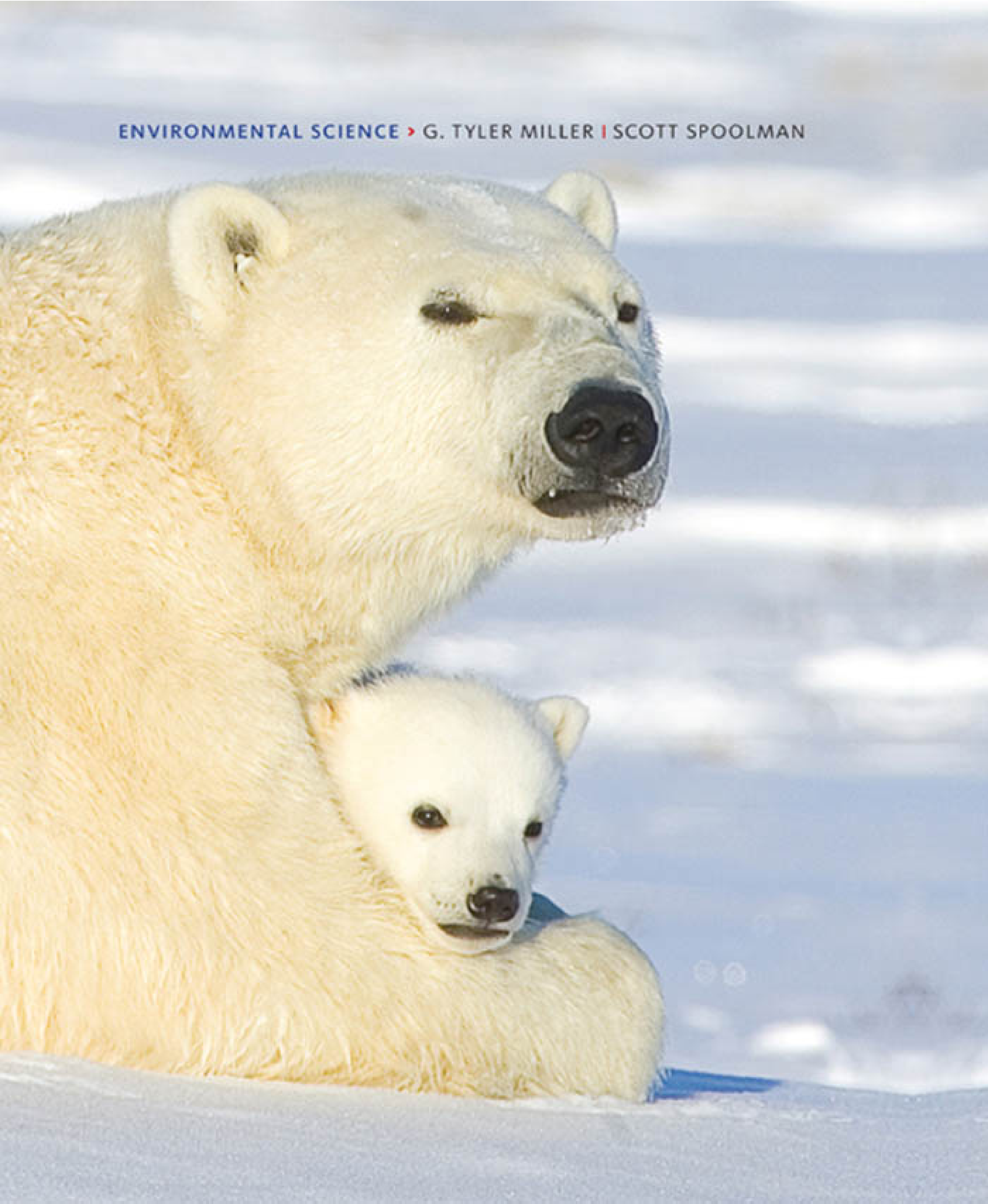

Environmental Science

Problems, Concepts, and Solutions

TWELFTH EDITION

G. Tyler Miller, Jr.

Scott Spoolman

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Brief Contents

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Detailed Contents

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Photo 1 Tree plantation.

Deb Kushal/Peter Arnold, Inc.

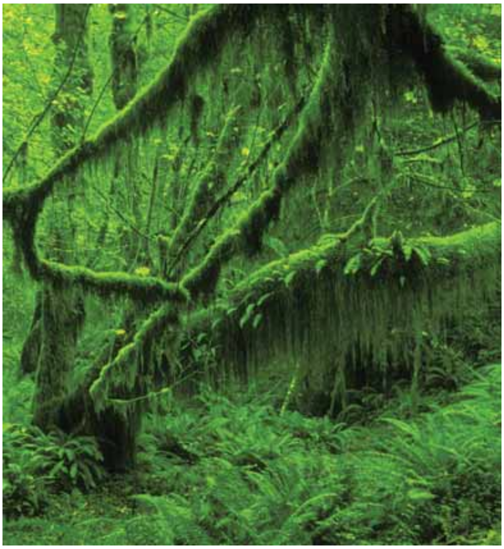
Photo 2 Air pollution from an industrial plant in India.

© Ernest Manewal/SuperStock

Photo 3 Scarlet macaw in Brazil's Amazon rain forest.

Paul W. Johnson/Biological Photo Service

Photo 4 Temperate deciduous forest, winter, Rhode Island (USA).



Newman and Associates/Phototake

Photo 5 Temperate rain forest at Olympic National Park in the U.S. state of Washington.

Francois Suchel/Peter Arnold, Inc.

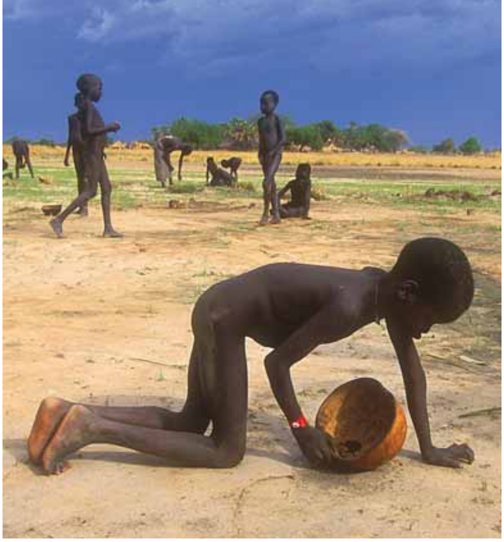
Photo 6 Cypress swamp, inland wetland in the U.S. state of Tennessee.

Tom and Pat Leeson, Ardea London Ltd.

Photo 7 Endangered southern sea otter in Monterey Bay, California (USA).

Steve Hillebrand/U.S. Fish and Wildlife Service

Photo 8 Confiscated products made from endangered species.



Harmut, Schwartzback/Peter Arnold, Inc.

Photo 9 Starving children collecting ants to eat in famine-stricken Sudan, Africa.

USDA, Natural Resources Conservation Service

Photo 10 Overgrazed (left) and lightly grazed (right) rangeland.

A. & J. Visage/Peter Arnold, Inc.

Photo 11 Ship stranded in desert formed by shrinkage of the Aral Sea.

Martin Bond/Peter Arnold, Inc.

Photo 12 Energy efficient, earth sheltered house with a green roof in Yorkshire, UK.

Photo 13 Photochemical smog in Mexico City, Mexico.

SUPPLEMENTS

Photo 14 Air pollution damage to trees in Mount Mitchell State Park, North Carolina (USA).

PREFACE

For Instructors

What's New

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

- A new concept-centered approach
- A new design with 140 pieces of new art and 55 new photos
- A chapter-opening Core Case Study integrated throughout each chapter and connected at the end of each chapter to the sustainability theme that, as in previous editions, integrates the material in this book

This edition also introduces a new coauthor, Scott Spoolman, who has worked as a contributing editor on this and other environmental textbooks by Tyler Miller for more than 3 years. Please see About the Authors, p. xxi.

A New Concept-Centered Approach

Each major chapter section is built around one to three **key concepts**—a major new feature of this edition. These concepts state the most important take-away messages of each chapter. They are listed at the front of each chapter (see p. 39), and each chapter section begins with a key question and concepts (see pp. 39, 42, 44, 48, 50, 54, and 59), which are highlighted and referenced throughout each chapter.

A CONCEPT LINK in the margin links the material in each chapter to appropriate key concepts in foregoing chapters (see pp. 43, 47, 50, 61, 62). The book's key concepts are also collected and listed by chapter for easy review in Supplement 19 (p. S81) at the end of this book.

For the most part, these concepts have been distilled from the major sections of past editions. In some cases, the concept approach revealed a need for reorganization of material within or among sections to improve flow.

A New Design

The concepts approach is well-served by our new design, which showcases the concepts, core case studies, and other new features as well as proven strengths of this textbook. The new design (see Chapter 5, pp. 75–104) also incorporates a thoroughly updated art program with 140 new figures and 148 upgraded figures.

Sustainability Remains as 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 *concept-centered, solutions oriented, science-based,* and *flexible* introductory environmental science textbook. In this edition, we showcase the sustainability theme even more to reflect its growing importance in understanding environmental problems and their solutions. You can see the sustainability emphasis by looking at the Brief Contents (p. iii).

Four **scientific principles of sustainability** play a major role in carrying out this book's sustainability theme. These principles are introduced in Chapter 1, depicted in Figure 1–13 (p. 20 and the back cover of the student edition), and used throughout the book, with each reference marked in the margin by SUSTAINABILITY (see pp. 35, 47, 118, and 280).

Core Case Studies and the Sustainability Theme

Each chapter opens with a **Core Case Study** (p. 198)—a new feature of this edition of *Environmental Science*—that is applied throughout the chapter. These connections to the **Core Case Study** are indicated in the book's margin by CORE CASE STUDY. (See pp. 200, 201, 211, 212, 213, 214, 222, 225, and 226).

Each chapter ends with a *Revisiting* box (see p. 225), which connects the **Core Case Study** and other material in the chapter to the **four scientific principles of sustainability. Thinking About** exercises strategically placed throughout each chapter (see pp. 201, 203, 213, 214, and 215) challenge students to make these and other connections for themselves—another new feature of this edition.

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.*

- ***Natural capital.*** Sustainability depends on the natural resources and natural services that support all life and economies. Some 21 diagrams illustrate this subtheme. Examples are Figures 1-3 (p. 8), 5-21 (p. 94), and 8-3 (p. 153).
- ***Natural capital degradation.*** We describe how human activities can degrade natural capital, and some 31 diagrams illustrate this. Examples are Figures 1-6 (p. 12), 5-27 (p. 99), and 10-14 (p. 212).
- ***Solutions.*** Next comes 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 41 figures and many chapter sections and subsections present proven and possible solutions to various environmental problems. Examples are Figures 10-26 (p. 224), 11-17 (p. 241), and 15-12 (p. 358).
- ***Trade-Offs.*** The search for solutions involves *trade-offs,* because any solution involves weighing advantages against disadvantages. Some 37 Trade-Offs diagrams present advantages and disadvantages of various environmental technologies and solutions to environmental problems. Examples are Figures 7-22 (p. 145), 10-22 (p. 219), and 13-38 (p. 314).
- ***Individuals Matter.*** Throughout the book *Individuals Matter* boxes describe what various concerned citizens and scientists have done to help us achieve sustainability. (See pp. 163, 376, and 410). Also, 16 *What Can You Do?* boxes describe how readers can deal with the problems we face. Examples are Figures 11-19 (p. 242), 13-44 (p. 320), and 16-7 (p. 385). Twelve especially important things individuals can do—the *sustainability dozen*—are summarized in Figure 17-19 (p. 428).

Science-Based Global Coverage

Chapters 2–9 present the scientific principles of ecology and biodiversity (see Brief Contents, p. iii) required 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 23 new **Science Focus** boxes distributed among the chapters (see pp. 27, 49, and 282). Science is also integrated throughout the book in **Case Studies** (see p. 108–109 and 120–121) and in figures (see Figure 13-14, p. 291, and Figure 15-17, p. 361).

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. To emphasize this feature we have added the labels "Global Outlook" and "Global Connections" to many of the book's figures (see Figure 7-13, p. 138, and Figure 14-11, p. 338) and maps in Supplements 3, 4, and 16.

ThomsonNOW, an online visual learning supplement, allows students to enhance their scientific understanding by viewing animations, many of them interactive, available for this book. There are 88 *ThomsonNOW* items for this text, some of them related to figures (see Figure 3-12, p. 48, and Figure 5-15, p. 88) and others to text (see pp. 79 and 154).

Two Levels of Flexibility

There are hundreds of ways to organize the content of this course to fit the needs of different instructors with a wide variety of professional backgrounds. Since the first edition of this book, our solution to this problem has been to design a highly flexible book that allows instructors to vary the order of chapters and sections within chapters.

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 2–9, which introduce basic science and ecological concepts. Instructors can then use the remaining chapters in any order they desire. 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.

In this edition we have added a *second level of flexibility* by providing 19 Supplements (see p. xii in the Detailed Contents and p. S1), which instructors can assign to meet the needs of their specific courses. Examples include maps of biodiversity and ecological footprints (Supplement 4), environmental history (Supplements 5 and 6), basic chemistry (Supplement 7), weather basics (Supplement 10), earthquakes, tsunamis, and volcanic eruptions (Supplement 12), maps of energy resources (Supplement 16), how to analyze a scientific article (Supplement 18), and a list of the book's key concepts by chapter (Supplement 19). These supplements contain 30 U.S. and global maps that provide a database of environmental and economic information. Virtually all of this material is new to this edition.

Case Studies

In addition to the 17 Core Case Studies described above, 37 additional **Case Studies** (see pp. 170–171, 275–276, and 316–317) appear throughout the book. (See items in **BOLD** type in the Detailed Contents, pp. v–xii.) The total of 54 case studies provides an in-depth look at specific environmental problems and their possible solutions.

Critical Thinking

The introduction on *Learning Skills* describes critical thinking skills (pp. 1–4). Specific critical thinking exercises are used throughout the book in several ways:

- As 105 **Thinking About** exercises—a new feature of this edition. This *interactive approach to learning* reinforces textual and graphic information and concepts by asking students to analyze material immediately after it is presented rather than waiting until the end of chapter (see pp. 13, 52, and 89).
- In all boxes (except *Individuals Matter* boxes)
- In the captions of most of the book's figures—another new feature of this edition (see Figure 8-15, p. 161; Figure 11-28, p. 254; and Figure 13-22, p. 301)
- As 65 *How Would You Vote?* exercises (see pp. 285, 314, and 371).
- As end-of-chapter questions (see pp. 104 and 259)

Visual Learning

This book's 288 diagrams—140 of them new to this edition—are designed to present complex ideas in understandable ways relating to the real world. See Figures 5-18 (p. 91), 6-4 (p. 112), and 8-15 (p. 161). We have also carefully selected 118 photographs—55 of them new to this edition—to illustrate key ideas. See Figures 11-7 (p. 233), 15-19 (p. 363), and 16-4 (p. 383). 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, 88 *ThomsonNOW* interactive animations, referenced to the text and diagrams, are available online. This learning tool—new to this edition—helps students assess their unique study needs through pretests, posttests, and personalized learning plans. These animations are available at no extra cost with new copies of the book. Access may also be purchased separately. 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:

- New co-author (see p. xxi).
- Concept-centered approach with each chapter section built around one to three **Key Concepts** that provide the most important messages of each chapter. Each chapter also links material to pertinent key concepts from previous chapters.
- A new design serving the concept-centered approach and integration of Core Case Studies, with a completely upgraded art program, which includes 140 new figures. See Figures 3-19 (p. 56), 11-11 (p. 235), and 16-5 (p. 384). The remaining 148 figures have also been improved or updated.
- Chapter-opening **Core Case Study** (p. 23) integrated throughout each chapter (pp. 24, 25, 26, 27, 28, 29, 31, 36, and 37) and connected at the end of each chapter to the sustainability theme (p. 36).
- 55 carefully selected new photographs. See Figures 5-11 (p. 83), 7-15 (p. 139), and 13-15 (p. 292).
- Expansion of the sustainability theme built around **four scientific principles of sustainability** (Figure 1-13, p. 20, and back cover of the student edition).
- **Science Focus** boxes that provide greater depth on scientific concepts and on the work of environmental scientists (see pp. 110, 153, and 364–365).
- A *second level of flexibility* in 19 optional supplements (see p. xii in the Detailed Contents and p. S1).
- Addition of 105 *Thinking About* interactive exercises (pp. 162, 189, and 300) that reinforce learning by asking students to think critically about the implications of various environmental issues immediately after they are discussed in the text. This complements the ongoing *How Would You Vote?* feature.
- Questions in many figure captions to encourage students to think about and evaluate their content. See Figures 7-18 (p. 141), 13-31 (p. 308), and 15-22 (p. 371).
- *Research Frontier* items to show students key areas that require more research (pp. 99, 301, and 385).
- Sixteen *Green Careers* shown in green type in the text (pp. 159, 234, and 311, and Figure 17-11, p. 414). Descriptions of many of these careers are available on the website.
- *Review Questions* at the end of each chapter (pp. 196 and 321).
- *Active Graphing exercises* on the websites for many chapters that involve students in the graphing and evaluation of data. A new supplement on graphing (pp. S4–S5) has been added.
- More than 4,000 updates based on information and data published in 2004, 2005, 2006, and 2007.
- Integration of material on the growing ecological and economic impacts of China and India throughout much of the book. (See pp. 13–14, 135–137, 288, 362, and Figure 11-24, p. 248).
- More than 100 new or expanded topics including the 2005 Millennium Ecosystem Report (pp. 9, 58, 61, and elsewhere); expanded treatment of ecological footprints (pp. 12–13, Figure 7-2, p. 125, and Supplement 4, pp. S16–S18 and 20–21); impacts of new affluent consumers in China (Case Study,

pp. 13–14); expanded introduction to biodiversity (pp. 48–50); climate change, catastrophes, and evolution (pp. 66–68); tsunamis (pp. S54–S56 in Supplement 12); golden rice (Core Case Study, p. 198); nanotechnology (Core Case Study, p. 261, and p. S38 in Supplement 7); world oil supplies (Core Case Study, p. 279); Canada's oil sand reserves (pp. 285–286); using feebates to improve motor vehicle efficiency (p. 300); plug-in hybrid cars (pp. 300–301); expanded discussion of ethanol and biodiesel as fuels (pp. 313–315); Iceland's vision of a renewable energy economy (Case Study, p. 316–317); the possibility of a global flu pandemic (Science Focus, p. 330); e-waste (Core Case Study, p. 380); maps of global economic, population, and hunger data (Supplement 3, pp. S6–S11); environmental history (Supplement 5, pp. S23–S30); introduction to basic chemistry (Supplement 7, pp. S32–38); expanded treatment of weather basics (Supplement 10, pp. S43–S47); maps of energy resources and carbon dioxide emissions (Supplement 16, pp. S62–S70); how to analyze a scientific article (Supplement 18, pp. S73–S80); and a summary list of key concepts (Supplement 19, pp. S81–S84).

In-Text Study Aids

Each chapter begins with a list of *key questions and concepts* to reveal how it 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.

Thinking About exercises reinforce learning by asking students to think critically about environmental issues 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 set of *Review Questions* (p. 226), which help students review key material, and a set of *Critical Thinking* (p. 226) questions to encourage students to think critically and apply what they have learned to their lives.

Qualified users of this textbook have free access to the Companion Website for this book at

http://www.thomsonedu.com/biology/miller

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

- *Learning objectives* to help guide student reading and study of each chapter
- *Flash cards,* which allow students to test their mastery of the terms and concepts to remember for each chapter
- *Chapter tests,* which provide multiple-choice practice quizzes
- Essays and information on a variety of environmental careers
- *Further readings,* which lists major books and articles consulted in writing each chapter and suggests articles, books, and websites that provide additional information
- A brief *What Can You Do?* list addressing key environmental problems
- *Weblinks,* an extensive list of websites with news, research, and images related to individual sections of the chapter
- *WebTutor* is available to qualified adopters of this textbook on WebCT or Blackboard. It provides access to a full array of study tools, including flash cards (with audio), practice quizzes, online tutorials, and weblinks.
- Teachers and students using *new* copies of this textbook also have free and unlimited access to *InfoTrac® College Edition* for a full year. This fully searchable online library gives users access to complete environmental articles from several hundred periodicals dating back over the past 24 years.

Other student learning tools include:

- *Audio Tools for study and review.* Students can purchase and download these study aids containing concept reviews, key terms, questions, clarifications of common misconceptions, and study tips.
- *Essential Study Skills for Science Students,* by Daniel D. Chiras. This book includes chapters on developing good study habits; sharpening memory; getting the most from lectures, labs, and reading assignments; improving test-taking abilities; and becoming a critical thinker. Instructors can have this book bundled FREE with the textbook.
- *Laboratory Manual,* by C. Lee Rockett and Kenneth J. Van Dellen. This manual includes a variety of laboratory exercises, workbook exercises, and projects that require a minimum of sophisticated equipment.

Supplements for Instructors

- *PowerLecture.* This DVD, free to adopters, allows you to create custom lectures using more than 1,400 pieces of high-resolution artwork, images, and animations from *ThomsonNOW* and the textbook, and create Microsoft® PowerPoint lectures using text slides and textbook figures. 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 color acetates of line art from the textbook and 300 black-and-white master sheets of key diagrams for making overhead transparencies. Free to adopters.
- *ABC Videos for Environmental Science.* These informative news stories, available on DVD, contain more than 30 short video clips of current news stories on environmental issues from around the world.
- *Instructor's Manual.* Free to adopters. Also available on PowerLecture.
- *Test Bank.* 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 three other books written for various types of environmental science courses: *Living in the Environment,* fifteenth edition (628 pages, Brooks/Cole 2007), *Sustaining the Earth: An Integrated Approach,* eighth edition (324 pages, Brooks/Cole, 2007) and *Essentials of Ecology,* fourth edition (269 pages, Brooks/Cole, 2007).

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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spoolman@tds.net

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

Acknowledgments

We wish to thank the many students and teachers who have responded so favorably to the 11 previous editions of *Environmental Science,* the 15 editions of *Living in the Environment,* the 8 editions of *Sustaining the Earth,* and the 4 editions of *Essentials of Ecology,* and who have corrected errors and offered many helpful suggestions for improvement. We are also deeply indebted to the more than 295 reviewers who pointed out errors and suggested many important improvements in the various editions of these four books.

The members of the talented production team, listed on the copyright page, have made vital contributions as well. Our special thanks go to development editor Christopher Delgado, production editors Andy Marinkovich and Nicole Barone, copy editor Andrea Fincke, layout expert Bonnie Van Slyke, photo researcher Abigail Reip, artist Patrick Lane of ScEYEnce, assistant editors Jessica Kuhn and Lauren Oliveira, and Brooks/Cole's hard-working sales staff. We also thank Keli Amann, Kristina Razmara, and the other members of the talented team who developed the multimedia, website, and advertising materials associated with this book.

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We also deeply appreciate the opportunity to have worked with Jack Carey, biology publisher at Brooks/Cole, for 40 years before his recent retirement. We now are fortunate and excited to welcome and work with Yolanda Cossio as the new biology publisher at Brooks/Cole.

G. Tyler Miller, Jr.
Scott Spoolman

Guest Essayists

Guest essays by the following authors are available on *ThomsonNOW:* **M. Kat Anderson,** ethnoecologist with the National Plant Center of the USDA's Natural Resource Conservation Center; **Lester R. Brown,** president, Earth Policy Institute; **Alberto Ruz Buenfil,** environmental activist, writer, and performer; **Robert D. Bullard,** professor of sociology and director of the Environmental Justice Resource Center at Clark Atlanta University; **Michael Cain,** ecologist and adjunct professor at Bowdoin College; **Herman E. Daly,** senior research scholar at the School of Public Affairs, University of Maryland; **Lois Marie Gibbs,** director, Center for Health, Environment, and Justice; **Garrett Hardin,** professor emeritus (now deceased) of human ecology, University of California, Santa Barbara; **John Harte,** professor of energy and resources, University of California, Berkeley; **Paul G. Hawken,** environmental author and business leader; **Jane Heinze-Fry,** environmental educator; **Paul F. Kamitsuja,** infectious disease expert and physician; **Amory B. Lovins,** energy policy consultant and director of research, Rocky Mountain Institute; **Bobbi S. Low,** professor of resource ecology, University of Michigan; **John J. Magnuson,** professor emeritus and former director of the University of Wisconsin Center for Limnology; **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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About the Authors

G. Tyler Miller, Jr.

G. Tyler Miller, Jr., has written 54 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 in 1975. Currently, he is the President of Earth Education and Research.

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—who live with small ecological footprints. I am especially privileged to have Kathleen Paul Miller as my brilliant and beautiful (inside and out) wife, best friend, and research associate. She is my hero. I dedicate this book to her and to the earth.

In this new edition, I want to introduce you to Scott Spoolman, a talented new coauthor. He has greatly improved this book and shares my lifelong passion for trying to make the earth a better place to live for all.

Scott Spoolman

Scott Spoolman is a writer and textbook editor with more than 25 years of experience in educational publishing. He has worked with Tyler Miller since 2003 as a contributing editor on two editions each of *Living in the Environment* and *Environmental Science* and one edition of *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 forestry textbooks. He has also worked as a consulting editor in the development of more than 70 textbooks in fields of the natural and social sciences.

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

Spoolman has the following to say about this new stage in his collaboration with Tyler Miller:

I am honored to be joining with Tyler Miller as a coauthor to continue the Miller tradition of thorough, clear, and engaging writing about the vast and complex field of environmental science. This is the greatest and most rewarding challenge I have ever faced. I share Tyler Miller's passion for ensuring that these textbooks and their multimedia supplements are valuable tools for students and instructors. To that end, we strive to introduce this field in ways that will be informative and sobering, but also tantalizing and motivational.

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

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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. Environmental issues affect every part of your life. Thus, the concepts, information, and issues discussed in this book and the course you are taking should 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 are affecting its life-support system, and how we can reduce our environmental impact?

We live in an incredibly challenging era. There is growing awareness that during this century we need to make a new cultural transition in which we learn how to live more sustainably by not continuing to degrade our life-support system. We hope this book will stimulate you to become involved in this change in the way we view and treat the earth that sustains us, our economies, and all other living things.

Ways to 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. According to renowned biologist E.O. Wilson, "The basic ingredient for a love of learning is the same as for romantic love, or love of country, or of God: passion for a particular subject."

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 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 to help you 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 play (dessert).

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

Look at the big picture first. Get an overview of an assigned reading in this book by looking at the *Key Questions and Concepts* box at the beginning of each chapter. It lists Key Questions explored in the chapter sections and the corresponding Key Concepts, which are the key lessons to be learned in the chapter. Use this as a chapter roadmap. When you finish a chapter you can also use it as a review. You will find the book's key concepts, listed by chapter, in Supplement 19 on pp. S81–S84.

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. 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 do this by marking key sentences and paragraphs with a highlighter or pen. We put an asterisk in the margin next to an idea we think is important and double asterisks next to an idea we think is especially important. We write comments in the margins, such as *Beautiful, Confusing, Misleading,* or *Wrong.* We fold down the top corners of pages with highlighted passages and the top and bottom corners of especially important pages. This way, we can flip through a chapter or book and quickly review the key ideas.

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

Become a better 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 have you think critically about key ideas and connect them to other ideas and your own lifestyle. Also, answer the review questions found at the end of each chapter. The website for each chapter also has a more detailed list of review questions. 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, thought, 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 better 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 keep your energizing feelings of realistic optimism slightly ahead of any immobilizing feelings of pessimism. Then you will always be moving forward.

Take time to enjoy life. Every day, take time to laugh and enjoy nature, beauty, and friendship. Becoming an effective and efficient learner is the best way to do this without falling behind in your work and living under a cloud of guilt and anxiety.

You Can Improve Your Critical Thinking Skills: Becoming a Good Baloney Detector

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

Question everything and everybody. Be skeptical, as any good scientist is. Do not believe everything you hear or read, including the content of this textbook, without evaluating the information you receive. Seek other sources and opinions. As the famous physicist and philosopher Albert Einstein put it, "The important thing is not to stop questioning."

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 and why? According to the American psychologist and philosopher William

James, "A great many people think they are thinking when they are merely rearranging their prejudices."

Be open-minded and flexible. Be open to considering different points of view. Suspend judgment until you gather more evidence, and be capable of changing 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 not what we don't know that's so bad. 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 (*incomplete* 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. 27)?

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 about 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 science is an ever-changing adventure that provides only a certain degree of certainty. And the more complex the system or process being investigated, the greater the degree of uncertainty. Scientists can disprove things but they cannot establish absolute proof or 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 reliability, as discussed on pp. 27–28). *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 a blog or other website with no editorial control or review by experts. As a result, evaluating information on the Internet is one of the best ways in which you can 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 concentrating on 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."

To help you practice critical thinking, we have supplied questions throughout this book—at the end of each chapter, and throughout each chapter in brief boxes labeled *Thinking about,* and in the captions of many figures to help you analyze these visual presentations. 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 288 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. The following are other techniques: working backward from where you want to be to where you are; reversing some or all of your assumptions and seeing where this leads; using analogies; visualizing the opposite of the situation; and analyzing a problem from another person's point of view.

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, and beliefs means that both teacher and student have failed. However, any conclusions one does reach must be based on using critical thinking to evaluate different ideas and 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. Our goal is to provide you with an interesting, accurate, balanced, and challenging book that furthers your understanding of this vital subject.

We invite you to contact us to point out any bias, correct any errors you find, or suggest ways to improve this book. Please e-mail your suggestions to Tyler Miller at **mtg89@hotmail.com** and 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 inherited. 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

Living in an Exponential Age

CORE CASE STUDY

Two ancient kings enjoyed playing chess. The winner claimed a prize from the loser. After one match, the winning king asked the losing king to pay him by placing one grain of wheat on the first square of the chessboard, two grains on the second square, four on the third, and so on, with the number doubling on each square until all 64 squares were filled.

The losing king, thinking he was getting off easy, agreed with delight. It was the biggest mistake he ever made. He bankrupted his kingdom because the number of grains of wheat he had promised was probably more than all the wheat that has ever been harvested!

This fictional story illustrates the concept of **exponential growth,** by which a quantity increases at a *fixed percentage* per unit of time, such as 2% per year. Exponential growth is deceptive. It starts off slowly, but after only a few doublings, it grows to enormous numbers because each doubling is more than the total of all earlier growth.

Here is another example. Fold a piece of paper in half to double its thickness. If you could continue doubling the thickness of the paper 42 times, the stack would reach from the earth to the moon—386,400 kilometers (240,000 miles) away. If you could double it 50 times, the folded paper would almost reach the sun—149 million kilometers (93 million miles) away!

Because of exponential growth in the human population (Figure 1-1), in 2007 there were almost 6.7 billion people on the planet. Collectively, these people consume vast amounts of food, water, raw materials, and energy and in the process produce huge amounts of pollution and wastes. Unless death rates rise sharply, there will probably be 9.2 billion of us by 2050 and perhaps as many as 10 billion by the end of this century (Figure 1-1).

The exponential rate of global population growth has declined some since 1963. Even so, each day we add an average of 225,000 more people on 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—in less than 4 years.

No one knows how many people the earth can support, and at what level of resource consumption, without seriously degrading the ability of the planet to support us and other forms of life and our economies. But there are some disturbing warning signs. Biologists estimate that by the end of this century, our exponentially increasing population and resource consumption could cause the irreversible loss of one-third to one-half of the world's known species.

There is growing evidence and concern that continued exponential growth in human activities such as burning fossil fuels and clearing forests will change the earth's climate during this century. This could ruin some areas for farming, shift water supplies, and disrupt economies in parts of the world.

Great news. We have solutions to these problems that we could implement within a few decades, as you will learn in this book.

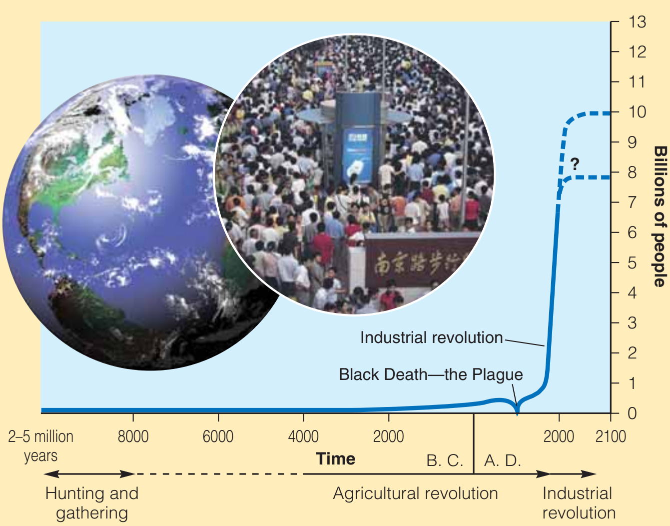


Figure 1-1 *Exponential growth:* the *J*-shaped curve of past exponential world population growth, with projections to 2100 showing possible population stabilization. (This figure is not to scale.) (Data from the World Bank and United Nations; photo of street in China by L. Yong/UNEP/Peter Arnold, Inc.)

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 (*solar capital*) 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 can environmentally sustainable societies grow economically?

CONCEPT 1-2 Societies can become more environmentally sustainable through economic development dedicated to improving the quality of life for everyone without degrading the earth's life-support systems.

1-3 How are our ecological footprints affecting the earth?

CONCEPT 1-3 As our ecological footprints grow, we are depleting and degrading more of the earth's natural capital.

1-4 What is pollution, and what can we do about it?

CONCEPT 1-4 Preventing pollution is more effective and less costly than cleaning up pollution.

1-5 Why do we have environmental problems?

CONCEPT 1-5A Major causes of environmental problems are population growth, unsustainable resource use, poverty, excluding the environmental costs of resource use from the market prices of goods and services, and trying to manage nature with insufficient knowledge.

CONCEPT 1-5B People with different environmental worldviews often disagree about the seriousness of environmental problems and what we should do about them.

1-6 What are four scientific principles of sustainability?

CONCEPT 1-6 Nature has sustained itself for billions of years by using solar energy, biodiversity, population regulation, and nutrient cycling—lessons from nature that we can apply to our lifestyles and economies.

*This is a *concept-centered* book, with each major chapter section built around one to three 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 overview as a preview and as a review of the key ideas in each chapter. Supplement 19 on pp. S81–S84 lists all key concepts by chapter.

Note: Supplements 3, 4, 5, and 6 can be used with this 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 (*solar capital*) 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. It includes all of the living and the nonliving things (air, water, and energy) with which we interact. Despite our many scientific and technological advances, we are utterly dependent on the environment for air, 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 humanity's rela-

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.

tionships with the earth's living and nonliving things. It integrates information and ideas from the *natural sciences,* such as biology, chemistry, and geology; the *social sciences,* such as economics, demography (the study of populations), and political science; and the *humanities,* including philosophy and ethics (Figure 1-2). The goals of environmental science are to learn *how nature works, how the environment affects us, how we affect the environment,* and *how to deal with environmental problems and live more sustainably.*

Ecology, a biological science that studies the relationships between organisms, or living things, and their environment, plays an important role in environmental science. A major focus of ecology is the study of ecosystems. An **ecosystem** is a set of organisms interacting with one another and with their environment of nonliving matter and energy within a defined area.

We should not confuse environmental science and ecology with **environmentalism,** a social movement dedicated to protecting the earth's air, water, soil, natural cleansing and recycling systems, and other components of its life-support systems for us and other species. Environmentalism is practiced more in the political arena than in the realm of science.

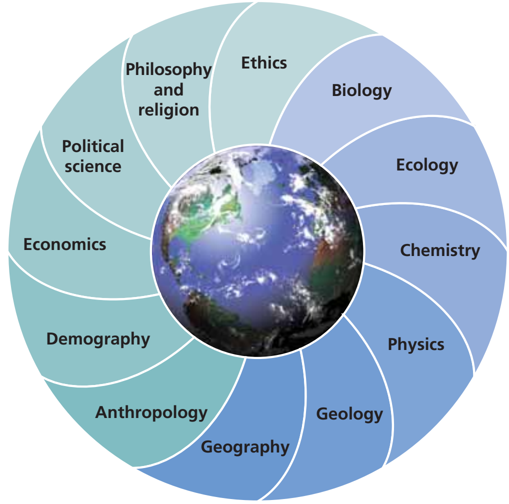


Figure 1-2 Environmental science is an interdisciplinary study of connections between the earth's life-support system and human activities.

Sustainability Is the Central Theme of This Book

Sustainability 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. It is the central theme of this book, and its components provide this book's subthemes.

Let us look more closely at sustainability. A critical component is **natural capital**—the natural resources and natural services provided by nature that keep us and other species alive and support our economies (Figure 1-3, p. 8). **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 functions of nature, such as purification of air and water, which support life and human economies.

A critical natural service is **nutrient cycling,** the circulation of chemicals necessary for life from the environment (mostly soil and water) through organisms and back to the environment (Figure 1-4, p. 9). Without this service, life as we know it could not exist.

Natural capital is supported by **solar capital:** energy from the sun that warms the planet and supports **photosynthesis**—a complex chemical 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, flowing water, and biofuels made from plants and plant residues. Thus, our lives and economies depend on energy from the sun (*solar capital*) and natural resources and natural services (*natural capital*) provided by the earth (**Concept 1-1A**).

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 nature can replenish them. We are also harvesting many species of ocean fish faster than they can replenish themselves.

This leads us to the third component of sustainability: the scientific search for *solutions* to these and other environmental problems. Implementing such solutions involves using our economic and political systems. For example, scientific solutions might be to stop clear-cutting biologically diverse, mature forests, and to harvest fish species no faster than they can replenish themselves. Implementing such solutions would probably require government laws and regulations.

The search for solutions often involves conflicts. Thus, another component of the shift toward sustainability involves trying to resolve these conflicts by making *trade-offs,* or compromises. To provide wood and paper, for example, paper companies can plant tree farms (see photo 1, p. vi) in areas that have already been cleared or degraded, in exchange for preserving mature forests.

Any shift toward environmental sustainability should be based on scientific concepts and results that are widely accepted by experts in a particular field, as

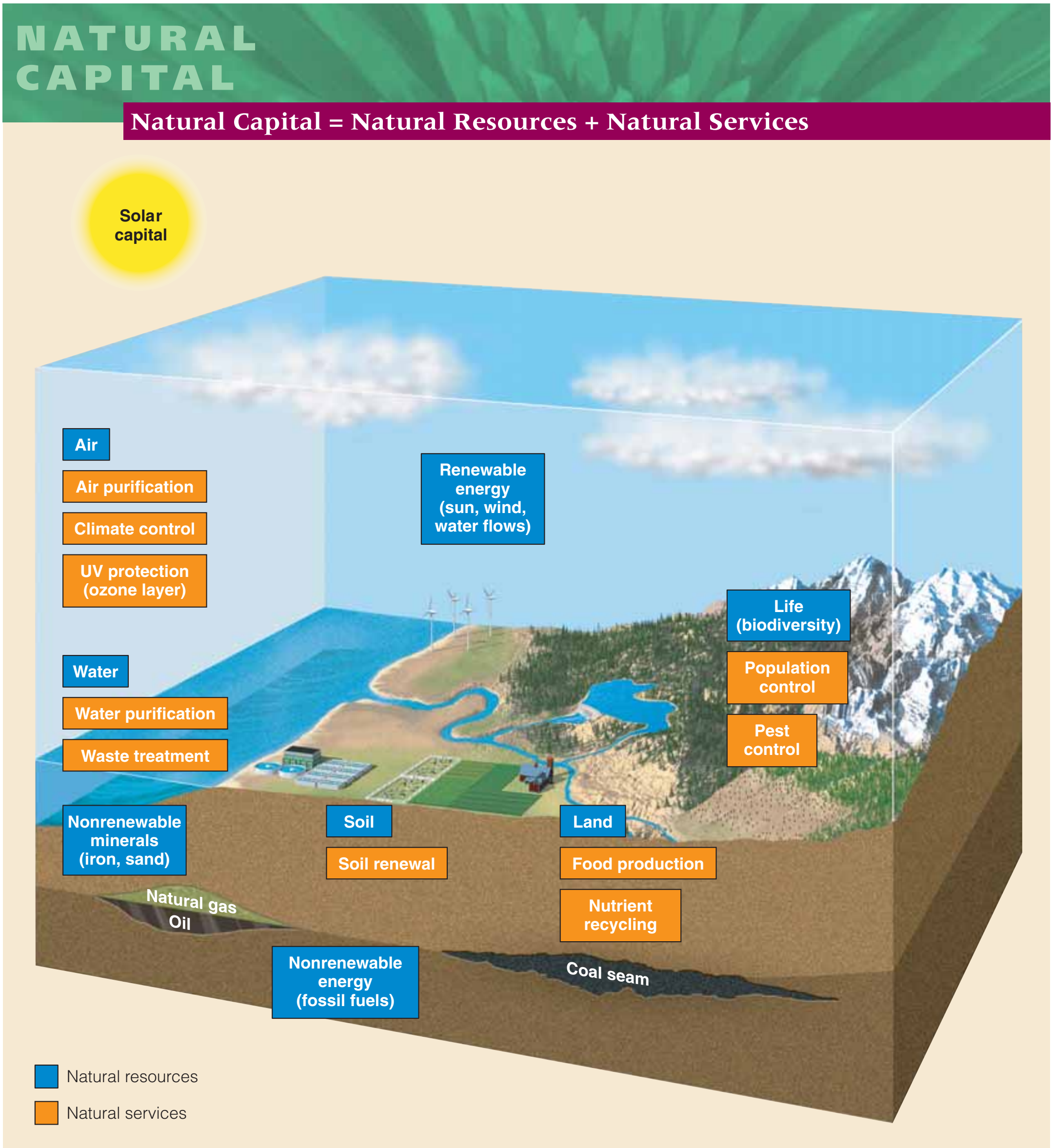


Figure 1-3 Examples of key *natural resources* (blue) and *natural services* (orange) that support and sustain the earth's life and economies (**Concept 1-1A**).

discussed in more detail in Chapter 2. In making such a shift, *individuals matter*—another subtheme of this book. Individuals vary widely in their abilities, but everyone can contribute to finding and implementing solutions to environmental problems. Some people are good at thinking of new ideas and inventing innovative technological solutions. Others are good at putting political pressure on government officials and business leaders, acting either alone or in groups to implement those solutions. Still others know how to be wise consumers who vote with their pocketbooks to help bring about environmental and social change. Regardless, every individual is as important as the next in bringing about a shift toward sustainability.

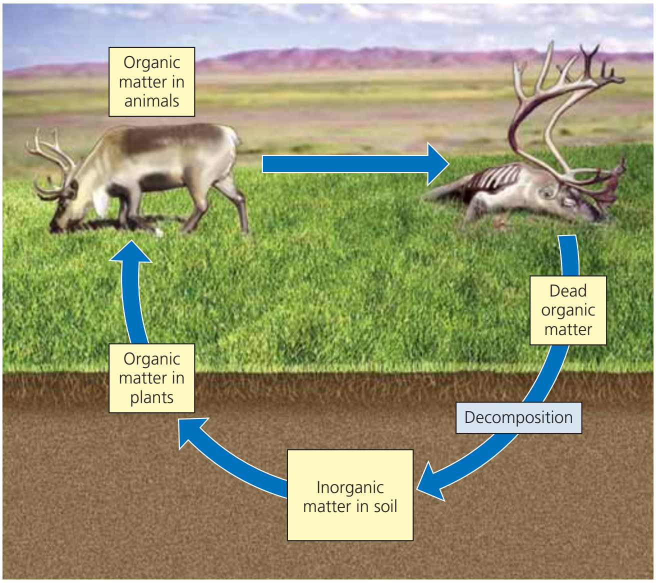


Figure 1-4 *Nutrient cycling:* an important natural service that recycles chemicals needed by organisms from the environment (mostly soil and water) through organisms and back to the environment.

Environmentally Sustainable Societies Protect Natural Capital and Live Off Its Income

SUSTAINABILITY

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. If you invest this money and earn 10% interest per year, you will have a sustainable income of $100,000 a year that you can live off of indefinitely without depleting your capital. However, if you spend $200,000 per year while allowing interest to accumulate on what is left after each withdrawal, 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 off 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. *Living sustainably* means living off **natural income,** the renewable resources such as plants, animals, and soil provided by natural capital. This means not depleting or degrading the earth's natural capital that supplies this income, and providing the human population with adequate and equitable access to this natural capital and natural income for the foreseeable future (**Concept 1-1B**).

The bad news is that, according to a growing body of scientific evidence, we are living unsustainably by wasting, depleting, and degrading the earth's natural capital at an exponentially accelerating rate (**Core Case Study***). In 2005, the United Nations (U.N.) released its *Millennium Ecosystem Assessment.* According to this four-year study by 1,360 experts from 95 countries, human activities are degrading or overusing about 62% of the earth's natural services (Figure 1-3). In its summary statement, the report warned that "human activity is putting such a strain on the natural functions of Earth that the ability of the planet's ecosystems to sustain future generations can no longer be taken for granted." The good news is that the report suggests we have the knowledge and tools to conserve the planet's natural capital, and it describes common-sense strategies for doing this.

CORE CASE STUDY

RESEARCH FRONTIER**

A crash program to gain better and more comprehensive information about the health of the world's life-support systems

HOW WOULD YOU VOTE?***

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

*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.

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

***To cast your vote, go the website for the 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 and the rest of the world.

1-2 How Can Environmentally Sustainable Societies Grow Economically?

CONCEPT 1-2 Societies can become more environmentally sustainable through economic development dedicated to improving the quality of life for everyone without degrading the earth's life-support systems.

There Is a Wide Economic Gap between Rich and Poor Countries

Economic growth is an increase in a nation's output of goods and services. It is usually measured by the percentage of change in a country's **gross domestic product (GDP):** the annual market value of all goods and services produced by all 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 total population at midyear.

The value of any country's currency changes when it is used in other countries. Because of such differences, a basic unit of currency in one country can buy more of a particular thing than the basic unit of currency of another country can buy. Consumers in the first country are said to have more *purchasing power* than consumers in the second country have. To help with comparing countries, economists use a tool called *purchasing power parity* (PPP). By combining per capita GDP and PPP, for any given country, they arrive at a **per capita GDP-PPP**—a measure of the amount of goods and services that a country's average citizen could buy in the United States.

While economic growth provides people with more goods and services, **economic development** has the goal of using economic growth to improve living standards. The United Nations classifies the world's countries as economically developed or developing based primarily on their degree of industrialization and their per capita GDP-PPP (see Figure 2 on p. S8 in Supplement 3). The **developed countries** (with 1.2 billion people) include the United States, Canada, Japan, Australia, New Zealand, and most of Europe. Most are highly industrialized and have a high per capita GDP-PPP.

All other nations (with 5.5 billion people) are classified as **developing countries,** most of them in Africa, Asia, and Latin America. Some are *middle-income, moderately developed countries* such as China, India, Brazil, Turkey, Thailand, and Mexico. Others are *low-income, least developed countries* where per capita GDP-PPP is steadily declining. These 49 countries with 11% of the world's population include Angola, Congo, Belarus, Nigeria, Nicaragua, and Jordan.

According to the United Nations, such *destitute* countries are in a desperate cycle of steadily worsening extreme poverty, disease, scarcities of key resources (such as water, cropland, firewood, and fish), dysfunctional government, violence, and social chaos. To survive, many of these counties are cutting down trees, depleting topsoil, and consuming natural resources they need for future survival. This competition for increasingly scarce resources can lead to civil violence, which can further impoverish a country. Figure 2 on p. S8 in Supplement 3 is a map of high, upper middle, lower middle, and low-income countries.

Figure 1-5 compares some key characteristics of developed and developing countries. About 97% of the projected increase in the world's population between 2007 and 2050 is expected to take place in developing countries, which are least equipped to handle such large population increases.

We live in a world of haves and have-nots. Despite a 40-fold increase in economic growth since 1900, *more*

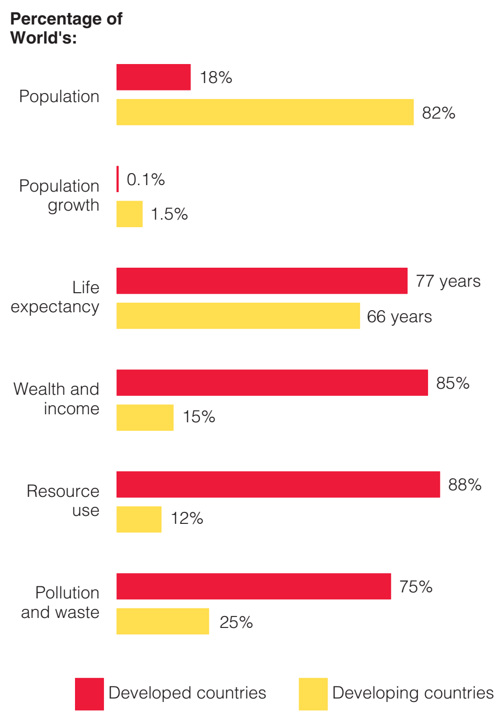


Figure 1-5 *Global outlook:* comparison of developed and developing countries, 2007. **Question:** Why do you think less developed, less wealthy countries have higher population growth rates? (Data from the United Nations and the World Bank)

than half of the people in the world live in extreme poverty and try to survive on a daily income of less than $2. And one of every six people, classified as desperately poor, struggle to survive on less than $1 a day. (All dollar figures are in U.S. dollars).

Some economists call for continuing conventional economic growth, which has helped increase food supplies, allowed people to live longer, and stimulated mass production of an array of useful goods and services for many people. They also see such growth as a cure for poverty as some of the resulting increase in wealth trickles down to countries near the bottom of the economic ladder.

Other environmental and ecological economists, call for us to put much greater emphasis on *environmentally sustainable economic development.* This involves using political and economic systems to *discourage* environmentally harmful and unsustainable forms of economic growth that degrade natural capital, and to *encourage* environmentally beneficial and sustainable forms of *economic development* that help sustain natural capital (**Concept 1-2**).

THINKING ABOUT

Economic Growth and Sustainability

Is exponential economic growth incompatible with environmental sustainability? What are three types of goods whose exponential growth would promote environmental sustainability?

1-3 How Are Our Ecological Footprints Affecting the Earth?

CONCEPT 1-3 As our ecological footprints grow, we are depleting and degrading more of the earth's natural capital.

Some Resources Are Renewable and Others Are Not

From a human standpoint, a **resource** is anything obtained from the environment to meet our needs and wants. **Conservation** is the management of natural resources with the goal of minimizing resource waste and sustaining supplies for current and future generations.

Some resources, such as solar energy, fresh air, wind, fresh surface water, fertile soil, and wild edible plants, are directly available for use. Other resources such as petroleum, iron, groundwater (water found underground), 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 (refine) 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.

On a human time scale, a **renewable resource** can be replenished fairly rapidly (from hours to decades) through natural processes as long as it is not used up faster than it is renewed. Examples are forests, grasslands, fisheries, fresh water, 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 we exceed a renewable resource's natural replacement rate, the available supply begins to shrink, a process known as **environmental degradation,** as shown in Figure 1-6 (p. 12).

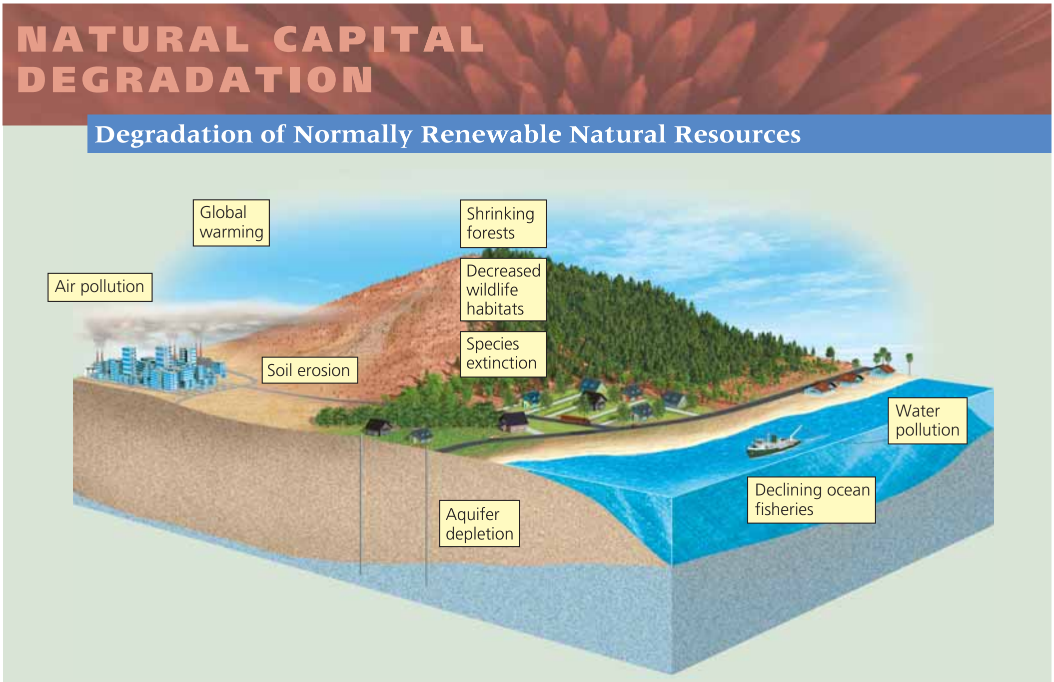
Nonrenewable resources exist in a fixed quantity or stock in the earth's crust. On a time scale of millions to billions of years, geological processes can renew such resources. But on the much shorter human time scale of hundreds to thousands of years, these resources can be depleted much faster than 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 such 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. Various types of plastics and composite materials can also replace certain 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. **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. **Reuse** is using a resource over and over in the same form. For example, glass bottles can be collected, washed, and refilled many times (Figure 1-7, p. 12). But energy resources such as oil and coal cannot be recycled. Once burned, their 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

Figure 1-6 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.



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.

Figure 1-7 *Reuse:* this child and his family in Kathmandu, Nepal, collect beer bottles and sell them for cash to a brewery where they will be reused.

Our Ecological Footprints Are Growing

Supplying people with renewable resources and dealing with 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 supply the people in a particular country or area with renewable resources and to absorb and recycle the wastes and pollution produced by 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 renewable resources and absorb the resulting waste products and pollution, it is said to have an *ecological deficit.* In 2006, the World Wildlife Fund (WWF) and the Global Footprint Network estimated that humanity's global ecological footprint exceeded the earth's *biological capacity* by about 25% (Figure 1-8, bottom). That figure was about 88% in the world's high-income countries, with the United States having the world's largest total ecological footprint. If the current exponential growth in the use of renewable resources continues, the Global Footprint Network estimates that by 2050 humanity will be trying to use twice as many renewable resources as the planet can supply (Figure 1-8) (**Concept 1-3**). See Figure 3 on pp. S16–S17 and Figure 5

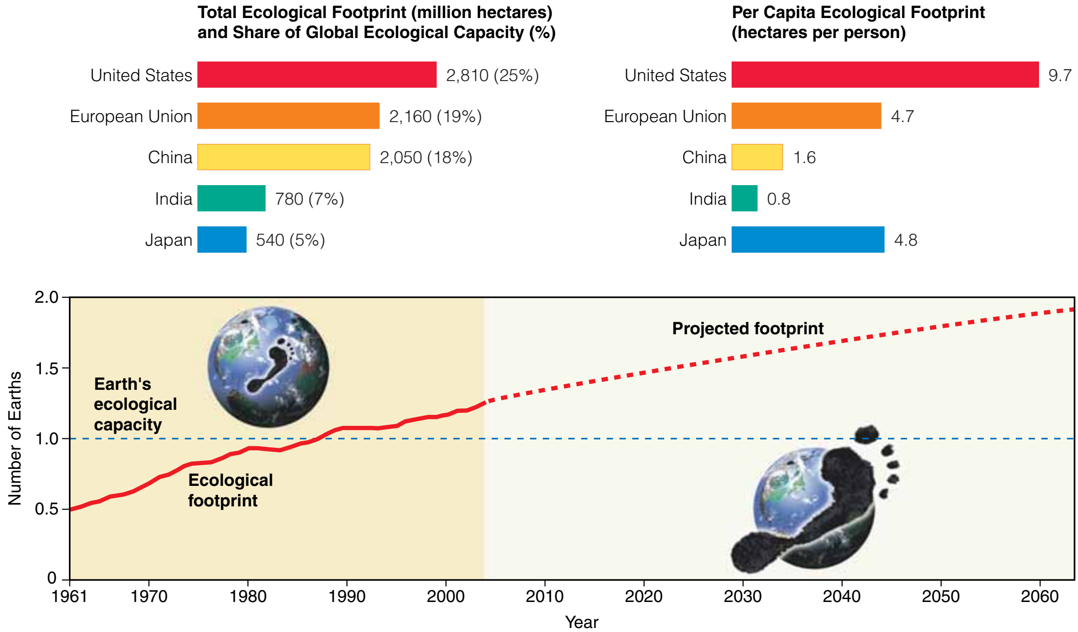


Figure 1-8 **Natural capital use and degradation:** total and per capita ecological footprints of selected countries (top). In 2003, humanity's total or global ecological footprint was about 25% higher than the earth's ecological capacity (bottom) and is projected to be twice the planet's ecological capacity by 2050. **Question:** If we are living beyond the earth's ecological capacity, why do you think the human population and per capita resource consumption are still growing exponentially? (Data from Worldwide Fund for Nature, Global Footprint Network)

on p. S19 in Supplement 4 for maps of human ecological footprints for the world and the United States and Figure 4 on p. S18 for a map of countries that are ecological debtors and those that are ecological creditors.

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

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 consumption with existing technology. Put another way, if everyone consumed as much as the average American does today, the earth's natural capital could support only about 1.3 billion people—not today's 6.7 billion. In other words, we are living unsustainably by depleting and degrading some of the earth's irreplaceable natural capital and the natural renewable income it provides as our ecological footprints grow and spread across the earth's surface (**Concept 1-3**). For more on this subject see the Guest Essay by Michael Cain at ThomsonNOW™. See the Case Study that follows about the growing ecological footprint of China.

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?

■ 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 natural capital. Another billion consumers are attaining middle-class, affluent lifestyles in rapidly developing countries such as China, India, Brazil, South Korea, and Mexico. The 600 million middle-class consumers in China and India are twice the U.S. population, and the number is growing rapidly! In 2006, the World Bank projected that by 2030, the number of middle-class consumers living in today's developing nations will reach 1.2 billion—four times the current U.S. population.

China is now the world's leading consumer of wheat, rice, meat, coal, fertilizers, steel, and cement, and it is the second largest consumer of oil after the United States. China leads the world in consumption of goods such as television sets, cell phones, refrigerators, and soon, personal computers. By 2020, China is projected to be the world's largest producer and consumer of cars and to have the world's leading economy in terms of GDP-PPP.

Suppose that China's economy continues growing exponentially at a rapid rate and its projected population size reaches 1.47 billion by 2031. Then China will need two-thirds of the world's current grain harvest, twice the world's current paper consumption, and more than the current global production of oil.

According to environmental 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 2031 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 ThomsonNOW.

THINKING ABOUT
China and Sustainability

What are three things China could do to shift towards more sustainable consumption? What are three things the United States, Japan, and the European Union could do to shift towards more sustainable consumption?

Cultural Changes Have Increased Our Ecological Footprints

Evidence from fossils of past organisms and studies of ancient cultures suggests that the current form of our species, *Homo sapiens,* has walked the earth for perhaps 90,000–195,000 years—less than an eye-blink in the earth's 3.7 billion years of life.

Culture is the whole of a society's knowledge, beliefs, technology, and practices. Until about 12,000 years ago, we were mostly hunter–gatherers who lived in small groups and moved as needed to find enough food for survival. Since then, three major cultural changes have occurred: the *agricultural revolution* (which began 10,000–12,000 years ago), the *industrial-medical revolution* (beginning about 275 years ago), and the *information-globalization revolution* (beginning about 50 years ago).

Each of these cultural changes gave us more energy and new technologies with which to alter and control more of the planet to meet our basic needs and increasing wants. They also allowed expansion of the human population, mostly because of increased food supplies and longer life spans. In addition, they each resulted in greater resource use, pollution, and environmental degradation as our ecological footprints expanded (Figure 1-8) and allowed us to dominate the planet.

For more background and details on the environmental history of the United States, see Supplement 5, pp. S23–S30.

1-4 What Is Pollution and What Can We Do about It?

CONCEPT 1-4 Preventing pollution is more effective and less costly than cleaning up pollution.

Pollution Comes from a Number of Sources

Pollution is any chemical or physical change in the environment that is harmful to humans or other living organisms. Pollutants can enter the environment naturally, such as from volcanic eruptions, or through human activities, such as burning coal and gasoline.

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 1-9 and photo 2 on p. vi), the drainpipe of a factory, and the exhaust pipe of an automobile. **Nonpoint sources** are dispersed and often difficult to identify. Examples are pesticides blown from the land into the air and the runoff of fertilizers 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.

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

We Can Prevent Pollution or Clean It Up

Suppose that smoke is coming out of the stack of a steel mill. We can try to deal with this 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 prevention,** or **input pollution control,** which reduces or eliminates the production of pollutants. The other is **pollution cleanup,** or **output pollution control,** which involves cleaning up or diluting pollutants after they have been produced.

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 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.

Ray Pfortner/Peter Arnold, Inc.

Figure 1-9 *Point-source air pollution* from a pulp mill in New York State (USA).

Pollution prevention (front-of-the-pipe) and pollution cleanup (end-of-the-pipe) solutions are both needed. But environmental scientists, some economists, and some major companies want us to put more emphasis on prevention because it works better and in the long run is cheaper than cleanup (**Concept 1-4**). We discuss this further in Chapter 17.

1-5 Why Do We Have Environmental Problems?

CONCEPT 1-5A Major causes of environmental problems are population growth, wasteful and unsustainable resource use, poverty, excluding the environmental costs of resource use from the market prices of goods and services, and trying to manage nature with insufficient knowledge.

CONCEPT 1-5B People with different environmental worldviews often disagree about the seriousness of environmental problems and what we should do about them.

Experts Have Identified Five Basic Causes of Environmental Problems

As we run more and more of the earth's natural resources through the global economy, in many parts of the world, forests are shrinking, deserts are expanding, soils are eroding, and rangelands are deteriorating. In addition, the lower atmosphere is warming, glaciers are melting, seas are rising, and storms are becoming more destructive. And in many areas, water tables are falling, rivers are running dry, fisheries are collapsing, coral reefs are disappearing, various forms of life are becoming extinct, environmental refugees are increasing, and outputs of some pollutants and wastes are rising.

According to a number of environmental and social scientists, the major causes of these and other environmental problems are population growth, wasteful and unsustainable resource use, poverty, failure to include in market prices the environmental costs of producing and using goods and services, and too little knowledge of how nature works (Figure 1-10, p. 16) (**Concept 1-5A**).

We have discussed the exponential growth of the human population (**Core Case Study**), and here we will examine other major causes of environmental problems in more detail.

CORE CASE STUDY

Poverty Has Harmful Environmental and Health Effects

Poverty occurs when people are unable to meet their basic needs for food, water, shelter, health, and education (Figure 1-11,p. 16). The daily lives of half of the world's people, who trying to live on the equivalent of

Figure 1-10 Environmental and social scientists have identified five basic causes of the environmental problems we face. **Question:** What are three ways in which your lifestyle contributes to these causes?

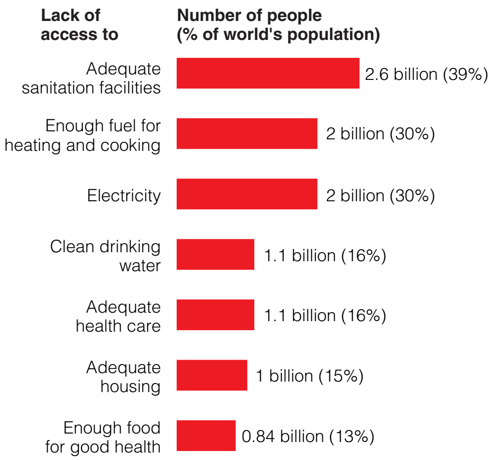


Figure 1-11 Some harmful results of poverty. **Question:** Which two of these effects do you think are the most harmful? Why? (Data from United Nations, World Bank, and World Health Organization)

less than $2 a day, are focused on getting enough food, water, and cooking and heating fuel to survive. Desperate for land to grow enough food, some of these people are increasingly depleting and degrading forests, soil, grasslands, fisheries, and wildlife for short-term survival. They do not have the luxury of worrying about long-term environmental quality or sustainability.

Poverty affects population growth. To many of the poor, 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 care for them 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.

While poverty can increase some types of environmental degradation, the reverse is also true. Pollution and environmental degradation have a severe impact on the poor and can increase poverty. Consequently, many of the world's desperately poor die prematurely from several preventable health problems.

One such problem is *malnutrition,* or a lack of protein and other nutrients needed for good health (Figure 1-12). The resulting weakened condition can increase the chances of death from normally nonfatal diarrhea and measles. A second problem is limited access to adequate sanitation facilities and clean drinking water. More than 2.6 billion people (39% of the world's population) have no decent bathroom facilities. They are forced to use fields, backyards, ditches, and streams. As a result, more than 1 billion people—one of every seven—get water for drinking, washing, and cooking from sources polluted by human and animal feces. A third problem is severe respiratory disease and prema-

Figure 1-12 *Global connections:* one in every three children under 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 under age 5 die prematurely from malnutrition and infectious diseases, most from drinking contaminated water and being weakened by malnutrition.

ture death from inhaling indoor air pollutants produced by burning wood or coal in open fires or in poorly vented stoves for heat and cooking.

According to the World Health Organization, these factors cause premature death for at least 7 million people each year. *This premature death for about 19,200 people per day is equivalent to 96 fully loaded 200-passenger jet planes 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 will to act.

Affluence Has Harmful and Beneficial Environmental Effects

The harmful environmental effects of poverty are serious but those of affluence are much worse (Figure 1-8, top). The lifestyles of many affluent consumers in developed countries and in rapidly developing countries such as India and China (Case Study, p. 13) are built upon high levels of consumption and unnecessary waste of resources. Such affluence is based mostly on the assumption—fueled by mass advertising—that buying more things will bring fulfillment and happiness.

This type of affluence has an enormous harmful environmental impact. 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, this number of trucks would reach beyond the sun!

While the United States has far fewer people than India, the average American consumes about 30 times as much as the average citizen of India and 100 times as much as the average person in the world's poorest countries. As a result, the average environmental impact or ecological footprint per person in the United States is much larger than the average impact per person in developing countries (Figure 1-8, top).

On the other hand, affluence 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.

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 more abundant and safer and the incidence of life-threatening infectious diseases has been greatly reduced.

Affluence financed these improvements in environmental quality, and education spurred citizens to insist that businesses and elected officials improve environmental quality. Affluence and education have also helped reduce population growth in most developed countries. However, 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 life styles.

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

When companies use resources to create goods and services for consumers, they are generally not required to pay the environmental costs of such resource use. For example, fishing companies pay the costs of catching fish but do not pay for the depletion of fish stocks. Timber companies pay for clear-cutting forests but not for the resulting environmental degradation and loss of wildlife habitat. These companies reasonably seek to maximize their profits, so they do not voluntarily pay these costs or even try to assess them, unless required to do so by government laws or regulations.

As a result, the prices of goods and services do not include their harmful environmental costs. Thus consumers are generally not aware of them and have no effective way to evaluate the harmful effects of the goods and services they buy on the earth's life-support systems.

Another problem is that governments give companies tax breaks and payments called *subsidies* to assist them with using resources to run their businesses. This helps create jobs and stimulate economies, but it can also result in degradation of natural capital, again, because the value of the natural capital is not considered. We explore these problems and some possible solutions in later chapters.

According to a 2006 study by the World Business Council for Sustainable Development and three conservation organizations, corporations that do not begin attaching economic value to the natural resources and natural services they use will face higher operating costs as a result of problems such as water scarcity, climate change, species and habitat loss, and increasing environmental degradation. According to this study, companies that recognize the links between healthy ecosystems and their business interests can profit from developing new, more sustainable technologies and products that reduce waste, pollution, and environmental degradation and restore parts of the world that we have damaged.

People Have Different Views about Environmental Problems and Their Solutions

Differing views about the seriousness of our environmental problems and what we should do about them 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. This involves **environmental ethics,** which are our 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 life forms? Should we try to protect all life forms or only some? How do we decide which ones to protect?
- Do we have an ethical obligation to pass on to future generations the extraordinary natural world in at least as good condition as 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 on this topic by Robert D. Bullard at ThomsonNOW.

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

People with widely differing environmental worldviews can take the same data, be logically consistent, and arrive at quite different conclusions because they start with different assumptions and moral, ethical, or religious beliefs (**Concept 1-5B**). 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 nature, that nature exists mainly to meet our needs and 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 discourage environmentally harmful forms.

The **environmental wisdom worldview** holds that we are part of and totally 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 and integrating such *environmental wisdom* into the ways we think and act.

Environmental worldviews play a role in the causes of environmental problems, and in how serious they get, because people with different environmental worldviews often disagree about the seriousness of environmental problems and what we should do about them (**Concept 1-5B**). For example, in an area where water pollution is not recognized by most people as an issue, it will likely grow to be a serious problem.

We Can Work Together to Solve Environmental Problems

Making the shift to more sustainable societies and economies involves building what sociologists call **social capital.** This involves 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. This means nurturing openness, communication, cooperation, and hope and discouraging closemindedness, polarization, confrontation, and fear.

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 can strive to build social capital by finding *trade-off solutions* to environmental problems—an important theme of this book. They can also try to agree on shared visions of the future and work together to develop strategies for implementing such visions beginning at the local level, as citizens of Chattanooga, Tennessee (USA), have done.

■ **CASE STUDY**

The Environmental Transformation of Chattanooga, Tennessee

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

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 flowing through the city's industrial center bubbled with toxic waste. People and industries fled the downtown area and left a wasteland of abandoned and polluting factories, boarded-up buildings, high unemployment, and crime.

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

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

The city also launched an innovative recycling program after environmentally concerned citizens blocked construction of a new garbage incinerator that would have emitted harmful air pollutants. These efforts paid off. Since 1989, the levels of the seven major air pollutants in Chattanooga have been lower than 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 35-kilometer-long (22-mile-long) riverfront park along both banks of the Tennessee River running through downtown. It draws more than 1 million visitors per year. As property values and living conditions have improved, people and businesses have moved back downtown.

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

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

THINKING ABOUT
Chattanooga

What are three things you would do to model the area where you live after the example of Chattanooga?

Individuals Matter

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

1-6 What Are Four Scientific Principles of Sustainability?

CONCEPT 1-6 Nature has sustained itself for billions of years by using solar energy, biodiversity, population regulation, and nutrient cycling—lessons from nature that we can apply to our lifestyles and economies.

Studying Nature Reveals Four Scientific Principles of Sustainability

How can we live more sustainably? According to environmental scientists, we should study how life on the earth has survived and adapted to major changes in environmental conditions for billions of years. We could make the transition to more sustainable societies by applying these lessons from nature to our lifestyles and economies, as summarized below and in Figure 1-13, p. 20 (**Concept 1-6**).

- **Reliance on Solar Energy:** the sun warms the planet and supports photosynthesis used by plants to provide food for themselves and for us and other animals.

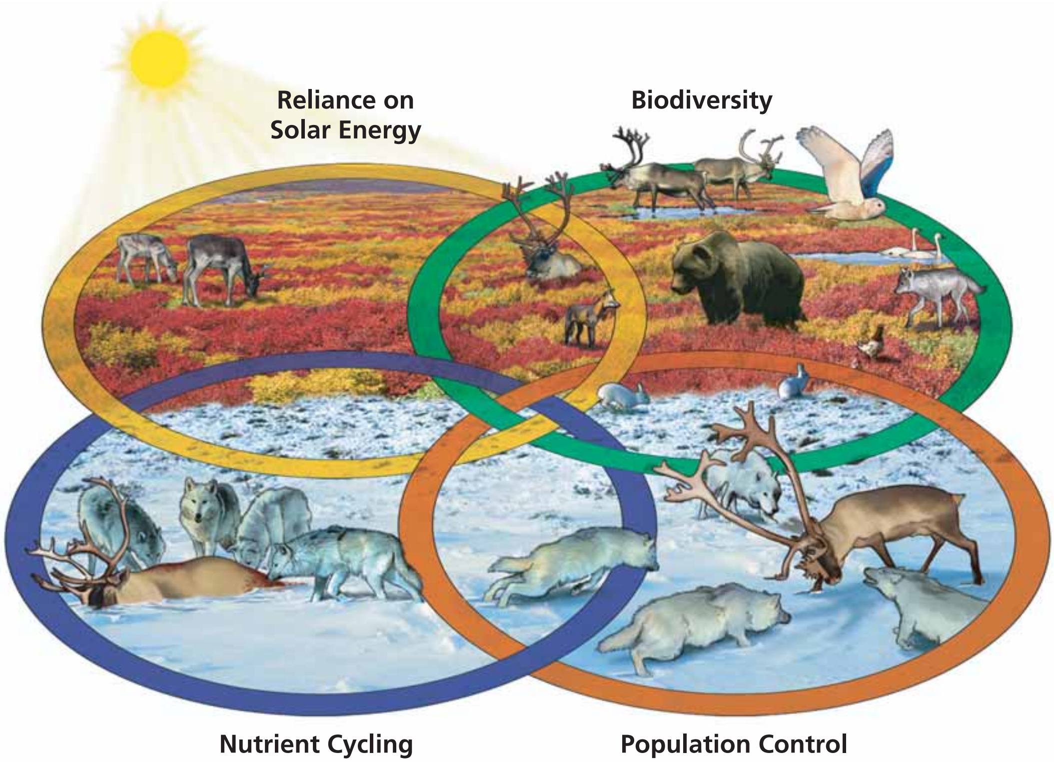


Figure 1-13 **Four scientific principles of sustainability:** these four interconnected principles of sustainability are derived from learning how nature has sustained a variety of life on the earth for about 3.7 billion years. The top left oval shows sunlight stimulating the production of vegetation in the Arctic tundra during its brief summer (*solar energy*) and the top right oval shows some of the diversity of species found there during the summer (*biodiversity*). The bottom right oval shows Arctic gray wolves stalking a caribou during the long cold winter (*population control*). The bottom left oval shows Arctic gray wolves feeding on their kill. This, plus huge numbers of tiny decomposers that convert dead matter to soil nutrients, recycle all materials needed to support the plant growth shown in the top left and right ovals (*nutrient cycling*).

- **Biodiversity** (short for *biological diversity*): the astounding variety of life forms, the genes they contain, the ecosystems in which they exist, and the natural services they provide have yielded countless ways for life to adapt to changing environmental conditions throughout the earth's history.
- **Population Control:** competition for limited resources among different life forms places a limit on how much their populations can grow.
- **Nutrient Cycling:** natural processes recycle chemicals that plants and animals need to stay alive and reproduce (Figure 1-4).

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 1-14 **Solutions:** some shifts involved in bringing about the *environmental* or *sustainability revolution.* **Question**: Which three of these shifts do you think are most important? Why?

Using the four **scientific principles of sustainability** to guide our lifestyles and economies can help us bring about an *environmental* or *sustainability revolution* during your lifetime (see the Guest Essay on this topic by Lester R. Brown at ThomsonNOW). Figure 1-14 lists some of the shifts involved in bringing about this new cultural change by learning how to live more sustainably.

Scientific evidence indicates that we have perhaps 50 years and no more than 100 years to make such a crucial cultural change. If this is correct, sometime during this century, we could come to a historical fork in the road, at which point we will choose a path toward sustainability or continue on our current unsustainable course. Everything you do, or do not do, will play a role in our collective choice of which path we will take. 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.

REVISITING Exponential Growth and Sustainability

CORE CASE STUDY

We face an array of serious environmental problems. This book is about *solutions* to these problems. Making the transition to more sustainable societies and economies challenges us to devise ways to slow down the harmful effects of exponential growth (**Core Case Study**) and to use the same power of exponential growth to implement more sustainable lifestyles and economies.

The key is to apply the four **scientific principles of sustainability** (Figure 1-13 and **Concept 1-6**) to the design of our economic and social systems and to our individual lifestyles. We can use such information 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, build social capital, and create a better world for ourselves, our children, our grandchildren, and beyond.

Exponential growth is a double-edged sword. It can cause environmental harm. But we can also use it positively to amplify beneficial changes in our lifestyles and economies by applying the four **scientific principles of sustainability**. Through our individual and collective actions or inactions, we choose which side of that sword to use.

We are rapidly altering the planet that is our only home. If we make the right choices during this century, we can create an extraordinary and sustainable future 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.

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 QUESTIONS

1. What is exponential growth? Why is living in an exponential age a cause for concern for everyone living on the planet?
2. Discuss the environmental factors that keep us alive. Explain the term *natural capital.* Describe the ultimate goal of an environmentally sustainable society.
3. What is the difference between economic growth and economic development? Discuss the key economic characteristics of developed versus developing countries.
4. What are the earth's main types of resources and how are they being degraded? What is an ecological footprint? What is a per capita ecological footprint? How do these compare and contrast on a global scale?
5. Describe the cultural changes that have occurred since humans arrived on the earth which have led to more environmental degradation as our ecological footprints have increased.
6. Define pollution. What are the two main sources of pollution? Describe two different ways that we can deal with pollution.
7. Identify the five basic causes of the environmental problems that we face today. In what ways do poverty and affluence affect the environment?
8. Discuss the lessons we can learn from the environmental transformation of Chattanooga, Tennessee.
9. List the four scientific principles of environmental sustainability. Explain how each is affected by exponential growth.
10. Describe the different types of environmental worldviews that are held by people on the planet. How are these linked to environmental ethics? What is social capital?

CRITICAL THINKING

1. List three ways in which you could apply **Concepts 1-5A** and **1-6** to making your lifestyle more environmentally sustainable.

2. Describe two environmentally beneficial forms of exponential growth (**Core Case Study**). CORE CASE STUDY

3. 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.

4. 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?

5. When you read that at least 19,200 people die prematurely each day (13 per minute) from preventable malnutrition and infectious disease, do you **(a)** doubt that it is true, **(b)** not want to think about it, **(c)** feel hopeless, **(d)** feel sad, **(e)** feel guilty, or **(f)** want to do something about this problem?

6. 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 perpetuate such problems, and which can help solve them?

7. Which one or more of the four **scientific principles of sustainability** (Figure 1-13, p. 20) are involved in each of the following actions: **(a)** recycling soda cans; **(b)** using a rake instead of leaf blower; **(c)** choosing to have no more than one child; **(d)** walking to class instead of driving; **(e)** taking your own reusable bags to the grocery store to carry things home in; **(f)** volunteering in a prairie restoration project; and **(g)** lobbying elected officials to require that 20% of your country's electricity be produced by renewable wind power by 2020? SUSTAINABILITY

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)** all economic growth is good, **(d)** the value of other forms of life depends only on whether they are useful to us, **(e)** because all forms of life eventually become extinct, we should not worry about whether our activities cause their premature extinction, **(f)** all forms of life have an inherent right to exist, **(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 of your environmental worldview (p. 18)? Record your answer. Then at the end of this course return to your answer to see if your environmental worldview has changed. Are the beliefs of your environmental worldview consistent with your answers to question 8? Are your daily choices consistent with your environmental worldview?

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

LEARNING ONLINE

Log on to the Student Companion Site for this book at **www.thomsonedu.com/biology/miller** and choose Chapter 1 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Web links, information on Green Careers, and InfoTrac® College Edition articles.

For access to animations and additional quizzing, register and log on to Thomson NOW! at **www.thomsonedu.com/thomsonnow** using the access code card in the front of your book.

Science, Matter, and Energy

2

Carrying Out a Controlled Scientific Experiment

CORE CASE STUDY

One way in which scientists learn about how nature works is to conduct a *controlled experiment.* To begin, scientists isolate *variables,* or factors that can change within a system or situation being studied. An experiment involving *single-variable analysis* is designed to isolate and study the effects of one variable at a time.

To do such an experiment, scientists set up two groups. One is an *experimental group* in which a chosen variable is changed in a known way and the other is a *control group* in which the chosen variable is not changed. With proper experimental design, any difference between the two groups should result from the variable that was changed in the experimental group.

In the 1960s, botanist Frank H. Bormann, forest ecologist Gene Likens, and their colleagues began carrying out a classic controlled experiment. The goal was to compare the loss of water and nutrients from an uncut forest ecosystem (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 anchored on impenetrable bedrock so all surface water leaving each forested valley had to flow across a dam, where scientists could measure its volume and dissolved nutrient content.

The first experiment measured the amounts of water and dissolved plant nutrients that entered and left an undisturbed forested area (the control site, Figure 2-1, left). These baseline data showed that an undisturbed mature forest is very efficient at storing water and retaining chemical nutrients in its soils.

The next experiment involved disturbing the system and observing any changes that occurred. One winter, the investigators cut down all trees and shrubs in one valley (the experimental site), left them where they fell, and sprayed with herbicides to prevent the regrowth of vegetation. Then they compared the inflow and outflow of water and nutrients in this modified experimental site (Figure 2-1, right) with those in the control site for 3 years.

With no plants to help absorb and retain water, runoff of water in the deforested valley increased by 30–40%. As this excess water ran rapidly over the surface of 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 undisturbed forest.

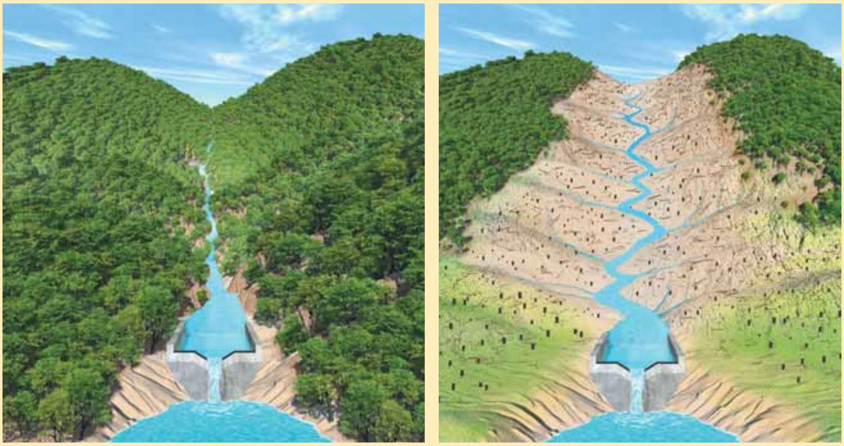


Figure 2-1 Controlled field experiment to measure the effects of deforestation on the loss of water and soil nutrients from a forest. V–notched dams were built into the impenetrable bedrock at the bottoms of several forested valleys (left) so that all water and nutrients flowing from each valley could be collected and measured for volume and mineral content. Baseline data were collected on the forested valley (left) that acted as the control site. Then all the trees in one valley (the experimental site) were cut (right) and the flows of water and soil nutrients from this experimental valley were measured for three years.

Key Questions and Concepts

2-1 What is science?

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

2-2 What is matter?

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

2-3 How can matter change?

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

2-4 What is energy and how can it change its form?

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

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

2-5 How can we use matter and energy more sustainably?

CONCEPT 2-5A The processes of life must conform to the law of conservation of matter and the two laws of thermodynamics.

CONCEPT 2-5B We can live more sustainably by using and wasting less matter and energy, recycling and reusing most matter resources, and controlling human population growth.

Note: Supplements 1, 2, 6, 7, and 18 can be used with this chapter.

Science is an adventure of the human spirit.
It is essentially an artistic enterprise,
stimulated largely by curiosity,
served largely by disciplined imagination,
and based largely on faith in the reasonableness, order,
and beauty of the universe.

WARREN WEAVER

2-1 What Is Science?

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

Science is a Search for Order in Nature

Have you ever seen an area in a forest where all the trees were cut down? If so, you might wonder about the effects of cutting down all those trees. You might wonder how it affected the animals and people living in that area and how it affected the land itself. That is exactly what scientists Bormann and Likens (**Core Case Study**) thought about when they designed their experiment.

Such curiosity is what motivates scientists. **Science** is an endeavor 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 orderly cause and effect patterns 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. Here is an example of applying the scientific process to an everyday situation:

Observation: You switch on your flashlight and nothing happens.

Question: Why didn't the light come on?

Hypothesis: Maybe the batteries are dead.

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

Result: Flashlight still does not work.

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.

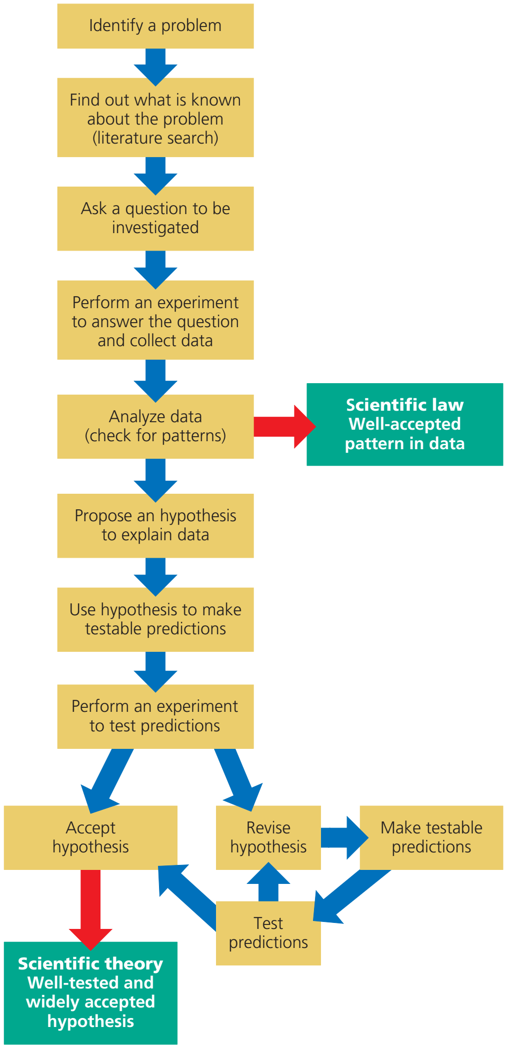


Figure 2-2 *What scientists do.* The essence of science is this process for testing ideas about how nature works. Scientists do not necessarily follow the order of steps described here. For example, sometimes a scientist might start by formulating an hypothesis to answer the initial questions and then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

New hypothesis: Maybe the bulb is burned out.

Experiment: Replace bulb with a new bulb, and switch on flashlight.

Result: Flashlight works.

Conclusion: Second hypothesis is verified.

Here is a more formal outline of steps scientists often take in trying to understand nature, although not always in the order listed:

- **Identify a problem.** Bormann and Likens (**Core Case Study**) 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 was known about the retention and loss of water and soil nutrients in forests.
- **Ask a question to be investigated.** The scientists asked: "How does clearing forested land affect its ability to store water and retain soil nutrients?
- **Design an experiment to answer the question and collect data.** To collect **data,** or information needed to answer their questions, scientists often conduct **experiments,** or procedures carried out under controlled conditions to gather information and test ideas. 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 which they had cleared of trees for their experiment (Figure 2-1, right).
- **Propose an hypothesis to explain the data.** Scientists suggest a **scientific hypothesis,** or possible explanation of what they observe in nature. The data collected by Bormann and Likens showed a decrease in the ability of a cleared forest to store water and retain soil nutrients such as nitrogen. They came up with the following hypothesis, or tentative explanation for their data: When a forest is cleared, it retains less water and loses large quantities of its soil nutrients when water from rain and melting snow flows across its exposed soil.
- **Make testable predictions.** Scientists use an hypothesis to make testable predictions about what should happen if the hypothesis is valid. They often do this by making "If . . . then" predictions. Bormann and Likens predicted that *if* their original hypothesis was valid for nitrogen, *then* a cleared forest should also lose other soil nutrients such as phosphorus.
- **Test the predictions with further experiments, models, or observations.** To test their prediction, Bormann and Likens repeated their controlled experiment and measured the phosphorus content of the soil. Another way to test predictions is to develop a **model,** an approximate representation or simulation of a system being studied. Since Bormann and Likens performed their experiments, scientists have developed increasingly sophisticated mathematical and computer models of how a forest system works. Data from Bormann and Likens's research and that of other scientists can be fed into such models and used to predict the loss of phosphorus and other types of soil nutrients. These predictions can be compared with the actual measured losses to test the validity of such models.

- **Accept or reject the hypothesis.** If their new data do not support their hypotheses, scientists come up with other testable explanations. This process continues until there is general agreement among 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. A well-tested and widely accepted scientific hypothesis or a group of related hypotheses is called a **scientific theory.** Thus, Bormann and Likens and their colleagues 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.

Three important features of any scientific process are *skepticism, peer review* of results by other scientists, and *reproducibility.* Scientists tend to be highly skeptical of new data and hypotheses until they can be verified. **Peer review** happens when scientists report details of the methods they used, the results of their experiments and models, and the reasoning behind their hypotheses for other scientists working in the same field (their peers) to examine and criticize. Ideally, other scientists repeat and analyze the work to see if the data can be reproduced and whether the proposed hypothesis is reasonable and useful.

For example, the results of the forest experiments by Bormann and Likens (**Core Case Study**) were submitted to other soil and forest experts for their review before a respected scientific journal would publish their results. 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 because scientists continually question measurements, make new measurements, and try to come up with new and better hypotheses (Science Focus, at right).

CORE CASE STUDY

Scientific Theories and Laws Are the Most Important Results of Science

If an overwhelming body of observations and measurements supports a scientific hypothesis, it becomes a scientific theory. *Scientific theories are not to be taken lightly.* They have been tested widely, are supported by extensive evidence, and are accepted by most scientists in a particular field or related fields of study.

Another important outcome of science is a **scientific,** or **natural, law:** 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 good way to summarize the most important outcomes of science is to say that scientists collect data and develop theories, models, and laws that describe and explain how nature works (**Concept 2-1**). Scientists use reasoning and critical thinking skills (pp. 2–4). But the best scientists also use intuition, imagination, and creativity in asking important questions, developing hypotheses, and designing ways to test them. Scientist Warren Weaver's quotation found at the opening of this chapter reflects this aspect of science.

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

A fundamental part of science is *testing.* Scientists insist on testing their hypotheses, models, methods, and results over and over again to establish the reliability of these scientific tools, and the resulting conclusions.

Media news reports often focus on disputes among scientists over the validity of scientific data, hypotheses, models, methods, or results. This reveals differences in the reliability of various scientific tools and results. Simply put, some science is more reliable than other science, depending on how carefully it has been done and on how thoroughly the hypotheses, models, methods, and results have been tested.

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, and laws that are widely accepted by scientists who are considered experts in the field. 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 (Science Focus, at right) may discredit or alter tried and 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

SCIENCE FOCUS

Easter Island: Some Revisions in a Popular Environmental Story

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

Scientists used anthropological evidence and scientific measurements to estimate the ages of certain artifacts found on Easter Island (also called Rapa Nui). They hypothesized that about 2,900 years ago, Polynesians used double-hulled, seagoing canoes to colonize the island. The settlers probably found a paradise with fertile soil that supported dense and diverse forests and lush grasses. According to this hypothesis, the islanders thrived, and their population increased to as many as 15,000 people.

Measurements made by scientists indicated that over time the Polynesians began living unsustainably by using the island's forest and soil resources faster than they could be renewed. When they had used up the large trees, the islanders could no longer build their traditional seagoing canoes for fishing in deeper offshore waters, and no one could escape the island by boat.

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

But in 2006, anthropologist Terry L. Hunt evaluated the accuracy of past measurements and other evidence and carried out new measurements to estimate the ages of various artifacts. He used these data to formulate an alternative hypothesis describing the human tragedy on Easter Island.

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

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

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

This story is an excellent example of how science works. The gathering of new scientific data and reevaluation of older data led to a revised hypothesis that challenged our thinking about the decline of civilization on Easter Island. The tragedy may not be as clear an example of ecological collapse caused mostly by humans as was once thought. However, there is evidence that other earlier civilizations did suffer ecological collapse largely from unsustainable use of soil, water, and other resources, as described in Supplement 6 on p. S31.

Critical Thinking

Does the new doubt about the original Easter Island hypothesis mean that we should not be concerned about our apparent and growing unsustainable use of essential natural capital on the island in space we call the earth? Explain.

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**). CORE CASE STUDY
- Have the data supporting the proposed hypotheses been verified? Have the results been reproduced by other scientists?
- Do the conclusions and hypotheses follow logically from the data?
- Are there no better scientific explanations?
- Are the investigators unbiased in their interpretations of the results? Are they free of a hidden agenda? Were they funded by an unbiased source?
- Have the conclusions been verified by impartial 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.* See Supplement 17 on pp. S73–S80 on How to Analyze a Scientific Paper.

Science and Environmental Science Have Some Limitations

Before we continue our study of environmental science, we need to recognize some of its limitations, as well as those of science in general. First, scientists can disprove things but cannot prove anything absolutely because there is always some degree of uncertainty in scientific measurements, observations, and models.

Instead scientists try to establish that a particular model, theory, or law has a very high *probability* (90–99%) of being true and thus is classified as reliable science. Most scientists rarely say something like, "Cigarettes cause lung cancer." Rather, they might say, "Overwhelming evidence from thousands of studies indicates that people who smoke have an increased risk of developing lung cancer."

> **THINKING ABOUT**
> **Scientific Proof**
> Does the fact that science can never prove anything absolutely mean that its results are not valid or useful? Explain.

Second, scientists are human and cannot be expected to be totally free of bias about their results and hypotheses. However, bias can be minimized and often uncovered by the high standards of evidence required through peer review.

A third problem is that many environmental phenomena involve a huge number of interacting variables and complex interactions, which makes it 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. Using *multivariable analysis* by developing mathematical models that include the interactions of many variables and running them on 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

A fourth problem is that environmental and other scientists must use statistical sampling and methods to estimate some numbers. For example, there is no way to measure accurately how much soil is eroded worldwide or how much forest is cleared every year. So these numbers are estimated by using the best available sampling and statistical techniques.

Finally, the scientific process is limited to understanding the natural world. It cannot be applied to answer moral or ethical questions for which we cannot collect data from the natural world.

2-2 What Is Matter?

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

Matter Consists of Elements and Compounds

To begin our study of environmental science, we start at the most basic level, looking at the stuff that makes up life and its environment—matter. **Matter** is anything that has mass and takes up space. It is found in two chemical forms. One is **elements:** the distinctive building blocks of matter that make up every material substance. For example, gold is an element that cannot be broken down into any other substance. Some matter consists of one element, but most matter consists of **compounds:** combinations of two or more different elements held together in fixed proportions. For example, water is a compound made of the elements hydrogen and oxygen, which have chemically combined with one another. (See Supplement 7 on pp. S32–S38 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. Just four elements—oxygen, carbon, hydrogen, and nitrogen—make up about 96% of your body weight and that of most other living things.

Table 2-1

Elements Important to the Study of Environmental Science

Element	Symbol	Element	Symbol
hydrogen	H	bromine	Br
carbon	C	sodium	Na
oxygen	O	calcium	Ca
nitrogen	N	lead	Pb
phosphorus	P	mercury	Hg
sulfur	S	arsenic	As
chlorine	Cl	uranium	U
fluorine	F		

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 retain its chemical properties. 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. (For more information on the nature of atoms see Supplement 7, p. S32.)

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 *subatomic particles.* There are three types of these atomic building blocks: positively charged **protons (p),** uncharged **neutrons (n),** 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 around the nucleus (see Figure 1 on p. S32 in Supplement 7). Each atom has equal numbers of positively charged protons and negatively charged electrons. Because these electrical charges cancel one another, *the atom as a whole has no net electrical charge.*

Each element has a unique **atomic number,** equal to the number of protons in the nucleus of its atom. The simplest element, hydrogen (H), has only 1 proton in its nucleus, so its atomic number is 1. Carbon (C), with 6 protons, has an atomic number of 6, whereas uranium (U), a much larger atom, has 92 protons and an atomic number of 92.

Because electrons have so little mass compared with the masses of protons or 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).

All atoms of an element have the same number of protons in their nuclei. But the nuclei may contain different numbers of neutrons and therefore have different 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 six protons and six neutrons), carbon-13 (with six protons and seven neutrons), and carbon-14 (with six protons and eight neutrons). Carbon-12 makes up about 98.9% of all naturally occurring carbon.

A second building block of matter is an **ion**—an atom or groups of atoms with one or more net positive or negative electrical charges. An ion forms when an atom gains or loses one or more electrons. An atom that loses one or more of its electrons has a positive electrical charge because the number of positively charged protons in its nucleus is now greater than the number of negatively charged electrons outside its nucleus. Similarly, when an atom gains one or more electrons, it becomes an ion with one or more negative electrical charges because the number of negatively charged electrons is greater than the number of positively charged protons. (For more details on how ions form see p. S33 in Supplement 7.)

The number of positive or negative charges on an ion is shown as a superscript after the symbol for an atom or a group of atoms. Examples encountered in this book include *positive* hydrogen ions (H^+) and *negative* chloride ions (Cl^-). These and other ions listed in Table 2-2 are used in other chapters in this book.

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 shows measurements of the loss of nitrate ions from the deforested area (Figure 2-1, right) in the controlled experiment run by Bormann and Likens (**Core Case Study**). Chemical analysis of the water

Table 2-2

Ions Important to the Study of Environmental Science

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

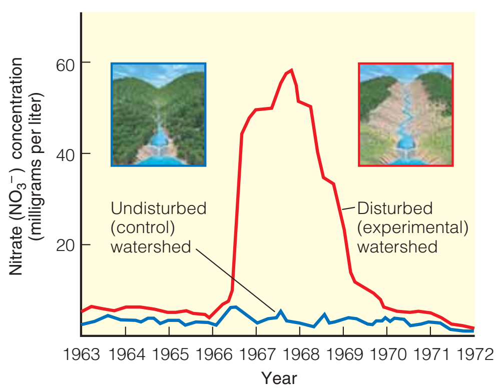


Figure 2-3 Loss of nitrate ions (NO_3^-) from a deforested watershed in the Hubbard Brook Experimental Forest in New Hampshire (Figure 2-1, right). The concentration of nitrate ions in runoff from the deforested experimental watershed was many times greater than in a nearby unlogged watershed used as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

flowing through the dams of the cleared forest area showed a 60-fold rise in the concentration of nitrate ions (NO_3^-) compared to water running off of the uncleared forest area. So much nitrate was lost from the experimental (cleared) valley that the stream below this valley became covered with algae whose populations soared as a result of an excess of nitrate plant nutrients. After a few years, however, vegetation began growing back on the cleared valley and nitrate levels in its runoff returned to normal levels.

Ions are also important for measuring a substance's *acidity* in a water solution, a chemical characteristic that helps determine how a substance dissolved in water will interact with and affect its environment. Scientists use **pH** as a measure of the 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 on p. S34 in Supplement 7 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 chemical bonds. Molecules are the basic units of some compounds (called *molecular compounds*). Examples are shown in Figure 5 on p. S34 in Supplement 7.

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.

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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, such as hydrogen, oxygen, nitrogen, sulfur, phosphorus, chlorine, and fluorine. One exception, methane (CH_4), has only one carbon atom. All other compounds are called **inorganic compounds.**

Figure 2-4 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 and is more widely dispersed than high-quality matter.

Table 2-3

Compounds Important to the Study of Environmental Science

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

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

- *Hydrocarbons:* compounds of carbon and hydrogen atoms. An 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 on p. S35 in Supplement 7. See Supplement 7, pp. S35–S36, for a discussion of larger and more complex organic compounds—the chemical building blocks of life—such as complex carbohydrates, proteins, nucleic acids (such as DNA), and lipids.

Some Forms of Matter Are More Useful Than Others

Matter quality is a measure of how useful a form of matter is to humans as a resource, based on its availability and concentration, as shown in Figure 2-4 (p. 30). **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 the atmosphere, and usually has little potential for use as a resource.

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

2-3 How Can Matter Change?

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

Matter Undergoes Physical, Chemical, and Nuclear Changes

When a sample of matter undergoes a **physical change,** its *chemical composition,* or the arrangement of its atoms or ions does not change. A piece of aluminum foil cut into small pieces is still aluminum foil. When solid water (ice) melts or liquid water boils, none of the H_2O molecules are changed; instead, the molecules are organized in different spatial (physical) patterns.

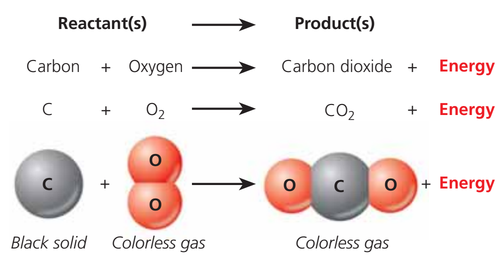
THINKING ABOUT

Controlled Experiments and Physical Changes

CORE CASE STUDY

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

In a **chemical change,** or **chemical reaction,** the arrangements of atoms, ions, or molecules change. Chemists use shorthand chemical equations to represent 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).

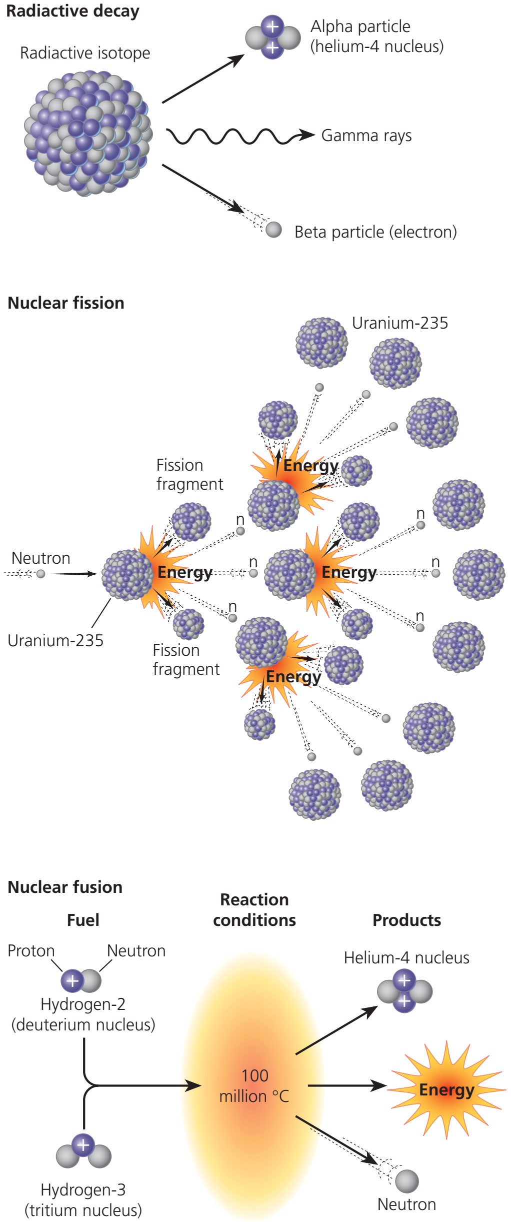


In addition to physical and chemical changes, matter can undergo three types of nuclear changes: natural radioactive decay, nuclear fission, and nuclear fusion (Figure 2-5, p. 32).

We Cannot Create or Destroy Matter

We can change elements and compounds from one physical or chemical form to another, but we can never create or destroy any of the atoms involved in any physical or chemical change. All we can do is rearrange the elements and compounds into different spatial patterns (physical changes) or combinations (chemical changes). These statements, based on many thousands of measurements, describe a scientific law known as

Figure 2-5 Types of nuclear changes: natural radioactive decay (top), nuclear fission (middle), and nuclear fusion (bottom).



Radiocative 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.

the **law of conservation of matter:** when a physical or chemical change occurs, no atoms are created or destroyed (**Concept 2-3**).

This law means there is no "away" as in "to throw away." *Everything we think we have thrown away remains here with us in some form.* We can reuse or recycle some materials and chemicals but the law of conservation of matter means we will always face the problem of what to do with some quantity of the wastes and pollutants we produce.

2-4 What Is Energy and How Can It Change Its Form?

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

CONCEPT 2-4B Whenever energy is changed from one form to another, we always 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 what is done when something is moved. Using energy to do work means moving or lifting something such as this book, propelling a car or plane, cooking your food, and using electricity to move electrons through a wire to light your room.

There are two major types of energy: *moving energy* (called kinetic energy) and *stored energy* (called potential energy). Moving matter has **kinetic energy** because of its mass and its velocity. 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, excluding the overall motion of the whole object. When two objects at different temperatures contact one another, heat flows from the warmer object to the cooler object.

In **electromagnetic radiation,** another form of kinetic energy, energy travels in the form of a *wave* as a result of the changes in electric and magnetic fields. There are many different forms of electromagnetic radiation, each having a different *wavelength* (distance between successive peaks or troughs in the wave) and *energy content.* Forms of electromagnetic radiation such as gamma rays (emitted by some radioactive isotopes, Figure 2-5 top), X rays, and ultraviolet (UV) radiation with short wavelengths have a higher energy content than forms such as visible light and infrared (IR) radiation with longer wavelengths. Visible light makes up most of the spectrum of electromagnetic radiation emitted by the sun (Figure 2-6).

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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, an unlit match, 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. Drop this book on your foot, and the potential energy that the book had when you were holding it changes into kinetic energy. When a car engine burns gasoline, the potential energy stored in the chemical bonds of gasoline molecules changes into mechanical (kinetic) energy that propels the car. Potential energy stored in various molecules such as carbohydrates that you can eat becomes kinetic energy when your body uses it.

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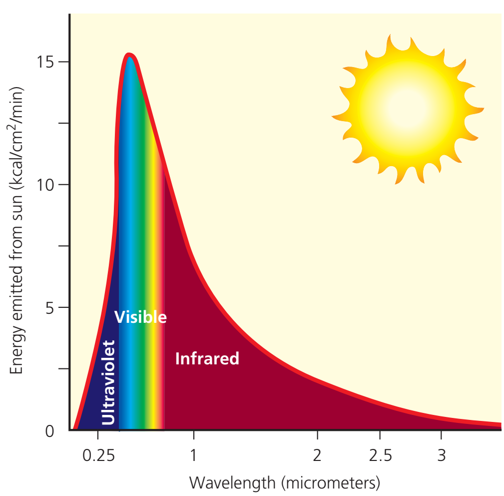
Some Types of Energy Are More Useful Than Others

Energy quality is a measure of an energy source's capacity to do useful work. **High-quality energy** is concentrated and can perform much 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



ThomsonNOW™ **Active Figure 2-6** *Solar capital:* the spectrum of electromagnetic radiation released by the sun consists mostly of visible light. *See an animation based on this figure* at ThomsonNOW.

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 things 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 **law of conservation of energy,** also known as the **first law of thermodynamics:** When energy is converted from one form to another in a physical or chemical change, no energy is created or destroyed (**Concept 2-4A**).

This scientific law tells us that when one form of energy is converted to another form in any physical or chemical change, *energy input always equals energy output.* No matter how hard we try or how clever we are, we cannot get more energy out of a system than we put in. This is one of nature's basic rules.

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. But 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 changes from one form to another, we always end up with less usable energy than we started with. These results have been summarized in the **second law of thermodynamics:** When energy changes from one form to another, we always end up with lower quality or less usable energy than we started with (**Concept 2-4B**). 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.

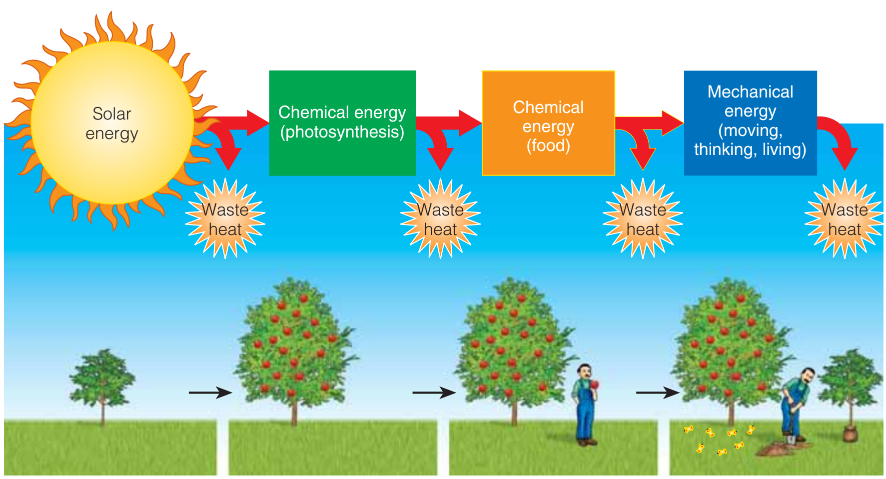
In other words, *energy always goes from a more useful to a less useful form when it changes from one form to another.* No one has ever found a violation of this fundamental scientific law. It is another one of nature's basic rules.

Consider three examples of the second law of thermodynamics in action. *First,* when you drive a car, only about 6% of the high-quality energy available in its gasoline fuel actually moves the car, according to energy expert Amory Lovins. (See his Guest Essay on this topic at ThomsonNOW™.) The remaining 94% is degraded to low-quality heat that is released into the environment. Thus, 94% of the money you spend for gasoline is not used to transport you anywhere.

Second, when electrical energy in the form of moving electrons flows through filament wires in an incandescent light bulb, about 5% of it changes into useful light and 95% flows into the environment as low-quality heat. In other words, the *incandescent light bulb* 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 (for 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 2-7 to see how this happens.

The second law of thermodynamics also means *we can never recycle or reuse high-quality energy to perform useful work.* Once the concentrated energy in a serving of



ThomsonNOW™ Active Figure 2-7 The second law of thermodynamics in action in living systems. Each time energy changes 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* ThomsonNOW. **Question:** What are three things that you did during the past hour that degraded high-quality energy?

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, or **energy productivity**, 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%).

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 can do so by driving fuel-efficient motor vehicles, living in well-insulated houses, and using energy-efficient lights, heating and cooling systems, and appliances. Ideally, we should get as much energy as possible for these purposes from the sun and from electricity produced indirectly from the sun by renewable flowing water (hydropower), wind, and biofuels. This involves using the first **scientific principle of sustainability** (Figure 1-13, p. 20, and **Concept 1-6**, p. 19).

SUSTAINABILITY

CONCEPT LINK

ThomsonNOW™ See examples of how the first and second laws of thermodynamics apply in our world at ThomsonNOW.

2-5 How Can We Use Matter and Energy More Sustainably?

CONCEPT 2-5A The processes of life must conform to the law of conservation of matter and the two laws of thermodynamics.

CONCEPT 2-5B We can live more sustainably by using and wasting less matter and energy, recycling and reusing most matter resources, and controlling human population growth.

Today's Advanced Industrialized Societies Waste Enormous Amounts of Matter and Energy

The processes of life must obey the law of conservation of matter and the two laws of thermodynamics (**Concept 2-5A**). We can use these physical laws to outline some ways for making a transition to more sustainable societies.

As a result of the law of conservation of matter and the second law of thermodynamics, using resources automatically adds some waste heat and waste matter to the environment. Most of today's advanced industrialized countries have **high-throughput (high-waste) economies** that attempt to boost economic growth by increasing the flow of matter and energy resources through their economic systems (Figure 2-8, p. 36). These resources flow through their economies into planetary *sinks* (air, water, soil, and organisms), where pollutants and wastes can accumulate to harmful levels.

What happens if more people continue to use and waste more energy and matter resources at an increasing rate? The law of conservation of matter and the two laws of thermodynamics tell us that this resource consumption will increasingly exceed the capacity of the environment to provide sufficient renewable resources, to dilute and degrade waste matter, and to absorb waste heat. This is already happening because of our large and growing ecological footprints (Figure 1-8, p. 13).

We Can Shift to Matter-Recycling and Reuse Economies

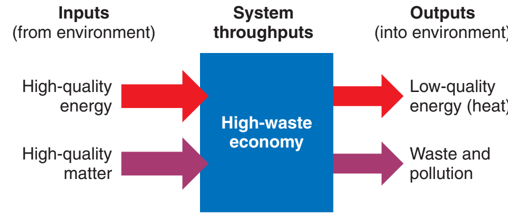
A temporary solution to this problem is to convert a linear throughput economy into a circular **matter recycling and reuse economy,** which mimics nature by recycling and reusing most matter outputs instead of dumping them into the environment. This involves applying another of the four **scientific principles of sustainability** (Figure 1-13, p. 20, and **Concept 1-6**, p. 19).

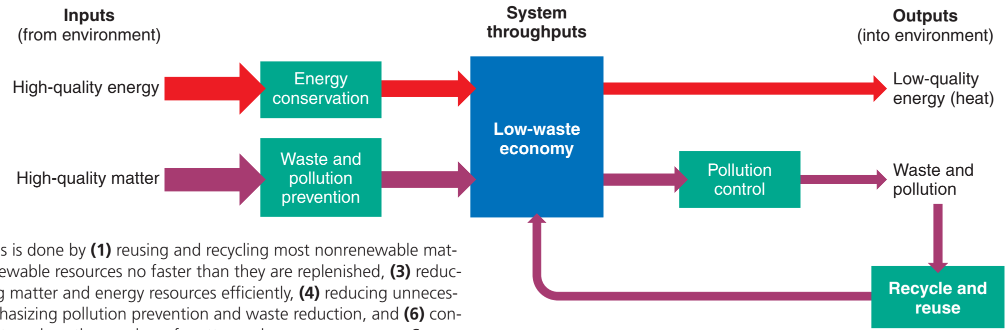
SUSTAINABILITY

CONCEPT LINK

Although changing to a matter-recycling-and-reuse economy would buy some time, it would not allow ever more people to use ever more resources indefinitely, even if all matter resources were somehow perfectly recycled or reused. The two laws of thermodynamics tell us that recycling and reusing matter resources always requires using high-quality energy (which cannot be recycled) and adds waste heat to the environment.

ThomsonNOW™ **Active Figure 2-8** The *high-throughput economies* of most developed countries rely on continually increasing the rates of energy and matter flow. This practice produces valuable goods and services, but it also converts high-quality matter and energy resources into waste, pollution, and low-quality heat. *See an animation based on this figure at* ThomsonNOW. **Question:** What are five things that you regularly do to add to this throughput of matter and energy?





ThomsonNOW™ **Active Figure 2-9** **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 (items shown in green). 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 efficiently, **(4)** reducing unnecessary 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* ThomsonNOW. **Question:** What are three ways in which your school or community could operate more like a low-throughput economy?

We Can Use Scientific Lessons from Nature to Shift to More Sustainable Societies

The three scientific laws governing matter and energy changes and the four **scientific principles of sustainability** (see back cover and **Concept 1-6**) suggest that the best long-term solution to our environmental and resource problems is to shift from an economy based on increasing matter and energy flow (throughput) to a more sustainable **low-throughput (low-waste) economy,** as summarized in Figure 2-9. In other words, we can live more sustainably by using and wasting less matter and energy, recycling and reusing most matter resources, and controlling human population growth (**Concept 2-5B**).

CONCEPT LINK

ThomsonNOW™ Compare how energy is used in high- and low-throughput economies at ThomsonNOW.

REVISITING The Hubbard Brook Experimental Forest and Sustainability

CORE CASE STUDY CONCEPT LINKS

The controlled experiment discussed in the **Core Case Study** that opened this chapter revealed that clearing a mature forest degrades some of its natural capital (Figure 1-3, p. 8). Specifically, the loss of trees and vegetation altered the ability of the forest to retain and recycle water and other critical plant nutrients—one of the four **scientific principles of sustainability** (Figure 1-13, p. 20). 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 loss of vegetation also violated the other three **scientific 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. This in turn reduced some of the interactions between different types of plants and animals that help control their populations.

Humans clear forests to grow food and build cities. The key question is, how far can we go in expanding our ecological footprints (Figure 1-8, p. 13, and **Concept 1-3**, p. 11) without threatening the quality of life for our own species and the other species that keep us alive and support our economies? To live more sustainably, we need to find and maintain a balance between preserving undisturbed natural systems and modifying others for our use.

The next five chapters apply the three basic laws of matter and thermodynamics to living systems, and they explore some *biological principles* that can help us live more sustainably by understanding and learning from nature.

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 QUESTIONS

1. What is science? Describe what a controlled scientific experiment is. Explain the steps involved in the scientific process.
2. What are three limitations of environmental science?
3. What is matter? Identify the two chemical forms of matter. Describe the building blocks of matter. What makes matter useful as a resource?
4. What is a physical change? What is a chemical change? Describe the three types of nuclear changes that matter can undergo.
5. Identify and discuss the scientific law that governs the changes of matter from one physical or chemical form to another.
6. What is energy? Describe the two major types of energy. Define the term energy quality and explain how it relates to the usefulness of energy as a resource.
7. Identify and define the two scientific laws that govern energy changes.
8. How are the scientific laws governing changes of matter and energy from one form to another related to resource use and environmental degradation?
9. What is a high-throughput economy? What is a low-throughput economy?
10. How can a society move from a high-throughput economy to a more sustainable lower-throughput economy?

CRITICAL THINKING

1. List three ways in which you could apply **Concept 2-5B** to making your lifestyle more environmentally sustainable.
2. 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? List two ways that you can apply this lesson to your own lifestyle. CORE CASE STUDY
3. 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.
4. A tree grows and increases its mass. Explain why this phenomenon is not a violation of the law of conservation of matter.
5. If there is no "away" where organisms can get rid of their wastes, why is the world not filled with waste matter?
6. Someone wants you to invest money in an automobile engine that will produce more energy than the energy in the fuel used to run the motor. What is your response? Explain.
7. 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 energy.
8.
   - **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?
9. What three changes could you make in your lifestyle to help implement the shift to a more sustainable, low-throughput society shown in Figure 2-9, p. 36? Which, if any, of these changes do you plan to make? SUSTAINABILITY
10. List two questions that you would like to have answered as a result of reading this chapter.

LEARNING ONLINE

Log on to the Student Companion Site for this book at www.thomsonedu.com/biology/miller and choose Chapter 2 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Web links, information on Green Careers, and InfoTrac® College Edition articles.

For access to animations and additional quizzing, register and log on to Thomson NOW! at **www.thomsonedu.com/thomsonnow** using the access code card in the front of your book.

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

CORE CASE STUDY Have You Thanked the Insects Today?

Insects have a bad reputation. We classify many insect species as *pests* because they compete with us for food, spread human diseases such as malaria, 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.

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 3-1, right). Without pollinating insects, we would have very few flowers, fruits, and vegetables to enjoy. Not all flowering plant species would disappear because some are pollinated by hummingbirds, bats, wind, and flowing water.

Insects that eat other insects—such as the praying mantis (Figure 3-1, left)—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 (Figure 1-3, p. 8). Some insects also play a key role in loosening and renewing the soil that supports terrestrial plant life.

Insects have been around for at least 400 million years—about 4,000 times longer than we have—and 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 newcomers such as us, we and most other land organisms need insects.

Learning about the roles of insects in nature helps us to understand how they and other organisms interact with one another and with their nonliving physical environment of chemicals and energy in most of the world's *ecosystems.* We reach this understanding through *ecology,* the science that studies such relationships and interactions in nature.

Peter J. Bryant/Biological Photo Service

John Henry Williams/Bruce Coleman USA

Figure 3-1 *Importance of insects:* the monarch butterfly, which feeds on pollen in a flower (right), and other insects pollinate flowering plants that serve as food for many plant eaters. The praying mantis, which is eating a house cricket (above), and many other insect species help control the populations of most of the insect species we classify as pests.

Key Questions and Concepts

3-1 What is ecology?

CONCEPT 3-1 Ecology is a study of how organisms interact with one another and with their physical environment of matter and energy.

3-2 What keeps us and other organisms alive?

CONCEPT 3-2 Life is sustained by the flow of energy from the sun through the biosphere, the cycling of nutrients within the biosphere, and gravity.

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

CONCEPT 3-3 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.

3-4 What is biodiversity and why is it important?

CONCEPT 3-4A The biodiversity found in the earth's genes, species, ecosystems, and ecosystem processes is vital to sustaining life on the earth.

CONCEPT 3-4B Soil is an important component of biodiversity that supplies most of the nutrients needed for plant growth and helps purify and store water and control levels of carbon dioxide in the atmosphere.

3-5 What happens to energy in an ecosystem?

CONCEPT 3-5 As energy flows through ecosystems in food chains and webs, the amount of chemical energy available to organisms at each succeeding feeding level decreases.

3-6 What happens to matter in an ecosystem?

CONCEPT 3-6 Matter cycles within and among ecosystems and in the biosphere, and human activities are altering these chemical cycles.

3-7 How do scientists study ecosystems?

CONCEPT 3-7 Scientists use field research, laboratory research, and mathematical and other models to learn about ecosystems.

Note: Supplements 7, 8, and 9 can be used with this chapter.

The earth's thin film of living matter is sustained by grand-scale cycles of chemical elements.

G. EVELYN HUTCHINSON

3-1 What Is Ecology?

CONCEPT 3-1 Ecology is a study of how organisms interact with one another and with their physical environment of matter and energy.

Cells Are the Basic Units of Life

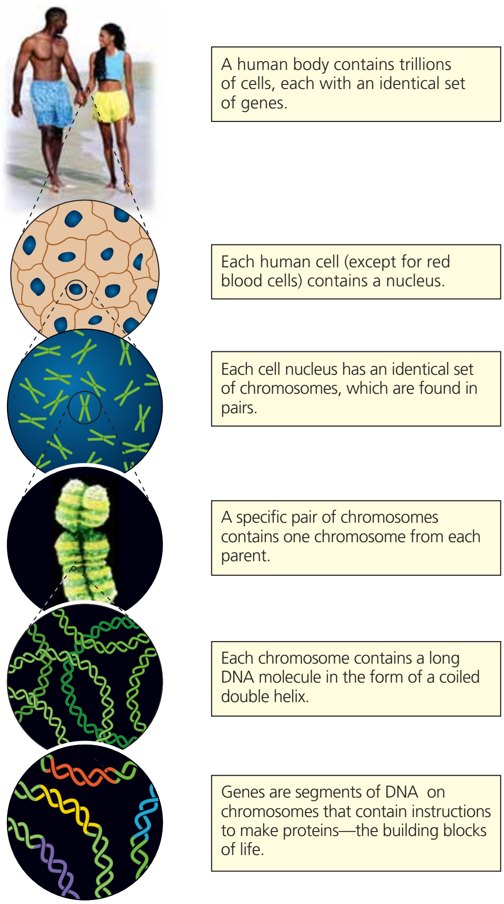
All organisms are composed of **cells:** the smallest and most fundamental structural and functional units of life. They are minute compartments covered with a thin membrane and within which the processes of life occur. The idea that all living things are composed of cells is called the **cell theory** and it is the most widely accepted scientific theory in biology. Organisms may consist of a single cell (bacteria, for instance) or plants and animals that contain huge numbers of cells.

Large and complex organic compounds, called *macromolecules,* make up the basic molecular units found in cells. Three of these molecules are *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 that consist of two or more monomers of simple sugars such as glucose linked together; *proteins* formed by linking together monomers of amino acids; and *nucleic acids* (such as DNA) formed by linking monomers called *nucleotides. Lipids* are a fourth type of macromolecule found in living organisms. Figures 8 through 12 on pp. S35–S36 in Supplement 7 give more details on the structures of these four types of macromolecules.

A **gene** consists of certain sequences of nucleotides found within a DNA molecule that contain instructions,

Figure 3-2 Relationships among cells, nuclei, chromosomes, DNA, and genes.



called *genetic information,* for making specific proteins. These coded units of genetic information are passed on from parents to offspring during reproduction.

A **chromosome** is a single DNA molecule, together with a number of proteins. Each chromosome typically contains thousands of genes. 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. This genetic information makes you a member of the human species but also allows you to be a unique member of that species. The relationships among genetic material and cells are depicted in Figure 3-2.

Species Make Up the Encyclopedia of Life

A **species** is a group of similar organisms that generally resemble one another in their appearance, behavior, chemistry, and genetic makeup. For sexually reproducing organisms, a **species** is a set of individuals who can mate and produce fertile offspring. Every organism is a member of a certain species. For example, all humans are members of the species *Homo sapiens sapiens.* Scientists use a specific system to classify and name each species, as discussed in Supplement 9 on pp. S41–S42.

We do not know how many species are on the earth. Estimates range from 4 million to 100 million—most of them microorganisms too small to be seen with the naked eye (Science Focus, below). The best guess is that there are 10–14 million species in the earth's encyclopedia of life. So far biologists have identified about 1.8 million species, about 54% of them

SCIENCE FOCUS

Which Species Rule the World?

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 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.

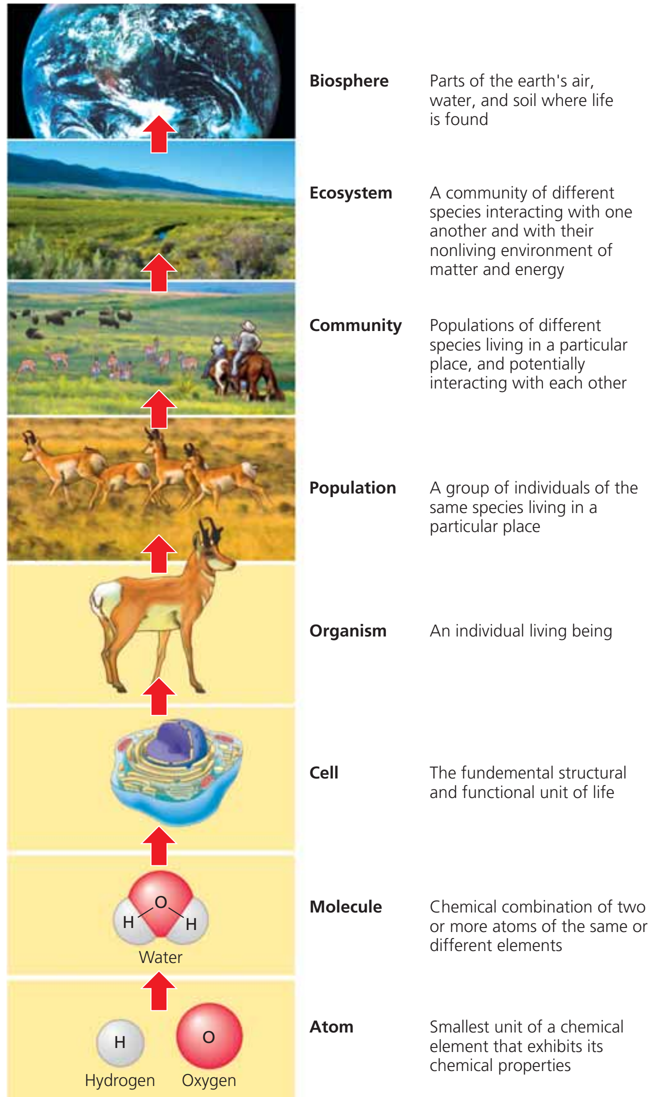
Bacteria and other microbes help purify the water we drink by breaking down wastes. Bacteria also help produce foods such as bread, cheese, yogurt, soy sauce, beer, and wine. Bacteria and fungi in the soil decompose organic wastes into nutrients that can be taken up by plants that we and most other animals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

Microbes, particularly phytoplankton in the ocean, provide, much of the planet's oxygen, and help slow global warming by removing some of the carbon dioxide produced when we burn coal, natural gas, and gasoline. 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 help clean up polluted water and soils.

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

Critical Thinking

List three advantages that microbes have over us for thriving in the world.



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

insects (**Core Case Study**), and know little about more than 99% of them.

Ecologists Study Connections in Nature

Ecology (from the Greek words *oikos,* meaning "house" or "place to live," and *logos,* meaning "study of") is the study of how organisms interact with their living (biotic) environment of other organisms and their nonliving (abiotic) environment of soil, water, other forms of matter, and energy mostly from the sun. In effect, it is a study of *connections in nature.*

To enhance their understanding of nature, scientists classify matter into levels of organization from atoms to the biosphere (Figure 3-3). Ecologists focus on organisms, populations, communities, ecosystems, and the biosphere (**Concept 3-1**).

A **population** is a group of individuals of the same species living in a particular place at the same time. Examples include channel catfish in a pond, white oak trees in a forest, and people in a country. In most natural populations, individuals vary slightly in their genetic makeup, which is why they do not all look or act alike. This variation in a population is called **genetic diversity** (Figure 3-4). The place where a population or an individual organism normally lives is its **habitat.** It may be as large as an ocean or as small as the intestine of a termite.

A **community,** or **biological community,** consists of all the populations of different species living in a particular area. For example, the catfish in a pond usually share the pond with other fish species, and with plants, insects, ducks, and many other species that make up the community.

An **ecosystem** is a community of different species interacting with one another and with their nonliving environment of soil, water, other forms of matter, and energy, mostly from the sun. Ecosystems can range in size from a puddle of water to an ocean, or from a patch of woods to a forest. Ecosystems can be natural or artificial (human created). Examples of artificial ecosystems are crop fields, tree farms (see photo 1 on page vi), and reservoirs.

The **biosphere** consists of the parts of the earth's air, water, and soil where life is found. In effect, it is the global ecosystem in which all living organisms exist and can interact with one another.

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

Figure 3-4 *Genetic diversity* among individuals in a population of a species of Caribbean snail is reflected in the 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.

3-2 What Keeps Us and Other Organisms Alive?

CONCEPT 3-2 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 3-5).

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. It contains the majority of the planet's 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,** because they help trap heat and warm the atmosphere. Almost all of the earth's weather occurs in this layer.

The atmospheric layer, stretching 17–48 kilometers (11–31 miles) above the earth's surface, is the **stratosphere.** Its lower portion contains enough ozone (O_3) gas to filter out most of the sun's harmful ultraviolet radiation. This global sunscreen allows life to exist on land and in the surface layers of bodies of water.

The **hydrosphere** consists of the earth's water. 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. Most of this water is in the oceans, which cover about 71% of the globe.

The **geosphere** consists of the earth's intensely hot *core,* a thick *mantle* composed mostly of rock, and a thin outer *crust.* The **lithosphere** is the earth's solid crust and upper mantle. It contains nonrenewable fossil fuels and minerals we use as well as renewable soil chemicals that organisms need to live, grow, and reproduce.

The *biosphere* occupies those 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 in this thin layer of air, water, soil, and organisms.*

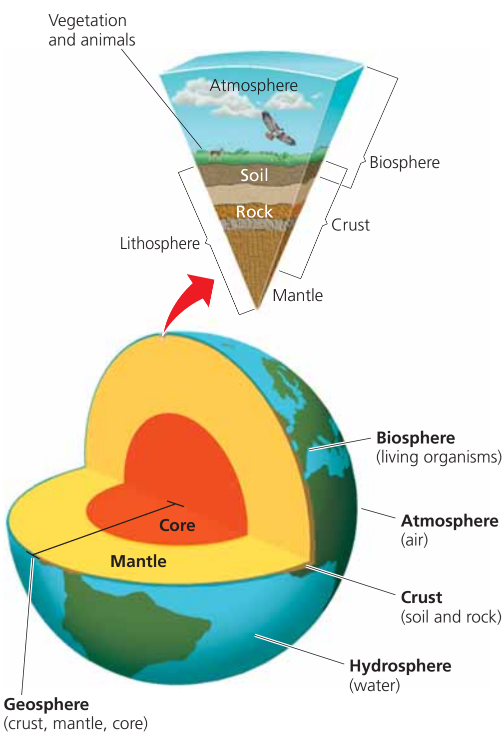


Figure 3-5 **Natural capital:** general structure of the earth.

Life Exists on Land and in Water

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 3-6 shows different major biomes along the 39th parallel spanning the United States (see Figure 5 on p. S19 in Supplement 4 for a map of the major biomes of North America).

Scientists divide the watery parts of the biosphere into **aquatic life zones,** each containing numerous ecosystems. There are *freshwater life zones* (such as lakes and streams) and *ocean* or *marine life zones* (such as coral reefs, coastal estuaries, and the deep ocean). The earth is mostly a water planet with saltwater and freshwater life zones covering almost three-fourths of its surface.

Three Factors Sustain Life on Earth

Life on the earth depends on three interconnected factors (**Concept 3-2**):

- 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

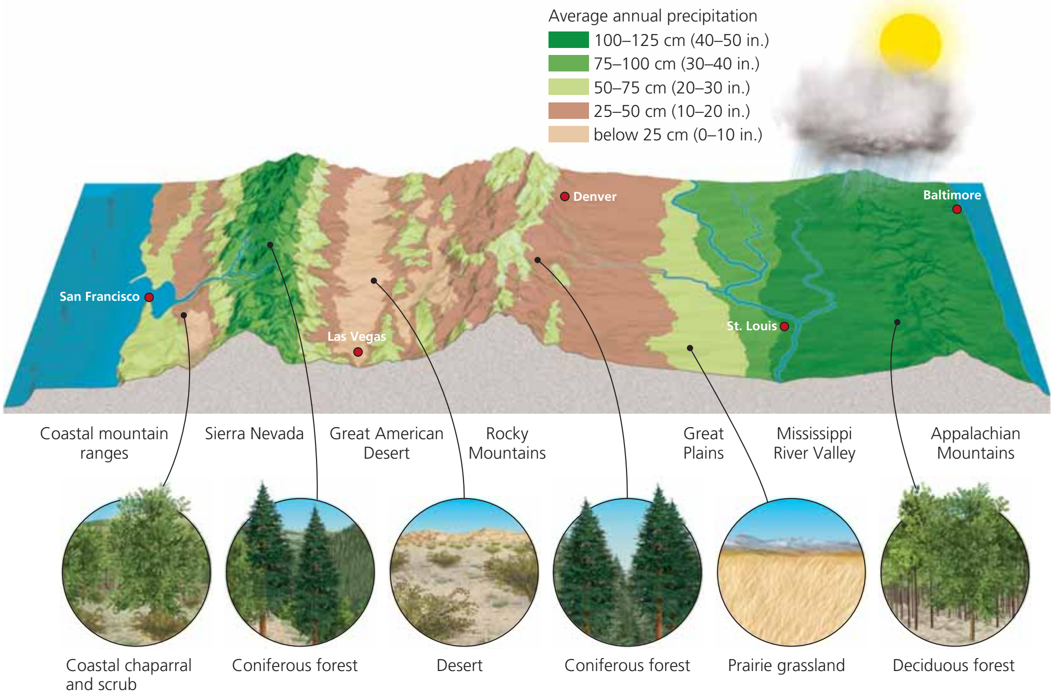


Figure 3-6 Major biomes found along the 39th parallel across the United States. The differences reflect changes in climate, mainly differences in average annual precipitation and temperature.

heat. No round-trips are allowed because energy cannot be recycled. The first law of thermodynamics (**Concept 2-4A**, p. 33) and the second law of thermodynamics (**Concept 2-4B**, p. 33) govern this energy flow. CONCEPT LINKS

- The *cycling of matter or nutrients* (the atoms, ions, or compounds needed for survival by living organisms) through parts of the biosphere (Figure 1-4, p. 9). 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. Nutrient movements in ecosystems and the biosphere are round-trips, which can take from seconds to centuries to complete. The law of conservation of matter (**Concept 2-3**, p. 31) governs this nutrient cycling process. CONCEPT LINK
- *Gravity,* which allows the planet to hold on to its atmosphere and helps enable the movement and cycling of chemicals through the air, water, soil, and organisms.

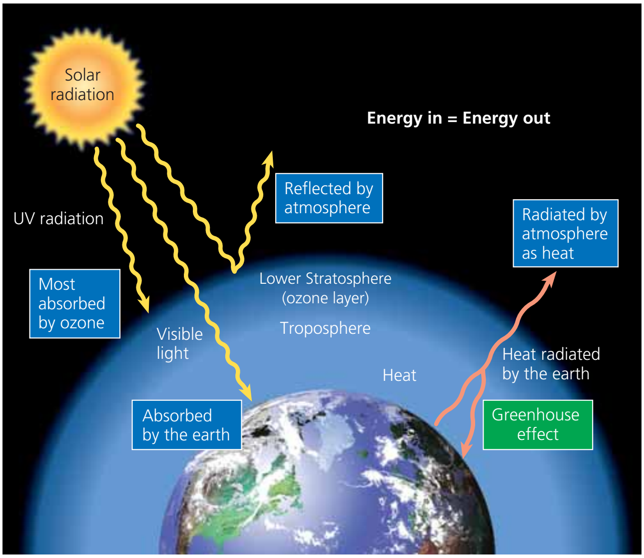
THINKING ABOUT
Energy Flow and the First and Second Laws of Thermodynamics

Explain the relationship between energy flow through ecosystems and the biosphere and the first and second laws of thermodynamics (p. 34).

What Happens to Solar Energy Reaching the Earth?

Millions of kilometers from the earth, in the immense nuclear fusion reactor that is the sun, nuclei of hydrogen fuse together to form larger helium nuclei (Figure 2-5, bottom, p. 32), releasing tremendous amounts of energy into space. Only a very small amount of this output of energy reaches the earth—a tiny sphere in the vastness of space. This energy reaches the earth in the form of electromagnetic waves, mostly as visible light, ultraviolet (UV) radiation, and heat (infrared radiation) (Figure 2-6, p. 33). Much of this energy is absorbed or reflected back into space by the earth's atmosphere, clouds, and surface (Figure 3-7, p. 44). Ozone gas (O_3) in the lower stratosphere absorbs about 95% of the sun's harmful incoming ultraviolet radiation. Without this ozone layer, life as we know it on the land and in the upper layer of water would not exist.

The UV, visible, and infrared energy that reaches the atmosphere lights the earth during daytime, warms the air, and evaporates and cycles water through the biosphere. Approximately 1% of this incoming energy generates winds. Green plants, algae, and some types of bacteria use less than 0.1% of it to produce the nutrients they need through photosynthesis, and in turn to feed animals that eat plants and flesh.



ThomsonNOW™ Active Figure 3-7 *Solar capital:* flow of energy to and from the earth. *See an animation based on this figure at* ThomsonNOW.

Of the total solar radiation intercepted by the earth, about 1% reaches the earth's surface, and most of it is then reflected as longer-wavelength infrared radiation. As this infrared radiation travels back up through the lower atmosphere toward space, it encounters the *greenhouse gases* such as water vapor, carbon dioxide, methane, nitrous oxide, and ozone. It causes these gaseous molecules to vibrate and release infrared radiation with even longer wavelengths. The vibrating gaseous molecules then have higher kinetic energy, which helps to warm the lower atmosphere and the earth's surface. Without this **natural greenhouse effect,** the earth would be too cold to support the forms of life we find here today.

Human activities add greenhouse gases to the atmosphere. For example, burning carbon-containing fuels such as coal, gasoline, and natural gas releases huge amounts of carbon dioxide (CO_2) into the atmosphere. Growing crops and raising livestock release large amounts of methane (CH_4) and nitrous oxide (N_2O). There is considerable and growing evidence that these inputs are increasing the natural greenhouse effect and warming the earth's atmosphere and surface—something often referred to as *human-enhanced global warming.* We discuss this at length in Chapter 16.

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

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

CONCEPT 3-3 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.

Ecosystems Have Living and Nonliving Components

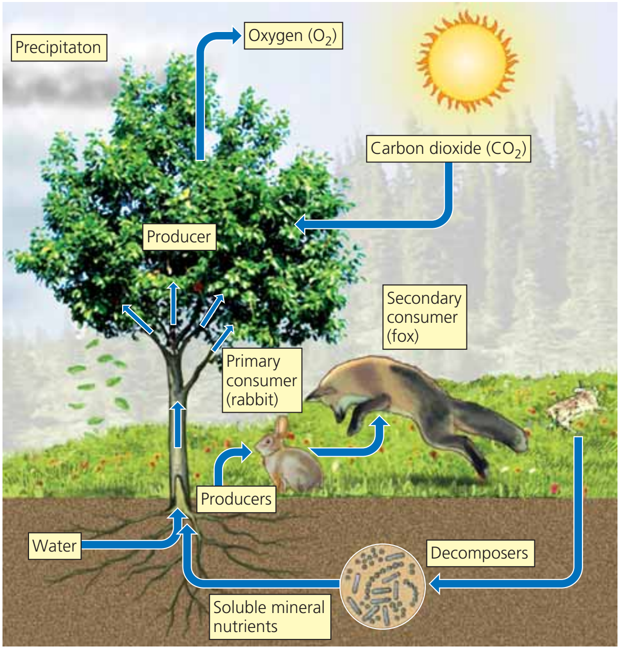
Two types of components make up the biosphere and its ecosystems: One type, called **abiotic,** consists of nonliving components such as water, air, nutrients, and solar energy. The other type, called **biotic,** consists of biological components—plants, animals, and microbes. Figure 3-8 is a greatly simplified diagram of some of the biotic and abiotic components of a terrestrial ecosystem.

Different species and their populations thrive under different physical and chemical conditions. Some need bright sunlight; others flourish in shade. Some need a hot environment; others prefer a cool or cold one. Some do best under wet conditions; others thrive under dry conditions.

Each population in an ecosystem has a **range of tolerance** to variations in its physical and chemical environment, as shown in Figure 3-9. Individuals within a population may also have slightly different tolerance ranges for temperature or other factors because of small differences in genetic makeup, health, and age. For example, a trout population may do best within a narrow band of temperatures (*optimum level* or *range*), but a few individuals can survive above and below that band. Of course, if the water becomes much too hot or too cold, none of the trout can survive.

Several Abiotic Factors Can Limit Population Growth

A variety of abiotic factors can affect the number of organisms in a population. Sometimes one or more factors, known as **limiting factors,** are more important in regulating population growth than other factors. This ecological principle is called the **limiting factor**



ThomsonNOW™ Active Figure 3-8 Major living (biotic) and nonliving (abiotic) components of an ecosystem in a field. *See an animation based on this figure at* ThomsonNOW.

principle: *Too much or too little of any abiotic factor can limit or prevent growth of a population, even if all other factors are at or near the optimal range of tolerance.* This principle describes one way in which population control—a **scientific principle of sustainability** (Figure 1-13, p. 20 and back cover, and **Concept 1-6**, p. 19)—is achieved.

SUSTAINABILITY

CONCEPT LINK

On land, precipitation often is the limiting abiotic factor. Lack of water in a desert limits plant growth. Soil nutrients also can act as a limiting factor on land. Suppose a farmer plants corn in phosphorus-poor soil. Even if water, nitrogen, potassium, and other nutrients are at optimal levels, the corn will stop growing when it uses up the available phosphorus. Too much of an abiotic factor can also be limiting. For example, too much water or fertilizer can kill plants. Temperature can also be a limiting factor. Both high and low temperatures can limit the survival and population sizes of various terrestrial species, especially plants.

Important limiting abiotic factors for aquatic life zones include temperature, sunlight, nutrient availability, and the low solubility of oxygen gas in water (*dissolved oxygen content*). Another limiting abiotic factor in aquatic life zones is *salinity*—the amounts of various inorganic minerals or salts dissolved in a given volume of water.

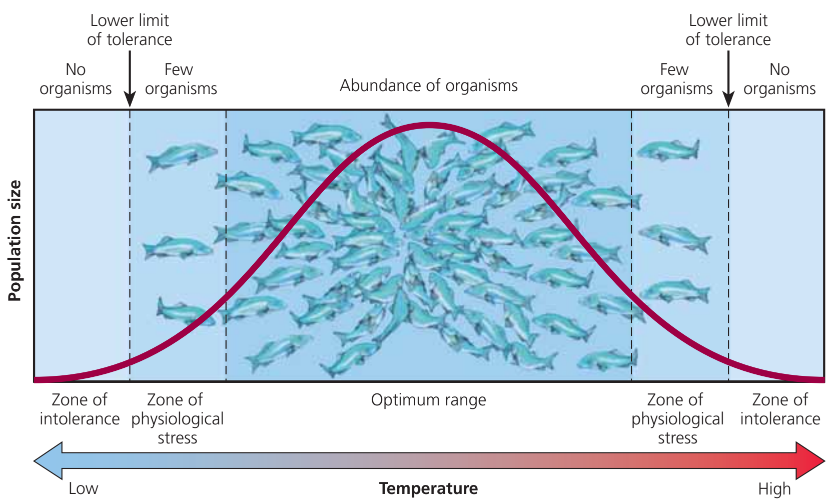


Figure 3-9 Range of tolerance for a population of organisms, such as fish, to an abiotic environmental factor—in this case, temperature. These restrictions keep particular species from taking over an ecosystem by keeping their population size in check. **Question:** Which scientific principle of sustainability (see back cover) is related to the range of tolerance concept?

Producers, Consumers, and Decomposers Are the Living Components of Ecosystems

Ecologists assign every organism in an ecosystem to a *feeding level,* or **trophic level,** depending on its source of food or nutrients. **Producers,** sometimes called **autotrophs** (self-feeders), make the nutrients they need from compounds and energy obtained from their environment.

On land, most producers are green plants, which generally capture about 1% of the energy that falls on their leaves and convert it to chemical energy stored in organic molecules such as carbohydrates. In freshwater and marine ecosystems, algae and plants are the major producers near shorelines. In open water, the dominant producers are *phytoplankton*—mostly microscopic organisms that float or drift in the water.

Most producers capture sunlight to produce energy-rich carbohydrates (such as glucose, $C_6H_{12}O_6$) by **photosynthesis,** which is the way energy enters most ecosystems. Although hundreds of chemical changes take place during photosynthesis, the overall reaction can be summarized as follows:

$$\text{carbon dioxide} + \text{water} + \textbf{solar energy} \rightarrow \text{glucose} + \text{oxygen}$$

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

See p. S37 in Supplement 7 for information on how to balance chemical equations such as this one. Also see pp. S36–S37 in Supplement 7 for more details on photosynthesis.

All other organisms in an ecosystem are **consumers,** or **heterotrophs** ("other-feeders") that cannot produce the nutrients they need through photosynthesis or other processes and must obtain their energy-storing organic molecules and many other nutrients by feeding on other organisms or their remains. **Primary consumers,** or **herbivores** (plant eaters), are animals such as rabbits and zooplankton that eat producers, mostly by feeding on green plants. **Secondary consumers,** or **carnivores** (meat eaters), are animals such as deer and some fish that feed on the flesh of herbivores. **Third** and **higher-level consumers** are carnivores such as tigers and wolves that feed on the flesh of other carnivores. Some of these relationships are shown in Figure 3-8. **Omnivores** such as pigs, foxes, cockroaches, and humans, play dual roles by feeding on both plants and animals.

> **THINKING ABOUT**
> **What You Eat**
> When you had your most recent meal, were you an herbivore, a carnivore, or an omnivore?

Other consumer organisms called decomposers and detritus feeders complete the cycling of nutrients by releasing nutrients from the dead bodies of plants and animals for reuse by producers. **Decomposers,** primarily certain types of bacteria and fungi, are specialized consumer organisms that recycle nutrients in ecosystems. They digest food outside of their bodies by secreting enzymes that break down the bodies of dead organisms into compounds such as water, carbon dioxide, minerals, and simpler organic compounds that producers can take up from the soil, water, and atmosphere and use as nutrients.

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 include small organisms such as mites and earthworms, some insects, and larger scavenger organisms such as vultures. These organisms extract some of the chemical energy stored in dead organic matter, and their bodies and wastes in turn serve as food for other detritus feeders and decomposers. Hordes of these organisms can transform a fallen tree trunk into a powder and finally into simple inorganic molecules that plants can absorb as nutrients (Figure 3-10). Thus, in natural ecosystems the wastes and dead bodies of organisms serve as resources for other organisms, as the nutrients that make life possible are recycled again and again—another **scientific principle of sustainability** (see back cover). In summary, some organisms produce the nutrients they need, others get the nutrients they need by consuming other organisms, and some recycle the nutrients in the wastes and remains of organisms so that producers can use them again (**Concept 3-3**).

> **THINKING ABOUT**
> **Insects**
> CORE CASE STUDY
> Note that some of the detritus feeders in Figure 3-10 are insects (**Core Case Study**). How would your life be changed if such insects disappeared? Why do timber companies want to eliminate many of these insects?

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:

$$\text{glucose} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water} + \textbf{energy}$$

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

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

Some decomposers get the energy they need by breaking down glucose (or other organic compounds) in the *absence* of oxygen. This form of cellular respiration

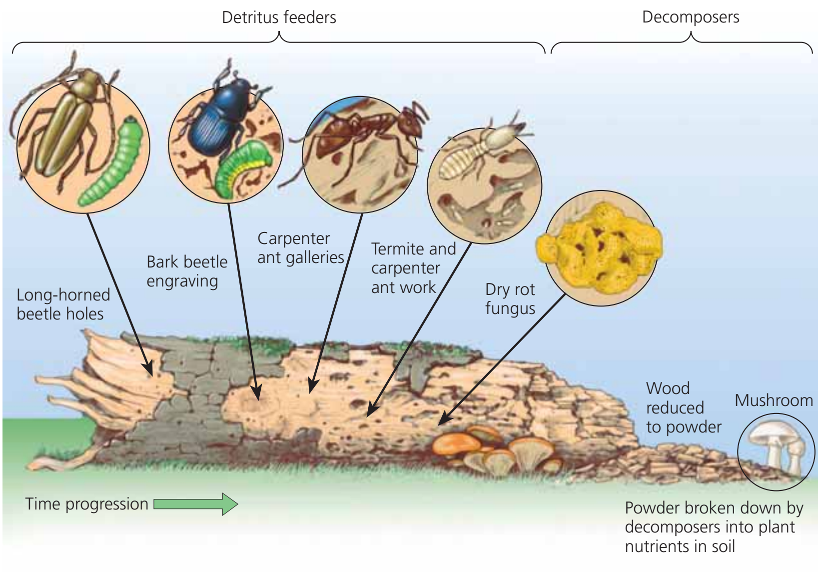


Figure 3-10 Various detritus feeders and decomposers (mostly fungi and bacteria) can "feed on" or digest parts of a log and eventually convert its complex organic chemicals into simpler inorganic nutrients that can be taken up by producers.

is called **anaerobic respiration,** or **fermentation.** The end products of this process are compounds such as methane gas (CH_4), ethyl alcohol (C_2H_6O), acetic acid ($C_2H_4O_2$, the key component of vinegar), and hydrogen sulfide (H_2S, when sulfur compounds are broken down). Note that all organisms get their energy from aerobic or anaerobic respiration, but only plants carry out photosynthesis.

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 2-3**, p. 31).

Energy Flow and Nutrient Recycling Sustain Ecosystems

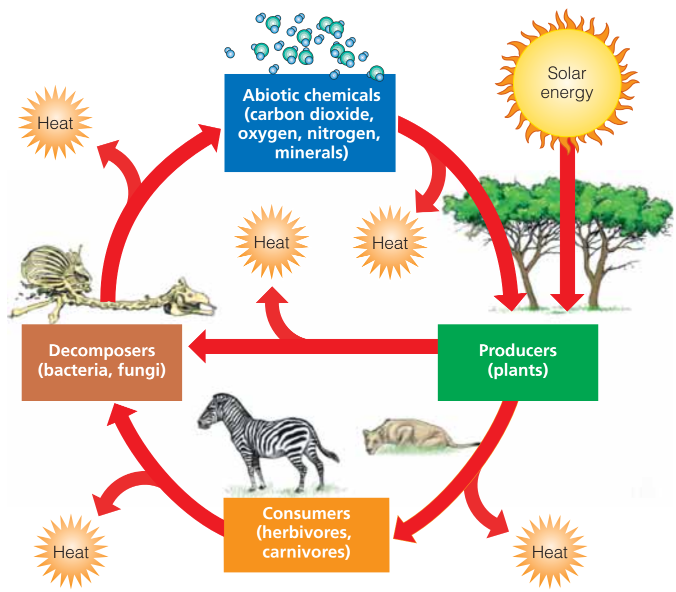
Ecosystems and the biosphere are sustained through a combination of *one-way energy flow* from the sun and *nutrient recycling.* These two **scientific principles of sustainability** arise from the structure and function of natural ecosystems (Figure 3-11), the law of conservation of matter (**Concept 2-3**, p. 31), and the two laws of thermodynamics (p. 34 and **Concepts 2-4A** and **2-4B**, p. 33).

SUSTAINABILITY

CONCEPT LINKS

Decomposers and detritus feeders are absolutely essential to life on the earth. They complete the cycling of matter by breaking down organic matter into simpler nutrients that can be reused by producers. Without decomposers and detritus feeders, the planet would be overwhelmed with plant litter, dead animal bodies, animal wastes, and garbage. In addition, most life as we know it could not exist because the nutrients stored in such wastes and dead bodies would be locked up and unavailable for use by other organisms.

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



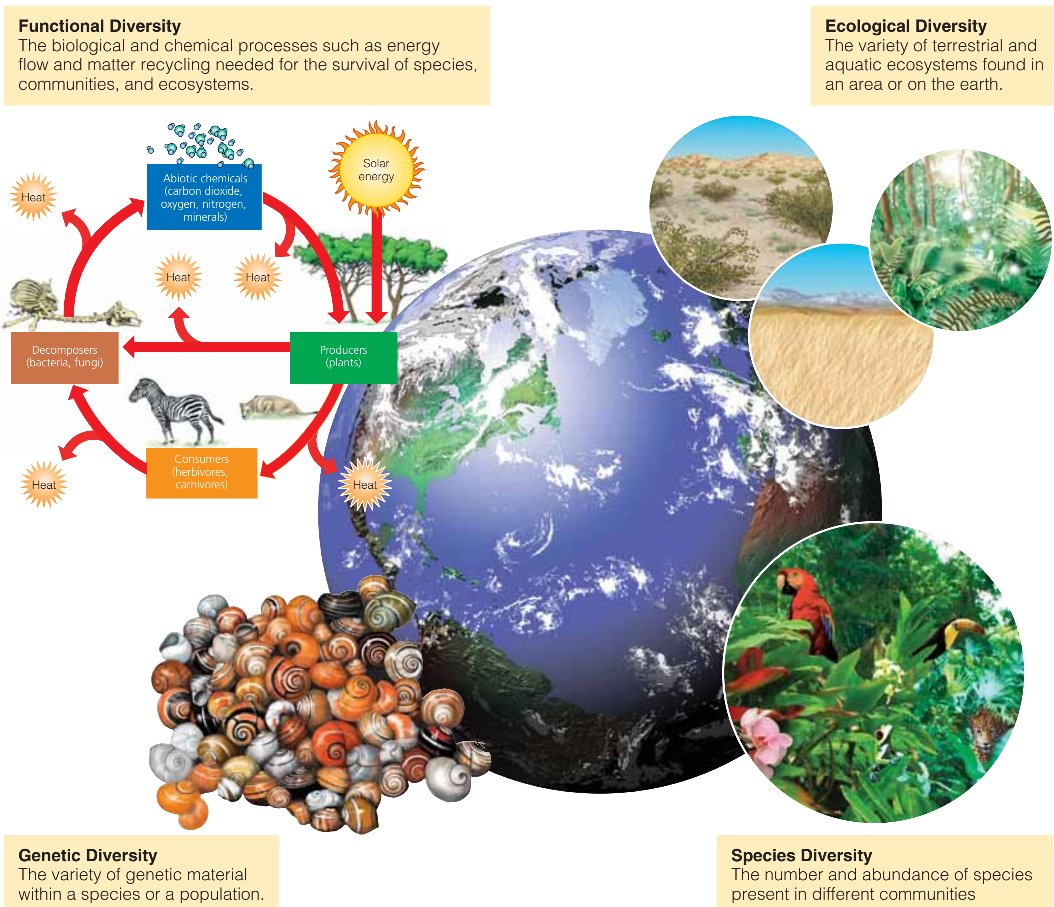
ThomsonNOW™ **Active Figure 3-11** **Natural capital:** the main structural components of an ecosystem (energy, chemicals, and organisms). Nutrient recycling and the flow of energy—first from the sun, then through organisms, and finally into the environment as low-quality heat—link these components.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

3-4 What Is Biodiversity and Why Is It Important?

> **CONCEPT 3-4A** The biodiversity found in the earth's genes, species, ecosystems, and ecosystem processes is vital to sustaining life on the earth.
>
> **CONCEPT 3-4B** Soil is an important component of biodiversity that supplies most of the nutrients needed for plant growth and helps purify and store water and control levels of carbon dioxide in the atmosphere.

Biodiversity Is a Crucial Part of the Earth's Natural Capital

Biological diversity, or **biodiversity,** is the diversity 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 3-12). Biodiversity is a vital renewable resource (**Concept 3-4A**). Figure 3-13 (p. 50) shows just two of the great variety of species found in tropical forests. Also, see photo 3, p. vii. Populations of these and countless other species in other ecosystems contain the variety of genes that make the genetic component of biodiversity. *Genetic diversity* provides a variety of



ThomsonNOW™ **Active Figure 3-12** **Natural capital:** the major components of the earth's *biodiversity*—one of the earth's most important renewable resources. *See an animation based on this figure at* ThomsonNOW. **Question:** What is an aspect of your lifestyle that degrades each of these types of biodiversity?

SCIENCE FOCUS

Soil Is the Base of Life on Land

Most land is covered thinly by **soil**—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. Figure 3-A shows a profile of different-aged soils.

Soil, the base of life on land, is a key component of the earth's natural capital and biodiversity. It supplies most of the nutrients needed for plant growth (Figure 1-4, p. 9), purifies and stores water, and helps control the earth's climate by removing carbon dioxide from the atmosphere and storing it as carbon compounds (**Concept 3-4B**).

Most mature soils—ones that have developed over a long period of time—contain at least three horizontal layers, or horizons, (Figure 3-A), each with a distinct texture and composition that varies with different types of soils. Think of them as floors in the 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 (**Core Case Study**) all interacting in complex ways. Bacteria and other decomposer microorganisms found by the billions in every handful of topsoil break down some of its complex organic compounds into simpler inorganic compounds soluble in water. Soil moisture carrying these dissolved nutrients is drawn up by the roots of plants and transported through stems and into leaves as part of the earth's chemical cycling processes.

The *B horizon* (*subsoil*) and the *C horizon (parent material*) contain most of a soil's inorganic matter, mostly broken-down rock consisting of varying mixtures of sand, silt, clay, and gravel, much of it transported by water from the A horizon (Figure 3-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.

Although topsoil is a renewable resource, it is renewed very slowly and thus can be depleted. Just 1 centimeter (0.4 inch) of topsoil can take hundreds of years to form, but it can be washed or blown away in a matter of weeks or months when we plow grassland or clear a forest and leave its topsoil unprotected.

Since the beginning of agriculture, human activities have accelerated natural soil erosion. We discuss erosion and ways to prevent or control it in Chapter 10.

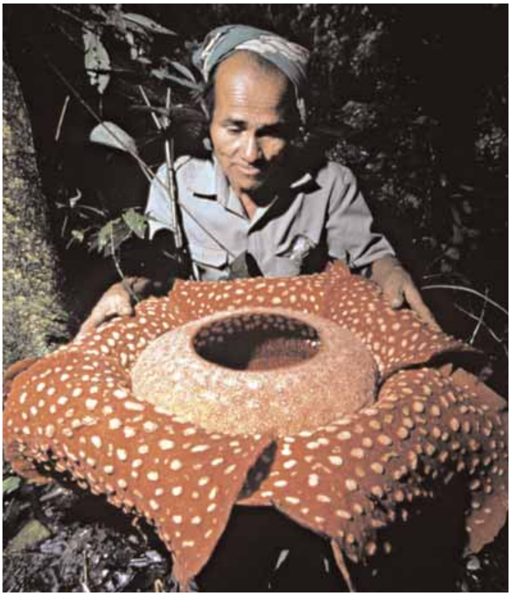
Image not available due to copyright restrictions

Critical Thinking

How does soil contribute to each of the four components of biodiversity described above and in Figure 3-12?

genes that enable life on the earth to adapt to and survive dramatic environmental changes.

Ecosystem diversity—the earth's variety of deserts, grasslands, forests, and mountains, oceans, lakes, rivers, and wetlands is another major component of biodiversity. Each of these ecosystems is a storehouse of genetic and species diversity. In terrestrial ecosystems, soil is an essential component of biodiversity (Science Focus, above). Another important component of biodiversity is *functional diversity*—the variety of processes of matter cycling and energy flow within ecosystems and the biosphere (Figure 3-11).



Roland Seitre/Peter Arnold, Inc.

Roland Seitre/Peter Arnold, Inc.

Figure 3-13 *Species diversity:* two species found in tropical forests are part of the earth's biodiversity. On the right is an endangered *white ukari* in a Brazilian tropical forest. On the left is the world's largest flower, the *flesh flower* (Rafflesia) growing in a tropical rain forest of West Sumatra, Indonesia. The flower of this leafless plant can be as large 1 meter (4.3 feet) in diameter and weigh 7 kilograms (15 pounds). The plant gives off a smell like rotting meat, presumably to attract flies and beetles that pollinate the flower. After blossoming once a year for a few weeks, the blood red flower dissolves into a slimy black mass.

The earth's biodiversity is a vital part of the natural capital that helps keep us alive. It supplies us with food, wood, fibers, energy, and medicines—all of which represent hundreds of billions of dollars in the world economy each year. Biodiversity also helps preserve the quality of the air and water, maintain the fertility of soils, dispose of wastes, and control populations of pests. In carrying out these ecological services that are part of the earth's natural capital (**Concept 1-1A**, p. 6), biodiversity helps sustain life on the earth.

CONCEPT LINKS

Biodiversity and threats to this important form of natural capital are discussed in more detail in Chapters 9 and 10.

ThomsonNOW™ Compare soil profiles from grassland, desert, and three types of forests at ThomsonNOW.

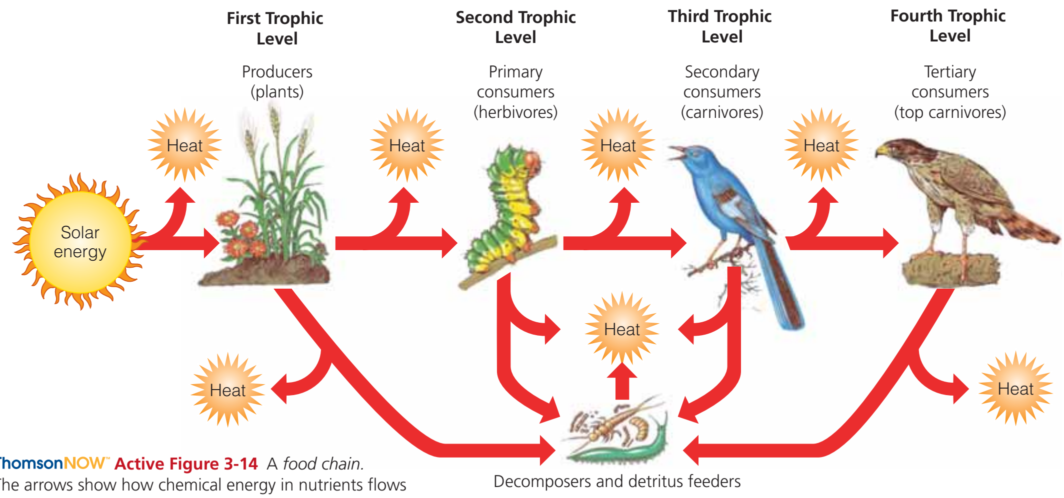
3-5 What Happens to Energy in an Ecosystem?

CONCEPT 3-5 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

All organisms, whether dead or alive, are potential sources of food for other organisms. A caterpillar eats a leaf, a robin eats the caterpillar, and a hawk eats the robin. Decomposers consume 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 for the next, is called a **food chain.** It determines how chemical energy and nutrients move from one organism to another and return their nutrients to the soil for reuse by producers through the



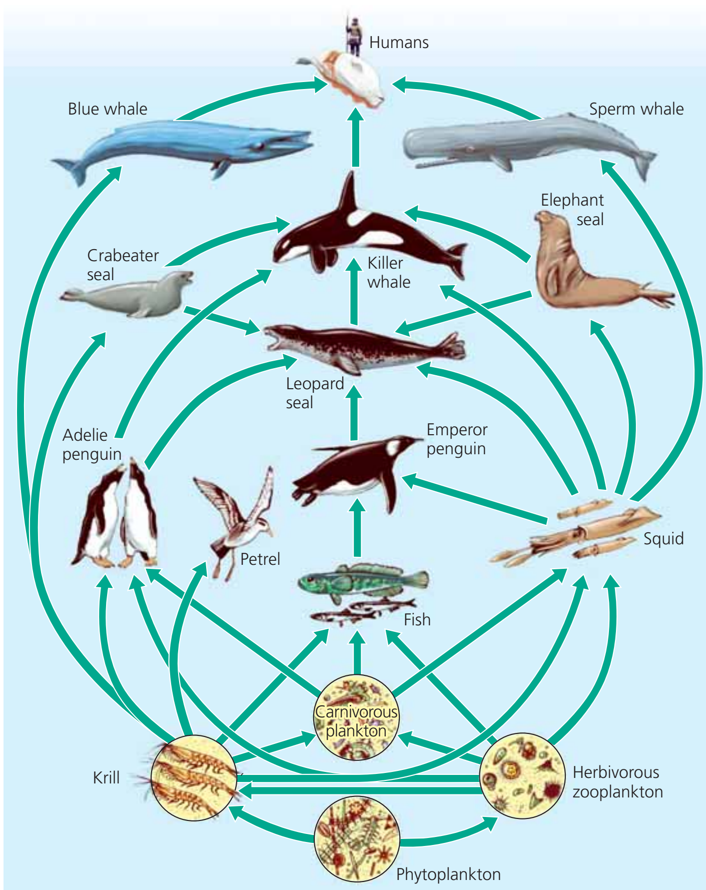
ThomsonNOW™ Active Figure 3-14 A *food chain.* The arrows show how chemical energy in nutrients flows through various *trophic levels* in energy transfers; most of the energy is degraded to heat, in accordance with the second law of thermodynamics. *See an animation based on this figure at* ThomsonNOW. **Question:** Think about what you ate for breakfast. At what level or levels on a food chain were you eating?

trophic levels in an ecosystem along the same pathways—primarily through photosynthesis, feeding, and decomposition—as shown in Figure 3-14.

In natural ecosystems, most consumers feed on more than one type of organism, and most organisms are eaten 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 3-15). 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



ThomsonNOW™ Active Figure 3-15 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* ThomsonNOW. **Question:** Can you imagine a food web of which you are a part? Try drawing a simple diagram of it.

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 decrease in the amount of chemical energy available to organisms at each succeeding feeding level (**Concept 3-5**).

The percentage of usable chemical energy transferred as biomass from one trophic level to the next is called **ecological efficiency.** It ranges from 2% to 40% (that is, a loss of 60–98%) depending on what types of species and ecosystems are involved, but 10% is typical.

Assuming 10% ecological efficiency (90% loss of usable energy) at each trophic transfer, if green plants in an area manage to capture 10,000 units of energy from the sun, then only about 1,000 units of chemical energy will be available to support herbivores, and only about 100 units will be available to support carnivores.

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 3-16 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 2-4B**, pp. 33–34) and the flow of energy through a food chain or web.

Energy flow pyramids explain why the earth can support more people if they eat at lower trophic levels by consuming grains, vegetables, and fruits directly rather than passing such crops through another trophic level and eating grain eaters or herbivores such as cattle. About two-thirds of the world's people survive primarily by eating wheat, rice, and corn at the first trophic level, mostly because they cannot afford meat. The large loss in chemical energy between successive trophic levels also 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.

THINKING ABOUT
Food Webs, Tigers, and Insects

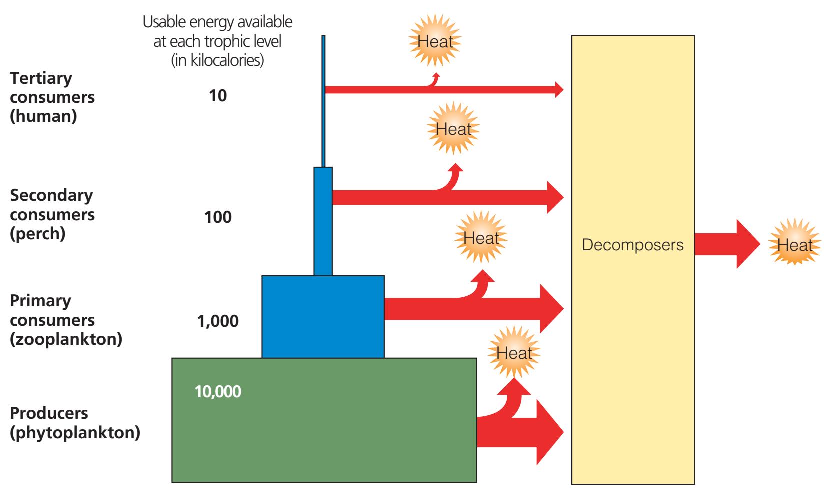
CORE CASE STUDY

Use Figure 3-16 to help explain **(a)** why there are not many tigers in the world and **(b)** why there are so many insects (**Core Case Study**) in the world.

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

Some Ecosystems Produce Plant Matter Faster Than Others Do

The amount of life (biomass) that a particular ecosystem can support is determined by the amount of energy captured and stored as chemical energy by the



ThomsonNOW™ Active Figure 3-16 Generalized *pyramid of energy flow* showing the decrease in usable chemical energy available at each succeeding trophic level in a food chain or web. In nature, ecological efficiency varies from 2% to 40%, with 10% efficiency being common. This model assumes a 10% ecological efficiency (90% loss in usable energy to the environment, in the form of low-quality heat) with each transfer from one trophic level to another. *See an animation based on this figure at* ThomsonNOW. **Question:** Why is a vegetarian diet more energy efficient than a meat-based diet?

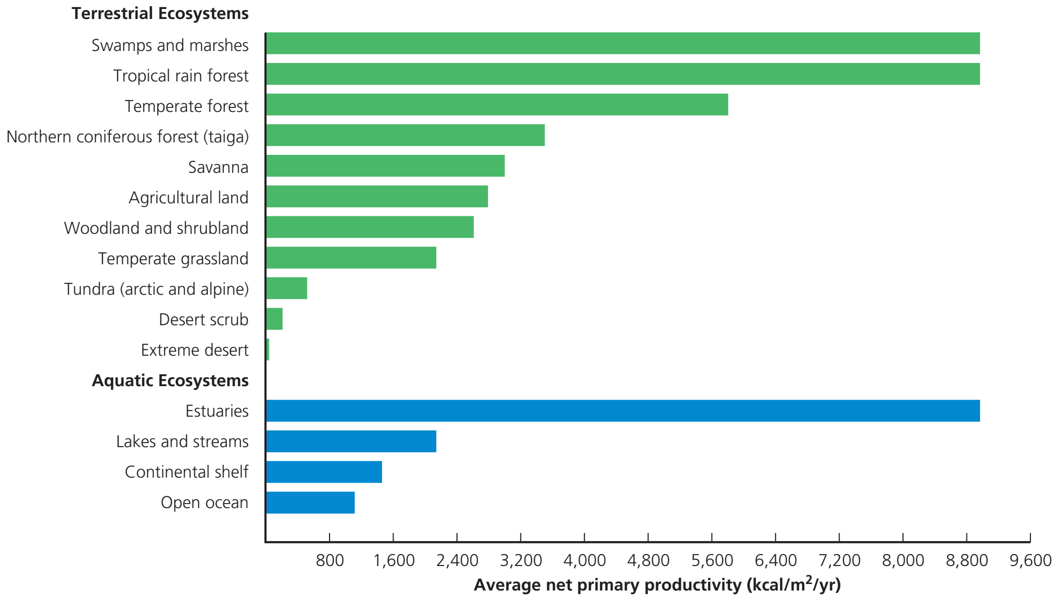


Figure 3-17 Estimated annual average *net primary productivity* in major life zones and ecosystems, expressed as kilocalories of energy produced per square meter per year (kcal/m^2/yr). **Question:** What are nature's three most productive and three least productive systems? (Data from R. H. Whittaker, *Communities and Ecosystems,* 2nd ed., New York: Macmillan, 1975)

producers of that ecosystem and how rapidly they can produce and store such chemical energy. **Gross primary productivity (GPP)** is the *rate* at which an ecosystem's producers convert solar energy into chemical energy as biomass. 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. In other words, NPP = GPP − R, where R is energy used in respiration. NPP measures how fast producers can provide the nutrients or chemical energy stored in their tissue that is potentially available to other organisms (consumers) in an ecosystem.

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

Ecosystems and life zones differ in their NPP as illustrated in Figure 3-17. 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, producers are the source of all nutrients or food in an ecosystem for themselves and for consumer organisms. 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 about 20–32% 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. These scientists contend that this is the main reason why we are crowding out or eliminating the habitats and nutrient supplies of so many other species and degrading or destroying some of the ecosystem services they provide.

THINKING ABOUT
Resource Consumption

What might happen to us and to other consumer species as the human population grows over the next 40–50 years and per capita consumption of resources such as food, timber, and grassland rises sharply? What are three ways to prevent this from happening?

3-6 What Happens to Matter in an Ecosystem?

CONCEPT 3-6 Matter cycles within and among ecosystems and in the biosphere, and human activities are altering these chemical cycles.

Matter Cycles within Ecosystems and in the Biosphere

The elements and compounds that make up nutrients move continually through air, water, soil, rock, and living organisms in cycles called **biogeochemical cycles** (literally, life-earth-chemical cycles) or **nutrient cycles**—prime examples of one of the four **scientific principles of sustainability** (see back cover). These cycles, driven directly or indirectly by incoming solar energy and gravity, include the hydrologic (water), carbon, nitrogen, and phosphorus cycles. Thus, matter cycles within ecosystems and the biosphere and human activities are altering these chemical cycles (**Concept 3-6**).

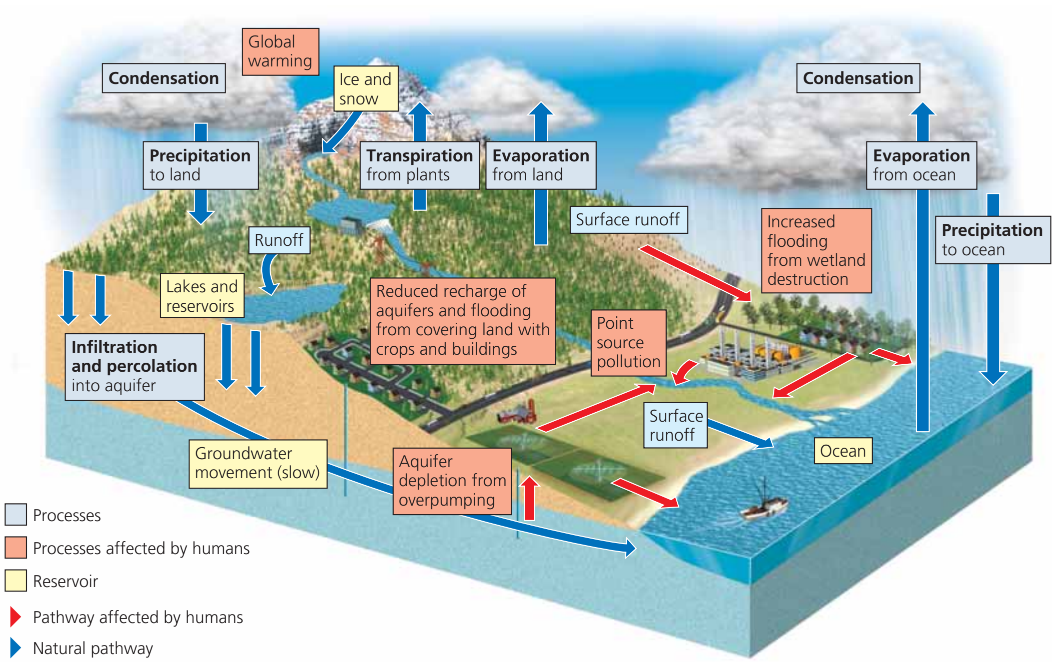
As nutrients move through the biogeochemical cycles, they may accumulate in one portion of the cycle and remain there for different lengths of time. These temporary storage sites such as the atmosphere, the oceans and other waters, and underground deposits are called *reservoirs.*

Nutrient cycles connect past, present, and future forms of life. Some of the carbon atoms in your skin may once have been part of a 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 oxygen molecules you just inhaled.

Water Cycles through the Biosphere

The **hydrologic cycle,** or **water cycle,** collects, purifies, and distributes the earth's fixed supply of water, as shown in Figure 3-18. Water is an amazing substance (Science Focus, at right), which makes the water cycle critical to life on earth.

The water cycle is powered by energy from the sun, which causes evaporation of water from the oceans, lakes, rivers, and soil. Evaporation changes liquid water to water vapor in the atmosphere, and gravity draws the water back to the earth's surface as precipitation



ThomsonNOW™ **Active Figure 3-18 Natural capital:** simplified model of the *hydrologic cycle* with major harmful impacts of human activities shown by red arrows and boxes. *See an animation based on this figure at* ThomsonNOW. **Question:** What are three ways in which your lifestyle directly or indirectly affects the hydrologic cycle?

Water's Unique Properties

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

- *Forces of attraction* (called *hydrogen bonds,* see Figure 7 on p. S35 in Supplement 7) *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 hydrogen bonds.* 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 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 hydrogen bonds.* 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 distribute heat throughout the world and determine regional and local climates. It also makes evaporation a cooling process—explaining why you feel cooler when perspiration evaporates from your skin.
- *Liquid water can dissolve a variety of compounds* (See Figure 4 on p. S33 in Supplement 7). 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 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 2-6, p. 33*) *that would harm some aquatic organisms.* However, up to a certain depth it is transparent to visible light needed for photosynthesis.
- *Hydrogen bonds allow water to adhere to a solid surface.* This enables narrow columns of water to rise through a plant from its roots to its leaves (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. 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

Water is a bent molecule (see Figure 7 on p. S35 in Supplement 7) and this allows it to form hydrogen bonds between its molecules. How would your life be different if water were a linear or straight molecule?

(rain, snow, sleet, and dew). About 84% of water vapor in the atmosphere comes from the oceans; the rest comes from land. Over land, about 90% of the water that reaches the atmosphere evaporates from the surfaces of plants through a process called **transpiration.**

Water returning to the earth's surface as precipitation takes various paths. Some of it evaporates from soil, lakes, and streams back into the atmosphere. Some 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 or by drinking it.

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. Water that seeps downward from ponds, lakes, and streams becomes groundwater in aquifers.

Surface runoff replenishes streams and lakes, but also causes soil erosion, which moves soil and rock fragments from one place to another. Water is the primary sculptor of the earth's landscape. Because water dissolves many nutrient compounds, it is a major medium for transporting nutrients within and between ecosystems.

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

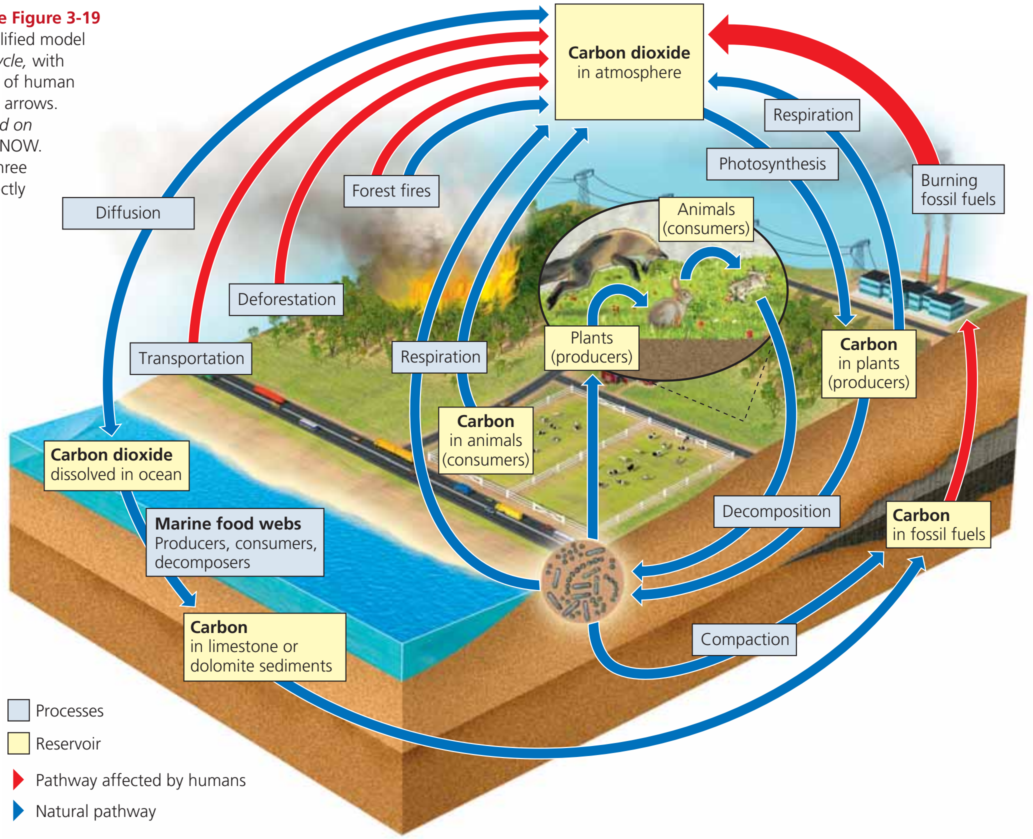
Only about 0.024% of the earth's vast water supply is available to us as liquid freshwater in accessible groundwater deposits and in lakes, rivers, and streams. The rest is too salty for us to use, is stored as ice, or is too deep underground to extract at affordable prices using current technology.

We alter the water cycle by withdrawing large amounts of freshwater, clearing vegetation and eroding soils, polluting surface and underground water, and contributing to climate change (red arrows and boxes in Figure 3-18).

THINKING ABOUT

How You Affect the Water Cycle

List three ways in which you interact with the water cycle.



ThomsonNOW™ Active Figure 3-19
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* ThomsonNOW. **Question:** What are three ways in which you directly or indirectly affect the carbon cycle?

Carbon Cycles through the Biosphere

Carbon, the basic building block of the carbohydrates, fats, proteins, DNA, and other organic compounds necessary for life, circulates through the biosphere in the **carbon cycle** shown in Figure 3-19.

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 nature'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 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. 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. 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. Over millions of years, buried deposits of dead plant matter and bacteria are compressed between layers of sediment, where high pressure and temperature converts them to carbon-containing *fossil fuels* such as coal, oil, and natural gas (Figure 3-19). This carbon is not released to the atmosphere as CO_2 for recycling until these fuels are extracted and burned, or until long-term geological processes expose these deposits to air. In only a few hundred years, we have extracted and burned large 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, adding large amounts of carbon dioxide to the atmosphere by burning fossil fuels and clearing photosynthesizing vegetation in forests and grasslands faster than they are replenished (red arrows in Figure 3-19). There is considerable evidence that CO_2 emissions from these human activities play an important role in the current warming of the atmosphere, and they are likely to play an increasing role during your lifetime. Projected global warming during this century could disrupt global food production and wildlife habitats, alter temperature and precipitation patterns, and raise the average sea level in various parts of the world.

Nitrogen Cycles through the Biosphere: Bacteria in Action

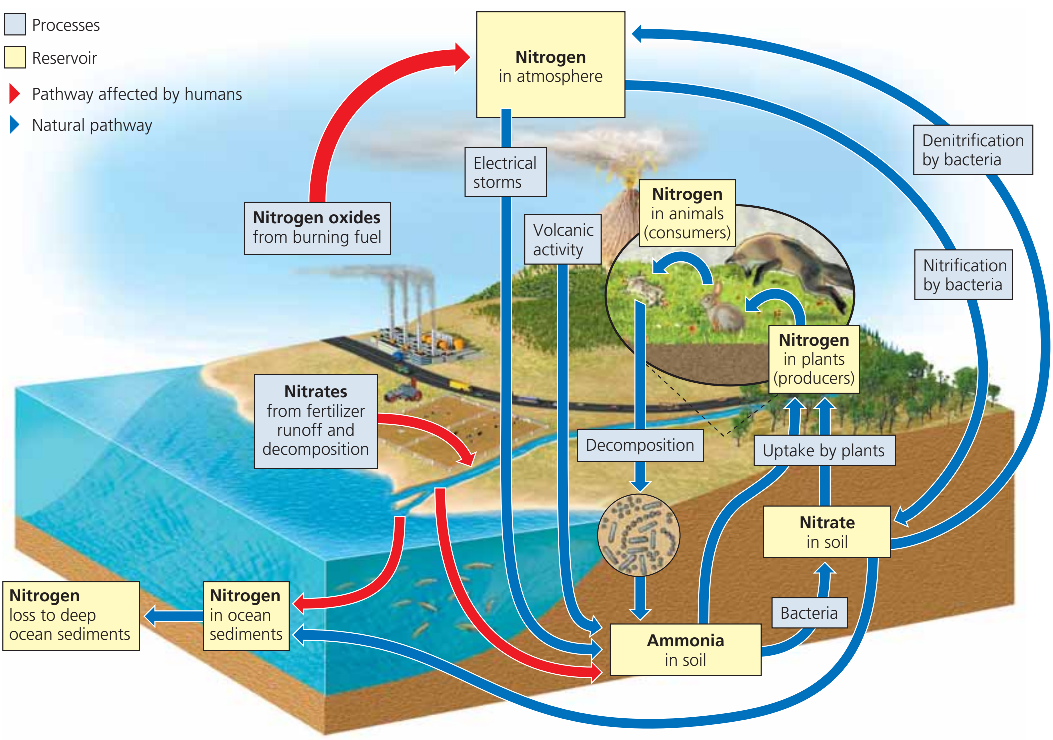
Nitrogen is the atmosphere's most abundant element. The major reservoir for nitrogen is the atmosphere. Chemically unreactive nitrogen gas (N_2) makes up 78% of the volume of the atmosphere. Nitrogen is a crucial component of proteins, many vitamins, and nucleic acids such as DNA. However, N_2 cannot be absorbed and used directly as a nutrient by multicellular plants or animals.

Fortunately, two natural processes convert or *fix* N_2 into compounds useful as nutrients for 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,** depicted in Figure 3-20.

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 by plants.

Ammonia not taken up by plants may undergo *nitrification.* In this two-step process, specialized soil bacteria convert most of the NH_3 and NH_4^+ in soil first to *nitrite ions* (NO_2^-), which are toxic to plants, and then 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 (see Supplement 7, pp. S35–S36). Animals that eat plants and detritus feeders, or decomposers eventually consume these nitrogen-containing compounds.

Plants and animals return nitrogen-rich organic compounds to the environment as wastes, cast-off



ThomsonNOW™ Active Figure 3-20 **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* ThomsonNOW. **Question:** What are three ways in which you directly or indirectly affect the nitrogen cycle?

particles, and through their bodies when they die and are decomposed or eaten by detritus feeders. In *ammonification,* vast armies of specialized decomposer bacteria convert this detritus into simpler nitrogen-containing inorganic compounds such as ammonia (NH_3) and water-soluble salts containing ammonium ions (NH_4^+).

In *denitrification,* specialized bacteria in waterlogged soil and in the bottom sediments of lakes, oceans, swamps, and bogs convert NH_3 and NH_4^+ back into nitrite and 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 (red arrows in Figure 3-20). 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. This excessive input of nitrogen into the air and water contributes to pollution, acid deposition, and other problems to be discussed in later chapters. Nitrogen overload is a serious local, regional, and global environmental problem that has attracted little attention, compared to problems such as global warming, depletion of ozone in the stratosphere, and biodiversity loss. 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.

Phosphorus Cycles through the Biosphere

Phosphorus circulates through water, the earth's crust, and living organisms in the **phosphorus cycle,** depicted in Figure 3-21. In contrast to the cycles of water, carbon, and nitrogen, the phosphorus cycle does not include the atmosphere. The major reservoirs for phosphorous is phosphate salts containing phosphate ions (PO_4^{3-}) in terrestrial rock formations and ocean bottom sediments. The phosphorus cycle is slow compared to the water, carbon, and nitrogen cycles.

As water runs over exposed phosphorus-containing rocks, it slowly erodes away inorganic compounds that contain phosphate ions (PO_4^{3-}). The dissolved phosphate can be absorbed by the roots of plants and by other producers. Phosphorous is transferred by food webs from such producers to consumers, eventually including detritus feeders and decomposers. In both producers and consumers, phosphorous is a component of biologically important molecules such as nucleic acids (Figure 9, p. S35, in Supplement 7) and energy transfer molecules such as ADP and ATP (Figure 14, p. S37, in Supplement 7). 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

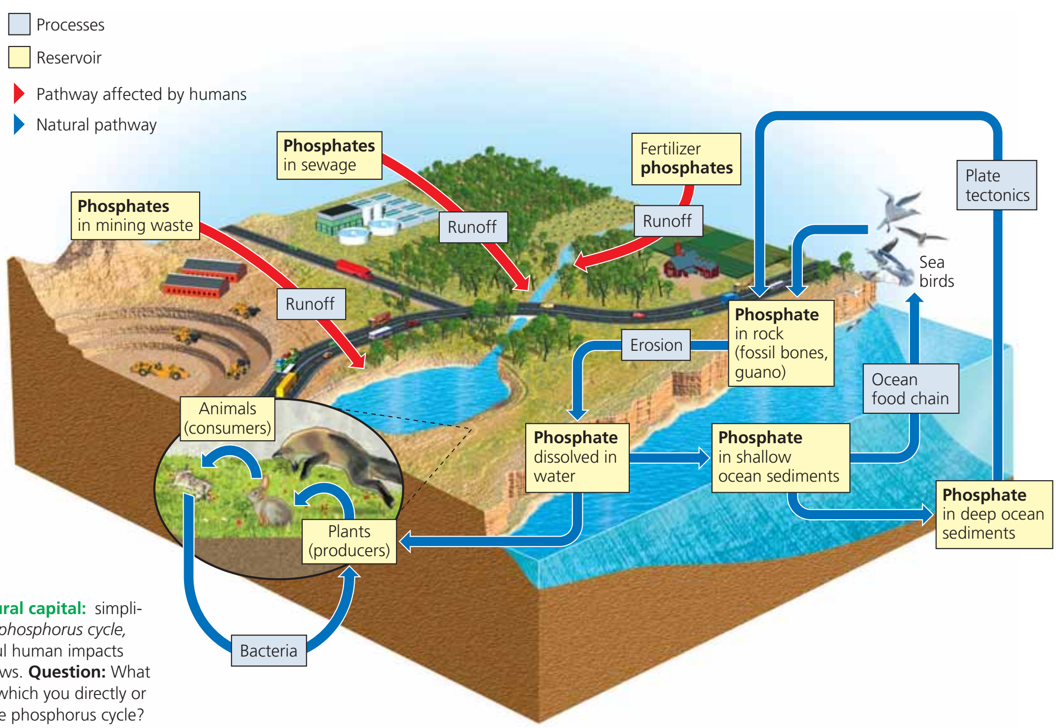


Figure 3-21 **Natural capital:** simplified model of the *phosphorus cycle,* with major harmful human impacts shown by red arrows. **Question:** What are three ways in which you directly or indirectly affect the phosphorus cycle?

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 is often the *limiting factor* for 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 (red items in Figure 3-21). This includes removing large amounts of phosphate from the earth to make fertilizer and reducing phosphorus in tropical soils by clearing forests. Soil that is eroded from fertilized crop fields 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.

Another nutrient that cycles through the biosphere is sulfur, an important component of many plant proteins. See Supplement 8, pp. S39–S40, for a discussion of the *sulfur cycle,* and how human activities affect it.

THINKING ABOUT
The Phosphorus Cycle

List three possible effects on your lifestyle that could occur if we continue to add excess phosphorus to the environment.

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

RESEARCH FRONTIER

The effects of human activities on the major nutrient cycles and how we can reduce these effects

3-7 How Do Scientists Study Ecosystems?

CONCEPT 3-7 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 3-7**). *Field research,* sometimes called "muddy-boots biology," involves going into nature and observing and measuring the structure of ecosystems and what happens in them. Most of what we know about the structure and functioning of ecosystems has come from such research. **GREEN CAREER:** Ecologist

Ecologists trek through forests, deserts, and grasslands and wade or boat through wetlands, lakes, streams, and oceans collecting and observing species. Sometimes they carry out controlled experiments by isolating and changing a variable in part of an area and comparing the results with nearby unchanged areas (**Core Case Study**, p. 23). Tropical ecologists erect 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 geographically or spatially based 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, pp. S12–S13, and Figure 2, pp. S14–S15, in Supplement 4), gross primary productivity (Figure 6, p. S20, in Supplement 4), temperature patterns (Figure 3-22, p. 60), air pollution emissions, and many other variables.

Scientists also use GIS programs and digital satellite images to produce two- or three-dimensional maps combining information about a variable such as land use with other data. Separate layers within such maps, each showing how a certain factor varies over an area, can be combined to show a composite effect (Figure 3-23, p. 60). Such composites of information can lead to a better understanding of environmental problems and to better decision making about how to deal with such problems.

In 2005, scientists launched the Global Earth Observation System of Systems (GEOSS)—a 10-year program to integrate into a unified whole the data from sensors, gauges, buoys, and satellites that monitor the earth's surface, atmosphere, and oceans. **GREEN CAREERS:** GIS analyst; remote sensing analyst

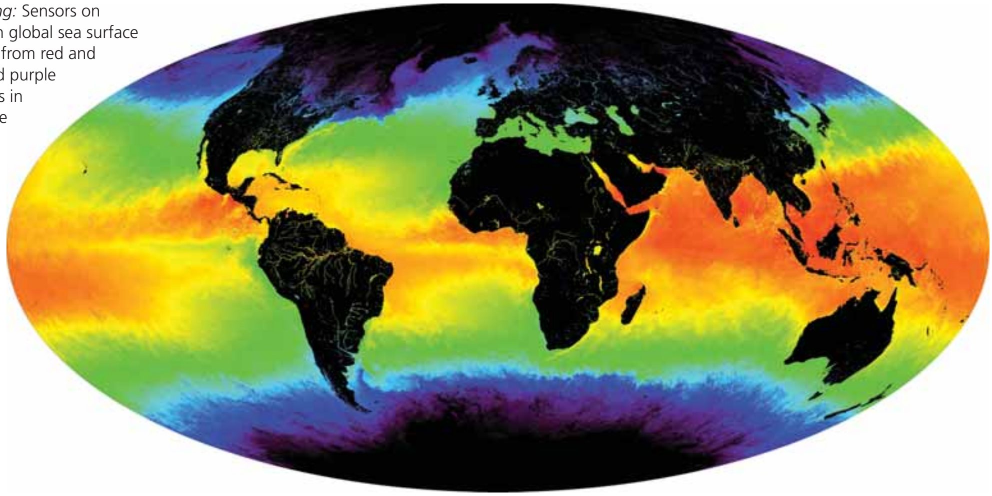


Figure 3-22 *Remote sensing:* Sensors on satellites can collect data on global sea surface temperatures, which range from red and yellow (warmer) to blue and purple (colder). Measuring changes in such temperatures over time can reveal the effects of short-term weather and long-term climate on ocean surface temperatures. (Modis Ocean Group, NASA GFSC, and the University of Miami)

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.

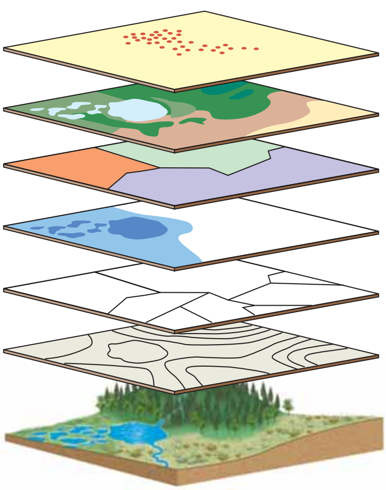


Figure 3-23 *Geographic information systems* (GIS) provide the computer technology for storing, organizing, and analyzing complex data collected over broad geographic areas. They enable scientists to produce maps of various geographic data sets and then to overlay and compare the layers of data (such as soils, topography, distribution of endangered populations, and land protection status).

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. In these experiments, scientists must consider whether 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.

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 rivers, oceans, forests, grasslands, cities, and climates) that cannot be adequately studied and modeled in field and laboratory research. 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.

Researchers can change values of the variables in their computer models to project possible changes in environmental conditions, help anticipate environmental surprises, and analyze the effectiveness of various alternative solutions to environmental problems. **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

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

REVISITING Insects and Sustainability

CORE CASE STUDY CONCEPT LINKS SUSTAINABILITY

This chapter applied two of the **scientific principles of sustainability** (see back cover and **Concept 1-6**, p. 19) by which natural ecosystems have been sustained over the long term. *First,* almost all of them use *solar energy* as their energy source. *Second, they recycle the chemical nutrients* that their organisms need for survival, growth, and reproduction.

These two principles arise from the structure and function of natural ecosystems (Figure 3-11), the law of conservation of matter (**Concept 2-3**, p. 31), and the two laws of thermodynamics (**Concepts 2-4A** and **2-4B**, p. 33). Nature's adherence to these two principles is enhanced by *biodiversity* (Figure 3-12), another sustainability principle that also helps to *regulate population levels* of interacting species—yet another of the **scientific principles of sustainability**.

This chapter started with a discussion of the importance of insects (**Core Case Study**), which play a vital role in implementing the four **scientific principles of sustainability**. They rely on solar energy by consuming a vast amount of biomass produced through photosynthesis. They take part in, and depend on, recycling of nutrients in the biosphere. They represent a huge and vital part of the earth's biodiversity. Insects also play a key role in controlling the populations of species they feed on and the species that feed on them.

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

MENANDER (342–290 B.C.)

REVIEW QUESTIONS

1. What are the basic units of life? Identify the major types of macromolecules that are found in living organisms. What is a species? Define ecology. Describe the levels of organization of matter that occur in nature.
2. Discuss the four main components of the earth's life support system. Describe the different major biomes along the 39th parallel spanning the United States. What three interconnected factors sustain life on earth?
3. Explain what happens to solar energy as it flows to and from the earth.
4. Describe the two types of components that make up the biosphere and its ecosystems. Explain the limiting factor principle.
5. Describe the roles that producers, consumers, and decomposers play in an ecosystem. What are the main structural components of an ecosystem and how are they linked?

6. Discuss the major components of the earth's biodiversity.
7. What are soils, and how are they formed? What are soil horizons?
8. Explain what happens to energy as it flows through the food chains and food webs of an ecosystem. Discuss the difference between gross primary productivity and net primary productivity, showing how they are they linked.
9. What happens to matter in an ecosystem? Identify and describe four major examples of biogeochemical cycles. Discuss the unique properties of water.
10. Explain the various ways scientists use to study ecosystems.

CRITICAL THINKING

1. List three ways you could apply **Concept 3-5** to making your lifestyle more environmentally sustainable.
2. How would you explain the importance of insects (**Core Case Study**) to someone who fears or hates most insects? How would you explain it to a farmer whose crops are devoured by insect pests? CORE CASE STUDY
3. Explain why **(a)** the flow of energy through the biosphere (**Concept 3-2**) depends on the cycling of nutrients, and **(b)** the cycling of nutrients depends on gravity.
4. Explain why microbes are so important. List two beneficial and two harmful effects of microbes on your health and lifestyle.
5. Make a list of the food you ate for lunch or dinner today. Trace each type of food back to a particular producer species.
6. Explain why microbes are so important. List two beneficial and two harmful effects of microbes on your health and lifestyle.
7. Use the second law of thermodynamics (**Concept 2-4B**, p. 34) to explain why many poor people in developing countries live on a mostly vegetarian diet. CONCEPT LINK
8. Why do farmers not need to apply carbon to grow their crops but often need to add fertilizer containing nitrogen and phosphorus?
9. 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?
10. 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 of its insects (**Core Case Study**) were eliminated? Could a balanced ecosystem exist with only producers and decomposers and no consumers such as humans and other animals? Explain. CORE CASE STUDY
11. List two questions that you would like to have answered as a result of reading this chapter.

LEARNING ONLINE

Log on to the Student Companion Site for this book at **www.thomsonedu.com/biology/miller** and choose Chapter 3 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Web links, information on Green Careers, and InfoTrac® College Edition articles.

For access to animations and additional quizzing, register and log on to ThomsonNOW! at **www.thomsonedu.com/thomsonnow** using the access code card in the front of your book. You can also explore the **Active Graphing** exercises that your instructor may assign.

Evolution and Biodiversity

4

The Adaptability of Life on the Earth

CORE CASE STUDY

Life on the earth (Figure 4-1) 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 to form rain. If it were much farther away, the earth's surface would be so cold—like Mars—that its water would exist only as ice. The earth also spins; if it did not, the side facing the sun would be too hot and the other side too cold for water-based life to 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 light gaseous molecules in its atmosphere (such as N_2, O_2, CO_2, and H_2O) from flying off into space.

On a time scale of millions of years, life on the earth has been enormously resilient and adaptive. During the 3.7 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. This has happened mostly because forms of life evolved to carry out photosynthesis and respiration in the carbon cycle (Figure 3-19, p. 56). By increasing or decreasing the amount of the greenhouse gas carbon dioxide in the atmosphere in response to changing environmental conditions, the earth's variety of species have helped keep the earth from getting too hot or too cold.

For several hundred million years oxygen has made up about 21% of the volume of earth's atmosphere. Again, living organisms have maintained such levels by using photosynthesis to add oxygen and respiration to remove oxygen from the 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.

Thanks to 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 ultraviolet radiation.

In short, this remarkable planet we live on is uniquely suited for life as we know it. Perhaps the two most amazing features of the planet are its incredible diversity of life (biodiversity) and its inherent ability to sustain life (sustainability) despite major changes in environmental conditions.

Understanding how organisms adapt to changing environmental conditions is important for understanding how nature works, how our activities affect the earth's life, and how we can help sustain the planet's biodiversity. This chapter shows how each species here today represents a long chain of genetic changes in response to changing environmental conditions and how each plays a unique ecological role in the earth's communities and ecosystems.

NASA

Figure 4-1 The earth appears as a blue and white planet in the black void of space. Currently, it has the right physical and chemical conditions to allow the development of life as we know it. **Question:** How do you think the earth would look from space if it contained no life forms?

Key Questions and Concepts

4-1 What is biological evolution and how does it occur?

CONCEPT 4-1A The scientific theory of evolution explains how life on earth changes over time through changes in the genes of populations.

CONCEPT 4-1B 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).

4-2 How do geological and climate changes affect evolution?

CONCEPT 4-2 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.

4-3 What is an ecological niche?

CONCEPT 4-3 As a result of biological evolution, each species plays a specific ecological role called its niche.

4-4 How do extinction, speciation, and human activities affect biodiversity?

CONCEPT 4-4A As environmental conditions change, the balance between formation of new species and extinction of existing ones determines the earth's biodiversity.

CONCEPT 4-4B Human activities decrease the earth's biodiversity by causing the premature extinction of species and by destroying or degrading habitats needed for the development of new species.

4-5 How might genetic engineering affect the earth's life?

CONCEPT 4-5 Genetic engineering enables scientists to transfer genetic traits between different species—a process that holds great promise and raises difficult issues.

Note: Supplements 4 and 9 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 Biological Evolution and How Does It Occur?

CONCEPT 4-1A The scientific theory of evolution explains how life on earth changes over time through changes in the genes of populations.

CONCEPT 4-1B 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 Is the Scientific Explanation of How the Earth's Life Changes over Time

How did we end up with an amazing array of 4–100 million species? The scientific answer involves **biological evolution:** the description of how the earth's life changes over time through changes in the genes of populations (**Concept 4-1A**).

According to the **theory of evolution,** all species descended from earlier, ancestral species. In other words, life comes from life. This scientific theory explains how life has changed over the past 3.7 billion years and why life is so diverse today. If we compress the earth's 4.7 billion years of geological and biological history into a 24-hour day, the human species arrived only about 0.1 of a second before midnight. In this eye blink of the earth's history, we have dominated much of the planet as our ecological footprints have

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.

grown (Figure 1-8, p. 13, and Figure 3 on pp. S16–S17 in Supplement 4).

Most of the evidence that supports the scientific theory of evolution comes from **fossils:** mineralized or petrified replicas of skeletons, bones, teeth, shells, leaves, and seeds, or impressions of such items found in rocks. Fossils provide physical evidence of ancient organisms and reveal what their internal structures looked like (Figure 4-2). Evidence about the earth's early history also comes from chemical analysis and measurements of elements in primitive rocks and fossils. Analysis of material in cores drilled out of buried ice and comparisons of the DNA of past and current organisms offer still more information.

Kevin Schafer/Peter Arnold, Inc.

Figure 4-2 Fossilized skeleton of an herbivore that lived during the Cenozoic era from 26–66 million years ago.

The Genetic Makeup of a Population Can Change

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* in a population. This genetic variety occurs through **mutations:** *random* changes in the structure or number of DNA molecules in a cell (Figure 11 on p. S36 in Supplement 7) that can be inherited by offspring. Most mutations result from random mistakes that sometimes occur in coded genetic instructions when DNA molecules are copied each time a cell divides and whenever an organism reproduces. Some mutations also occur from exposure to external agents such as radioactivity, X rays, and natural and human-made chemicals (called *mutagens*).

Mutations can occur in any cell, but only those in reproductive cells are passed on to offspring. Sometimes a mutation can result in a new genetic trait that gives an individual and its offspring better chances for survival and reproduction under existing environmental conditions or when such conditions change.

Individuals in Populations with Beneficial Genetic Traits Can Leave More Offspring

The next step in conventional biological evolution is **natural selection.** It occurs when some individuals of a population have genetically based traits (resulting from mutations) that enhance their ability to survive and produce offspring with these traits (**Concept 4-1B**). Note that natural selection acts on individuals, but evolution occurs in populations.

ThomsonNOW™ Get a detailed look at early biological evolution by natural selection at ThomsonNOW.

An **adaptation,** or **adaptive trait,** is any heritable trait that enables an organism to survive through natural selection and to reproduce more than other individuals without the trait under prevailing environmental conditions. For natural selection to occur a trait must be *heritable,* meaning that it can be passed from one generation to another. The trait must also lead to **differential reproduction,** which enables individuals with the trait to leave more offspring that other members of the population leave. Humans evolved certain traits that have allowed them to take over much of the world (Science Focus, p. 66).

When faced with a change in environmental conditions, a population of a species has three possibilities: *adapt* to the new conditions through natural selection, *migrate* (if possible) to an area with more favorable conditions, or *become extinct.*

The process of biological evolution by natural selection can be summarized simply: *Genes mutate, individuals are selected, and populations evolve such that they are better adapted to survive and reproduce under existing environmental conditions.* Figure 1 on p. S41 in Supplement 9 gives an overview of how life evolved into six different kingdoms of species as a result of natural selection.

ThomsonNOW™ How many moths can you eat? Find out and learn more about adaptation at ThomsonNOW.

SCIENCE FOCUS

How Did We Become Such a Powerful Species?

Like many other species, humans have survived and have 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; an ability to *walk upright;* and a *complex brain.* These adaptations have helped us develop weapons, protective devices, and technologies that extend our limited senses and help make up for some of our deficiencies. Thus, in just a twitch of the 3.7-billion-year history of life on earth, we have developed powerful technologies and taken over much of the earth's life-support systems and net primary productivity.

But adaptations that make a species successful during one period of time may not be enough to insure 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.

The *good news* is that we can learn to live more sustainability 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 1-6**, p. 19). CONCEPT LINK

Critical Thinking

An important adaptation of humans is a strong opposable thumb, which allows 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.

Populations of Different Species Compete to Change Their Genes and Leave the Most Offspring

Some biologists have proposed that when populations of two different species interact 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. This process is called **coevolution.** In this give-and-take evolutionary game, each species is in a genetically programmed race to produce the largest number of surviving offspring.

Consider the interactions between bats and moths. Some bats like to eat moths, and they hunt at night and use echolocation to navigate and locate their prey. To do so, they emit extremely high frequency and high-intensity pulses of sound. They capture the returning echoes and create a sonic "image" of their prey. (We have copied this natural technology by using sonar to detect submarines, whales, and schools of fish.)

As a countermeasure, some 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 falling to the ground or flying evasively.

Some bat species evolved ways to counter this defense by switching the frequency of their sound pulses. In turn, some moths evolved their own high-frequency clicks to jam the bats' echolocation system. Some bat species then adapted by turning off their echolocation system and using the moths' clicks to locate their prey.

Coevolution is like an arms race between interacting populations of different species. Sometimes the predators surge ahead; at other times the prey get the upper hand. Coevolution is one of nature's ways of maintaining long-term sustainability through population control (see back cover).

4-2 How Do Geological and Climate Changes Affect Evolution?

CONCEPT 4-2 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 very slowly atop the earth's mantle (Figure 4-3).

This process has had two important effects on the evolution and location of life on the earth. *First,* the locations of continents and oceanic basins greatly influence the earth's climate and thus help determine where plants and animals can live. *Second,* the movement of continents has allowed species to move, adapt

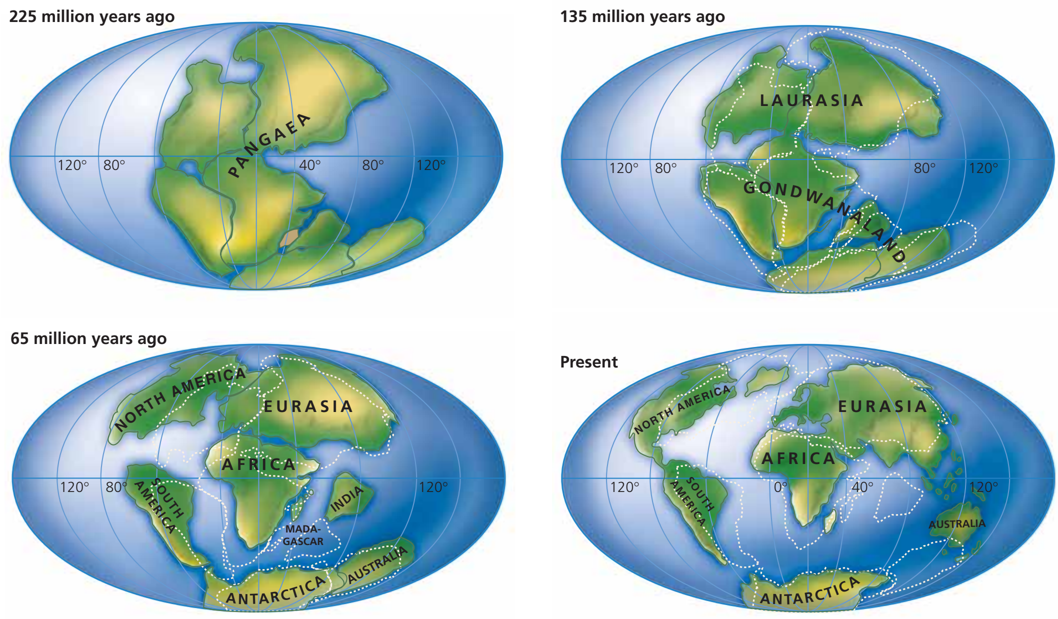


Figure 4-3 Over millions of years, the earth's continents have moved very slowly on several gigantic tectonic plates. This process plays a role in the extinction of species as land areas split apart and also in the rise of new species when once isolated land areas combine. Rock and fossil evidence indicates that 200–250 million years ago all of the earth's present-day continents were locked together in a supercontinent called Pangaea (top left). About 180 million years ago, Pangaea began splitting apart as the earth's huge plates separated, and their movements eventually resulted in the present-day locations of the continents (bottom right). **Question:** How might an area of land splitting apart cause the extinction of a species?

to new environments, and form new species through natural selection.

Earthquakes (see Figure 1 on p. S54 in Supplement 12) can also affect biological evolution by separating and isolating populations of species. Over long periods of time, this can lead to the formation of new species in response to new environmental conditions. *Volcanic eruptions* (see Figure 6 on p. S57 in Supplement 12) affect biological evolution by destroying habitats and reducing or wiping out populations of species (**Concept 4-2**).

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 (Figure 4-4). At other times it has warmed, melted ice, and drastically raised sea levels.

These long-term climate changes have a major effect on biological evolution by determining where

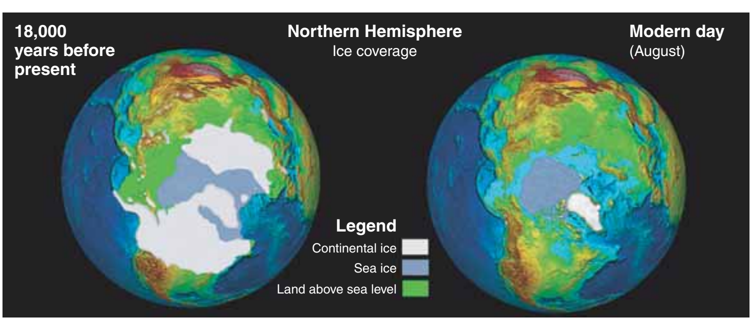


Figure 4-4 Changes in ice coverage in the northern hemisphere during the past 18,000 years. **Question:** What are two characteristics of an animal and two characteristics of a plant that natural selection would have favored as these ice sheets (left) advanced? (Data from the National Oceanic and Atmospheric Administration).

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 4-2**).

Evidence indicates that more than half of all life on the earth has been wiped out in five mass extinctions over the past 500 million years. Scientific hypotheses explaining the causes of these mass extinctions include asteroids colliding with the earth, large-scale emissions of toxic hydrogen sulfide (H_2S) from the ocean into the atmosphere, and climate change. Such mass extinctions opened up opportunities for the evolution of new species and shifts in the locations of some ecosystems. On a long-term basis, the four **scientific principles of sustainability** (see back cover), especially biodiversity (Figure 3-12, p. 48), have enabled the earth to adapt to drastic changes in environmental conditions (**Core Case Study**).

SUSTAINABILITY

CORE CASE STUDY

4-3 What Is an Ecological Niche?

CONCEPT 4-3 As a result of biological evolution, each species plays a specific ecological role called its niche.

Each Species Plays a Unique Role in Its Ecosystem

If asked what role a certain species, such as an alligator, plays in an ecosystem, an ecologist would describe its **ecological niche,** or simply **niche** (pronounced "nitch"). It is a species' way of life or role in a community or ecosystem and includes everything that affects its survival and reproduction. A species *habitat* is the place where it lives and its *niche* is its pattern of living.

A particular niche is the result of long-term evolutionary changes in a species. 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 (Science Focus, at right), mice, rats, white-tailed deer, raccoons, and humans are generalist species.

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. This makes specialists 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. Some shorebirds occupy specialized niches, feeding on crustaceans, insects, and other organisms on sandy beaches and their adjoining coastal wetlands (Figure 4-5).

In other words, as a result of long-term evolutionary changes each species plays a specific ecological role, called its niche, with generalist species having broad

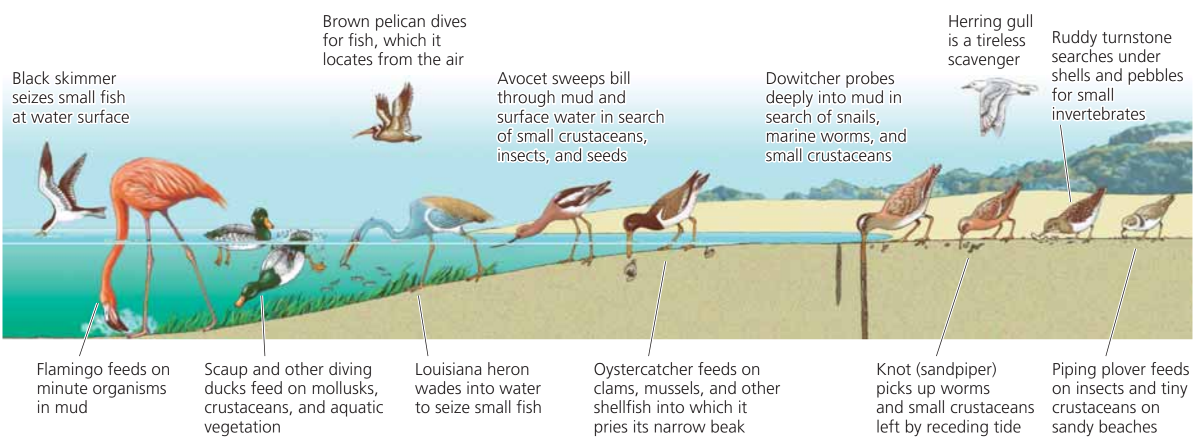


Figure 4-5 Specialized feeding niches of various bird species in a coastal wetland. This specialization reduces competition and allows sharing of limited resources.

SCIENCE FOCUS

Cockroaches: Nature's Ultimate Survivors

Cockroaches (Figure 4-A), the bugs many people love to hate, have been around for 350 million years—longer than the dinosaurs lasted. One of evolution's great success stories, they have thrived because they are rapidly reproducing *generalists.*

The earth's 3,500 known cockroach species can eat almost anything, including algae, dead insects, fingernail clippings, electrical cords, glue, 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 from a dishrag, 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 to detect minute movements of air, sensors in their knee joints to detect vibration, and they can respond faster than you can blink. Some even have wings. They also have compound eyes, each with about 2,000 lenses, that allow them to see in almost all directions at once.

Clemson University–USDA Cooperative Extension Slide Series

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

Cockroaches also 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 develop genetic resistance quickly through natural selection to almost any poison we throw at them.

About 25 species of cockroaches live in homes. They can carry viruses and bacteria that cause hepatitis, polio, typhoid fever, plague, and salmonella. Some people, including 60% of Americans suffering from asthma, are allergic to live or dead cockroaches.

Cockroaches also play a role in nature's food webs. They make a tasty meal for birds and lizards.

Critical Thinking

If you could, would you exterminate all cockroach species? What might be some ecological consequences of this action?

ecological roles and specialist species having narrower ecological roles (**Concept 4-3**). Is it better to be a generalist or a specialist? It depends. When environmental conditions are fairly constant, as in a tropical rain forest, specialists have an advantage because they have fewer competitors. But under rapidly changing environmental conditions, the generalist usually is better off than the specialist.

4-4 How Do Extinction, Speciation, and Human Activities Affect Biodiversity?

CONCEPT 4-4A As environmental conditions change, the balance between formation of new species and extinction of existing ones determines the earth's biodiversity.

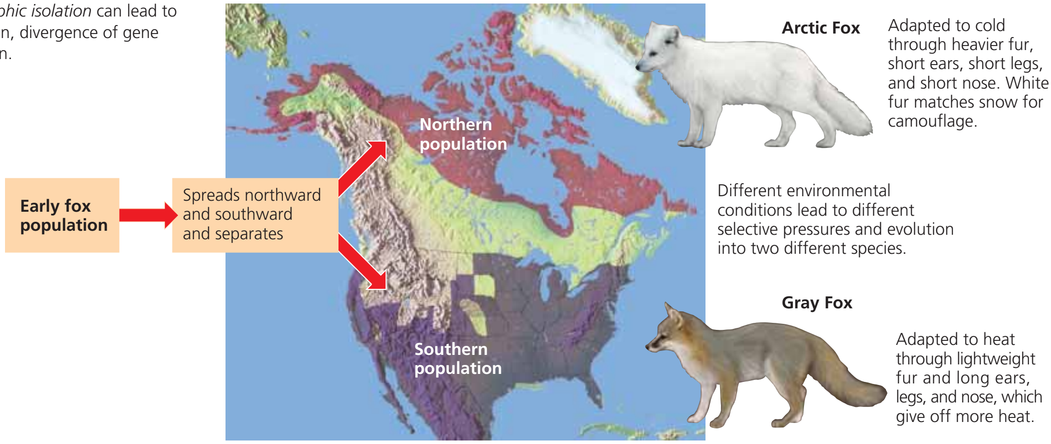
CONCEPT 4-4B Human activities can decrease the earth's biodiversity by causing the premature extinction of species and by destroying or degrading habitats needed for the development of new species.

How Do New Species Evolve?

Under certain circumstances, natural selection can lead to an entirely new species. In this process, called **speciation,** two species arise from one. For sexually reproducing species, a new species is formed when some members of a population have evolved to the point where they can no longer breed with other members to produce fertile offspring.

The most common mechanism of speciation (especially among sexually reproducing animals) takes place 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 long periods. For example, part of a population may migrate in search of food and then begin living in another area with different environmental conditions. Populations can be separated by a physical barrier (such as a mountain range, stream, or road), by a volcanic eruption or earthquake, or when a few individuals are carried to a new area by wind or flowing water.

Figure 4-6 *Geographic isolation* can lead to reproductive isolation, divergence of gene pools, and speciation.



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 isolated populations 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 4-6).

For some rapidly reproducing organisms, this type of speciation may occur within hundreds of years. For most species, it takes from tens of thousands to millions of years—making it difficult to observe and document the appearance of a new species.

ThomsonNOW™ Learn more about different types of speciation and ways in which they occur at ThomsonNOW.

Michael P. Fogden/Bruce Coleman USA

Figure 4-7 **Depleted natural capital:** male golden toad in Costa Rica's high-altitude Monteverde Cloud Forest Reserve. This species has recently become extinct because changes in climate dried up its habitat.

THINKING ABOUT

Speciation and the Earth's Resiliency

CORE CASE STUDY

Explain how speciation can contribute to the ability of life on the earth to adapt to environmental changes (**Core Case Study**).

Extinction Is Forever

Another process affecting the number and types of species on the earth is **extinction,** in which an entire species ceases to exist. 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 are highly specialized.

One example is the brilliantly colored golden toad (Figure 4-7) once found only in a small area of lush cloud rain forests in Costa Rica's mountainous region. Despite living in the country's well-protected Monteverde Cloud Forest Reserve, by 1989, the golden toad had apparently become extinct. Warmer air from global climate change caused the area's moisture-bearing clouds blowing in from the Caribbean Sea to rise and dry out the habitat for this frog and many other species. The golden toad appears to be one of the first victims of current global warming because warmer air reduced the moisture in its forest habitat. A 2007 study found that global warming has also contributed to the extinction of five other toad and frog species in the jungles of Costa Rica.

Species Become Extinct Individually and in Large Groups

All species eventually become extinct, but drastic changes in environmental conditions can eliminate large groups of species. As local environmental conditions change, species disappear 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 (often global) event, large groups of existing species (perhaps 25–70%) are wiped out in a geological period lasting up to 5 million years. Fossil and geological evidence indicate that the earth's species have experienced five mass extinctions (20–60 million years apart) during the past 500 million years.

A mass extinction provides an opportunity for the evolution of new species that can fill the unoccupied niches or newly created ones. As environmental conditions change, the balance between formation of new species (speciation) and extinction of existing ones determines the earth's biodiversity (**Concept 4-4A**). The existence of millions of species today means that speciation, on average, has kept ahead of extinction.

THINKING ABOUT
Extinction and the Earth's Resiliency

CORE CASE STUDY

Explain how extinction can contribute to the ability of the earth's life to adapt to environmental changes (**Core Case Study**).

Human Activities Can Cause the Premature Extinction of Species

Although extinction is a natural process, the scientific consensus is that humans have become a major force in the premature extinction of species. Human activities decrease the earth's biodiversity when they cause the premature extinction of species and destroy or degrade habitats needed for the development of new species (**Concept 4-4B**).

According to biologists Stuart Pimm and Edward O. Wilson and the 2005 Millennium Ecosystem Assessment, extinction rates increased by 100–1,000 times the natural background extinction rate during the 20th century. As human population and resource consumption increase over the next 50–100 years, our ecological footprints (Figure 1-8, p. 13; Figure 3 on pp. S16–S17 in Supplement 4; and **Concept 1-3**, p. 11) are likely to expand. In addition, we are also expected to take over an even larger share of the earth's surface and net primary productivity (NPP) that supports all consumers (Figure 3-17, p. 53).

CONCEPT LINK

According to Wilson and Pimm, this plus climate change may cause the premature extinction of at least one-fourth of the earth's current species by 2050 and up to half of those species could be gone or headed for early extinction by the end of this century. This could deplete and degrade the natural capital that supports all life and our economies. According to Wilson, if this massive loss of species continues unabated, the cost to humanity in wealth, environmental security, and quality of life, will be catastrophic. Wilson also says that if we make an "all-out effort to save the biologically richest parts of the world, the amount of loss can be cut at least by half."

It took millions of years after each of the earth's past mass extinctions for life to recover to the previous level of biodiversity. Thus, on our short time scale, such major losses cannot be recouped by formation of new species. To make matters worse, we are also destroying or degrading ecosystems such as tropical forests, coral reefs, and wetlands that are centers for future speciation. See the Guest Essay on this topic by Norman Myers at ThomsonNOW™.

4-5 How Might Genetic Engineering Affect Evolution?

CONCEPT 4-5 Genetic engineering enables scientists to transfer genetic traits between different species—a process that holds great promise and raises difficult issues.

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 end up with 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.

Artificial selection has yielded food crops with higher yields, cows that give more milk, trees that grow faster, and many different types of dogs and cats. But

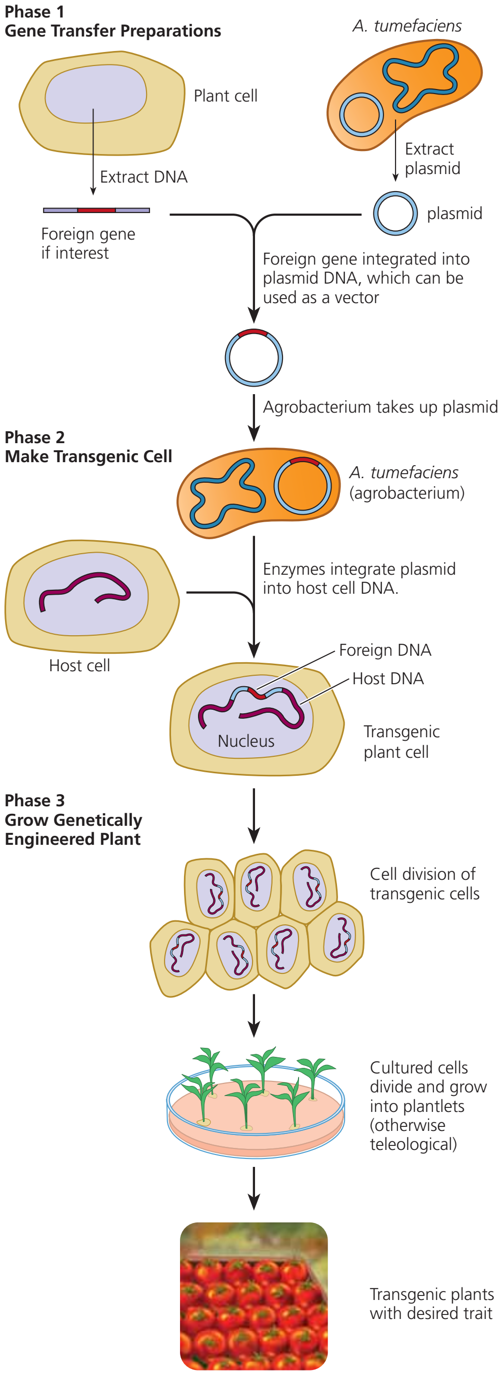


Figure 4-8 *Genetic engineering:* steps in genetically modifying a plant. **Question:** How does this process change the nature of evolution by natural selection?

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,** or **gene splicing,** is the alteration of an organism's genetic material, through adding, deleting, or changing segments of its DNA (Figure 11 on p. S36 in Supplement 7), 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.

The resulting organisms are called **genetically modified organisms (GMOs)** or **transgenic organisms.** Figure 4-8 outlines the steps involved in developing a genetically modified plant.

Compared to traditional crossbreeding, gene splicing takes about half as much time to develop a new crop or animal variety. It also enables us to transfer genes from different types of species without breeding them—a process that both holds great promise and raises a number of legal, ethical, and environmental issues (**Concept 4-5**).

Scientists have used gene splicing to develop modified crop plants, new drugs, pest-resistant plants, and animals that grow rapidly (Figure 4-9). 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.

Bioengineers have developed many beneficial GMOs: chickens that lay low-cholesterol eggs, wheat that thrives in drought conditions, bananas that don't rot on the way to market, and tomatoes with genes that can help prevent some types of cancer.

Genetic engineers have also produced two mice, the *Schwarzenegger mouse,* which has muscle-building genes, and the *marathon mouse,* which never seems to tire. And they are in hot pursuit of a *Methuselah mouse* that can live much longer than a conventional mouse.

Our Ability to Manipulate Genes Holds Great Promise but Raises Some Serious Questions

We are rapidly improving our understanding of genes, what they do, and how to modify them. A *genome* is an organism's entire set of genes. At the beginning of this century, scientists completed the mapping of the human genome.

Our rapidly increasing understanding of the human genome and those of other organisms means that we are becoming capable of genetically modifying ourselves by cutting out, rearranging, and adding various snippets of our own DNA molecules and implanting DNA sequences from other organisms. This *secondary evolution* will allow us to change the course and speed

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

Figure 4-9 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 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?

of *primary evolution* (based mostly on the glacially slow process of natural selection) of our own species and other species by creating types of genes not currently found in the rest of nature.

Application of such increasing genetic knowledge holds great promise, but it raises some serious and controversial ethical and privacy issues (**Concept 4-5**). For example, some people have genes that make them more likely to develop certain genetic diseases or disorders. We now have the power to detect these genetic deficiencies, even before birth. Will this lead to more abortions of genetically defective fetuses? Will health insurers refuse to insure people with certain genetic defects that could lead to health problems? Will employers refuse to hire them? If gene therapy is developed for correcting genetic deficiencies, who will get it? Will it be reserved mostly for the rich?

Soon we may enter the age of *designer babies* where people can walk into fertility clinics and choose the traits they want in their offspring from a genetic shopping list. Will some want to use these new tools to create geniuses, people who are superior musicians, or people with great beauty? Will generals and athletic coaches want to create superior soldiers and athletes? Will one gender be chosen more often and how will this affect population growth, marriage opportunities, and other social interactions? How will this affect the ratios of minorities in societies? Will such modifications be reserved mostly for the rich?

For the first time, it appears that we may have the power to change the nature of what it means to be human, but what should we change human nature to? These are some of the most important and controversial questions of the 21st century.

RESEARCH FRONTIER

Learning more about the beneficial and harmful environmental impacts of genetic engineering

THINKING ABOUT

Genetic Engineering and the Earth's Resiliency

CORE CASE STUDY

Do you think that widespread use of genetic engineering will enhance or hinder the ability of the earth's life to adapt to environmental changes (**Core Case Study**)? Explain.

REVISITING The Adaptability of the Earth's Life and Sustainability

CORE CASE STUDY CONCEPT LINKS SUSTAINABILITY

In this chapter, we have learned that through changes in their genes every species on the earth is related to every other species past and present through evolution. These historic and ongoing connections have helped make the earth a habitable planet for life as we know it, and they allow life to adapt to changing environmental conditions, as described in the **Core Case Study** that opened this chapter.

The four **scientific principles of sustainability** (see back cover and **Concept 1-6**, p. 19) underlie the amazing ability of life to adapt to minor and drastic changes in environmental conditions. Without the sun and chemical cycling, life as we know it would not exist. And life could not adapt to environmental changes through natural selection without the diverse and changing array of genes, species, ecosystems, and ecosystem processes that make up the earth's biodiversity (Figure 3-12, p. 48) and the population control provided by multiple interactions and competition for resources among species.

We are fortunate to live on such an amazing planet, and should not harm its life-sustaining processes. What is at risk is not the earth, but the future of our own species and the millions of other species that our activities may eliminate prematurely during your lifetime.

All we have yet discovered is but a trifle in comparison with what lies hid in the great treasury of nature.

ANTOINE VAN LEEUWENHOCK

REVIEW QUESTIONS

1. Discuss how the earth is uniquely suited to sustain life as we know it.
2. Where does most of the evidence supporting the theory of evolution come from and how is that evidence obtained?
3. Summarize the process of biological evolution by natural selection.
4. Explain the process of coevolution.
5. Describe how the movement of tectonic plates has affected the evolution and location of life on earth.
6. Discuss the consequences that long-term climate change has had on biological evolution.
7. How is the ecological niche of a species related to its habitat? Explain the differences between a generalist species and a specialist species.
8. Describe how the process of speciation results in two species arising from one species.
9. Define extinction and discuss the difference between background extinction and mass extinction. How are human activities affecting the earth's biodiversity?
10. Describe the process of genetic engineering and comment on the pros and cons of such gene manipulation.

CRITICAL THINKING

1. List three ways you could apply **Concept 4-5** to live a more environmentally sustainable lifestyle.
2. Explain how tectonic plate movement, volcanic eruptions, earthquakes, and climate change can contribute to the ability of the earth's life to adapt to changes in environmental conditions (**Core Case Study**). CORE CASE STUDY
3. How would you respond to:
   - **a.** someone who tells you that he or she does not believe in biological evolution because it is "just a theory"?
   - **b.** a statement that we should not worry about air pollution because natural selection will enable humans to develop lungs that can detoxify pollutants?
   - **c.** someone who says that because extinction is a natural process, we should not worry about the loss of biodiversity?
4. What role does each of the following processes play in helping implement the four **scientific principles of sustainability** (see back cover and **Concept 1-6**, p. 19): **(a)** natural selection, **(b)** speciation, and **(c)** extinction? SUSTAINABILITY CONCEPT LINK
5. Describe the major differences between the ecological niches of humans and cockroaches. Are these two species in competition? If so, how do they manage to coexist?
6. Explain why you are for or against using genetic engineering to develop "superior" human beings.
7. Some say that we should change the name of our species from *Homo sapiens* (the wise species) to *Homo ignoramus* because there is considerable and growing evidence that we are degrading our life-support systems. Do you agree or disagree with this idea? Explain.
8. Congratulations! You are in charge of the future evolution of life on the earth. What are the three most important things you would do?
9. List two questions that you would like to have answered as a result of reading this chapter.

LEARNING ONLINE

Log on to the Student Companion Site for this book at **www.thomsonedu.com/biology/miller** and choose Chapter 4 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Web links, information on Green Careers, and InfoTrac® College Edition articles.

For access to animations and additional quizzing, register and log on to ThomsonNOW! at **www.thomsonedu.com/thomsonnow** using the access code card in the front of your book. You can also explore the **Active Graphing** exercises that your instructor may assign.

Climate and Biodiversity

5

Blowing in the Wind: Connections between Wind, Climate, and Biomes

CORE CASE STUDY

Why is one area of the earth's land surface a desert, another a grassland, and another a forest? The general answer is differences in *climate.*

Wind is an important factor in the earth's climate. Without wind, the tropics would be unbearably hot and most of the rest of the planet would freeze.

Winds also transport nutrients from one place to another. For example, winds carry dust rich in phosphates and iron across the Atlantic from the Sahara Desert in Africa (Figure 5-1). These deposits help build agricultural soils in the Bahamas and supply nutrients for plants in upper canopies of rain forests in Brazil. Dust blown from China's Gobi Desert deposits iron into the Pacific Ocean between Hawaii and Alaska. The iron stimulates the growth of phytoplankton, the minute producers that support ocean food webs.

Wind also has a downside. Wind-blown dust storms in the Sahara Desert have increased tenfold since 1950 mostly because of drought due to climate change, and human population growth. Another reason is the *SUV connection.* Increasing numbers of four-wheel vehicles speeding over the sand break the desert's surface crust. Wind storms can then blow the dusty material into the atmosphere.

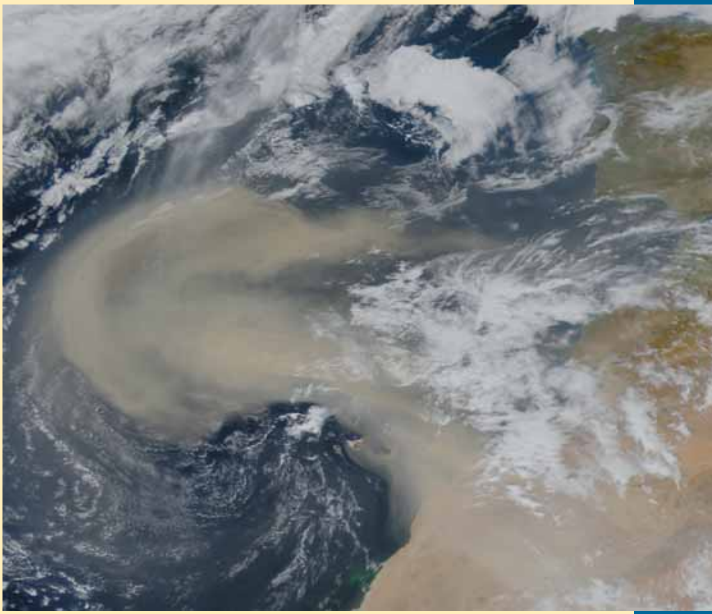
Wind also transports harmful substances. Particles of reddish-brown soil and pesticides banned in the United States are blown from Africa's deserts and eroding farmlands into the sky over the U.S. state of Florida. Some types of fungi in this dust may play a role in degrading or killing coral reefs in the Florida Keys and in the Caribbean.

Particles of iron-rich dust from Africa that enhance the productivity of algae have been linked to outbreaks of toxic algal blooms—referred to as *red tides*—in Florida's coastal waters. People who eat shellfish contaminated by a toxin produced in red tides can become paralyzed or even die. These red tides can also cause fish kills.

Dust and long-lived air pollutants from rapidly industrializing China and central Asia are blown across the Pacific Ocean and degrade air quality over parts of the western United States. Asian pollution makes up as much as 10% of West Coast smog—a problem that is expected to intensify as China continues to industrialize.

The ecological lesson: *There is no away* because *everything is connected.* Wind acts as part of the planet's circulatory system for heat, moisture, plant nutrients, and long-lived pollutants. Movement of soil particles from one place to another by wind and water is a natural phenomenon. However, when we disturb the soil and leave it unprotected, we hasten and intensify this process.

In this chapter, we examine the key role that climate, including wind, plays in the formation of the deserts, grasslands, forests, oceans, rivers, and lakes that provide habitats for the earth's terrestrial and aquatic biodiversity.



NOAA. USGS/MND EROS Data Center

Figure 5-1 Some of the dust shown here, blown from Africa's Sahara Desert, can end up as soil nutrients in Amazonian rain forests and toxic air pollutants in the U.S. state of Florida and the Caribbean.

Key Questions and Concepts

5-1 **What factors influence climate?**

CONCEPT 5-1 An area's climate is determined mostly by solar radiation, the earth's rotation, global patterns of air and water movement, gases in the atmosphere, and the earth's surface features.

5-2 **How does climate affect the nature and location of biomes?**

CONCEPT 5-2 Differences in average annual precipitation and temperature lead to the formation of tropical, temperate, and cold deserts, grasslands, and forests, and largely determine their locations.

5-3 **How have we affected the world's terrestrial ecosystems?**

CONCEPT 5-3 In many areas, human activities are impairing ecological and economic services provided by the earth's deserts, grasslands, forests, and mountains.

5-4 **What are the major types of aquatic systems?**

CONCEPT 5-4A Saltwater and freshwater aquatic life zones cover almost three-fourths of the earth's surface with oceans dominating the planet.

CONCEPT 5-4B Most aquatic organisms live in the surface, middle, or bottom layers of saltwater and freshwater systems.

5-5 **What are the major ocean zones and how have we affected them?**

CONCEPT 5-5 In many areas, human activities are impairing ecological and economic services provided by the earth's saltwater systems, especially coastal wetlands, shorelines, mangrove forests, and coral reefs.

5-6 **What are the major types of freshwater systems and how have we affected them?**

CONCEPT 5-6 Human activities are impairing ecological and economic services provided by many rivers and freshwater lakes and wetlands.

Note: Supplements 4, 5, 10, 11, and 12 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

5-1 What Factors Influence Climate?

CONCEPT 5-1 An area's climate is determined mostly by solar radiation, the earth's rotation, global patterns of air and water movement, gases in the atmosphere, and the earth's surface features.

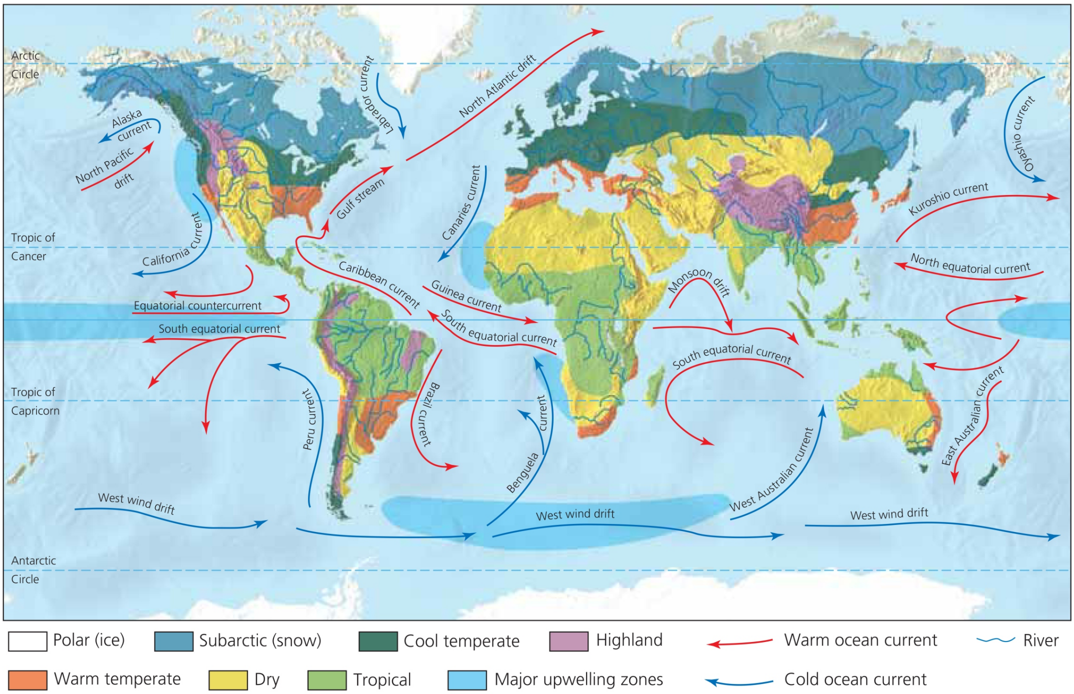
The Earth Has Many Different Climates

Weather is a local area's short-term temperature, precipitation, humidity, wind speed, cloud cover, and other physical conditions of the lower atmosphere over hours or days. Supplement 10 on pp. S43–S47 introduces you to weather basics.

Climate is an area's general pattern of atmospheric or weather conditions over long periods of time. As American writer and humorist Mark Twain once said, "Climate is what we expect, weather is what we get."

Average temperature and *average precipitation* are the two main factors determining climate, along with the closely related factors of **latitude** (distance from the equator) and **elevation** (distance above sea level). Solar radiation, the earth's rotation, global patterns of air and water movement, gases in the atmosphere, and the earth's surface features affect average temperature and precipitation and thus determine the climate of an area (**Concept 5-1**). Figure 5-2 depicts the earth's major climate zones, an important part of the earth's natural capital (Figure 1-3, p. 8).

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.



ThomsonNOW™ Active Figure 5-2 Generalized map of the earth's current climate zones, showing the major contributing ocean currents and drifts and upwelling areas (which bring nutrients from the ocean bottom to the surface). Winds play an important role in distributing heat and moisture in the atmosphere that leads to such climates and in causing currents that help distribute heat throughout the world's oceans. *See an animation based on this figure at* ThomsonNOW. **Question:** Based on this map, what is the general type of climate where you live?

Global Air Circulation and Ocean Currents Distribute Heat and Precipitation Unevenly

Three major factors determine how air circulates in the atmosphere and helps distribute heat and moisture from the tropics to other parts of the world. First is the *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. These differences in the distribution of incoming solar energy help explain why tropical regions near the equator are hot, why polar regions are cold, and why temperate regions in between generally have intermediate average temperatures (Figure 5-2). Temperature also generally becomes progressively colder as elevation above sea level increases in the lower atmosphere.

A second factor is the *rotation of the earth on its axis.* As the earth rotates around its axis, its equator spins faster than its polar regions. 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 5-3).

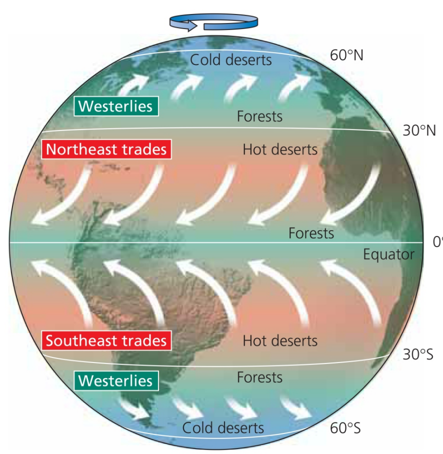


Figure 5-3 *Creation of prevailing winds:* the earth's rotation deflects the movement of the air over different parts of the earth. This creates global patterns of prevailing winds that help distribute heat and moisture in the atmosphere.

The direction of air movement in the resulting huge regions in the atmosphere called *cells* sets up belts of *prevailing winds*—major surface winds that blow almost continuously and distribute air, heat, moisture, and dust (**Core Case Study**) over the earth's surface.

CORE CASE STUDY

A third factor affecting global air circulation is *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 5-4.

The earth's air circulation patterns, prevailing winds, and mixture of continents and oceans result in six giant convection cells—three north of the equator and three south of the equator—in which warm, moist air rises and cools, and the cool, dry air sinks. This leads to an irregular distribution of climates and patterns of vegetation, as shown in Figure 5-5.

ThomsonNOW™ Watch the formation of six giant convection cells and learn more about how they affect climates at ThomsonNOW.

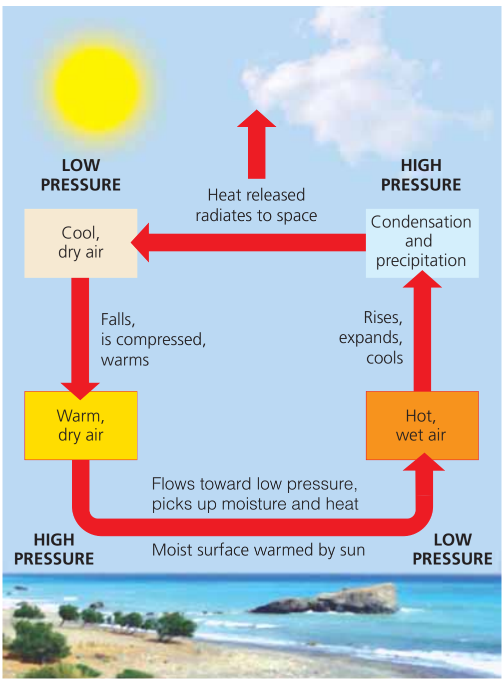


Figure 5-4 Transfer of energy by convection in the atmosphere. *Convection* occurs when hot and wet warm air rises, cools, and releases moisture as precipitation and heat (right side). Then the denser cool, dry air sinks, gets warmer, and picks up moisture as it flows across the earth's surface to begin the cycle again.

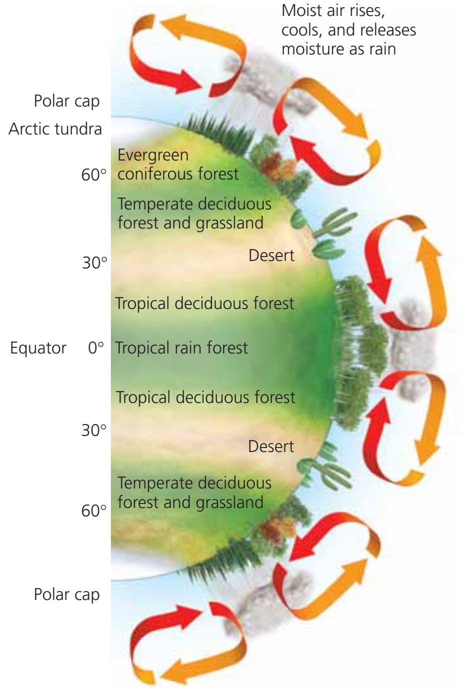


Figure 5-5 *Global air circulation and biomes:* heat and moisture are distributed over the earth's surface by vertical currents, which form six giant convection cells at different latitudes. The resulting uneven distribution of heat and moisture over the planet's surface leads to the forests, grasslands, and deserts that make up the earth's biomes.

THINKING ABOUT
Winds and Biomes

How might the distribution of the world's forests, grasslands, and deserts shown in Figure 5-5 differ if the prevailing winds shown in Figure 5-3 did not exist?

Prevailing winds (Figure 5-3) blowing over the oceans produce mass movements of surface water called **currents.** The major ocean currents (Figure 5-2) also affect regional climates. The oceans absorb heat from the earth's air circulation patterns, with the bulk of this heat being absorbed near the warm tropical areas. This heat and differences in water **density** (mass per unit volume) create warm and cold ocean currents. The earth's rotation (Figure 5-3) 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 (Figure 5-2).

Driven by winds and the earth's rotation, these currents help redistribute heat from the sun from one place to another, thereby influencing climate and vegetation, especially near coastal areas. Ocean currents also help mix ocean waters and distribute nutrients and dissolved oxygen needed by aquatic organisms.

Heat is also distributed to the different parts of the ocean and the world when ocean water mixes vertically in shallow and deep ocean currents, mostly as a result of differences in the density of seawater. Because it has a higher density, colder seawater sinks and flows beneath warmer and less dense seawater. This creates a connected loop of deep and shallow ocean currents, which act like a giant conveyer belt that moves heat to and from the deep sea and transfers warm and cold water between the tropics and the poles (Figure 5-6).

The ocean and the atmosphere are strongly linked in two ways: ocean currents are affected by winds in the atmosphere (**Core Case Study**) and heat from the ocean affects atmospheric circulation (Figure 5-4). One example of the interactions between the ocean and the atmosphere is the *El Niño–Southern Oscillation,* or *ENSO,* as discussed on pp. S44–S45 in Supplement 10. This large-scale climate phenomenon occurs every few years when prevailing winds in the tropical Pacific Ocean weaken and change direction (Figure 4, right, p. S44 in Supplement 10). The resulting above-average warming of Pacific waters can affect populations of marine species by changing the distribution of plant nutrients and can alter the weather of at least two-thirds of the earth for one or two years (Figure 5, p. S45, in Supplement 10).

CORE CASE STUDY

ThomsonNOW™ Learn more about how oceans affect air movements where you live and all over the world at ThomsonNOW.

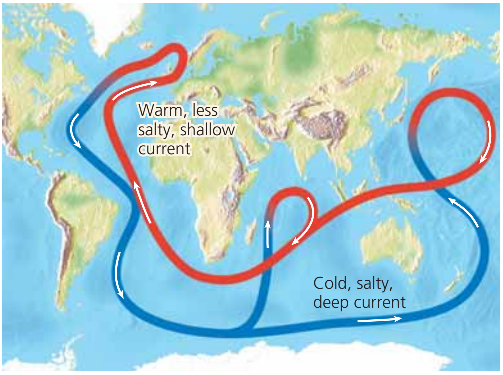


Figure 5-6 *Connected deep and shallow ocean currents:* a connected loop of shallow and deep ocean currents transports warm and cool water to various parts of the earth. This loop, which rises in some areas and falls in others, results when ocean water in the North Atlantic near Iceland is dense enough (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 can cool and sink to begin this extremely slow cycle again. **Question:** How might the climate in Western Europe and in the northeastern United States be affected if this loop slows down or stops because of the effects of global warming?

Greenhouse Gases Warm the Lower Atmosphere

Figure 3-7 (p. 44) shows how energy flows to and from the earth. Small amounts of greenhouse gases, including water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) in the atmosphere play a key role in determining the earth's average temperatures and thus its climates. Recall that these gases tend to warm the atmosphere through what is called the *natural greenhouse effect* (Figure 3-7, p. 44). Without the warming caused by these greenhouse gases, 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. Considerable evidence and climate models indicate that there is a 90–99% chance that the large inputs of greenhouse gases into the atmosphere from human activities is enhancing the earth's natural greenhouse effect. This *human-enhanced global warming* could cause climate changes in various places on the earth that last for centuries to thousands of years. As this process intensifies during this century, climate scientists expect it to alter precipitation patterns, shift areas where we can grow crops, raise average sea levels, and shift habitats for some types of plants and animals.

ThomsonNOW™ Witness the natural greenhouse effect and see how human activity has affected it at ThomsonNOW.

The 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 climates of nearby lands.

Various 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 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 5-7, p. 80). Sometimes this leads to the formation of deserts such as Death Valley in the United

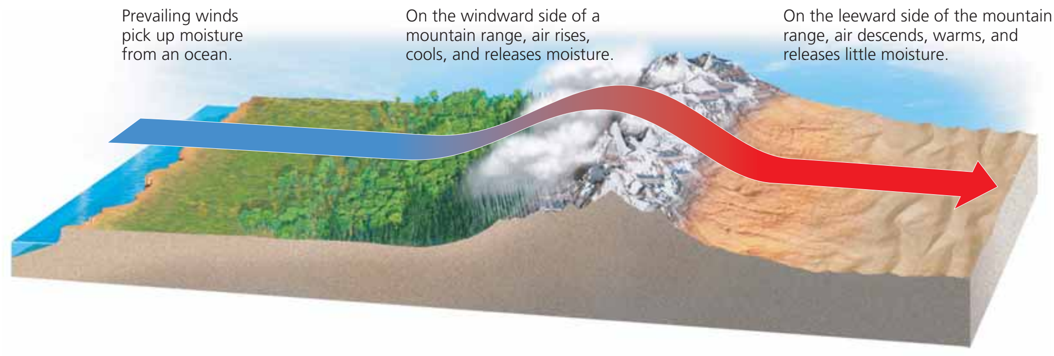


Figure 5-7 The *rain shadow effect* is a reduction of rainfall and loss of moisture from the landscape on the side of mountains facing away from prevailing surface winds. Warm, moist air in onshore winds loses most of its moisture as rain and snow on the windward slopes of a mountain range. This leads 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 are both produced by this effect.

States, which is in the rain shadow of Mount Whitney, the highest mountain in the Sierra Nevadas. Thus, winds (**Core Case Study**) play a key role in forming some of the earth's deserts. CORE CASE STUDY

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.

THINKING ABOUT
Winds and Your Life

CORE CASE STUDY

List three changes in your lifestyle that would take place if there were no winds where you live.

RESEARCH FRONTIER

Modeling and other research to learn more about how human activities affect climate

5-2 How Does Climate Affect the Nature and Location of Biomes?

CONCEPT 5-2 Differences in average annual precipitation and temperature lead to the formation of tropical, temperate, and cold deserts, grasslands, and forests, and largely determine their locations.

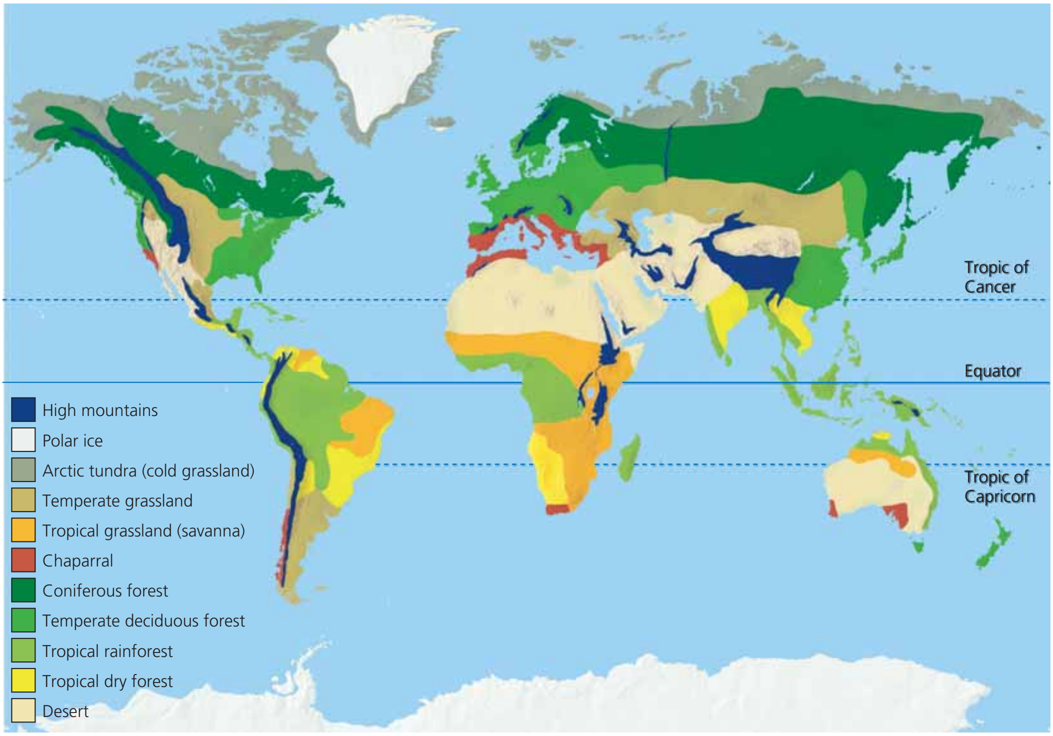
Climate Affects Where Organisms Can Live

Climate differences (Figure 5-2) explain why one area of the earth's land surface is a desert, another a grassland, and another a forest (Figure 5-5) and why there are different types of deserts, grasslands, and forests caused by global air circulation (**Concept 5-2**).

Figure 5-8 shows how scientists have divided the world into several major **biomes**—large terrestrial regions characterized by similar climate, soil, plants, and animals, regardless of where they are found in the world. The variety of terrestrial biomes and aquatic systems is one of the four components of the earth's biodiversity (Figure 3-12 and **Concept 3-4A**, p. 48)—a vital part of the earth's natural capital. CONCEPT LINK

By comparing Figure 5-8 with Figure 5-2 and Figure 1 on pp. S12–S13 in Supplement 4, you can see how the world's major biomes vary with climate. Figure 3-6 (p. 43) shows how major biomes in the United States are related to its different climates.

On maps such as the one in Figure 5-8, 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 with



ThomsonNOW™ **Active Figure 5-8** The earth's major *biomes*—the main types of natural vegetation in various undisturbed land areas—result primarily from differences in climate. Each biome contains many ecosystems whose communities have adapted to differences in climate, soil, and other environmental factors. Figure 5 on p. S19 in Supplement 4 shows the major biomes of North America. Human activities (Figure 3 on pp. S16–S17 in Supplement 4) 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 an animation based on this figure at* ThomsonNOW. **Question:** If you factor out human influences such as farming and urban areas, what kind of biome do you live in?

somewhat different biological communities but with similarities typical of the biome. These patches occur mostly because the resources that plants and animals need are not uniformly distributed and because human activities remove and alter the natural vegetation in many areas.

Figure 5-9 shows how climate and vegetation vary with *latitude* and *elevation*. If you climb a tall

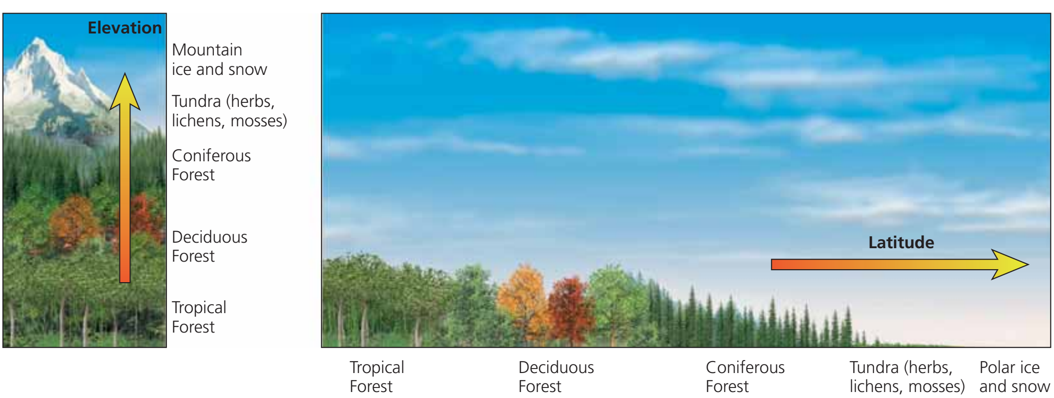


Figure 5-9 Generalized effects of elevation (left) and latitude (right) on climate and biomes. Parallel changes in vegetation type occur when we travel from the equator to the poles or from lowlands to mountaintops.

Image not available due to copyright restrictions

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 poles. For example, if you hike up a tall mountain in Ecuador, your trek can begin in a tropical rain forest and end on a glacier at the summit.

ThomsonNOW™ Find a map showing all the world's biomes and zoom in for details at ThomsonNOW.

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 (Figure 5-10) (**Concept 5-2**).

There Are Three Major Types of Deserts

A **desert** is an area where evaporation exceeds precipitation. Annual precipitation is low and often scattered unevenly throughout the year. During the day, the baking sun warms the ground in the desert. 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 5-10 and 5-11).

Tropical deserts (Figure 5-11, top photo), such as the Sahara and Namib of Africa, are hot and dry most of the year (Figure 5-11, 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 5-11, center photo), such as the Mojave 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 5-11, 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. Figure 1 on p. S48 in Supplement 11 shows some components and food web interactions in a temperate desert ecosystem.

In *cold deserts,* such as the Gobi Desert in Mongolia, vegetation is sparse (Figure 5-11, bottom photo). Winters are cold, summers are warm or hot, and precipitation is low (Figure 5-11, bottom graph). Desert plants

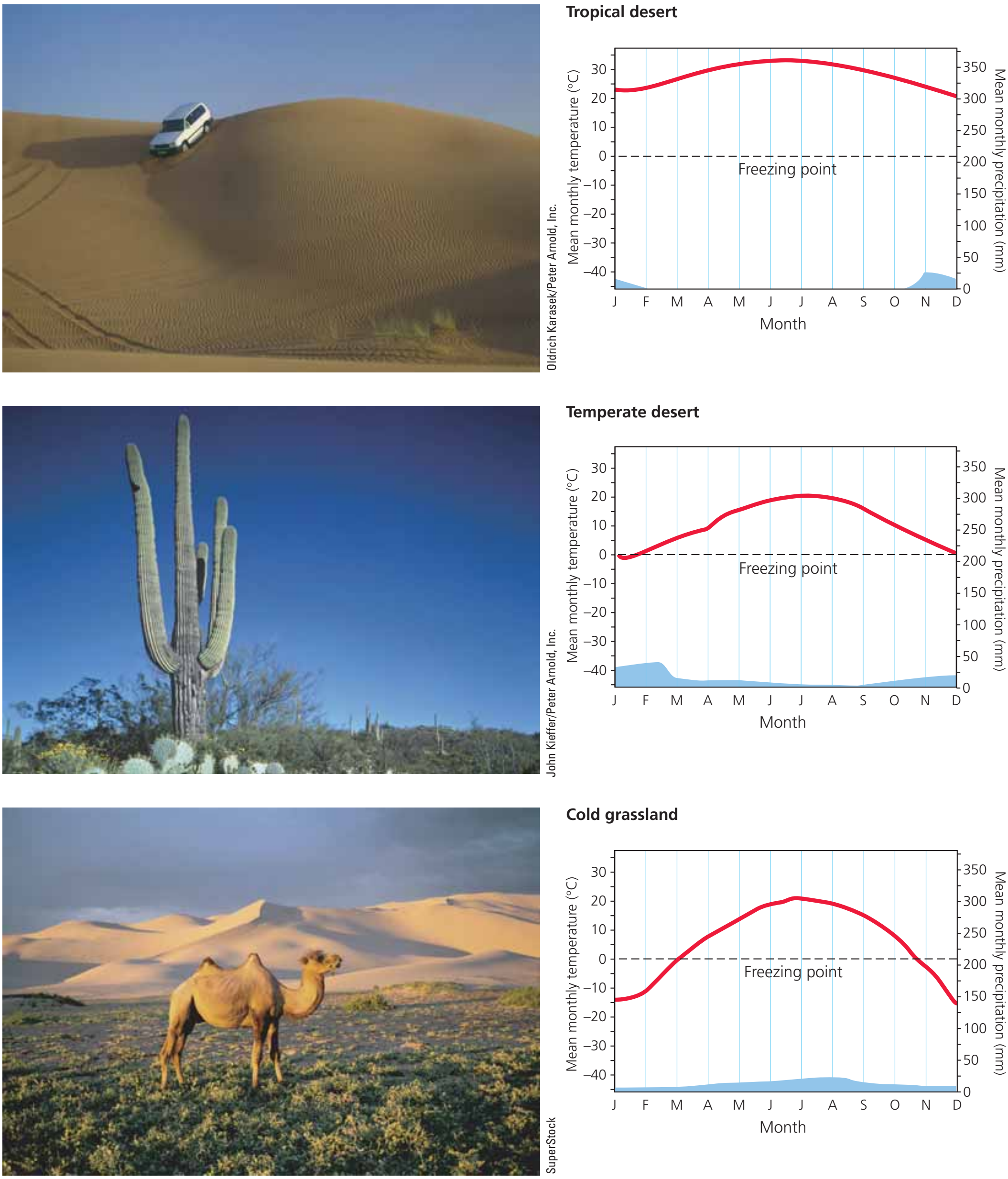


Figure 5-11 Climate graphs showing typical variations in annual temperature (red) and precipitation (blue) in tropical, temperate, and cold deserts. Top photo: a popular (but destructive) SUV rodeo in United Arab Emirates (tropical desert). Center photo: saguaro cactus in the U.S. state of Arizona (temperate desert). Bottom photo: a Bactrian camel in Mongolia's Gobi (cold) desert. **Question:** What month of the year has the highest temperature and the lowest rainfall for each of the three types of deserts?

and animals have adaptations that help them stay cool and get enough water to survive (Science Focus, p. 84).

Desert ecosystems are fragile. Their soils take decades to hundreds of years to recover from disturbances such as off-road vehicles (Figure 5-11, top photo) because of slow plant growth, low species diversity, slow nutrient cycling (because of low bacterial activity in their soils), and lack of water.

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 for doing this. 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 (See Figure 5-11, middle photo), have three adaptations: they have no leaves, which can lose water by evapotranspiration; 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 (see Figure 1 on p. S48 in Supplement 11) and saguaro cacti use widely spread, shallow roots to collect water after brief showers and store it in their spongy tissue.

Evergreen plants conserve water by having wax-coated leaves or needles 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 a dazzling array of colorful flowers that last only 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 (Figure 5-11, bottom left) 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.

Desert insects and reptiles 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?

THINKING ABOUT
Winds and Deserts

CORE CASE STUDY

What roles do winds (**Core Case Study**) play in creating and sustaining deserts?

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 5-8). 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 grasslands—tropical, temperate, and cold (Arctic tundra)—result from combinations of low average precipitation and various average temperatures (Figures 5-10 and 5-12).

One type of tropical grassland, called a *savanna,* contains widely scattered clumps of trees such as acacia, (Figure 5-12, top photo), which are covered with thorns that help keep herbivores away. This biome usually has warm temperatures year-round and alternating dry and wet seasons (Figure 5-12, top graph).

Tropical savannas in East Africa have herds of *grazing* (grass- and herb-eating) and *browsing* (twig- and leaf-nibbling) hoofed animals, including wildebeests (Figure 5-12, top photo), gazelles, zebras, giraffes, and antelopes and their predators such as lions, hyenas, and humans. Herds of these grazing and browsing animals migrate to find water and food in response to seasonal and year-to-year variations in rainfall (Figure 5-12, blue region in top graph) and food availability.

In finding their niches, these and other large herbivores have evolved specialized eating habits that minimize competition among species for the vegetation found on the savanna. For example, giraffes eat leaves and shoots from the tops of trees, elephants eat leaves and branches farther down, wildebeests prefer short grass, and zebras graze on longer grass and stems. Savanna plants, like those in deserts, are adapted to survive drought and extreme heat. Many have deep roots that can tap into groundwater.

In a *temperate grassland,* winters are bitterly cold, summers are hot and dry, and annual precipitation is fairly sparse and falls unevenly through the year (Figure 5-12, 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 *tall-grass prairies* and *short-grass prairies* (Figure 5-12, center photo) of the midwestern and western United States and Canada. Here, winds blow almost continuously, and evaporation is rapid, often leading to fires in the summer and fall. This combination of winds (**Core Case Study**) and fire helps maintain such grasslands by hindering tree growth. Figure 2 on p. S49 in Supplement 11 shows some components and food-web interactions in a temperate tall-grass prairie ecosystem in North America.

CORE CASE STUDY

Many of the world's natural temperate grasslands have disappeared because their fertile soils are useful for growing crops (Figure 5-13, p. 86) and grazing cattle.

Cold grasslands, or *arctic tundra* (Russian for "marshy plain"), lie south of the arctic polar ice cap (Figure 5-8). During most of the year, these treeless plains are bit-

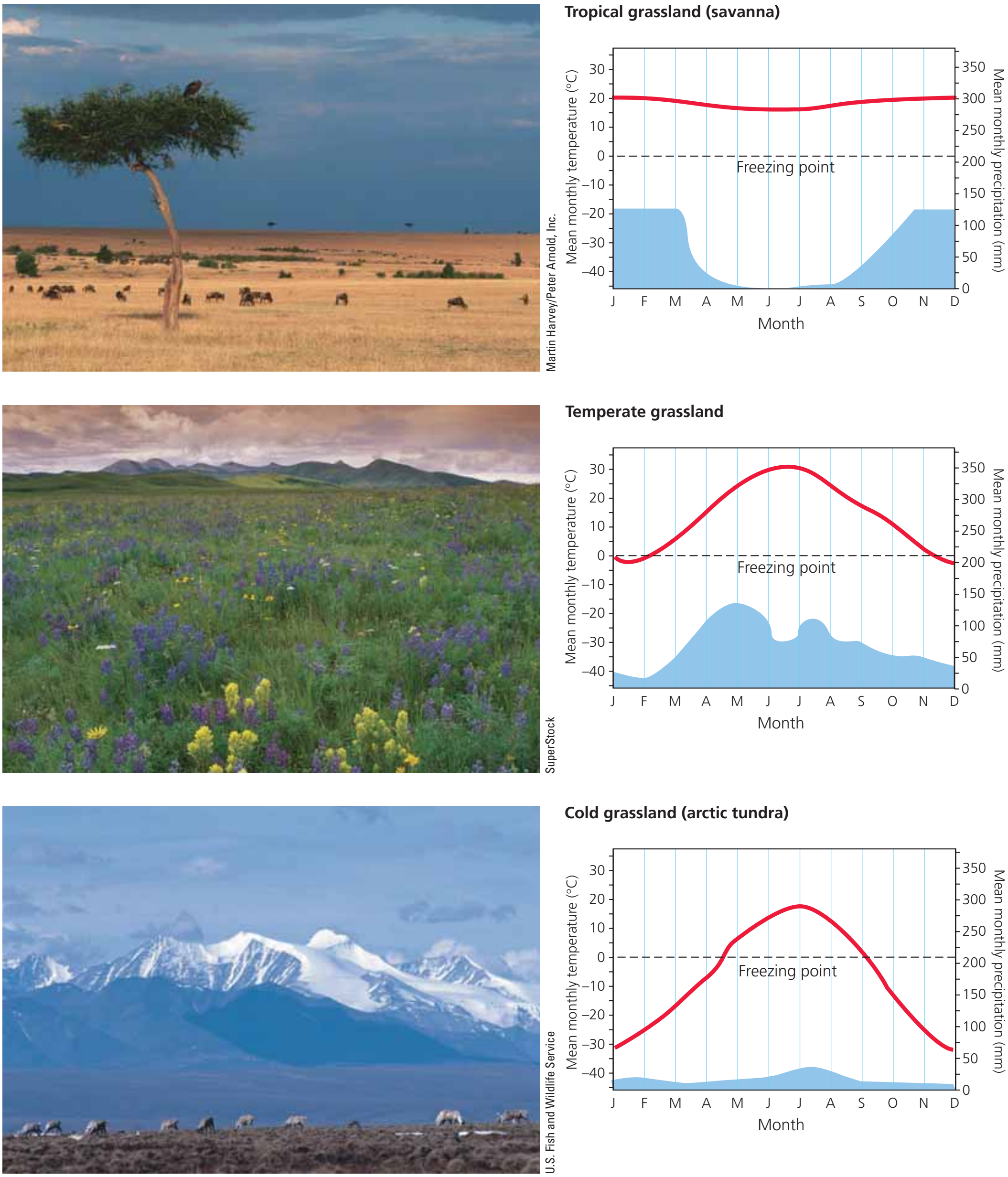


Figure 5-12 Climate graphs showing typical variations in annual temperature (red) and precipitation (blue) in tropical, temperate, and cold (arctic tundra) grasslands. Top photo: wildebeests grazing on a savanna in Maasai Mara National Park in Kenya, Africa (tropical grassland). Center photo: wildflowers in bloom on a prairie near East Glacier Park in the U.S. state of Montana (temperate grassland). Bottom photo: arctic tundra with caribou in Alaska's Arctic National Wildlife Refuge (cold grassland). **Question:** What month of the year has the highest temperature and the lowest rainfall for each of the three types of grassland?

terly cold (Figure 5-12, 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 5-12, bottom photo and Figure 1-13, p. 20). Trees or tall plants cannot

Figure 5-13 **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 (see Case Study on p. S30 in Supplement 5) unless it is covered with some type of vegetation.

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 5- to 8-week summer, when the sun shines almost around the clock. Figure 3 on p. S50 in Supplement 11 shows some components and food-web interactions in an arctic tundra ecosystem.

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 during the short summer.

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 (Figure 5-11, bottom).

The permafrost in parts of Canada, Alaska, China, Russia, and Mongolia is melting as a result of global warming. 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 accelerate global warming and cause more permafrost to melt, which can lead to further warming. The melting permafrost also causes the soil to sink (subside), which can damage buildings, roads, powerlines, 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 4-4, p. 67). These soils usually are nutrient poor and have little detritus. Because of the tundra's short growing season, its soil and vegetation recover very slowly from damage or disturbance. Human activities in the arctic tundra—mostly the construction of 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 5-9, left). The vegetation is similar to that found in arctic tundra, but it receives more sunlight than arctic vegetation. During the brief summer, alpine tundra can be covered with an array of beautiful wildflowers.

THINKING ABOUT
Winds and Grasslands

CORE CASE STUDY

What roles do winds play in creating and sustaining grasslands?

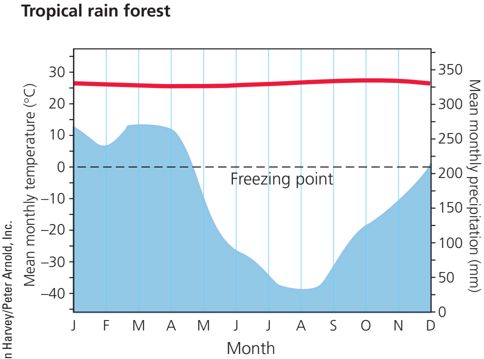
There Are Three Major Types of Forests

Forest systems are lands dominated by trees. The three main types of forest—*tropical, temperate,* and *cold* (*northern coniferous* and *boreal*)—result from combinations of the precipitation level and various average temperatures (Figures 5-10 and 5-14).

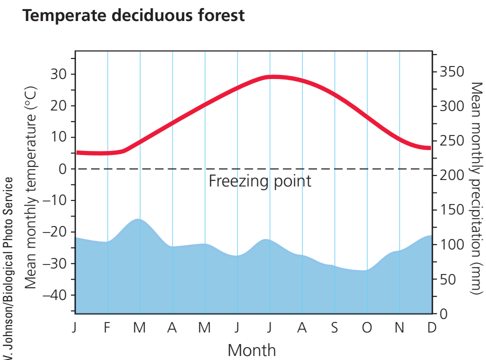
Tropical rain forests (Figure 5-14, top photo) are found near the equator (Figure 5-8), where hot, moisture-laden air rises and dumps its moisture (Figure 5-5). These lush forests have year-round, uniformly warm temperatures, high humidity, and heavy rainfall almost daily (Figure 5-14, top graph).

Figure 5-15 (p. 88) 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 5-14, top photo), which blocks most


Martin Harvey/Peter Arnold, Inc.




Paul W. Johnson/Biological Photo Service




Dave Powell, USDA Forest Service

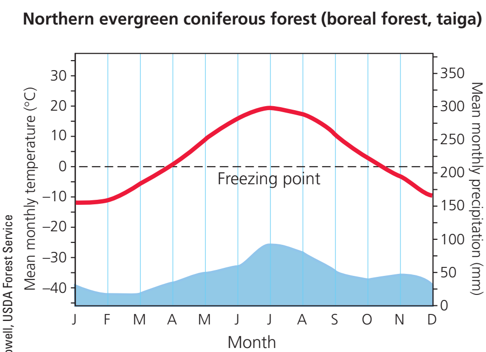


Figure 5-14 Climate graphs showing typical variations in annual temperature (red) and precipitation (blue) in tropical, temperate, and cold (northern coniferous and boreal) forests. Top photo: the closed canopy of a tropical rain forest in the western Congo Basin of Gabon, Africa. Middle photo: a temperate deciduous forest in the U.S. state of Rhode Island during the fall. (Photo 4 on p. vii 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 months of the year have the highest temperature and the lowest rainfall for each type of forest?

light from reaching the forest floor, limiting illumination to a dim greenish light.

Some trees are draped with vines (called lianas) that reach 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.

ThomsonNOW™ Active Figure 5-15 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* ThomsonNOW.

Tropical rain forests 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.

These life forms occupy a variety of specialized niches in distinct layers—in the plants' case, based mostly on their need for sunlight, as shown in Figure 5-16. Stratification of specialized plant and animal niches in a tropical rain forest enables the coexistence of a great variety of species. See Figure 3-13, p. 50, and photo 3 on p. vii. 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.

ThomsonNOW™ Learn more about how plants and animals in a rain forest are connected in a food web at ThomsonNOW.

Dropped leaves, fallen trees, and dead animals decompose quickly because of the warm, moist conditions and hordes of decomposers. This rapid recycling of scarce soil nutrients explains why little litter is found on the ground. Instead of being stored in the soil, about 90% of plant nutrients released by decomposition are taken up quickly and stored by trees, vines, and other plants. This is in sharp contrast to temperate forests where most plant nutrients are found in the soil. This helps 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 of destruction and degradation of these centers of terrestrial biodiversity is increasing (**Concept 3-4A**, p. 48). CONCEPT LINK Ecologists warn that without strong conservation measures, most of these forests will probably be gone within your lifetime, and with them perhaps a quarter of the world's species. This will reduce the earth's biodiversity and help accelerate global warming by eliminating large areas of trees that remove carbon dioxide from the atmosphere.

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 reduce this loss?

Temperate deciduous forests (Figure 5-14, 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 5-14, center graph).

This biome is dominated by a few species of *broadleaf deciduous trees* such as oak, hickory, maple, poplar, and beech. They survive cold winters by dropping their leaves in the fall and becoming dormant through the winter (see photo 4, p. vii). Each spring they grow new leaves whose colors change in the fall into an array of reds and golds before the leaves drop (Figure 5-14, center photo).

Because of a slow rate of decomposition, these forests accumulate a thick layer of slowly decaying leaf litter that is a storehouse of nutrients. Figure 4 on p. S51 in Supplement 11 shows some components and food web interactions in a temperate deciduous forest ecosystem. On a global basis, this biome has been disturbed by human activity more than any other terrestrial biome.

Evergreen coniferous forests (Figure 5-14, 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 5-8) and above certain altitudes in the High Sierra and Rocky Mountains of the United States. In this subarctic climate, winters are long, dry, and extremely cold; in the northernmost taigas, sunlight is available only 6–8 hours per day. Summers are short, with cool to warm temperatures (Figure 5-14, bottom graph), and the sun shines up to 19 hours a day.

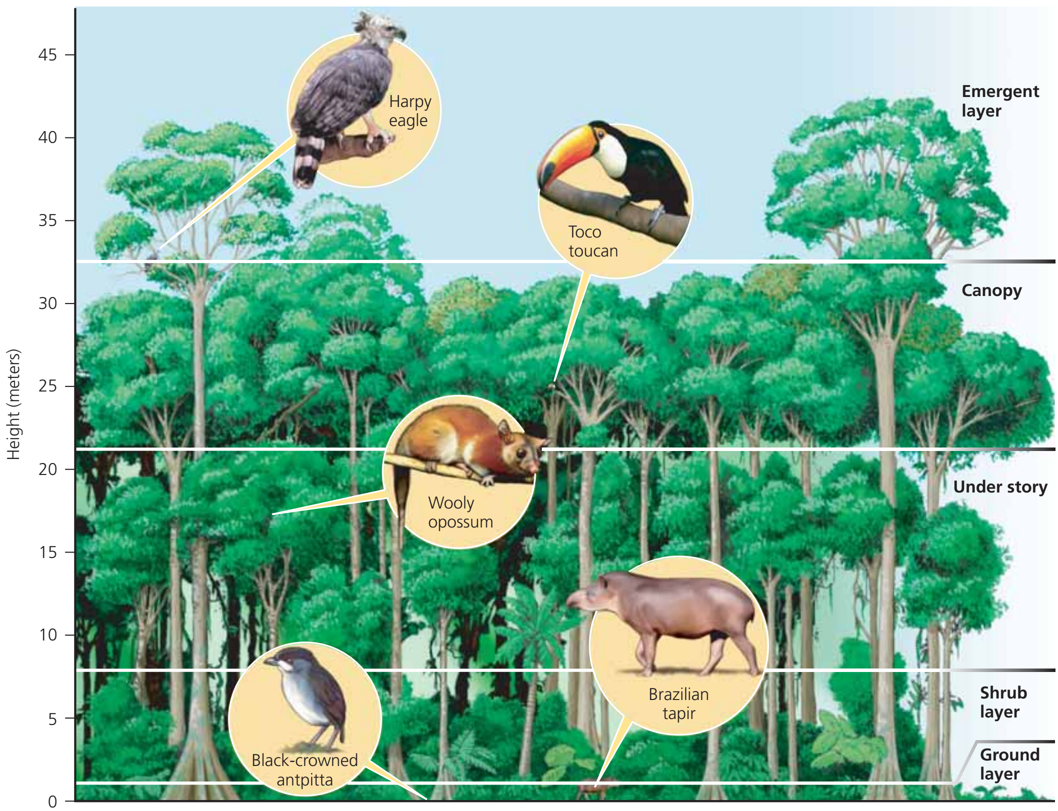


Figure 5-16 Stratification of specialized plant and animal niches in a *tropical rain forest.* Filling such specialized niches enables species to avoid or minimize competition for resources and results in the coexistence of a great variety of species.

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 5-14, 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 in these areas without taking 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 the low temperatures, 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 5-12, bottom). During the brief summer, warblers and other insect-eating birds feed on hordes of flies, mosquitoes, and caterpillars. Figure 5 on p. S52 of Supplement 11 shows some components and food web interactions in an evergreen coniferous forest ecosystem.

Mark Hamblin/WWI/Peter Arnold, Inc.

Figure 5-17 Mountains such as these in Mount Rainier National Park in the U.S. state of Washington play important ecological roles.

Coastal coniferous forests or *temperate rain forests* (see photo 5 on p. viii) are found in scattered coastal temperate areas with ample rainfall or moisture from dense ocean fogs. Dense stands of large conifers such as Sitka spruce, Douglas fir, and redwoods once dominated undisturbed areas of these biomes along the coast of North America, from Canada to northern California in the United States.

THINKING ABOUT
Winds and Forests

CORE CASE STUDY

What roles do winds play in creating temperate and coniferous forests?

Mountains Play Important Ecological Roles

Some of the world's most spectacular environments are high on *mountains* (Figure 5-17), which cover about one-fourth of the earth's land surface (Figure 5-8). Mountains are places where dramatic changes in altitude, climate, soil, and vegetation take place over a very short distance (Figure 5-9, left).

About 17% (1.2 billion) of the world's people live in mountains or on their edges, and 4 billion people (60% of the world's population) depend on mountains 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 driven from lowland areas.

Mountains also help regulate the earth's climate. Mountaintops covered with ice and snow affect climate by reflecting solar radiation back into space. This helps cool the earth and offset global warming. However, many of the world's mountain glaciers are melting mostly because of global warming. As the earth gets warmer, mountaintop glaciers and other land-based glaciers could melt and help raise sea levels.

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. Despite their ecological, economic, and cultural importance, the fate of mountain ecosystems has not been a high priority of governments or for many environmental organizations.

5-3 How Have We Affected the World's Terrestrial Ecosystems?

CONCEPT 5-3 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

Humans dominate most of the planet. In many areas, human activities are impairing some of the ecological and economic services provided by the world's deserts, grasslands, forests, and mountains (**Concept 5-3**).

According to the 2005 Millennium Ecosystem Assessment, about 62% of the world's major terrestrial ecosystems are being degraded or used unsustainably (see Figure 3 on pp. S16–S17 and Figure 7 on pp. S20–S21 in Supplement 4), as the human ecological footprint intensifies and spreads across the globe (Figure 1-8, p. 13, and **Concept 1-3**, p. 11). This environmental destruction and degradation is increasing in many parts of the world. Figure 5-18 summarizes some of the human impacts on the world's deserts, grasslands, forests, and mountains.

How long can we keep eating away at these terrestrial forms of the earth's natural capital without

Figure 5-18 Major human impacts on the world's deserts, grasslands, forests, and mountains. **Question:** Which two of the impacts on each of these biomes do you think are the most harmful? Why?

threatening our economies and the long-term survival of our own and other species? No one knows. But there are increasing signs that we need to come to grips with this issue.

This will require protecting the world's remaining wild areas from development. In addition, many of the land areas we have degraded will need to be restored. However, such efforts to achieve a balance between exploitation and conservation are highly controversial because of the timber, mineral, and other resources found on or under many of the earths land areas.

RESEARCH FRONTIER

Better understanding of the effects of human activities on terrestrial biomes and how we can reduce these impacts

THINKING ABOUT
Sustainability

Develop four guidelines for preserving the earth's terrestrial biodiversity based on the four **scientific principles of sustainability** (see back cover).

5-4 What Are the Major Types of Aquatic Systems?

CONCEPT 5-4A Saltwater and freshwater aquatic life zones cover almost three-fourths of the earth's surface with oceans dominating the planet.

CONCEPT 5-4B Most aquatic organisms live in the surface, middle, or bottom layers of saltwater and freshwater systems.

Most of the Earth Is Covered with Water

We live on the water planet, with a precious film of water—most of it saltwater—covering about 71% of the earth's surface (Figure 5-19). Thus, a more accurate name for Earth would be Ocean.

Although the *global ocean* is a single and continuous body of water, geographers divide it into four large areas separated by the continents: the Atlantic, Pacific, Arctic, and Indian Oceans. The largest is the Pacific, which contains more than half of the earth's water and covers one-third of the earth's surface.

The aquatic equivalents of biomes are called **aquatic life zones.** The major types of organisms found in aquatic environments are determined 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* (particularly oceans and their accompanying estuaries, coastal wetlands, shorelines, coral reefs, and mangrove swamps) and *freshwater* (particularly lakes, rivers, and inland wetlands). Figure 5-20 shows the distribution of the world's major oceans, coral reefs, mangroves, lakes, and rivers—another important part of the earth's natural capital.

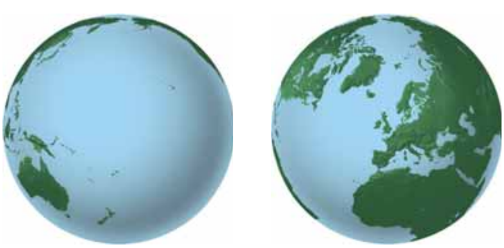
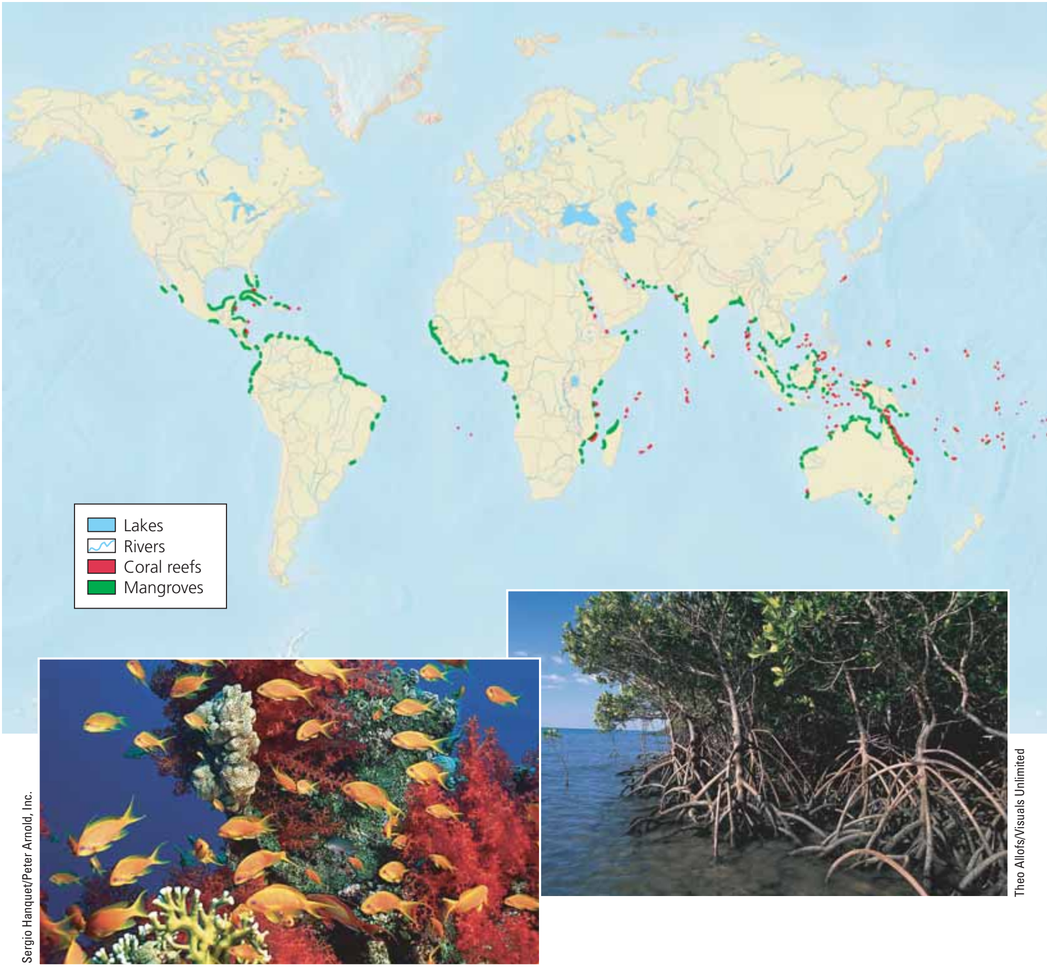


Figure 5-19 **Natural capital:** the ocean planet (**Concept 5-4A**). The salty oceans cover 71% of the earth's surface. About 97% of the earth's water is in the interconnected oceans, which cover 90% of the planet's mostly ocean hemisphere (left) and 50% of its land–ocean hemisphere (right). Freshwater systems cover less than 1% of the earth's surface.

Most Aquatic Species Live in Top, Middle, or Bottom Layers of Water

Saltwater and freshwater life zones contain several major types of organisms. One group consists of weakly swimming, free-floating **plankton.** They are mostly *phytoplankton* (plant plankton) and *zooplankton* (animal plankton).

A second group of organisms consists of **nekton,** strongly swimming consumers such as fish, turtles, and whales. A third group, **benthos,** are bottom dwellers such as barnacles and oysters that anchor themselves to one spot, worms that burrow into the sand or mud, and lobsters and crabs that walk about on the seafloor. A fourth group consists of **decomposers** (mostly bacteria) that break down the organic compounds in the dead bodies and wastes of aquatic organisms into simple nutrient compounds for use by aquatic producers. Most forms of aquatic life are found in the *surface, middle,* and *bottom* layers of saltwater and freshwater systems (**Concept 5-4B**). Important factors determining the types and numbers of organisms



Sergio Hanquet/Peter Arnold, Inc.

Theo Allofs/Visuals Unlimited

Figure 5-20 **Natural capital:** distribution of the world's major saltwater oceans, coral reefs, mangroves, and freshwater lakes and rivers. Left photo: coral reef in the Red Sea. Right photo: mangrove forest in Daintree National Park in Queensland, Australia. By 2005, an estimated 20% of the world's coral reefs and mangrove forests had been destroyed, mostly by human activities, and the rate of degradation and destruction is increasing. **Question:** Why do you think most coral reefs lie in the southern hemisphere?

found in these layers of most systems are *temperature; access to sunlight for photosynthesis; dissolved oxygen content;* and *availability of nutrients* such as carbon (as dissolved CO_2 gas), nitrogen (as NO_3^-), and phosphorus (mostly as PO_4^{3-}) for producers.

In deep aquatic systems, photosynthesis is largely confined to the upper layer, or *euphotic* zone, through which sunlight can penetrate. The depth of the euphotic zone in oceans and deep lakes can be reduced when excessive algal growth (algal blooms from nutrient overload) clouds the water.

In shallow waters in streams, ponds, and oceans, ample supplies of nutrients for primary producers are usually available. By contrast, nitrates, phosphates, iron, and other nutrients are often in short supply in the open ocean and this limits net primary productivity (NPP; see Figure 3-17, p. 53). NPP is much higher in some parts of the open ocean, where upwellings (Figure 5-2, p. 77, and Figure 3 on p. S44 in Supplement 10) bring nutrients from the ocean bottom to the surface for use by producers.

Many creatures living on the bottoms of the deep ocean and deep lakes depend on *marine snow,* animal and plant plankton that die and drift downward from the lighted regions above. Because this food is limited, deep-dwelling fish species tend to reproduce slowly. This makes them especially vulnerable to depletion from overfishing.

5-5 What Are the Major Ocean Zones and How Have We Affected Them?

> **CONCEPT 5-5** In many areas, human activities are impairing ecological and economic services provided by the earth's saltwater systems, especially coastal wetlands, shorelines, mangrove forests, and coral reefs.

Oceans Provide Important Ecological and Economic Resources

The world's oceans occupy most of the earth's surface and provide many important ecological and economic services (Figure 5-21).

As land dwellers, we have a distorted and limited view of the blue aquatic wilderness that covers most of the earth's surface. We know more about the surface of the moon than about the oceans. We also have far too little knowledge of the planet's freshwater aquatic systems.

> **RESEARCH FRONTIER**
> Discovering, cataloging, and studying the huge number of unknown aquatic species and their interactions

Figure 5-21 Major ecological and economic services provided by marine systems (**Concept 5-5**). **Question:** Which two ecological services and which two economic services do you think are the most important? Why?

Most of the Ecological Action Takes Place in the Coastal Zone

Oceans have three major life zones: the *coastal zone, open sea,* and *ocean bottom* (Figure 5-22). 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). Because of its numerous interactions with the land, human activities have a major impact on this zone.

ThomsonNOW™ Learn about ocean provinces where all ocean life exists at ThomsonNOW.

The coastal zone makes up less than 10% of the world's ocean area but contains 90% of all marine species and is the site of most large commercial marine fisheries. Most coastal zone aquatic systems, such as coastal wetlands, mangrove forests, and coral reefs, have a high NPP per unit of area (Figure 3-17, p. 53). 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. Human activities are disrupting and degrading some of the ecological and economic services provided by the world's saltwater systems, especially coastal wetlands, shorelines, mangrove forests, and coral reefs (**Concept 5-5**).

Estuaries and Coastal Wetlands Are Highly Productive

One highly productive coastal ecosystem facing increasing stress from human activities is **estuaries,** where rivers meet the sea. In these partially enclosed bodies of water, seawater mixes with freshwater and with nutrients and pollutants from rivers, streams, and runoff from land (Figure 5-23). Estuaries and their associated **coastal wetlands**—land areas covered with water all or part of the year—include river mouths, inlets, bays, sounds, salt marshes in temperate zones (Figure 5-24, p. 96), and mangrove forests in tropical zones.

Estuaries and coastal wetlands are some of the earth's most productive ecosystems (Figure 3-17, p. 53) because of high nutrient inputs from rivers and nearby

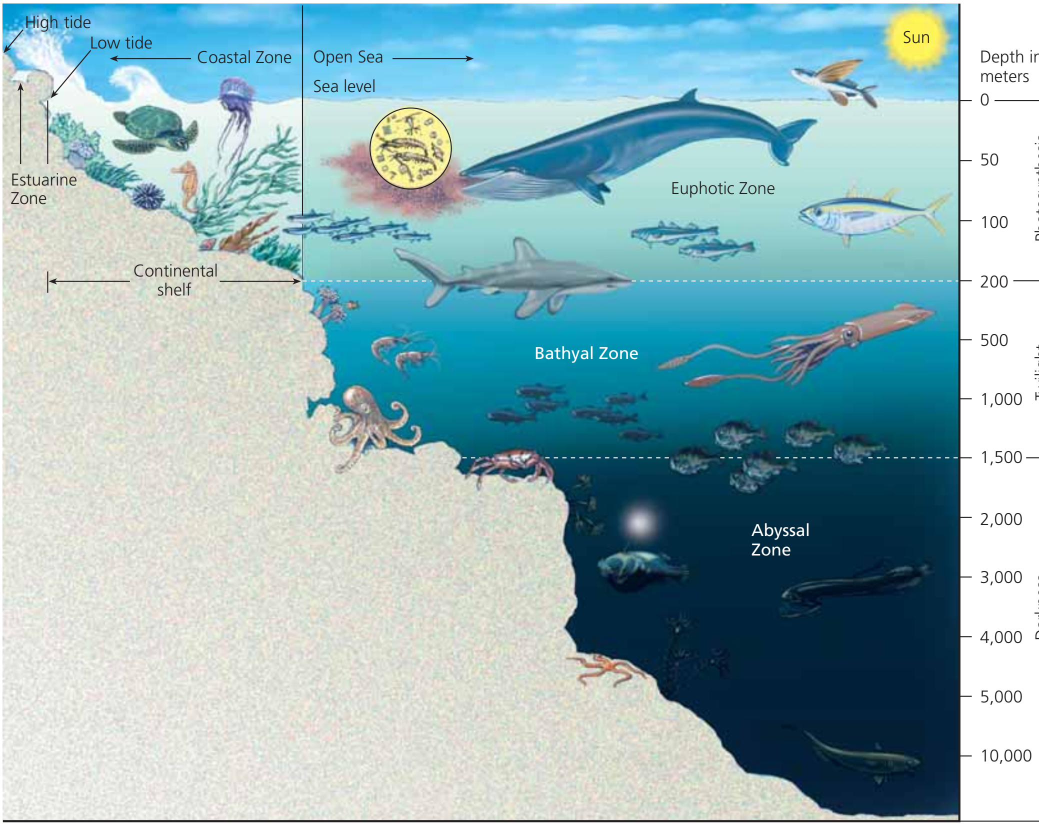


Figure 5-22 **Natural capital:** major life zones in an ocean (not drawn to scale). Actual depths of zones may vary. **Question:** How is an ocean like a rain forest? (*Hint:* see Figure 5-16.)

land, rapid circulation of nutrients by tidal flows, presence of many producer plants, and ample sunlight penetrating the shallow waters. These coastal aquatic systems provide important ecological and economic services. They filter toxic pollutants, excess plant nutrients, sediments, and other pollutants. They reduce storm damage and coastal erosion by absorbing waves and storing excess water produced by storms and tsunamis (Figure 4 on p. S55 and Figure 5 on p. S56 in Supplement 12). They also absorb some pollutants, and provide food, habitats, and nursery sites for a variety of aquatic species. Unfortunately, we are degrading or destroying some of these important ecological services provided by nature.

THINKING ABOUT
Mangrove Forests

How can clearing mangrove forests (Figure 5-20, bottom right) increase the economic damage and loss of human life from tropical cyclones (Figure 6, on p. S45 in Supplement 10) and tsunamis (Figures 4 on p. S55 and Figure 5 on p. S56 in Supplement 12)?

NASA

Figure 5-23 View of an *estuary* taken from space. The photo shows the sediment plume 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 5-24 Some components and interactions in a *salt marsh ecosystem* in a temperate area such as the United States. When these organisms die, decomposers break down their organic matter into minerals used by plants. Colored arrows indicate transfers of matter and energy between consumers (herbivores), secondary or higher-level consumers (carnivores), and decomposers. Organisms are not drawn to scale. Photo below: a salt marsh in Peru.

Living with the Tides: Rocky and Sandy Shores Have Different Types of Organisms

The gravitational pull of the moon and sun causes *tides* to rise and fall about every 6 hours in certain coastal areas. The area of shoreline between low and high tides is called the **intertidal zone.** Organisms living in this zone must be able to avoid being swept away or crushed by waves, and must cope with being immersed during high tides and left high and dry (and much hotter) at low tides. They must also survive changing levels of salinity when heavy rains dilute saltwater. To deal with such stresses, most intertidal organisms hold on to something, dig in, or hide in protective shells.

On some coasts, steep *rocky shores* are pounded by waves. The numerous pools and other niches in their intertidal zones contain a great variety of species that occupy different niches in response to daily and seasonal changes in environmental conditions such as temperature, water flows, and salinity (Figure 5-25, top).

Other coasts have gently sloping *barrier beaches,* or *sandy shores,* with niches for different marine organisms (Figure 5-25, bottom). Most of them keep hidden from view and survive by burrowing, digging, and tunneling in the sand. These sandy beaches and their adjoining coastal wetlands are also home to a variety of shorebirds that feed in specialized niches on crustaceans, insects, and other organisms (Figure 4-5, p. 68).

Undisturbed barrier beaches generally have one or more rows of natural sand dunes in which the sand is held in place by the roots of grasses (Figure 5-26, p. 98). These dunes are the first line of defense against the ravages of the sea. Such real estate is so scarce and valuable that coastal developers frequently remove the protective dunes or build behind the first set of dunes and cover them with buildings and roads. Large storms can then flood and even sweep away seaside buildings and severely erode the sandy beaches. Some people incorrectly call these human-influenced events "natural disasters."

THINKING ABOUT
Living in Risky Places

Should governments help subsidize property insurance and rebuilding costs for dwellings and beach replenishment on coasts, near major rivers, in earthquake zones, or in other risky areas? Explain your position.

Coral Reefs Are Dazzling Centers of Aquatic Biodiversity

Coral reefs form in clear, warm coastal waters of the tropics and subtropics (Figure 5-20). These stunningly beautiful natural wonders are among the world's oldest, most diverse, and most productive ecosystems. In terms of biodiversity (**Concept 3-4A**, p. 48), they are the marine equivalents of tropical rain forests.

CONCEPT LINK

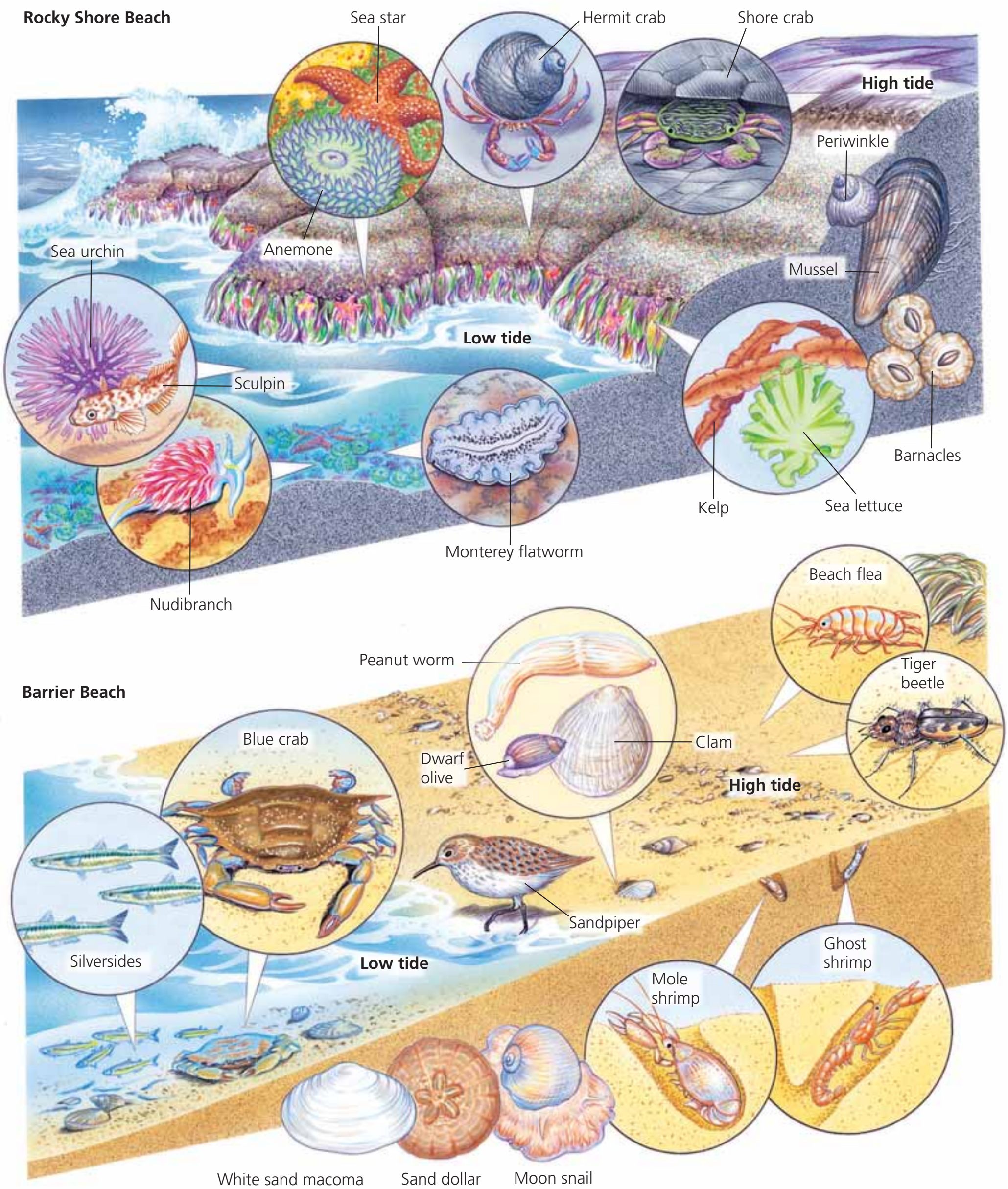


Figure 5-25 Living between the tides. Some organisms with specialized niches found in various zones on rocky shore beaches (top) and barrier or sandy beaches (bottom). Organisms are not drawn to scale.

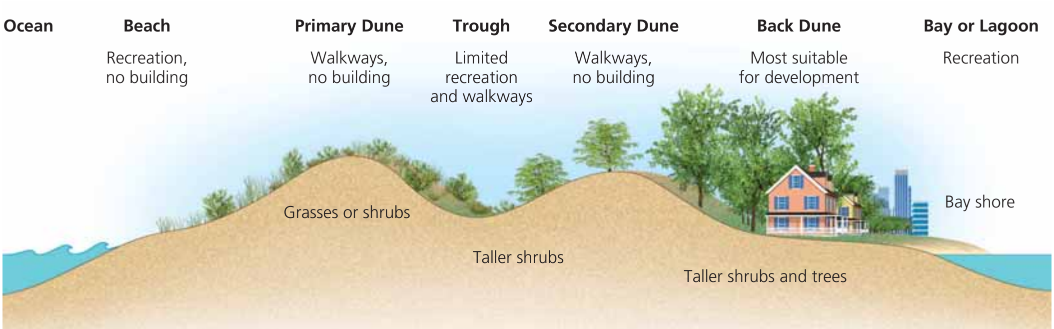


Figure 5-26 Primary and secondary dunes on gently sloping sandy barrier beaches help protect land from erosion by the sea. The roots of grasses that colonize the dunes help hold the sand in place. Ideally, construction is allowed only behind the second strip of dunes, and walkways to the ocean beach are built so as not to damage the dunes. This helps preserve barrier beaches and protect buildings from damage by wind, high tides, beach erosion, and flooding from storm surges. Such protection is rare because the short-term economic value of oceanfront land is considered much higher than its long-term ecological value. Rising sea levels from global warming may put many barrier beaches under water by the end of this century. **Question:** Do you think that the ecological values of oceanfront dunes outweigh the economic value of removing them for coastal development? Explain.

Coral reefs are formed by massive colonies of tiny animals called *polyps* (close relatives of jellyfish). They slowly build reefs by secreting a protective crust of limestone (calcium carbonate) around their soft bodies. When the polyps die, their empty crusts remain behind as a platform for more reef growth. The resulting elaborate network of crevices, ledges, and holes serves as calcium carbonate "condominiums" for a variety of marine animals.

Coral reefs represent a mutually beneficial relationship between the polyps and the single-celled algae called *zooxanthellae* ("zoh-ZAN-thel-ee") that live in the tissues of the polyps. The algae provide the polyps with color, food, and oxygen through photosynthesis. The polyps, in turn, provide the algae with a well-protected home and some of their nutrients. Figure 6 on p. S53 in Supplement 11 shows some components and interactions in a coral reef ecosystem.

Although coral reefs occupy only about 0.1% of the world's ocean area, these diverse and productive ecosystems provide numerous ecological and economic services. They help moderate the earth's temperatures by removing CO_2 from the atmosphere and act as natural barriers that help protect 15% of the world's coastlines from erosion by battering waves and storms. They provide habitats for as many as 1 million species, including a fourth of known marine fish species. Molecules derived from coral reef species have been used to develop antibiotics and drugs for treating certain cancers and HIV.

Economically, coral reefs produce about one-tenth of the global fish catch and one-fourth of the catch in developing countries, and they provide jobs and building materials for some of the world's poorest countries. They also support fishing and tourism industries worth billions of dollars each year.

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). The biggest long-term threat to these reefs may be global warming, which can raise the water temperature above this limit. 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.

In 2005, 240 experts from 96 countries estimated that one-fifth of the world's coral reefs are so damaged that they are unlikely to recover. They also projected that by 2050 half of the world's remaining coral reefs are likely be lost due to climate change, habitat loss, pollution (especially eroded sediment), and overfishing. Thus, about 70% of the world's coral reefs are now destroyed or likely to be destroyed, up from 59% in 2000. Only about 300 of the world's 6,000 coral reefs are protected (at least on paper) as reserves or parks. Coral reefs, which are early indicators of life-degrading environmental conditions, are sending us an alarming message.

In the Open Sea, Light Rules

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 a brightly lit surface layer, a dimly lit middle layer, and a dark bottom zone (see Figure 5-22).

The *euphotic zone* is the brightly lit upper zone where drifting phytoplankton carry out photosynthesis and are responsible for about 40% of the world's photosynthetic activity. Nutrient levels are low (except around upwellings, Figure 5-2), and levels of dissolved oxygen are high. Large, fast-swimming predatory fish such as swordfish, sharks, and bluefin tuna populate this zone.

The *bathyal zone* is the dimly lit middle zone, which because it has little sunlight does not contain photosynthesizing producers. Zooplankton and smaller fish, many of which migrate to feed on the surface at night, populate this zone.

The lowest zone, called the *abyssal zone,* is dark and very cold; it has little dissolved oxygen. Nevertheless, the ocean floor is teeming with life because it contains enough nutrients to support a large number of species, even though there is no sunlight to support photosynthesis.

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 5-2). However, because the open sea covers so much of the earth's surface, it makes the largest contribution to the earth's overall NPP.

Human Activities Are Disrupting and Degrading Marine Systems

In their desire to live near the coast, people are destroying or degrading the natural resources and services (Figure 5-21) that make coastal areas so enjoyable and economically and ecologically valuable (**Concept 5-5**). In 2006, about 45% of the world's population and more than half of the U.S. population lived along or near coasts. By 2010, up to 80% of the world's people are projected to be living in or near the coastal zone.

Major threats to the ocean from human activities include

- Coastal development, which destroys and pollutes coastal habitats.
- Overfishing, which depletes populations of commercial fish species.
- Runoff of nonpoint source pollution such as fertilizers, pesticides, livestock wastes and eroded soil sediment (Figure 5-23) from the land.
- Point source pollution such as sewage from passenger cruise ships and spills from oil tankers.
- Habitat destruction from coastal development and trawler fishing boats that drag weighted nets across the ocean bottom.
- Invasive species that can deplete populations of native aquatic species and cause economic damage.
- Climate change, which can cause a rise in sea level that can destroy coral reefs and flood coastal marshes.

Figure 5-27 shows some of the effects of such human impacts on marine systems (left) and coral reefs (right).

THINKING ABOUT
Coral Reefs

What are two direct and two indirect harmful effects of your lifestyle on coral reefs?

RESEARCH FRONTIER

Learning more about the harmful human impacts on marine ecosystems and how to reduce these impacts

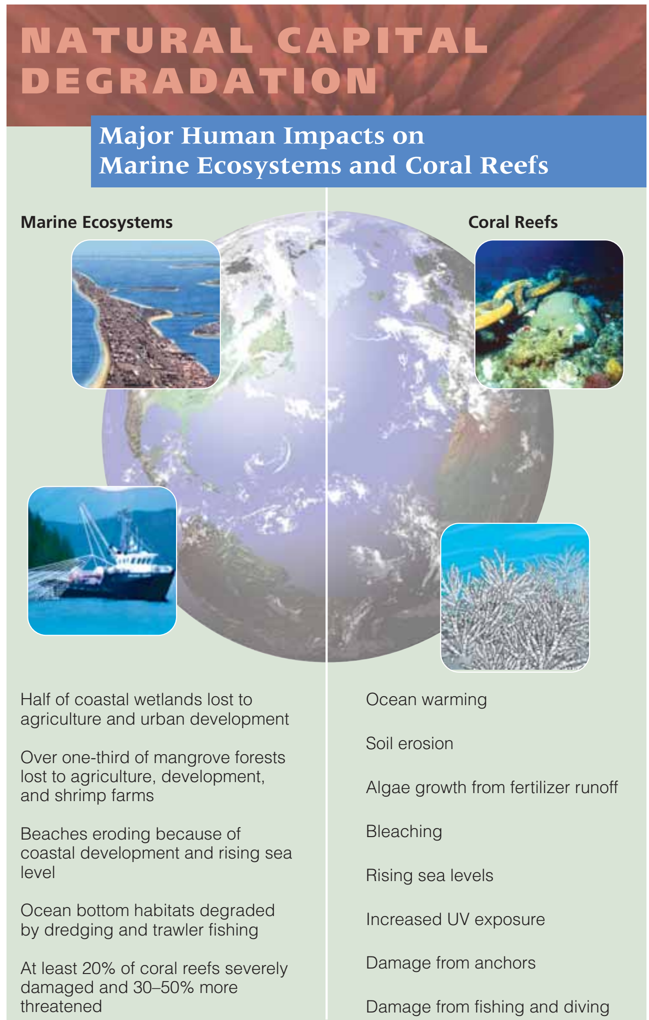


Figure 5-27 Major threats to marine ecosystems (left) and coral reefs (right) from human activities (**Concept 5-5**). **Questions:** Which two of the threats to marine ecosystems do you think are the most serious? Why? Which two of the threats to coral reefs do you think are the most serious? Why?

5-6 What Are the Major Types of Freshwater Systems and How Have We Affected Them?

CONCEPT 5-6 Human activities are impairing ecological and economic services provided by many rivers and freshwater lakes and wetlands.

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 only about 2.2% of the earth's surface, they provide a number of important ecological and economic services (Figure 5-28). *Bad news:* human activities are disrupting and degrading many of the ecological and economic services provided by the world's freshwater rivers, lakes, and wetlands (**Concept 5-6**).

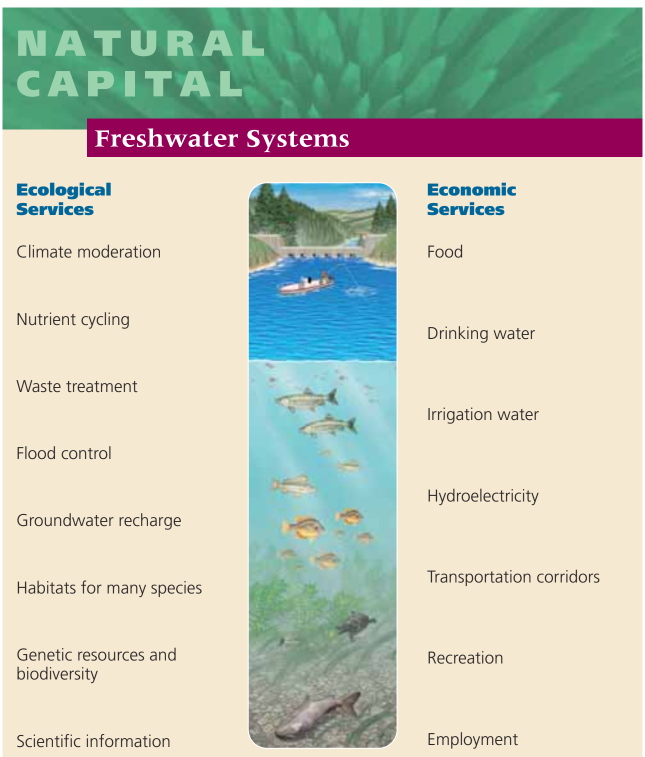


Figure 5-28 Major ecological and economic services provided by freshwater systems. **Question:** Which two ecological services and which two economic services do you think are the most important? Why?

Lakes Are Depressions Filled with Freshwater

Lakes are large natural bodies of standing freshwater formed when precipitation, runoff, or groundwater seepage fills depressions in the earth's surface. Causes of such depressions include glaciation (the Great Lakes of North America), crustal displacement (Lake Nyasa in East Africa), and volcanic activity (Crater Lake in the U.S. state of Oregon). Lakes are supplied with water from rainfall, melting snow, and streams that drain their surrounding watershed.

Freshwater lakes vary tremendously in size, depth, and nutrient content. Deep lakes normally consist of four distinct zones that are defined by their depth and distance from shore (Figure 5-29). The top layer, called the *littoral* ("LIT-tore-el") *zone,* is near the shore and consists of the shallow sunlit waters to the depth at which rooted plants such as cattails stop growing. It has a high biological diversity because of ample sunlight and inputs of nutrients from the surrounding land.

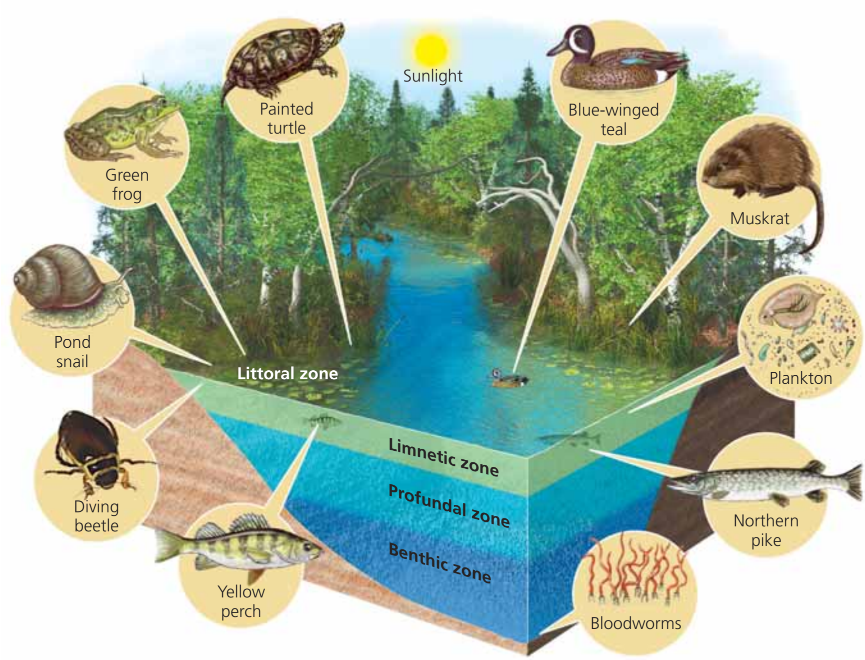
Next is the *limnetic* ("lim-NET-ic") *zone:* the open, sunlit surface layer away from the shore that extends to the depth penetrated by sunlight. The main photosynthetic body of the lake, this zone produces the food and oxygen that support most of the lake's consumers.

Next comes the *profundal* ("pro-FUN-dahl") *zone:* the deep, open water where it is too dark for photosynthesis. Without sunlight and plants, oxygen levels are low here. Fish adapted to the lake's cooler and darker water are found in this zone.

The bottom of the lake contains the *benthic* ("BEN-thic") *zone.* Decomposers, detritus feeders, and fish that swim from one zone to the other inhabit the benthic zone. It is nourished mainly by dead matter that falls from the littoral and limnetic zones and by sediment washing into the lake.

Some Lakes Have More Nutrients Than Others

Ecologists classify lakes according to their nutrient content and primary productivity. A newly formed lake generally has a small supply of plant nutrients and is



ThomsonNOW™ Active Figure 5-29 Distinct zones of life in a fairly deep temperate zone lake. *See an animation based on this figure at* ThomsonNOW. **Question:** How are deep lakes like tropical rain forests? (*Hint:* See Figure 5-16.)

called an **oligotrophic** (poorly nourished) **lake** (Figure 5-30, 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 a low NPP. But 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 or excessive supply of nutrients needed by producers is called a **eutrophic** (well-nourished) **lake** (Figure 5-30, right). Such lakes typically are shallow and have murky brown or green water with poor visibility. Because of their high levels of nutrients, these lakes have a high NPP.

Jack Carey

W. A. Bannazewski/Visuals Unlimited

Figure 5-30 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* that 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.

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.**

ThomsonNOW™ Learn more about the zones of a lake, how its water turns over between seasons, and how lakes differ below their surfaces at ThomsonNOW.

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.

Streams often begin in mountainous or hilly areas that collect and release water falling to the earth's surface as rain or snow that melts during warm seasons. The downward flow of surface water and groundwater from mountain highlands to the sea typically takes place in three aquatic life zones characterized by different environmental conditions: the *source zone,* the *transition zone,* and the *floodplain zone* (Figure 5-31).

Coastal deltas and wetlands and inland floodplains are important parts of the earth's natural capital (Figure 1-3, p. 8, and **Concept 1-1A**, p. 6). CONCEPT LINKS They absorb and slow the velocity of floodwaters from coastal storms, hurricanes, and tsunamis. Unfortunately, human activities have degraded and destroyed these natural protectors of coastal communities. Such destruction played an important role in increasing the damage to the U.S. city of New Orleans, Louisiana, when it was flooded by Hurricane Katrina in 2005.

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.

Streams receive many of their nutrients from the ecosystems of bordering land. Such nutrient inputs come from falling leaves, animal feces, insects, and other forms of biomass washed into streams during heavy rainstorms or by melting snow. To protect a stream or river system from excessive inputs of nutrients and pollutants, we must protect its 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, see photo 6, p. viii), 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.

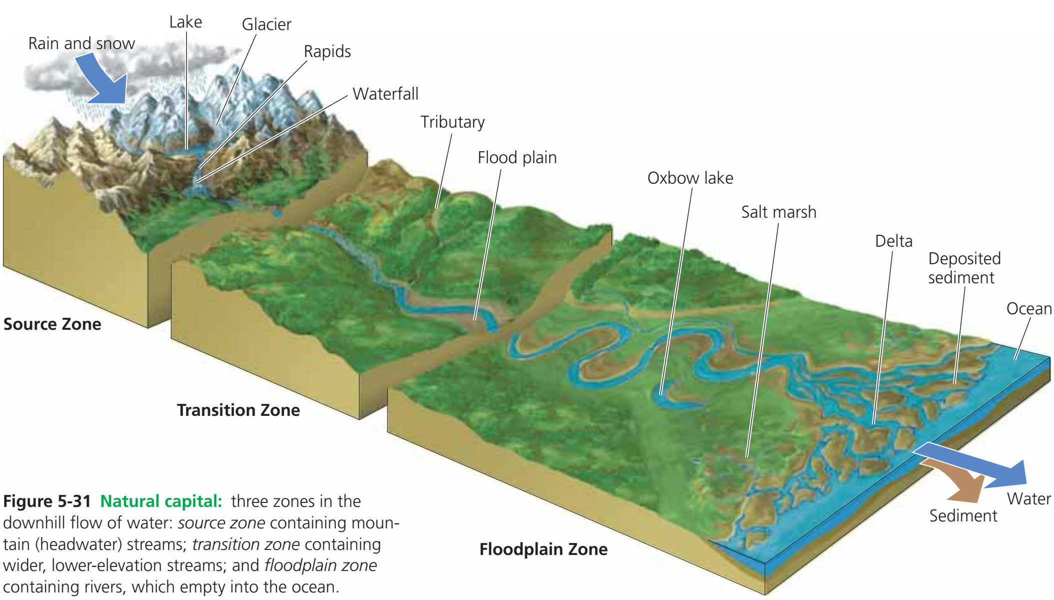


Figure 5-31 **Natural capital:** three zones in the downhill flow of water: *source zone* containing mountain (headwater) streams; *transition zone* containing wider, lower-elevation streams; and *floodplain zone* containing rivers, which empty into the ocean.

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. They provide wildlife habitats, filter toxic wastes, and help reduce flooding and erosion by serving as huge sponges that absorb and store excess water from storms. They replenish stream flows during dry periods and recharge groundwater aquifers. They also provide recreational opportunities and valuable products such as fish, shellfish, cranberries, and wild rice.

Human Activities Are Disrupting and Degrading Freshwater Systems

Human activities are disrupting and degrading many of the ecological and economic services provided by the world's freshwater rivers, lakes, and wetlands (**Concept 5-6**), 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 alter and destroy aquatic habitats. *Third,* cities and farmlands add pollutants and excess plant nutrients to nearby streams, rivers, and lakes. *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. This loss of natural capital has been an important factor in increased flood and drought damage in the United States—more examples of *unnatural disasters.* Many other countries have suffered similar losses. For example, 80% of all wetlands in Germany and France have been destroyed.

RESEARCH FRONTIER

Learning more about the harmful human impacts on freshwater aquatic biodiversity and how to reduce these impacts

REVISITING Winds and Sustainability

CORE CASE STUDY

SUSTAINABILITY

This chapter's opening **Core Case Study** described how winds connect all parts of the planet to one another. Next time you feel or hear the wind blowing, think about these global connections. As part of the global climate system, winds play important roles in creating and sustaining the world's deserts, grasslands, forests, mountains, and aquatic life zones.

Winds play a key role in sustaining these ecosystems through the four **scientific principles of sustainability** (see back cover). They promote sustainability by helping to distribute solar energy and to recycle the earth's nutrients. In turn, this helps support biodiversity, and it affects species interactions that help control population sizes.

Scientists have made a good start in understanding the ecology of the world's terrestrial and aquatic systems. One of the major lessons from their research: in nature, *everything is connected.* According to these scientists, we urgently need more research on the workings of the world's terrestrial and aquatic systems and on how they are interconnected. With such 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 QUESTIONS

1. Provide examples that show how wind connects most life on earth.
2. What is the difference between the weather and climate of a region? Identify the main factors that determine climate.
3. Explain how the ocean and atmosphere are closely linked, resulting in the uneven global distribution of heat and precipitation.
4. How do the composition of the earth's atmosphere and the earth's surface features affect climate?

5. How does climate determine where the earth's major biomes are found?
6. Describe the three major types of **(a)** deserts, **(b)** grasslands, and **(c)** forests. What is the ecological significance of mountains?
7. Summarize the effect that human impacts have had on terrestrial ecosystems.
8. Describe the major types of aquatic systems found on earth.
9. Identify the major types of ocean zones and explain how humans are affecting them.
10. Identify the major types of freshwater ecosystems and explain how humans are affecting them.

CRITICAL THINKING

1. List three ways you could apply **Concepts 5-3** and **5-6** to make your lifestyle more environmentally sustainable.
2. What would happen to **(a)** the earth's species and **(b)** your lifestyle if the winds stopped blowing? CORE CASE STUDY
3. List a limiting factor for each of the following ecosystems: **(a)** a desert, **(b)** arctic tundra, **(c)** alpine tundra, **(d)** the floor of a tropical rain forest, **(e)** a temperate deciduous forest, **(f)** the surface layer of the open sea, and **(g)** the bottom of a deep lake.
4. Why do deserts and arctic tundra support a much smaller biomass of animals than do tropical forests?
5. Why do most animals in a tropical rain forest live in its trees?
6. Which biomes are best suited for **(a)** raising crops and **(b)** grazing livestock? Use the four **scientific principles of sustainability** (see back cover) to come up with four guidelines for growing food and grazing livestock in these biomes on a more sustainable basis. SUSTAINABILITY
7. What type of biome do you live in? List three ways in which your lifestyle is harming this biome.
8. You are a defense attorney arguing in court for sparing **(a)** an undeveloped old-growth tropical rain forest and **(b)** a coral reef from severe degradation or destruction by development. Give your three most important arguments for the defense of each of these ecosystems. If the judge decides you can save only one of the ecosystems, which one would you choose, and why?
9. Congratulations! You are in charge of the world. What are the three most important features of your plan to help sustain **(a)** the earth's terrestrial biodiversity and **(b)** the earth's aquatic biodiversity?
10. List two questions that you would like to have answered as a result of reading this chapter.

LEARNING ONLINE

Log on to the Student Companion Site for this book at **www.thomsonedu.com/biology/miller** and choose Chapter 5 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Web links, information on Green Careers, and InfoTrac® College Edition articles.

For access to animations and additional quizzing, register and log on to ThomsonNOW! at **www.thomsonedu.com/thomsonnow** using the access code card in the front of your book.

Community and Population Ecology

6

Why Should We Care about the American Alligator?

CORE CASE STUDY

The American alligator (Figure 6-1), 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, which has been around for nearly 200 million years, has outlived the dinosaurs. It has been able to adapt to numerous changes in the earth's environmental conditions.

This changed when 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. Between l950 and 1960, hunters wiped out 90% of the alligators in the U.S. state of Louisiana. By the 1960s, the alligator population in the Florida Everglades was also near extinction.

People who say "So what?" are overlooking the alligator's important ecological role—its *niche* (**Concept 4-3**, p. 68) —in subtropical wetland communities. 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 many animals. Large alligator nesting mounds provide nesting and feeding sites for species of herons and egrets. Alligators eat large numbers of gar, a predatory fish. This helps maintain populations of game fish such as bass and bream.

CONCEPT LINK

As alligators move from gator holes to nesting mounds, they help keep areas of open water free of invading vegetation. Without these free ecosystem services, freshwater ponds and coastal wetlands found 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 maintain the structure, function, and sustainability of the communities 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 those who find alligators in their backyards and swimming pools, and to duck hunters whose retriever dogs are sometimes eaten by alligators. Since 1948, alligators have killed about 20 people in Florida.

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. In 1987, this reclassification was extended to seven more states. Currently, Florida, Louisiana, Texas, and Georgia allow alligator hunting. Today there are 1–2 million alligators in Florida and the state now allows property owners to kill rogue alligators on their property instead of filing a request for professional help.

The recent increase in demand for alligator meat and hides has created a booming business for alligator farms, especially in Florida. Such farms reduce the need for illegal hunting of wild alligators.

To biologists, the comeback of the American alligator is an important success story in wildlife conservation. Its tale illustrates how each species in a community or ecosystem fills a unique role, and it highlights how interactions between species can affect ecosystem structure and function. In this chapter, we will look at how species interact and how biological communities and populations respond to changes in environmental conditions.

A. & J. Visage/Peter Arnold, Inc.

Figure 6-1 The American alligator plays an important ecological role in its marsh and swamp habitats in the southeastern United States. Since being classified as an endangered species in 1967, it has recovered enough to have its status changed from endangered to threatened—an outstanding success story in wildlife conservation.

Key Questions and Concepts

6-1 **How Does Species Diversity Affect the Sustainability of a Community?**

CONCEPT 6-1 Species diversity is a major component of biodiversity and tends to increase the sustainability of communities and ecosystems.

6-2 **What roles do species play in a community?**

CONCEPT 6-2 Based on certain ecological roles they play in communities, species are described as native, nonnative, indicator, keystone, or foundation species.

6-3 **How do species interact?**

CONCEPT 6-3A Five basic species interactions—competition, predation, parasitism, mutualism, and commensalism—affect the resource use and population sizes of the species in a community.

CONCEPT 6-3B Some species develop adaptations that allow them to reduce or avoid competition for resources with other species.

6-4 **How do communities respond to changing environmental conditions?**

CONCEPT 6-4A The structure and species composition of communities change in response to changing environmental conditions through a process called ecological succession.

CONCEPT 6-4B According to the *precautionary principle,* we should take measures to prevent or reduce harm to human health and natural systems even if some possible cause-and-effect relationships have not been fully established scientifically.

6-5 **What limits the growth of populations?**

CONCEPT 6-5 No population can continue to grow indefinitely because of limitations on resources and because of competition among species for those resources.

Note: Supplements 4, 6, 9, and 11 can be used with this chapter.

Animal and vegetable life is too complicated a problem
for human intelligence to solve,
and we can never know how wide a circle of disturbance we produce
in the harmonies of nature when we throw
the smallest pebble into the ocean of organic life.

GEORGE PERKINS MARSH

6-1 How Does Species Diversity Affect the Sustainability of a Community?

CONCEPT 6-1 Species diversity is a major component of biodiversity and tends to increase the sustainability of communities and ecosystems.

What Is Species Diversity?

Recall that a *community* is a collection of populations of different species in a given area that can potentially interact with one another. Biological communities differ in the types and numbers of species they contain and the ecological roles those species play (**Concept 4-3**, p. 68). CONCEPT LINK These communities are shaped by the species they contain and by feeding relationships and other interactions among those species. An important characteristic of a community 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 with a large number of different species (high species richness) generally has only a few members of each species (low species evenness). Biologist Terry Erwin found an estimated 1,700 different beetle species in a single tree in a tropical forest in Panama but only a few individuals of each species. On the other hand, an evergreen forest community in the U.S. state of Alaska may have only ten plant species (low species richness) but large numbers of each species (high species evenness).

Such species diversity is one of the major components of biodiversity (Figure 3-12, p. 48, and **Concept 3-4A**, p. 48). CONCEPT LINKS Another community characteristic is its *niche structure:* how many ecological niches occur, how they resemble or differ from one another, and how the species occupying different niches interact (**Concept 4-3**, p. 68).

THINKING ABOUT
The American Alligator's Niche

CORE CASE STUDY

Does the American alligator (**Core Case Study**) have a specialist or a generalist niche? Explain.

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. The most species-rich environments are tropical rain forests, coral reefs, the ocean bottom zone, and large tropical lakes—most of them under severe and increasing pressure from human activities.

ThomsonNOW™ Learn about how latitude affects species diversity and about the differences between big and small islands at ThomsonNOW.

Sustainability Involves Resisting or Responding to Changing Environmental Conditions

All living systems, from a cell to the biosphere (Figure 3-3, p. 41), maintain some degree of sustainability or stability by constantly changing in response to changing environmental conditions. It is useful to distinguish among three aspects of stability or sustainability in living systems. One is **inertia,** or **persistence:** the ability of a living system to resist being disturbed or altered. A second is **constancy:** the ability of a living system such as a population to keep its numbers within the limits imposed by available resources. A third factor is **resilience:** the ability of a living system to repair damage after an external disturbance that is not too drastic.

Species-Rich Communities Tend to Be Productive and Sustainable

Does a community with a high species richness tend to have greater sustainability and productivity than one with a lower species richness? Is a species-rich community better able to recover or "bounce back" from, say, a drought than a community that is not as diverse? 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, a complex community 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."

SCIENCE FOCUS

Community Sustainability: A Closer Look

Ecologists disagree on how to define *sustainability* or *stability.* For example, does a community need both high inertia and high resilience to be considered sustainable?

Evidence suggests that some communities have one of these properties but not the other. Tropical rain forests have high species richness and high inertia and thus are resistant to significant alteration or destruction. But once a large tract of tropical forest is severely degraded, the community's resilience may be so low that the forest may not be restored. Nutrients (which are stored primarily in the vegetation, not in the soil), and other factors needed for recovery may no longer be present. Such a large-scale loss of tropical forest cover may also change the local or regional climate so that forests can no longer be supported.

By contrast, grasslands have a much lower species richness than most forests and have low inertia because they burn easily. However, because most of their plant matter is stored in underground roots, these ecosystems have high resilience and recover quickly. 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.

Another difficulty is that populations, communities, and ecosystems are rarely, if ever, at equilibrium. Instead, nature is in a continuing state of disturbance, fluctuation, and change.

Critical Thinking

Are deserts fairly sustainable communities? Explain.

Is this a valid hypothesis? Because no community can function without some producers and decomposers (**Concept 3-3**, p. 44), there is a minimum threshold of species diversity below which communities and ecosystems either cannot function or function poorly. Many studies support the idea that some level of species diversity provides insurance against catastrophe. But how much species richness is needed to help sustain various communities remains uncertain.

CONCEPT LINK

Some recent research suggests that the average annual NPP of an ecosystem reaches a peak with 10–40 producer species. Many ecosystems contain more than 40 producer species, but it is difficult to distinguish among those that are essential and those that are not. At any rate, communities vary in their likely level of sustainability, related in some way to differences in species richness and the ecological roles played by their species (**Concept 6-1**). While there may be some exceptions to this idea, most ecologists now accept it as a useful hypothesis. The Science Focus above sheds more light on this issue.

RESEARCH FRONTIER

Learning more about the relationship between species diversity and sustainability in communities

6-2 What Roles Do Species Play in a Community?

CONCEPT 6-2 Based on certain ecological roles they play in communities, species are described as native, nonnative, indicator, keystone, or foundation species.

Niches Can Be Occupied by Native and Nonnative Species

Each species in a community occupies a unique *ecological niche* that describes its role in a community. It includes the particular habitat in which it lives, the environmental conditions such as temperature (Figure 3-9, p. 45) necessary for its survival, and the methods it uses to acquire its supply of nutrients.

Ecologists focus on the different ecological roles or niches that native, nonnative, indicator, keystone, and foundation species play in communities (**Concept 6-2**). Any given species may play more than one of these ecological roles in a particular community.

Native species are those species that normally live and thrive in a particular community. Other species that migrate into a community, or are deliberately or accidentally introduced, are called **nonnative species, invasive species,** or **alien species.** Some people tend to think of nonnative species as villains. 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.

Sometimes, however, a nonnative species can reduce some or most of 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. Since then, these nonnative bees—popularly known as "killer bees"—have moved northward into Central America and parts of the southwestern 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 or because they fell down or became trapped and could not flee.

Nonnative species can spread rapidly if they find new niches that are as suitable as their original niches were. In their new niches, these species often do not face predators and diseases they had before, or they may be able to out-compete some native species in their new niches. We will examine this environmental problem in greater detail in Chapter 9.

Indicator Species Are Biological Smoke Alarms

Species that provide early warnings of harmful environmental changes taking place in a community or an ecosystem are called **indicator species.** For example, the presence or absence of trout species in water at temperatures within their range of tolerance (Figure 3-9, p. 45) 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. Some amphibians are also classified as indicator species (Case Study, below).

■ **CASE STUDY**

Why Are Amphibians Vanishing?

Amphibians (frogs, toads, and salamanders) live part of their lives in water and part on land, and some are classified as indicator species. Frogs, for example, are especially vulnerable to environmental disruption at various points in their life cycle, shown in Figure 6-2.

As tadpoles, they live in water and eat plants; as adults, they live mostly on land and eat insects that can expose them to pesticides. Frogs' eggs have no protective shells to block ultraviolet (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.

Since 1980, populations of hundreds of the world's almost 6,000 amphibian species have been vanishing or declining in almost every part of the world, even in protected wildlife reserves and parks. According to the 2004 Global Amphibian Assessment, about 33% of all known amphibian species are threatened with extinction, and populations of 43% of the species are declining—a catastrophic loss of biological diversity.

No single cause has been found to explain the amphibian declines. However, scientists have identified a number of factors that can affect frogs and other amphibians at various points in their life cycles:

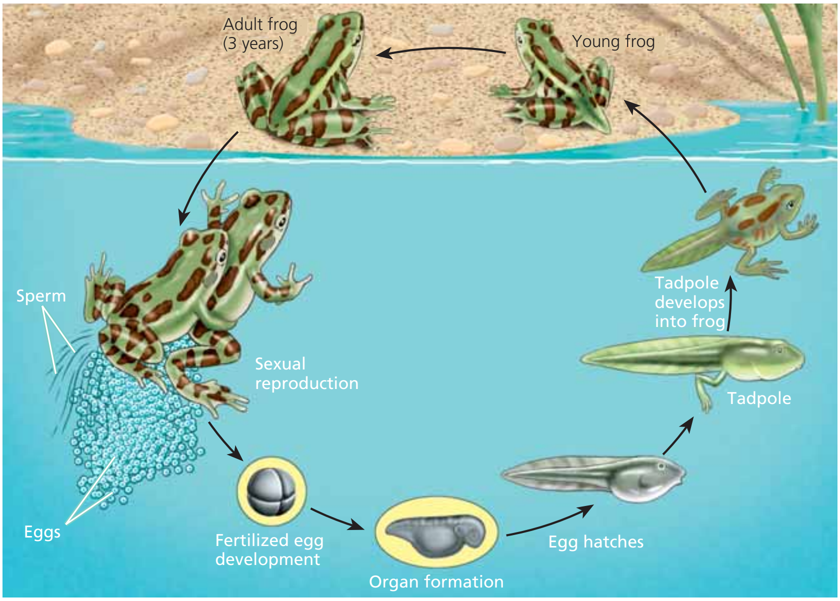


Figure 6-2 Typical *life cycle of a frog.* Populations of various frog species can decline because of the effects of harmful factors at different points in their life cycle. Such factors include habitat loss, drought, pollution, increased ultraviolet radiation, parasitism, disease, overhunting, and nonnative predators and competitors.

- *Habitat loss and fragmentation* (especially from draining and filling of inland wetlands, deforestation, and development).
- *Prolonged drought* (which dries up breeding pools so few tadpoles survive).
- *Pollution* (particularly from exposure to pesticides, which can make frogs more vulnerable to bacterial, viral, and fungal diseases and can cause sexual abnormalities).
- *Increases in ultraviolet radiation* caused by reductions in stratospheric ozone (which can harm embryos of amphibians in shallow ponds).
- *Parasites* (organisms that feed on amphibians).
- *Viral and fungal diseases* (especially a fungus that attacks the skin of frogs).
- *Climate change.* Global warming evaporates water and increases cloud cover in tropical forests. This lowers daytime temperatures, making nights warmer and creating conditions favorable for the spread of a skin fungus deadly to frogs. It can also dry up frog habitat, which led to the extinction of Costa Rica's golden toad (Figure 4-7, p. 70).
- *Overhunting* (especially in Asia and France, where frog legs are a delicacy).
- *Natural immigration or deliberate introduction of nonnative predators and competitors* (such as fish).

A combination of such factors probably is responsible for the decline or disappearance of most amphibian species.

Why should we care if some amphibian species become extinct? Scientists give three reasons. *First,* this trend suggests that environmental health is deteriorating in parts of the world because amphibians are sensitive biological indicators of changes in environmental conditions such as habitat loss and degradation, pollution, UV radiation exposure, and climate change.

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.

Third, amphibians represent a genetic storehouse of pharmaceutical products waiting to be discovered. Compounds in secretions from amphibian skin have been isolated and used as painkillers and antibiotics and as treatment for burns and heart disease.

The plight of some amphibian indicator species is a warning signal. They may not need us, but we and other species need them.

THINKING ABOUT
Amphibians

List three ways in which your lifestyle could be contributing to the decline of some amphibian species.

Keystone Species Play Important Roles in Communities

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, ecologists hypothesize

SCIENCE FOCUS

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 the tops of food webs (**Concept 3-5**, p. 50), remove injured and sick animals from the ocean, and thus play an important ecological role. Without their services, the oceans would be teeming with dead and dying fish. CONCEPT LINK

Many people—influenced by movies and popular novels—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 60–100 people worldwide. Since 1990, sharks have killed an average of seven people per year. For risk comparison purposes, poverty kills about 11 million people a year, tobacco 5 million a year, and air pollution 3 million a year.

For every shark that injures a person, humans kill at least 1 million sharks. Sharks are caught mostly for their valuable fins and are often thrown back alive into the water, fins hacked off, where they bleed to death or drown because they can no longer swim. 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. Declining fish stocks in some parts of the world has lead to increased fishing of sharks for their meat. Some sharks die when they are trapped in nets or lines deployed to catch swordfish, tuna, shrimp, and other species. And overfishing threatens about one of every five shark species.

Sharks might save human lives if we can learn from them how to fight cancer, which they almost never get. Scientists are also studying their highly effective immune system, which allows wounds to heal without becoming infected.

Sharks are especially vulnerable to overfishing because they grow slowly, mature late, and have only a few young each generation. Today, they are among the most vulnerable and least protected animals on earth.

In 2003, experts at the National Aquarium in the U.S. city of Baltimore, Maryland, estimated that populations of some shark species have decreased by 90% since 1992. Eight of the world's shark species are considered critically endangered or endangered and 82 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 hunting sharks for their fins in their territorial waters. But such bans are difficult to enforce.

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

Critical Thinking

What are three things you would do to help protect sharks from premature extinction?

that **keystone species** serve a similar role by having a much larger effect than their numbers would suggest on the types and abundances of other species in those communities. Eliminating a keystone species may dramatically alter the structure and function of a community.

Keystone species play critical ecological roles. One is *pollination* of flowering plant species by bees, butterflies (Figure 3-1, right, p. 38), hummingbirds, bats, and other species. In addition, *top predator* keystone species feed on and help regulate the populations of other species. Examples are the wolf, leopard, lion, alligator (**Core Case Study**), and some shark species (Science Focus, above). CORE CASE STUDY

Figure 6-3 *A keystone species:* this dung beetle has rolled up a ball of fresh dung. They roll the balls into tunnels where they have laid eggs. When the eggs hatch, the larvae have an easily accessible food supply. These hardworking recyclers play keystone roles in many communities.

Michael Rauch/Peter Arnold, Inc.

HOW WOULD YOU VOTE?

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

Have you thanked a *dung beetle* today? Perhaps you should. These keystone species (Figure 6-3) rapidly remove, bury, and recycle dung. They also churn and aerate soil, making it more suitable for plant life. Without them, in many places we would be up to our eyeballs in animal wastes and many plants would be starved for nutrients.

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 explains why it is so important for scientists to identify and protect keystone species.

THINKING ABOUT
The American Alligator

CORE CASE STUDY

What species might disappear or suffer sharp population declines if the American alligator (**Core Case Study**) became extinct in subtropical wetland ecosystems?

Foundation Species Also Play Important Ecological Roles

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

Some bat and bird foundation species can regenerate deforested areas and spread fruit plants by depositing plant seeds in their droppings. Beavers acting as "ecological engineers" create wetlands used by other species. They do this by felling trees along shorelines and using them to build dams across streams, which serve as their lodge homes.

In general, the main difference between keystone and foundation species is that foundation species, such as beavers, help create habitats and ecosystems. A foundation species thus strengthens and sometimes expands the *foundation* of its community.

RESEARCH FRONTIER

Identifying, studying, and protecting keystone and foundation species

6-3 How Do Species Interact?

CONCEPT 6-3A Five basic species interactions—competition, predation, parasitism, mutualism, and commensalism—affect the resource use and population sizes of the species in a community.

CONCEPT 6-3B Some species develop adaptations that allow them to reduce or avoid competition for resources with other species.

Most Species Compete with One Another for Resources

When different species in a community have activities or resource needs in common, they may interact with one another. Members of these species may be harmed, helped, or unaffected by the interaction. Ecologists identify five basic types of interactions between species: *interspecific competition, predation, parasitism, mutualism,* and *commensalism.*

These interactions have profound effects on the resource use and population sizes of species in a community (**Concept 6-3A**). They influence the abilities of the interacting species to survive and reproduce, and thus the interactions serve as agents of natural selection (**Concept 4-1B**, p. 64). Some interactions also help limit population sizes, illustrating one of the four **scientific principles of sustainability** (see back cover).

CONCEPT LINK

SUSTAINABILITY

The most common interaction between species is *competition* for shared or limited resources such as space and food. Ecologists call such competition between species **interspecific competition.** No two species can share the same vital and limited resource for very long. When intense competition for resources such as food, sunlight, water, and nesting sites occurs, one of the competing species must migrate to another area (if possible), shift its feeding habits or behavior through natural selection, suffer a sharp population decline, 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 competing for the same resources develop adaptations that allow them to reduce or avoid competition for resources with other species (**Concept 6-3B**). 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.

When lions and leopards live in the same area, for example, lions take mostly larger animals as prey, and leopards take smaller ones. Hawks and owls feed on similar prey, but hawks hunt during the day and owls hunt at night.

Figure 6-4 (p. 112) shows resource partitioning by some insect-eating bird species. Figure 4-5 (p. 68) shows how the evolution of specialized feeding niches of bird species in a coastal wetland has reduced their competition for resources.

Figure 6-4 *Sharing the wealth: resource partitioning* of 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)

Some Species Feed on Other Species: Predation

In **predation,** a member of one species (the *predator*) feeds directly on all or part of a living organism of another species (the *prey*) as part of food webs (**Concept 3-3**, p. 44). Together, the two kinds of organisms, such as lions (the predator or hunter) and zebras (the prey or hunted), form a **predator–prey relationship.** Such relationships are depicted in Figures 3-8 (p. 45) and 3-14 (p. 51).

CONCEPT LINK

At the individual level, members of the prey species are clearly harmed. At the population level, predation plays a role in evolution by natural selection. 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 help them avoid predation.

Some people tend to view 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.

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. *Carnivores* feeding on mobile prey have two main options: *pursuit* and *ambush.* Some, such as the cheetah, catch prey by running fast; others, such as the American bald eagle, can fly and have keen eyesight; still others, such as wolves and African lions, capture their prey by hunting in packs.

Other predators use *camouflage* to hide in plain sight and ambush their prey. For example, praying mantises (Figure 3-1, left, p. 38) 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 abilities 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 (as on armadillos and turtles), thick bark (giant sequoia), spines (porcupines), and thorns (cacti and rosebushes). Many lizards have brightly colored tails that break off when they are attacked, often giving them enough time to escape.

Other prey species use the camouflage of certain shapes or colors or the ability to change color (chameleons and cuttlefish). Some insect species have shapes that look like twigs (Figure 6-5a), bark, thorns, or even bird droppings on leaves. A leaf insect can be almost invisible against its background (Figure 6-5b), as can an arctic hare in its white winter fur.

Chemical warfare is another common strategy. Some prey species discourage predators with chemicals that are *poisonous* (oleander plants), *irritating* (stinging nettles and bombardier beetles, Figure 6-5c), *foul smelling* (skunks, skunk cabbages, and stinkbugs), or *bad tasting* (buttercups and monarch butterflies, Figure 6-5d). When attacked, some species of squid and octopus emit clouds of black ink, allowing them to escape by confusing their predators.

Many bad-tasting, bad-smelling, toxic, or stinging prey species have evolved *warning coloration,* brightly colored advertising that enables experienced predators to recognize and avoid them. They flash a warning: "Eating me is risky." Examples are brilliantly colored poisonous frogs (Figure 6-5e); and foul-tasting monarch butterflies (Figure 6-5d).

Based on coloration, biologist Edward O. Wilson gives us two rules 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 6-5f), gain protection by looking and acting like the monarch, a protective device known as *mimicry.* Other prey species use *behavioral strategies* to avoid predation. Some attempt to scare off predators by puffing up (blowfish), spreading their wings (peacocks), or mimicking a predator (Figure 6-5h). Some moths have wings that look like the eyes of much larger animals (Figure 6-5g). Other prey species gain some protection by living in large groups such as schools of fish and herds of antelope.

THINKING ABOUT

Predation and the American Alligator

CORE CASE STUDY

What traits does the American alligator (**Core Case Study**) have that helps it **(a)** catch prey and **(b)** avoid being preyed upon?

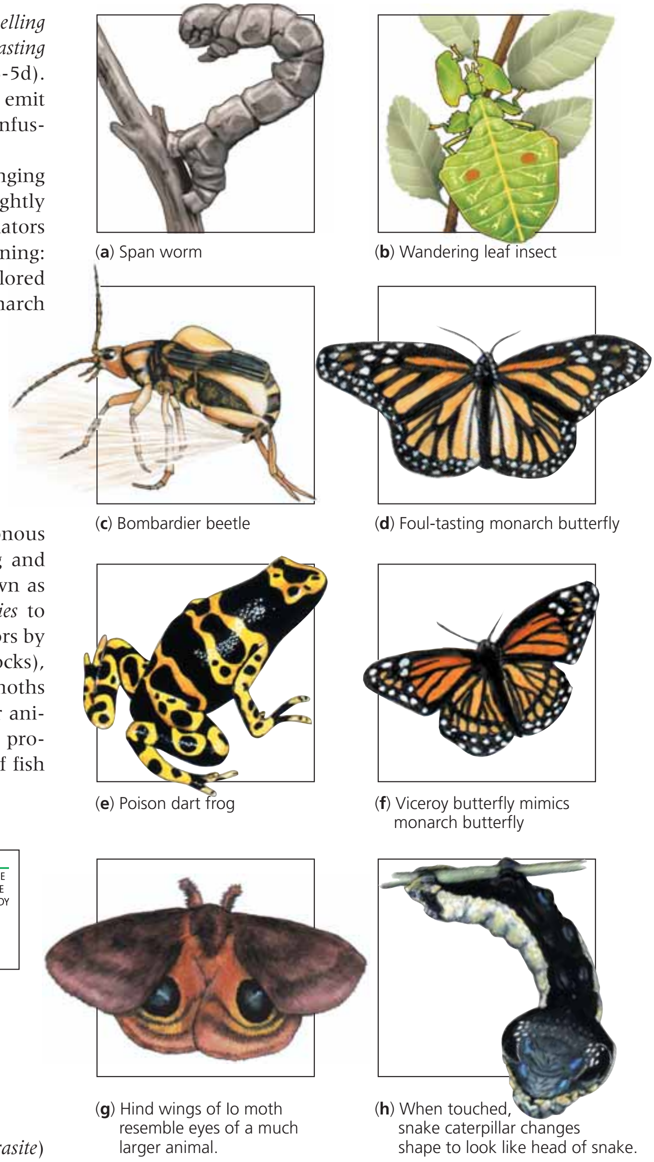


Figure 6-5 Some ways in which prey species avoid their predators: **(a, b)** *camouflage,* **(c, e)** *chemical warfare,* **(d, e)** *warning coloration,* **(f)** *mimicry,* **(g)** *deceptive looks,* and **(h)** *deceptive behavior.*

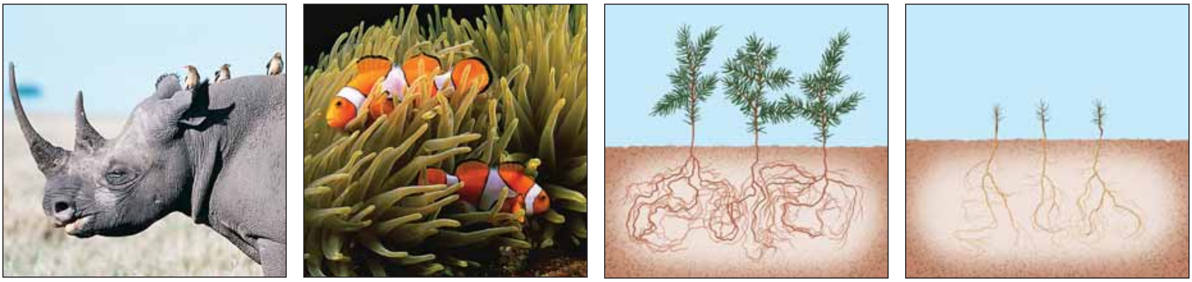
Some Species Feed Off Other Species by Living On or In Them: Parasitism

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.

Parasitism can be viewed as a special form of predation. But unlike the typical predator, a parasite usually is much smaller than its host (prey) 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, and sea lampreys, which use their sucker-like mouths to attach themselves to fish and feed on their blood. 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.

Some parasites have little contact with their host. For example, North American cowbirds take over the nests of other birds by laying their eggs in them and then letting the host birds raise their young.



(a) Oxpeckers and black rhinoceros **(b)** Clownfish and sea anemone **(c)** Mycorrhizal fungi on juniper seedlings in normal soil **(d)** Lack of mycorrhizal fungi on juniper seedlings in sterilized soil

Figure 6-6 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 protect the anemones from some of their predators. **(c)** Beneficial effects of mycorrhizal fungi attached to roots of juniper seedlings on plant growth compared to **(d)** growth of such seedlings in sterilized soil without mycorrhizal fungi. (Oxpeckers and black rhinoceros: Joe McDonald/Tom Stack & Associates; clownfish and sea anemone: Fred Beavendam/Peter Arnold, Inc.)

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 their hosts' populations in check.

In Some Interactions, Both Species Benefit: Mutualism

In **mutualism,** two species behave in a way that benefits both by providing each with food, shelter, or some other resources. For example, honeybees, caterpillars, and other insects feed on a male flower's nectar, picking up pollen in the process, and then pollinate female flowers when they feed on them. Coral reefs (p. 93) survive by a mutualistic relationship between reef-building coral animals and bacteria that live in their tissues.

Figure 6-6 shows three 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 6-6a). 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 clownfish species, which live within sea anemones, whose tentacles sting and paralyze most fish that touch them and thus protect the clownfish from some of its predators (Figure 6-6b). The sea anemones benefit because the clownfish protect them from some of their predators.

Luiz C. Marigo/Peter Arnold, Inc.

Figure 6-7 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 the 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.

A third example is the highly specialized fungi that combine with plant roots to form mycorrhizae (from the Greek words for *fungus* and *roots*). The fungi get nutrition from the plant's roots. In turn, the fungi benefit the plant by using their myriad networks of hair-like extensions to improve the plant's ability to extract nutrients and water from the soil (Figure 6-6c and d).

In *gut inhabitant mutualism,* vast armies of bacteria in the digestive systems of animals help break down (digest) their host's food. The bacteria receive a sheltered habitat and food from their host. Hundreds of millions of bacteria in your gut help you to digest the food you eat.

It is tempting to think of mutualism as an example of cooperation between species. In reality, there is no agreement between them to help one another. Instead, each species benefits by unintentionally exploiting the other as a result of traits they obtained through natural selection.

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, effect on the other. For example, in tropical forests certain kinds of silverfish insects move along with columns of army ants to share the food obtained by the ants in their raids. The army ants receive no apparent harm or benefit from the silverfish.

Another 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 6-7). 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 affecting the trees in any way.

ThomsonNOW™ Review the way species can interact and see the results of an experiment on species interaction at ThomsonNOW.

6-4 How Do Communities Respond to Changing Environmental Conditions?

CONCEPT 6-4A The structure and species composition of communities change in response to changing environmental conditions through a process called ecological succession.

CONCEPT 6-4B According to the *precautionary principle,* we should take measures to prevent or reduce harm to human health and natural systems even if some possible cause-and-effect relationships have not been fully established scientifically.

Communities and Ecosystems Change over Time: Ecological Succession

All communities change their structure and composition in response to changing environmental conditions such as fires, climate change, or the clearing of forests to plant crops. The gradual change in species composition of a given area is called **ecological succession** (**Concept 6-4A**).

Ecologists recognize two types of ecological succession, depending on the conditions present at the beginning of the process. **Primary succession** involves the gradual establishment of communities in lifeless areas where there is no soil in a terrestrial community (Figure 6-8) or no bottom sediment in an aquatic community. Examples include bare rock exposed by a retreating glacier or severe soil erosion, newly cooled lava, an abandoned highway or parking lot, and a newly created shallow pond or reservoir.

Primary succession usually takes a long time—typically thousands or even tens of thousands of years. Before a community can become established on land, there must be soil. Depending mostly on the climate, it takes natural processes several hundred to several thousand years to produce fertile soil.

With the other, more common type of ecological succession, called **secondary succession,** a series

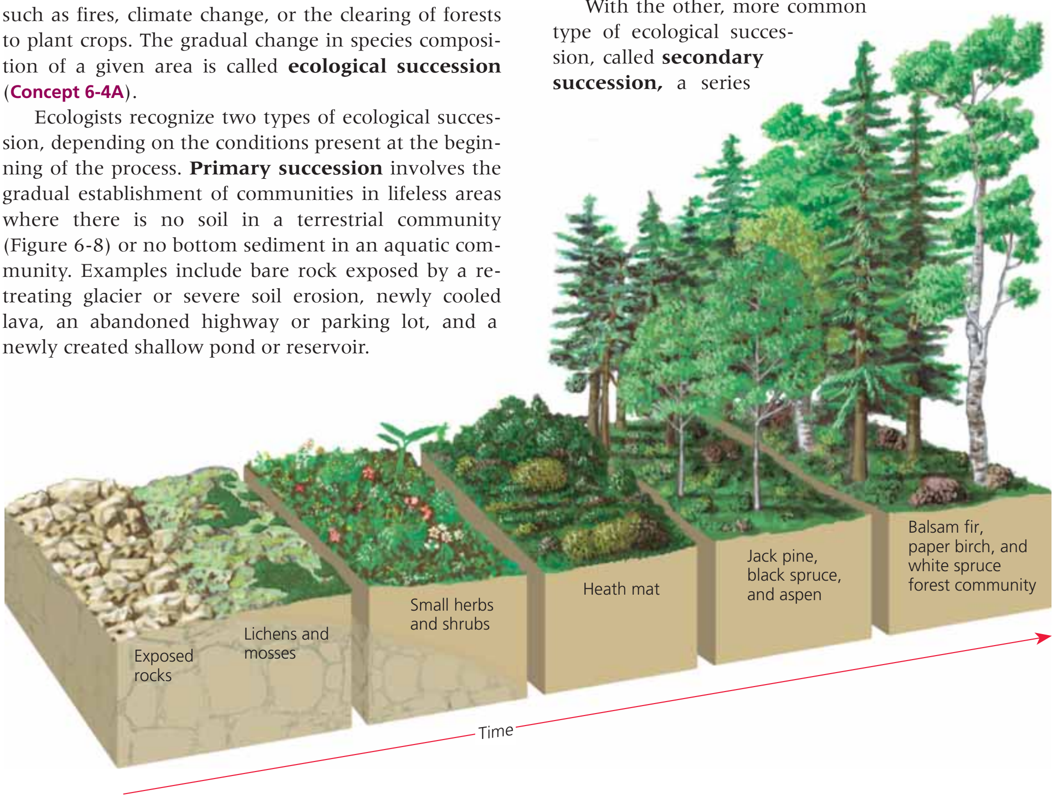


Figure 6-8 *Primary ecological succession:* over almost a thousand years, plant communities developed starting on bare rock exposed by a retreating glacier on Isle Royale, Michigan (USA), in northern Lake Superior. The details of this process vary from one site to another.

of communities with different species can develop in places containing soil or bottom sediment. This development begins in an area where the natural community of organisms has been disturbed, removed, or destroyed, but some soil or bottom sediment remains. Candidates for secondary succession include abandoned farmlands (Figure 6-9), 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, from seeds already in the soil and from those imported by wind or by birds and other animals.

During primary or secondary succession, disturbances such as fires, clear-cutting forests, plowing of grasslands, or invasions by nonnative species can interrupt a particular stage of succession, setting it back to an earlier stage. Such disturbances create new conditions that encourage some species and discourage or eliminate others.

We tend to think of environmental disturbances as harmful. But many ecologists contend that in the long run, disturbances such as fires and hurricanes can be beneficial for the species richness of certain communities and ecosystems. Such disturbances create new conditions that can harm or eliminate some species, while releasing nutrients and creating unfilled niches for others. According to the *intermediate disturbance hypothesis,* fairly frequent but moderate disturbances lead to the greatest species richness.

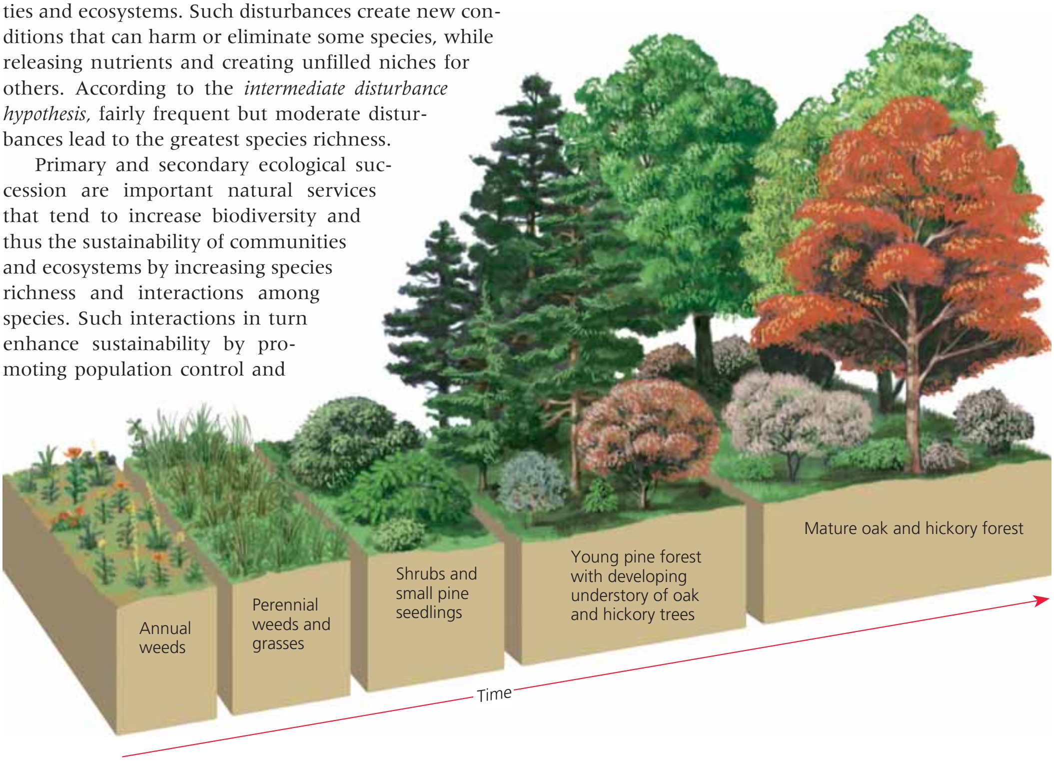
Primary and secondary ecological succession are important natural services that tend to increase biodiversity and thus the sustainability of communities and ecosystems by increasing species richness and interactions among species. Such interactions in turn enhance sustainability by promoting population control and by increasing the complexity of food webs for the energy flow and nutrient cycling that make up the functional component of biodiversity (Figure 3-12, p. 48).

ThomsonNOW™ Explore the difference between primary and secondary succession at ThomsonNOW.

Succession Doesn't Follow a Predictable Path

According to 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 hypothesis, a large



ThomsonNOW™ **Active Figure 6-9** *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. *See an animation based on this figure at* ThomsonNOW. **Questions:** Do you think the annual weeds (left) would continue to thrive in the mature forest (right)? Why or why not?

terrestrial community undergoing succession eventually became covered with an expected type of climax vegetation such as a mature forest (Figure 6-9). But a close look at almost any community 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 the course of a given succession or view it as preordained progress toward an ideally adapted climax community. Rather, succession reflects the ongoing struggle by different species for enough light, nutrients, food, and space. Most ecologists now recognize that mature late-successional communities are not in a state of permanent equilibrium, but rather a state of continual disturbance and change.

Should We Protect Natural Systems from Harmful Human Activities? The Precautionary Principle

Some land developers argue that if we cannot predict the course of succession and if nature is not in balance, there is no point in trying to preserve and manage old-growth forests and other ecosystems. They conclude that we should cut down diverse old-growth forests, use the timber resources, and replace the forests with tree plantations of single-tree species (see photo 1, p. vi), a food crop, or homes and other buildings.

Furthermore, they say, we should convert most of the world's grasslands to cropfields, drain and develop inland wetlands, dump our toxic and radioactive wastes into the deep ocean, and not worry about the premature extinction of species. You can imagine that these ideas make ecologists and conservation biologists go ballistic.

Ecologists point out that just because a system is not in equilibrium or balance does not mean that it cannot suffer from environmental degradation. They point to overwhelming evidence that human disturbances (Figure 1-6, p. 12, Figure 1-8, p. 13, and Supplement 4, pp. S12–S22) are disrupting vital natural services that support and sustain all life and all economies. They contend that our uncertainty and unpredictability about the effects of our actions means we need to use great caution in making potentially harmful changes to communities and ecosystems. They urge taking precautionary action to help *prevent* potentially serious losses 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 possible cause-and-effect relationships have not been fully established scientifically (**Concept 6-4B**). It is based on the commonsense idea behind many adages such as "Better safe than sorry," "Look before you leap," "First, do no harm," and "Slow down for speed bumps."

The precautionary principle is a useful idea. But it can be taken too far. If we don't take some risks, we will never learn what works and what doesn't.

The message is that we should take some risks, possibly disturbing some ecosystems, but always think carefully about the possible short- and long-term expected and unintended effects. Using the precautionary principle comes in when the potential risks seem too great, or when we don't have much information about the possible risks. Then it is time to step back, think about what we are doing, and do more research. Doing something just because it can be done is not always a wise choice.

6-5 What Limits the Growth of Populations?

CONCEPT 6-5 No population can continue to grow indefinitely because of limitations on resources and because of competition among species for those resources.

Most Populations Live in Clumps or Patches

Populations differ in factors such as *distribution, numbers,* and *age structure* (proportions of individuals in different age groups). Three general patterns of *population distribution* or *dispersion* in a habitat are *clumping, uniform dispersion,* and *random dispersion* (Figure 6-10, p. 118).

Individuals in the populations of most species live in clumps or patches (Figure 6-10a). Examples are patches of desert vegetation around springs, cottonwood trees clustered along streams, wolf packs, and schools of fish. The locations and sizes of these clumps vary with the availability of resources.

Why clumping? There are four reasons: *First,* the resources a species needs vary greatly in availability from place to place. *Second,* living in groups protects some animals from predators and therefore from population declines. *Third,* living in packs gives some predator species a better chance of getting a meal. *Fourth,* some species form temporary groups for mating and caring for young.

Some species maintain a fairly constant distance between individuals. Such a pattern gives creosote bushes in a desert (Figure 6-10b) better access to scarce water resources. Organisms with a random distribution (Figure 6-10c) are fairly rare. The living world is mostly clumpy and patchy.

Figure 6-10 Generalized *dispersion patterns* for individuals in a population throughout their habitat. The most common pattern is *clumps* of members of a population throughout their habitat, mostly because resources are usually found in patches. **Question:** Why do you think the creosote bushes are uniformly spaced while the dandelions are not?

(a) Clumped (elephants) **(b)** Uniform (creosote bush) **(c)** Random (dandelions)

Populations Can Grow, Shrink, or Remain Stable

Four variables—*births, deaths, immigration,* and *emigration*—govern changes in population size. A population increases by birth and immigration (arrival of individuals from outside the population) and decreases by death and emigration (departure of individuals from the population):

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

A population's **age structure**—the proportion of individuals at various ages—can have a strong effect on how rapidly it increases or decreases in size. Age structures are usually described in terms of organisms not mature enough to reproduce (the *pre-reproductive stage*), those capable of reproduction (the *reproductive stage*), and those too old to reproduce (the *post-reproductive stage*).

The size of a population will likely increase if it is made up mostly of individuals in their reproductive stage, or soon to enter this stage. In contrast, a population dominated by individuals past their reproductive stage will tend to decrease over time. The size of a population with a fairly even distribution among these three age groups tends to remain stable because reproduction by younger individuals will be roughly balanced by the deaths of older individuals.

No Population Can Grow Indefinitely: J-Curves and S-Curves

Species vary in their **biotic potential** or capacity for growth. The **intrinsic rate of increase (*r*)** is the rate at which a population would grow if it had unlimited resources.

Some species have an astounding biotic potential. For example, with no controls on their population growth, bacteria that can reproduce every 20 minutes would form a layer 0.3 meter (1 foot) deep over the entire earth's surface in only 36 hours.

Fortunately, this is not a realistic scenario. Research reveals that *no population can grow indefinitely* because of limitations on resources and competition between species for those resources (**Concept 6-5**). In the real world, a rapidly growing population reaches some size limit imposed by one or more *limiting factors,* such as light, water, space, or nutrients, or by exposure to too many competitors, predators, or infectious diseases. *There are always limits to population growth in nature.* This is one of nature's four **scientific principles of sustainability** (see back cover and **Concept 1-6**, p. 19).

CONCEPT LINK

Environmental resistance is the combination of all factors that act to limit the growth of a population. Together, biotic potential and environmental resistance determine the **carrying capacity (*K*):** the maximum population of a given species that a particular habitat can sustain indefinitely without being degraded. 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 grows exponentially at a fixed rate such as 1% or 2% per year. *Exponential* or *geometric growth* (Figure 1-1, p. 5) 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 6-11, bottom half of curve).

Logistic growth involves rapid exponential population growth followed by a steady decrease in population growth until the population size levels off (Figure 6-11, top half of curve). This slowdown occurs as the population encounters environmental resistance and approaches the carrying capacity of its environment. After leveling off, a population with this type of growth typically fluctuates slightly above and below the carrying capacity.

A plot of the number of individuals against time yields a sigmoid, or S-shaped, logistic growth curve (the whole curve in Figure 6-11). Figure 6-12 depicts such a curve for sheep on the island of Tasmania, south of Australia, in the early 19th century.

ThomsonNOW™ Learn how to estimate a population of butterflies and see a mouse population growing exponentially at ThomsonNOW.

Some species do not make a smooth transition from exponential growth to logistic growth. 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 *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 6-13, p. 120).

Species Have Different Reproduction Patterns

Species use different reproductive patterns to help ensure their survival. Species with a capacity for a high rate of population increase (*r*) are called ***r*-selected species** (Figure 6-14, p. 120). These species have many, usually small, offspring and give them little or no parental care or protection. They overcome typically massive losses of their offspring by producing so many that a few will likely survive to reproduce many more offspring to begin this reproductive pattern again. Examples include algae, bacteria, rodents, annual plants (such as dandelions), and most insects.

Such species tend to be *opportunists.* They reproduce and disperse rapidly when conditions are favorable or when a disturbance opens up a new habitat or niche for invasion, as in the early stages of ecological succession.

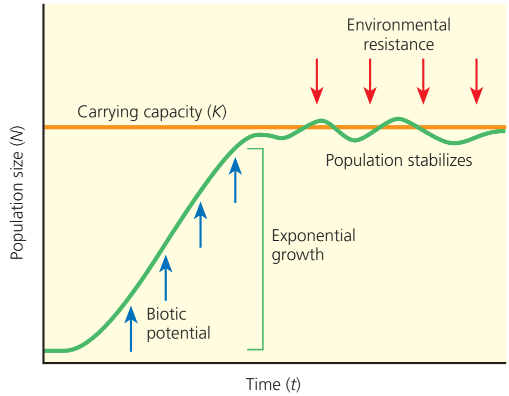
Environmental changes caused by disturbances can allow opportunist species to gain a foothold. However, once established, their populations may crash because of unfavorable changes in environmental conditions or invasion by more competitive species. This helps explain why most opportunist species go through irregular and unstable boom-and-bust cycles in their population sizes.

At the other extreme are *competitor* or ***K*-selected species** (Figure 6-14). They tend to reproduce later in life and have a small number of offspring with fairly long life spans. Typically the offspring of such species develop inside their mothers (where they are safe), are born fairly large, 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. This reproductive pattern results in a few big and strong individuals that can compete for resources and reproduce a few young to begin the cycle again.

Such species are called *K*-selected species because they tend to do well in competitive conditions when their population size is near the carrying capacity (*K*) of their environment. Their populations typically follow a logistic growth curve (Figure 6-12).

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) are *K*-selected species. Ocean fish such as orange roughy and swordfish, which are now being depleted by overfishing, are also *K*-selected. Many of these species—especially those with long times between generations and low reproductive rates like elephants, rhinoceroses, and sharks—are prone to extinction.

Most organisms have reproductive patterns between the extremes of *r*-selected and *K*-selected species. In agriculture we raise both *r*-selected species (crops) and *K*-selected species (livestock).



ThomsonNOW™ Active Figure 6-11 No population can continue to increase in size indefinitely (**Concept 6-5**). *Exponential growth* (lower part of the curve) occurs when resources are not limiting and a population can grow at its *intrinsic rate of increase* (*r*) or *biotic potential.* Such exponential growth is converted to *logistic growth,* in which the growth rate decreases as the population becomes larger and faces environmental resistance. Over time, the population size stabilizes at or near the *carrying capacity* (*K*) of its environment, which results in a sigmoid (S-shaped) population growth curve. Depending on resource availability, the size of a population often fluctuates around its carrying capacity, although a population may temporarily exceed its carrying capacity and then suffer a sharp decline or crash in its numbers. *See an animation based on this figure at* ThomsonNOW. **Question:** What is an example of environmental resistance that humans have not been able to overcome?

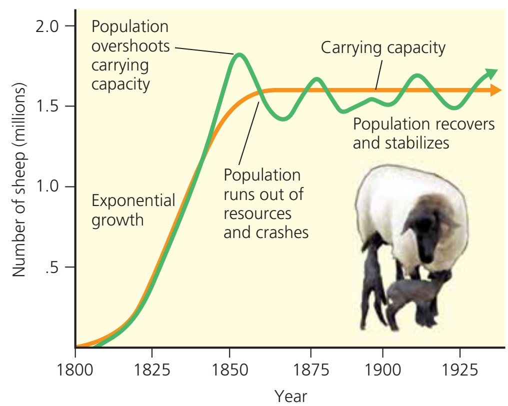


Figure 6-12 *Logistic growth* of a sheep population on the island of Tasmania between 1800 and 1925. After sheep were introduced in 1800, their population grew exponentially thanks to an ample food supply. By 1855, they had overshot the land's carrying capacity. Their numbers then stabilized and fluctuated around a carrying capacity of about 1.6 million sheep.

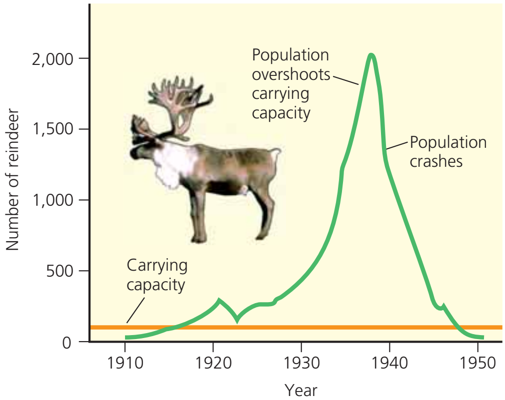


Figure 6-13 Exponential growth, overshoot, and population crash of reindeer introduced to the small Bering Sea island of St. Paul. When 26 reindeer (24 of them female) were introduced in 1910, lichens, mosses, and other food sources were plentiful. By 1935, the herd size had soared to 2,000, overshooting 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 this population grew faster and crashed, unlike the sheep in Figure 6-12?

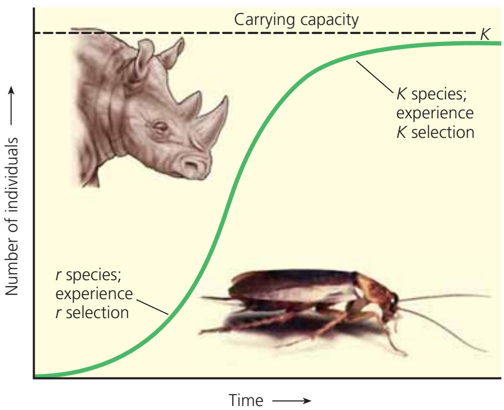


Figure 6-14 Positions of *r-selected* and *K-selected* species on the sigmoid (S-shaped) population growth curve.

THINKING ABOUT

***r*-Selected and *K*-selected Species**

If the earth experiences significant warming during this century as projected, is this likely to favor *r*-selected or *K*-selected species? Explain.

RESEARCH FRONTIER

Calculating carrying capacity more exactly for various species and ecosystems and for the earth

Humans Are Not Exempt from Nature's Population Controls

Humans are not exempt from population overshoot and dieback. Ireland experienced a population crash after a fungus destroyed the potato crop in 1845. About 1 million people died, and 3 million people migrated to other countries.

During the 14th century the *bubonic plague* spread through densely populated European cities and killed at least 25 million people. There is growing concern that a global flu epidemic may kill hundreds of millions of people.

Currently, the world is experiencing a global epidemic of eventually fatal AIDS, caused by infection with the human immunodeficiency virus (HIV). Since 1980, AIDS has killed more than 25 million people and claims another 3 million lives each year—an average of 6 deaths per minute. Between 2006 and 2050, the World Health Organization estimates that AIDS will kill at least 50 million more people, with the annual death toll reaching 5 million per year.

So far, technological, social, and other cultural changes have extended 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 normally uninhabitable areas. As humans spread into other areas, they interact with and attempt to control the populations of other species such as alligators (**Core Case Study**) and white-tailed deer in the United States (Case Study, below). CORE CASE STUDY

Some say we can keep expanding our ecological footprint 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.thomsonedu.com/biology/miller**.

THINKING ABOUT

The Human Species

If the human species suffered a sharp population decline, name three species that might move in to occupy part of our ecological niche.

■ CASE STUDY

Exploding White-Tailed Deer Populations in the United States

By 1900, habitat destruction and uncontrolled hunting had reduced the white-tailed deer population in the United States to about 500,000 animals. In the 1920s and 1930s, laws were passed to protect the remaining deer. Hunting was restricted and predators such as wolves and mountain lions that preyed on the deer were nearly eliminated.

It worked, and to some suburbanites and farmers, perhaps too well. Today there are 25–30 million white-tailed deer in the United States. During the last 50 years, large numbers of Americans have moved into the wooded habitat of deer and provided them with flowers, garden crops, and other plants they like to eat.

Deer like to live in the woods for security and go to nearby fields, orchards, lawns, and gardens for food. Suburbanization has created an all-you-can-eat paradise for deer, and their populations in such areas have soared. In some forests, they are consuming native ground cover vegetation and allowing nonnative weed species to take over. Deer also spread Lyme disease (carried by deer ticks) to humans. In addition, each year in the United States, 1.5 million deer–vehicle collisions injure at least 14,000 people and kill at least 200 (up from 101 deaths in 1993).

There are no easy answers to the deer population problem in the suburbs. Changing hunting regulations to allow killing of more female deer cuts down the overall deer population. But these actions have little effect on deer in suburban areas because it is too dangerous to allow widespread hunting with guns in such populated communities. Some areas have hired experienced and licensed archers who use bows and arrows to help reduce deer numbers. To protect nearby residents, the archers hunt from elevated tree stands and shoot their arrows only downward. However, animal activists strongly oppose killing deer on the ethical grounds that hunting them is cruel and inhumane treatment.

Some communities spray the scent of deer predators or rotting deer meat in edge areas to scare off deer. Others use electronic equipment that emits high-frequency sounds, which humans cannot hear, for the same purpose. Some homeowners surround their gardens and yards with a high black plastic mesh fencing that is invisible from a distance. Such deterrents may protect one area but cause the deer to seek food in someone else's yard or garden.

Deer can also be trapped and moved from one area to another, but this is expensive and must be repeated whenever deer move back into an area. Also, there are questions concerning where to move the deer and how to pay for such programs.

Should we put deer on birth control? Darts loaded with a contraceptive could be shot into female deer to hold down their birth rates. But this is expensive and must be repeated every year. One possibility is an experimental single-shot contraceptive vaccine that causes females to stop producing eggs for several years. Another approach is to trap dominant males and use chemical injections to sterilize them. Both of these approaches will require years of testing.

Meanwhile, people living in the suburbs can expect deer to chow down on their shrubs, flowers, and gardens unless they erect high deer-proof fences or use other methods to repel them. Deer have to eat every day just as we do. Suburban dwellers might consider avoiding use of plants that deer like to eat.

THINKING ABOUT
White-Tailed Deer

Some blame the white-tailed deer for invading farms and suburban yards and gardens to find food. Others say humans are mostly to blame because they have invaded deer territory, eliminated most of the predators that kept deer populations down, and provided the deer with plenty to eat in their lawns and gardens. Which view do you hold? Do you see a solution to this problem? If so, what is it?

REVISITING The American Alligator and Sustainability

CORE CASE STUDY

SUSTAINABILITY

The Case Study of the American alligator at the beginning of the chapter illustrates the power humans have over the environment, both to do harm and to make amends. As most American alligators were eliminated from their natural areas in the 1950s, scientists began pointing out the ecological benefits these animals had been providing to their habitats (such as building water holes, nesting mounds, and feeding sites for other species). Scientific understanding of these ecological connections led to protection of this species and its recovery.

In this chapter, we have seen how interactions among organisms in a community determine their abundances and distribution, help limit population size, influence evolutionary change, and help sustain biodiversity. We have also seen how communities respond to changes in environmental conditions by undergoing ecological succession. And we have explored how populations of various species grow and shrink within their habitats' carrying capacities based on natural limits to growth.

Biological communities are functioning examples of the four **scientific principles of sustainability** (see back cover) in action. Populations of their species depend directly or indirectly on solar energy and participate in the chemical cycling of nutrients. They tend to develop and maintain a diversity of species to take advantage of all available niches and to provide alternative paths for energy flow and nutrient cycling. And a community's populations are controlled by interactions among its species, as well as by limits imposed by its environment.

Chapter 7 applies the principles of population ecology, along with the scientific principles of sustainability, to the human population and its environmental impact.

We cannot command nature except by obeying her.

SIR FRANCIS BACON

REVIEW QUESTIONS

1. Explain why the American alligator is considered to be a keystone species. Why do biologists consider its comeback an important success story in wildlife conservation?
2. Define the term *species diversity* and distinguish between *species richness* and *species evenness*. Explain how ecosystems with high or low species diversity can both display stability.
3. Explain why the disappearance of an amphibian indicator species, such as a frog, is a cause for ecological concern.
4. What are keystone species and how are they similar to, or different from, a foundation species? Provide an argument for the protection of sharks.
5. Provide two examples of the basic types of interactions between species: interspecific competition, predation, parasitism, mutualism, and commensalism.
6. How does resource partitioning reduce competition for resources among species?
7. Describe eight ways in which prey species can avoid their predators.
8. Describe the ecological processes of primary and secondary succession.
9. What are the pros and cons of using the precautionary principle to protect natural systems?
10. Explain the underlying ecological principles that support the observation that no population can grow indefinitely.

CRITICAL THINKING

1. List three ways you could apply **Concept 6-4B** to make your lifestyle and that of any children and grandchildren you might have more environmentally sustainable.
2. CORE CASE STUDY Some homeowners in the U.S. state of Florida believe they should have the right to kill any alligator found on their property. Others argue against this notion, saying alligators are a threatened species, and that housing developments have invaded the habitats of alligators, not the other way around. Some would say the American alligator has an inherent right to exist, regardless of how we feel about it. What is your opinion on this issue? Explain. What would likely happen ecologically in the areas where alligators live if they were all killed or removed from those areas?
3. How would you experimentally determine whether **(a)** an organism is a keystone species and **(b)** two bird species feeding on the same plant are competing for the same resources or are engaged in resource partitioning?
4. How would you respond to someone who claims it is not important to protect areas of temperate and polar biomes because most of the world's biodiversity is found in the tropics?
5. CONCEPT LINK Use the second law of thermodynamics (**Concept 2-4B**, p. 33) to help explain why predators are generally less abundant than their prey.
6. How would you reply to someone who argues that **(a)** we should not worry about our effects on natural systems because succession will heal the wounds of human activities and restore the balance of nature, **(b)** efforts to preserve natural systems are not worthwhile because nature is largely unpredictable, and **(c)** because there is no balance in nature, we should cut down diverse old-growth forests and replace them with tree farms?
7. Explain why most species with a high capacity for population growth (high biotic potential) tend to have a small size (such as bacteria and flies) while those with a low capacity for population growth tend to be large (such as humans, elephants, and whales).
8. Why are pest species likely to be extreme *r*-selected species? Why are many endangered species likely to be extreme *K*-selected species?
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.

LEARNING ONLINE

Log on to the Student Companion Site for this book at **www.thomsonedu.com/biology/miller** and choose Chapter 6 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Web links, information on Green Careers, and InfoTrac® College Edition articles.

For access to animations and additional quizzing, register and log on to Thomson NOW! at **www.thomsonedu.com/thomsonnow** using the access code card in the front of your book. You can also explore the **Active Graphing** exercises that your instructor may assign.

7

Applying Population Ecology: Human Population and Urbanization

The Ecocity Concept in Curitiba, Brazil

CORE CASE STUDY

Hardly any of today's urban areas, where half of the world's people live, are environmentally sustainable, although some are striving to become more sustainable. During this century, environmental and urban designers envision more of the world's growing urban population living in more environmentally sustainable cities, called *ecocities* or *green cities.* This is not just a futuristic dream. One such ecocity is Curitiba, a city of 2 million people that is known as the "ecological capital" of Brazil.

Planners in this city, with its clean air and tree-lined streets, 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 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 7-1). Only high-rise apartment buildings are allowed near major bus routes, and each building must devote its bottom two floors to stores—a practice that reduces the need for residents to travel. Bike paths run throughout most of the city. 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.

The city transformed flood-prone areas along its rivers into a series of interconnected parks crisscrossed with bicycle paths. 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 cut down.

Curitiba recycles roughly 70% of its paper and 60% of its metal, glass, and plastic, which is collected from households three times a week. Recovered materials are sold mostly to the city's more than 500 major industries, which must meet strict pollution standards.

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, which are open 11 hours a day and are free for low-income parents.

The city tries to provide water, sewage, and bus service for most of its growing and unplanned squatter settlements. It has designed tracts of land for settlements with clean running water as a way to reduce the spread of infectious disease. The city has a *build-it-yourself* system that gives a poor family a plot of land, building materials, two trees, and an hour's consultation with an architect.

About 95% of its 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.

This internationally acclaimed model of urban planning and sustainability is the brainchild of architect and former college teacher Jaime Lerner, who has served as the city's mayor three times since 1969. It will be an exciting challenge during this century to reshape existing cities and design new ones using the Curitiba model.

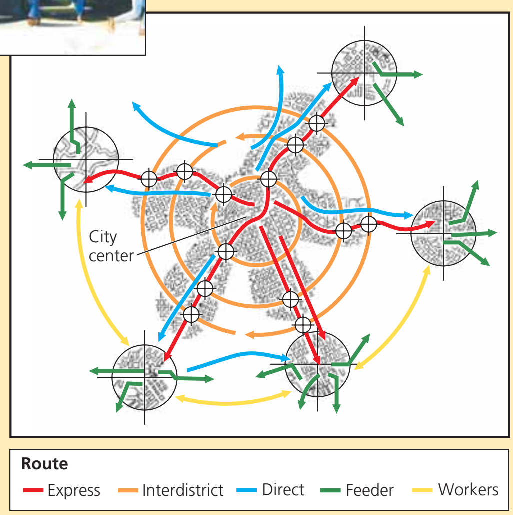


Figure 7-1 **Solutions:** bus system in Curitiba, Brazil. This system moves large numbers of passengers around rapidly because each of the five major spokes has two express lanes used only by buses. Double- and triple-length bus sections are hooked together as needed to carry up to 300 passengers. Boarding is speeded up by the use of extra-wide doors and raised tubes that allow passengers to pay before getting on the bus (top left).

Key Questions and Concepts

7-1 How many people can the earth support?

CONCEPT 7-1 We do not know how long we can continue increasing the earth's carrying capacity for humans without seriously degrading the life-support system for us and many other species.

7-2 What factors influence population size?

CONCEPT 7-2A Population size increases because of births and immigration and decreases through deaths and emigration.

CONCEPT 7-2B The average number of children born to women in a population (*total fertility rate*) is the key factor that determines the population size.

7-3 How does a population's age structure affect its growth or decline?

CONCEPT 7-3 The numbers of males and females in young, middle, and older age groups determine how fast populations grow or decline.

7-4 How can we slow population growth?

CONCEPT 7-4 Experience indicates that the most effective ways to slow population growth are to invest in family planning, to reduce poverty, and to elevate the status of women.

7-5 What are the major population and environmental problems of urban areas?

CONCEPT 7-5 Cities can improve individual lives, but most cities are unsustainable because of high levels of resource use, waste, pollution, and poverty.

7-6 How does transportation affect urban development?

CONCEPT 7-6 A combination of plentiful land, inexpensive fuel, and an expanding network of highways results in dispersed cities that depend on motor vehicles for most transportation.

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

CONCEPT 7-7 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 3 and 4 can be used with this chapter.

The problems to be faced are vast and complex,
but come down to this:
6.7 billion people are breeding exponentially.
The process of fulfilling their wants and needs
is stripping earth of its biotic capacity to produce life;
a climactic burst of consumption
by a single species is overwhelming
the skies, earth, waters, and fauna.

PAUL HAWKEN

7-1 How Many People Can the Earth Support?

CONCEPT 7-1 We do not know how long we can continue increasing the earth's carrying capacity for humans without seriously degrading the life-support system for us and many other species.

Human Population Growth Continues But Is Unevenly Distributed

For most of history, the human population grew slowly (Figure 1-1, left part of curve, p. 5). But for the past 200 years, the human population has experienced rapid exponential growth reflected in the characteristic J-curve (Figure 1-1, right part of curve, p. 5).

Three major factors account for this population increase. *First,* humans developed the ability to expand into diverse new habitats and different climate zones. *Second,* the emergence of early and modern agriculture

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.

allowed more people to be fed per unit of land area. *Third,* the development of sanitation systems, antibiotics, and vaccines helped control infectious disease agents. As a result, death rates dropped sharply below birth rates and the population grew rapidly.

About 10,000 years ago when agriculture began, there were about 5 million humans on the planet; now there are 6.7 billion of us. It took from the time we arrived 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 (**Core Case Study**, p. 5). By 2012 we will be trying to support 7 billion people and perhaps 9.2 billion by 2050.

The rate of population growth has slowed, but the world's population is still growing exponentially at a rate of 1.23% a year. This meant that 82 million people were added to the world's population during 2007—an average of nearly 225,000 more people each day, or 2.4 more people every time your heart beats.

Geographically this growth is unevenly distributed. About 1.2 million of these people were added to the 1.2 billion people living in the developed countries growing at 0.1% a year. About 80.8 million were added to the 5.6 billion people in developing countries growing 15 times faster at 1.5% a year. In other words, most of the world's population growth takes place in already heavily populated parts of the world, which are the least equipped to deal with the pressures of such rapid growth.

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, or 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 on p. S16–S17 in Supplement 4), as our ecological footprints have spread across the globe (**Concept 1-3**, p. 11, and Figure 1-8, p. 13). CONCEPT LINK

We have used technology to alter much of the rest of nature to meet our growing needs and wants in eight major ways (Figure 7-2).

ThomsonNOW™ Examine how resources have been depleted or degraded around the world at ThomsonNOW.

ThomsonNOW™ Active Figure 7-2 Major ways humans have altered the rest of nature to meet our growing population and its resource needs and wants (**Concept 7-1**) *See an animation based on this figure at* ThomsonNOW. **Questions:** Which three of these items do you believe have been the most harmful? Why? How does your lifestyle contribute directly or indirectly to each of these items?

Scientific studies of populations of other species tell us that *no population can continue growing indefinitely* (**Concept 6-5**, p. 117), which is one of the four **scientific principles of sustainability** (Figure 1-13, p. 20). How long can we continue increasing the earth's carrying capacity for our species by sidestepping many of the factors that sooner or later limit the growth of any population? CONCEPT LINK

No one knows, but mounting evidence indicates that we are steadily degrading the natural capital (**Concept 1-1A**, p. 6, and Figure 1-6, p. 12) that keeps us and other species alive and supports our economies (**Concept 7-1**). CONCEPT LINK

How many of us are likely to be here in 2050? Answer: 7.2–10.6 billion people, depending mostly on projections about the average number of babies women are likely to have. The medium projection is 9.2 billion people (Figure 7-3, p. 126). About 97% of this growth is projected to take place in developing countries, where acute poverty is a way of life for about 1.4 billion people. Are there too many people on the earth? Some say yes and some say no, as discussed in the Case Study that follows.

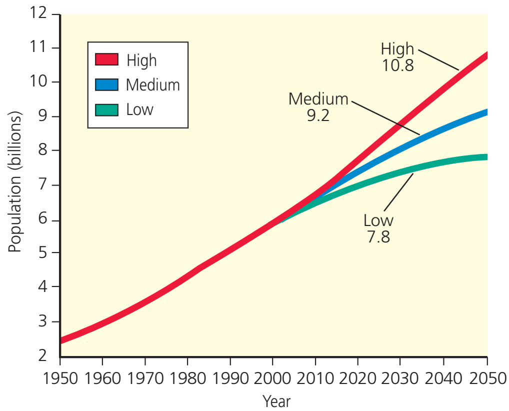


Figure 7-3 *Global connections:* UN world population projections, assuming that by 2050 women have an average of 2.5 children (high estimate), 2.0 children (medium), or 1.5 children (low). The most likely projection is the medium one—9.2 billion by 2050. (Data from United Nations)

CASE STUDY
Are There Too Many of Us?

Each week about 1.6 million people are added to the world's population. As a result, the number of people on the earth is projected to increase from 6.7 to 9.2 billion or more between 2007 and 2050 (Figure 7-3), with most of this growth occurring in developing countries. This raises an important question: *Can the world provide an adequate standard of living for a projected 2.5 billion more people by 2050 without suffering widespread environmental damage?* There is disagreement over the answer to this question.

According to some analysts, the planet already has too many people collectively degrading the earth's natural capital. To some, the problem is the sheer number of people in developing countries with 82% of the world's population. To others, it is high resource consumption rates in developed countries—and to an increasing extent in rapidly developing countries such as China and India—that magnify the environmental impact of each person (Figure 1-8, p. 13, and Case Study, p. 13). To many, both population growth and resource consumption per person are important causes of the environmental problems we face (**Concept 1-5A**, p. 15). CONCEPT LINK

Others point out that technological advances have allowed humans to avoid the environmental resistance that all populations face (Figure 6-11, p. 119) and increase the earth's carrying capacity for humans. They see no reason for this to end and believe that the world can support billions more people. They also see more people as a valuable resource for solving environmental and other problems and for stimulating economic growth by increasing the number of consumers.

As a result, they see no need for controlling the world's population growth. Some people also view any form of population regulation 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.

Proponents of slowing and eventually stopping population growth have a different view. They point out that we now fail to provide the basic necessities for about one of every five people—a total of about 1.4 billion (Figure 1-11, p. 16). They ask, how will we be able to do so for the projected 2.5 billion more people by 2050?

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 environmental degradation (Figure 1-6, p. 12) may intensify as more consumers increase their already large ecological footprints in developed and rapidly developing countries (**Concept 1-3**, p. 11, and Figure 1-8, p. 13). This could increase environmental stresses such as infectious disease, biodiversity losses, water shortages, traffic congestion, pollution of the seas, and climate change. CONCEPT LINK

This debate over interactions among population growth, economic growth, politics, and moral beliefs is one of the most important and controversial issues in environmental science.

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.thomsonedu.com/biology/miller**.

How many people can the earth support indefinitely? Some say about 2 billion. Others say as many as 30 billion.

Some analysts believe this is the wrong question. Instead, they say, we should ask what the *optimum sustainable population* of the earth might be, based on the planet's *cultural carrying capacity.* Such an optimum level would allow most people to live in reasonable comfort and freedom without impairing the ability of the planet to sustain future generations. (See the Guest Essay on this topic by Garrett Hardin at ThomsonNOW™.)

THINKING ABOUT
Population Growth

What do you think is **(a)** the maximum human population size and **(b)** the optimum human population size? How do your answers reflect your position on whether the world is overpopulated?

RESEARCH FRONTIER

Determining the optimum sustainable population size for the earth and for various regions

7-2 What Factors Influence Population Size?

CONCEPT 7-2A Population size increases because of births and immigration and decreases through deaths and emigration.

CONCEPT 7-2B The average number of children born to women in a population (*total fertility rate*) is the key factor that determines population size.

Populations Can Grow, Decline, or Remain Fairly Stable

On a global basis, if there are more births than deaths during a period of time, the earth's population increases and when the reverse is true, it decreases. When births equal deaths, population size stabilizes (**Concept 7-2A**).

In particular countries, cities, or other areas, human populations grow or decline 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 7-2A**).

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

When births plus immigration exceed deaths plus emigration, population increases; when the reverse is true, population declines.

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 five countries had the largest numbers of people in 2007? Number 1 is China with 1.3 billion people, or one of every five people in the world. Number 2 is India with 1.1 billion people, or one of every six people. Together China and India have 37% of the world's population. The United States, with 300 million people in 2007, has the world's third largest population but only 4.5% of the world's people.

Can you guess the next two most populous countries? What three countries are expected to have the most people in 2025? Look at Figure 7-4 to see if your answers are correct.

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

Another measurement used in population studies is **fertility rate,** the number of children born to a woman during her lifetime. Two types of fertility rates affect a country's population size and growth rate. The first type, called the **replacement-level fertility rate,** is the average number of children that couples in a population must bear to replace themselves. It is slightly higher than two children per couple (2.1 in developed countries and as high as 2.5 in some developing countries), mostly because some children die before reaching their reproductive years.

Does reaching replacement-level fertility bring an immediate halt to population growth? No, because so many *future* parents are alive. If each of today's couples had an average of 2.1 children, they would not be contributing to population growth. But if all of today's girl children also have 2.1 children, the world's population will continue to grow for 50 years or more (assuming death rates do not rise).

The second type of fertility rate, the **total fertility rate (TFR),** is the average number of children born to women in a population during their reproductive years. This factor plays a key role in determining population size (**Concept 7-2B**). The average fertility rate has been declining. In 2007, the average global TFR was 2.7 children per woman: 1.6 in developed countries

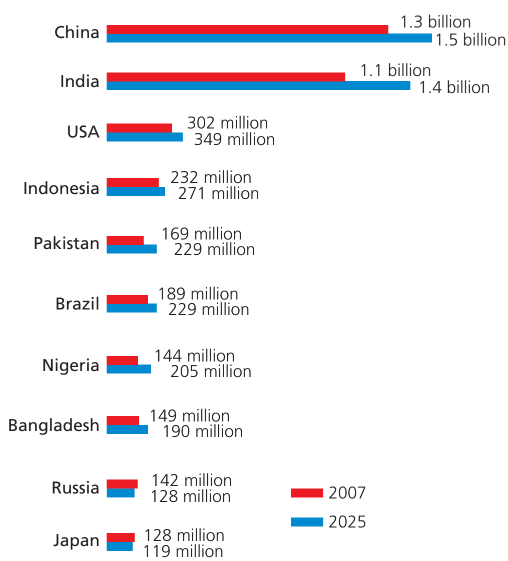


Figure 7-4 *Global connections:* the world's 10 most populous countries in 2007, with projections of their population sizes in 2025 (Data from World Bank and Population Reference Bureau)

(down from 2.5 in 1950) and 2.9 in developing countries (down from 6.5 in 1950). Although the decline in TFR in developing countries is impressive, the TFR remains far above the replacement level of 2.1, not low enough to stabilize the world's population in the near future.

■ **CASE STUDY**

The U.S. Population Is Growing Rapidly

The population of the United States grew from 76 million in 1900 to 302 million in 2007, despite oscillations in the country's TFR (Figure 7-5) and birth rates. The period of high birth rates between 1946 and 1964 is known as the *baby boom,* when 79 million people were added to the U.S. population. In 1957, the peak of the baby boom, the TFR reached 3.7 children per woman. Since then, it has generally declined, remaining at or below replacement level since 1972. In 2007, the TFR was 2.05 children per woman, compared to only 1.6 in China.

The drop in the TFR has led to a decline in the rate of population growth in the United States. But the country's population is still growing faster than that of any other developed country, and that of China, and is not close to leveling off. About 2.8 million people (one person every 11 seconds) were added to the U.S. population in 2007. About 60% (1.7 million) of this growth occurred because births outnumbered deaths and 40% (1.1 million) came from legal and illegal immigration (with someone migrating to the U.S. every 30 seconds).

In addition to the almost fourfold increase in population growth since 1900, some amazing changes in lifestyles took place in the United States during the 20th century (Figure 7-6), which led to dramatic increases in

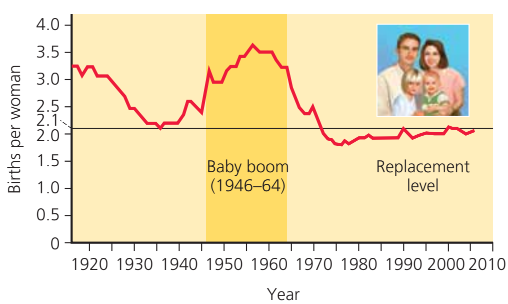


Figure 7-5 Total fertility rates for the United States between 1917 and 2007. **Question:** The U.S. fertility rate has declined and remained at or below replacement levels since 1972, so why is the population of the United States still increasing? (Data from Population Reference Bureau and U.S. Census Bureau)

per capita resource use and a much larger U.S. ecological footprint (**Concept 1-3**, p. 11).

According to U.S. Census Bureau, the U.S. population is likely to increase from 302 million in 2007 to 419 million by 2050 and then to 571 million by 2100. In contrast, population growth has slowed in other major developed countries since 1950, 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 1-8, p. 13, and Figure 7 on pp. S20–S21 in Supplement 4).

THINKING ABOUT
Overpopulation

Do you think the United States or the country where you live is overpopulated? Explain.

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.* Proportions of children working tend to be higher 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, it costs about $250,000 to raise a middle-class child from birth to age 18.

The *availability of private and public pension systems* can affect a couple's decision on how many children to have. 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 where children are often needed to help raise crops and carry daily water and fuelwood supplies.

Another important factor is *the educational and employment opportunities available for women.* TFRs 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.

Another factor is the **infant mortality rate**—the number of children per 1,000 live births who die before one year of age. In areas with low infant mortality rates, people tend to have fewer children because fewer children die at an early age.

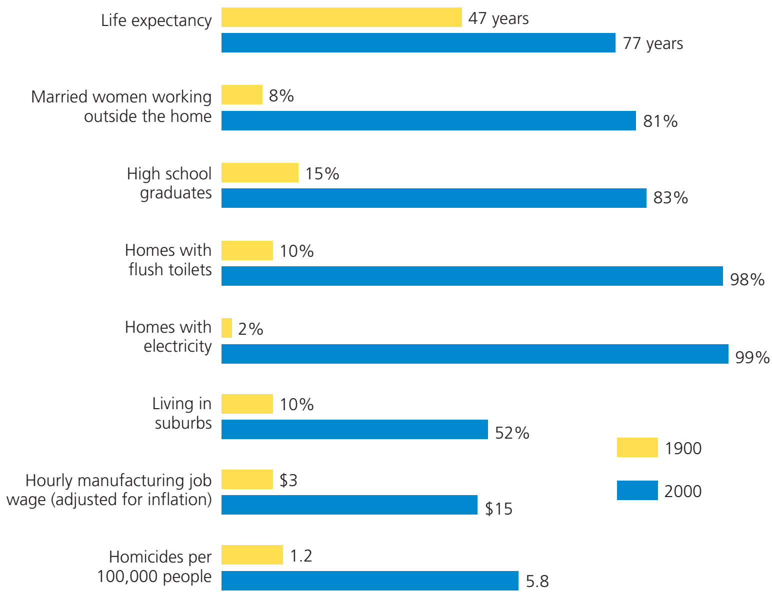


Figure 7-6 Some major changes that took place in the United States between 1900 and 2000. **Question:** Which two of these changes do you think were the most important? Why? (Data from U.S. Census Bureau and Department of Commerce)

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 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 crude birth rate. Instead, it has been caused largely by a decline in crude death rates, especially in developing countries.

More people 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. Between 1955 and 2007, the global life expectancy increased from 48 years to 68 years (77 years in developed countries and 66 years in developing countries) and is projected to reach 74 by 2050. Between 1900 and 2007, life expectancy 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 because of more deaths from AIDS.

Infant mortality is viewed as one of the best single 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 contaminated drinking water and weakened disease resistance due to undernutrition and malnutrition).

Between 1965 and 2007, the world's infant mortality rate dropped from 20 to 6.0 in developed countries and from 118 to 49 in developing countries. This is good news, but annually, 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 airline jets, 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 6.5 in 2007. This sharp decline was a major factor in the marked increase in U.S. average life expectancy during this period. Still, some 49 countries (most in Europe) had lower infant mortality rates than the United States in 2007. Three factors helped 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.*

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 some are driven by religious persecution, ethnic conflicts, political oppression, wars, and environmental degradations such as water and food shortages and soil erosion. According to a U.N. study, there were about 25 million *environmental refugees* in 2005 and the number could reach 50 million by 2010. In a globally warmer world, the number could soar to at least 150 million and perhaps to 250 million or more before the end of this century (See more on this in the Guest Essay on this topic by Norman Myers at ThomsonNOW.).

■ CASE STUDY

The United States: A Nation of Immigrants

Since 1820, the United States has admitted almost twice as many immigrants and refugees as all other countries combined. The number of legal immigrants (including refugees) has varied during different periods because of changes in immigration laws and rates of economic growth (Figure 7-7). Currently, legal and illegal immigration account for about 40% 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 2007, Latinos (67% of them from Mexico) made up 14% of the U.S. population, and by 2050, are projected to make up 25% of the population. According to the Pew Hispanic Center, 53% of the 100 million Americans that were added to the population between 1967 and 2006 were either immigrants or their children.

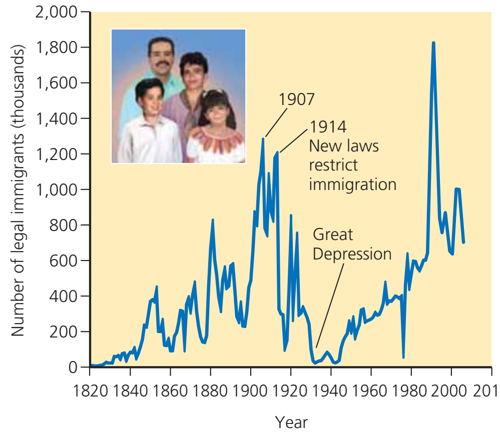


Figure 7-7 Legal immigration to the United States, 1820–2003 (the last year for which data are available). The large increase in immigration since 1989 resulted mostly from the Immigration Reform and Control Act of 1986, which granted legal status to illegal immigrants who could show they had been living in the country for several years. (Data from U.S. Immigration and Naturalization Service and the Pew Hispanic Center)

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 reduce the country's enormous environmental impact from its huge ecological footprint (Figure 1-8, p. 13). Polls show that almost 60% of the U.S. public strongly supports reducing legal immigration.

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 and as a source of cultural diversity that has been a hallmark of American culture since its beginnings. In addition, according to several studies, including a 2006 study by the Pew Hispanic Center, immigrants and their descendants pay taxes, 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 succeed in the global economy. Also, according to the U.S. Census Bureau, after 2020, higher immigration levels will be needed to supply enough workers as baby boomers retire.

HOW WOULD YOU VOTE? ✓

Should legal immigration into the United States, or the country where you live, be reduced? Cast your vote online at **www.thomsonedu.com/biology/miller**.

7-3 How Does a Population's Age Structure Affect Its Growth or Decline?

CONCEPT 7-3 The numbers of males and females in young, middle, and older age groups determine how fast populations grow or decline.

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

As mentioned earlier, even if the replacement-level fertility rate of 2.1 children per woman were magically achieved globally tomorrow, the world's population would keep growing for at least another 50 years (assuming no large increase in the death rate). This results mostly from the **age structure:** the distribution of males and females among age groups in a population—in this case, the world population (**Concept 7-3**).

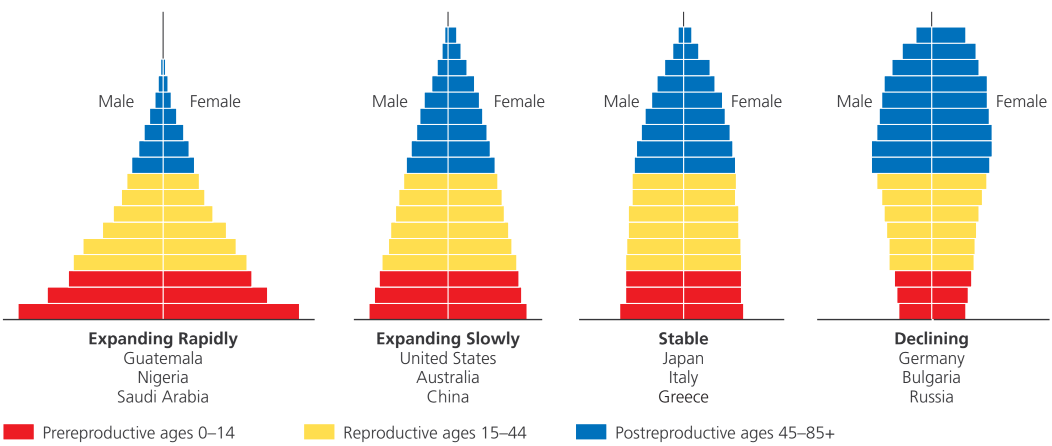
Population experts construct a population age-structure diagram by plotting the percentages or numbers of males and females in the total population in each of three age categories: *prereproductive* (ages 0–14), *reproductive* (ages 15–44), and *postreproductive* (ages 45 and older). Figure 7-8 presents generalized age-structure diagrams for countries with rapid, slow, zero, and negative population growth rates.

Any country with many people younger than age 15 (represented by a wide base in Figure 7-8, far left) has a powerful built-in momentum to increase its population size unless death rates rise sharply. The number of births will rise even if women have only one or two children, because a large number of girls will soon be moving into their reproductive years.

What is one of the world's most important population statistics? *About 28% of the people on the planet were under 15 years old in 2007.* These 1.9 billion young people are poised to move into their prime reproductive years. In developing countries, the percentage is even higher: 31% on average (41% in Africa) compared with 17% in developed countries (20% in North America and 16% in Europe). These differences in population structure between developed and developing countries are dramatic, as Figure 7-9 (p. 132) reveals. This figure shows why almost all future population growth will be 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



ThomsonNOW™ **Active Figure 7-8** Generalized population age structure diagrams for countries with rapid (1.5–3%), slow (0.3–1.4%), zero (0–0.2%), and negative population growth rates (a declining population). 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* ThomsonNOW. **Question:** Which of these figures best represents the country where you live? (Data from Population Reference Bureau)

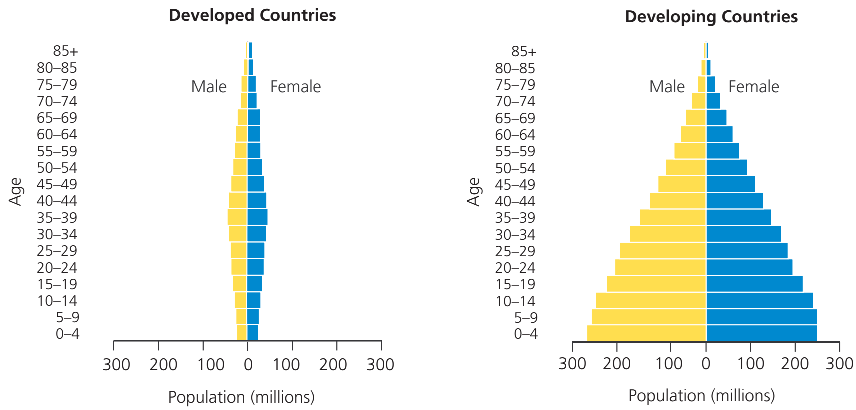
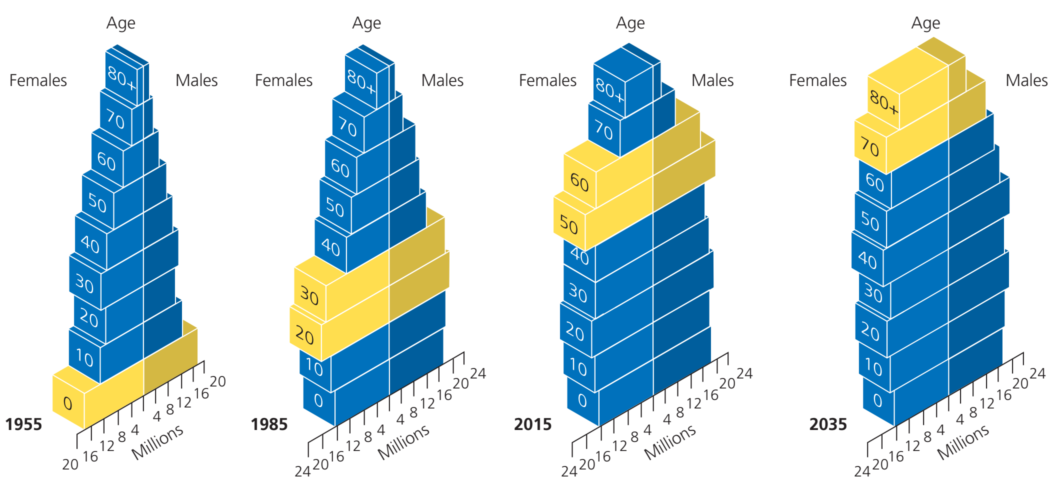


Figure 7-9 *Global connections:* population structure by age and sex in developing countries and developed countries, 2006. **Question:** If all girls under 15 were somehow limited to having only one child during their lifetimes, how do you think these structures would change over time? (Data from United Nations Population Division and Population Reference Bureau)

added 79 million to its population. Over time, this group looks like a bulge moving up through the country's age structure, as shown in Figure 7-10.

Baby boomers now make up almost half of all adult Americans. As a result, they dominate the population's demand for goods and services and play increasingly important roles in deciding who gets elected 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 will soon move 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.* In 2007, about 12% of Americans are 65 or older but that number is projected to increase to about 25% by 2043.



ThomsonNOW™ Active Figure 7-10 Tracking the baby-boom generation in the United States. U.S. population by age and sex, 1955, 1985, 2015, and 2035 (projected). *See an animation based on this figure at* ThomsonNOW. (Data from U.S. Census Bureau)

According to some analysts, the 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. Retired baby boomers are likely to use their political clout to force the smaller number of people in the baby-bust generation that followed them to pay higher income, health-care, and social security taxes. However, the rapidly increasing number of immigrants and their descendants may dilute their political power.

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

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.

However, 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.

Figure 7-11 lists some of the problems associated with rapid population decline. Countries faced with a rapidly declining population include Japan, Russia, Germany, Bulgaria, Hungary, Poland, Ukraine, Croatia, Romania, and Latvia.

Some Problems with Rapid Population Decline

- Can threaten economic growth
- Labor shortages
- Less government revenues with fewer workers
- Less entrepreneurship and new business formation
- Less likelihood for new technology development
- Increasing public deficits to fund higher pension and healthcare costs
- Pensions may be cut and retirement age increased

Figure 7-11 Some problems with rapid population decline. **Question:** Which three of these problems do you think are the most important? Why?

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. Between 2000 and 2050, AIDS is projected to cause the premature deaths of 278 million people in 53 countries—38 of them in Africa. Unlike hunger and malnutrition, which kill mostly infants and children, AIDS kills many young adults.

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 is a loss of a country's most productive young adult workers and trained personnel such as scientists, farmers, engineers, teachers, and government, business, and health-care workers. This causes a sharp drop in the number of productive adults available to support the young and the elderly and to grow food and provide essential services.

Analysts call for the international community—especially developed countries—to create and fund a massive program to help countries ravaged by AIDS in Africa and elsewhere. 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 help compensate for the missing young-adult generation.

THINKING ABOUT
AIDS

Should government and private interests in developed countries fund a massive program to help AIDS-ravaged countries prevent HIV infections and rebuild their work forces? Why or why not?

7-4 How Can We Slow Population Growth?

CONCEPT 7-4 Experience indicates that the most effective ways to slow population growth are to invest in family planning, to reduce poverty, and to elevate the status of women.

As Countries Develop, Their Populations Tend to Grow Slower

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, first their death rates and then their birth rates decline. According to the hypothesis, this transition takes place in four distinct stages (Figure 7-12).

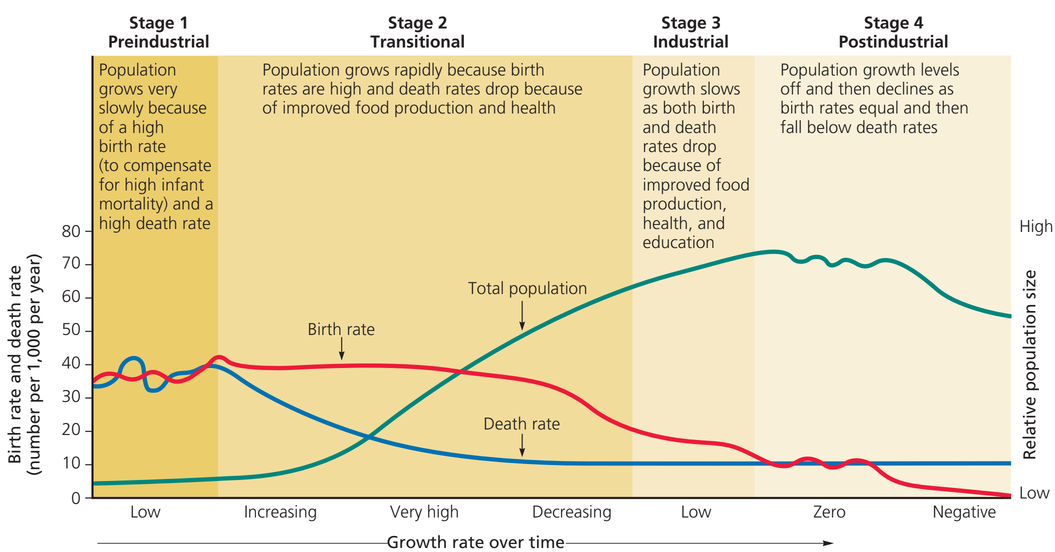
Some analysts believe that most of the world's developing countries will make a demographic transition over the next few decades mostly because modern technology can bring economic development and family planning to such countries. Others fear that the still-rapid population growth in some developing countries might outstrip economic growth and overwhelm some local life-support systems. As a consequence, some of these countries could become caught in a *demographic trap* at stage 2. This is now happening as death rates rise in a number of developing countries, especially in Africa. Indeed, countries in Africa being ravaged by the HIV/AIDS epidemic are falling back to stage 1.

Other factors that could hinder the demographic transition in some developing countries are a lack of scientists and engineers (with 94% of them in the industrialized world), shortages of skilled workers, lack of financial capital, large debts to developed countries, and a drop in economic assistance from developed countries since 1985.

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

Planning for Babies Works

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.



ThomsonNOW™ **Active Figure 7-12** Four stages of the *demographic transition,* which the population of a country can experience when it becomes industrialized. There is uncertainty over whether this model will apply to some of today's developing countries. *See an animation based on this figure at* ThomsonNOW. **Question:** At what stage is the country where you live?

Family planning has been a major factor in reducing the number of births throughout most of the world, mostly because of increased knowledge and availability of contraceptives. In 2007, 58% of married women ages 15–49 in developed countries and 53% in developing countries used modern contraception. Family planning has also reduced the number of legal and illegal abortions performed each year and decreased deaths of mothers and fetuses during pregnancy.

Studies show that family planning is responsible for at least 55% of the drop in TFRs in developing countries, from 6.0 in 1960 to 2.9 in 2007. Between 1971 and 2007, for example, Thailand used family planning to cut its annual population growth rate from 3.2% to 0.8% and its TFR from 6.4 to 1.7 children per family.

Despite such successes, two problems remain. *First,* according to the United Nations Population Fund, 42% of all pregnancies in developing countries are unplanned, and 26% end with abortion. *Second,* an estimated 201 million couples in developing countries want to limit the number and determine the spacing of their children, but they lack access to family planning services. According to a recent study by the United Nations 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.

Some analysts call for expanding family planning programs to include teenagers and sexually active unmarried women, who are excluded from many existing programs. Another suggestion is to develop programs that educate men about the importance of having fewer children and taking more responsibility for raising them. Proponents also call for greatly increased research on developing more effective and more acceptable birth control methods for men.

In 1994, the United Nations held its third Conference on Population and Development in Cairo, Egypt. One of the conference's goals was to encourage action to stabilize the world's population at 7.8 billion by 2050 instead of the projected 9.2 billion.

The experiences of Japan, Thailand, South Korea, Taiwan, Iran, and China 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 *investing in family planning, reducing poverty,* and *elevating the social and economic status of women* (**Concept 7-4**).

Empowering Women Can Slow Population Growth

Women tend to have fewer children if they are educated, hold a paying job outside the home, and live in societies where their human rights are not suppressed. Although women make up roughly half of the world's population, in most societies they don't have the same rights and educational and economic opportunities as men.

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 all of the world's organized health services combined. Women also do 60–80% of the work associated with growing food, gathering wood 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 the world's 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 girls—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 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 United Nations 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 and reducing environmental degradation.

■ CASE STUDY

Slowing Population Growth in China: The One-Child Policy

China has made impressive efforts to feed its people, bring its population growth under control, and encourage economic growth. Between 1972 and 2007, the country cut its crude birth rate in half and trimmed its TFR from 5.7 to 1.6 children per woman, compared to 2.05 in the United States. Despite such drops China is the world's most populous country (photo in Figure 1-1, p. 5). If current trends continue, China's population is expected to peak around 2040 and then begin a slow decline.

Since 1980, China has moved 350 million people (an amount greater than the entire U.S. population) from extreme poverty to middle-class consumers and is likely to double that number by 2010. China also has a literacy rate of 91% and has boosted life expectancy to 72 years. By 2020, some economists project that China could become the world's leading economic power.

In the 1960s, government officials concluded that the only alternative to strict population control was mass starvation. To achieve a sharp drop in fertility, China established the most extensive, intrusive, and strict family planning and population control program in the world. It discourages premarital sex and urges people to delay marriage and limit their families to one child each. Married couples who pledge to have no more than one child receive more food, larger pensions, better housing, free health care, salary bonuses, free school tuition, and preferential employment opportunities for their child. Couples who break their pledge lose such benefits.

The government also provides married couples with free sterilization, contraceptives, and abortion. However, reports of forced abortions and other coercive actions have brought condemnation from the United States and other national governments.

In China, there is a strong preference for male children, because unlike sons, daughters are likely to marry and leave their parents. A folk saying goes, "Rear a son, and protect yourself in old age." Some pregnant Chinese women use ultrasound to determine the gender of their fetus, and some get an abortion if it is female. The result: a rapidly growing *gender imbalance* or "bride shortage" in China's population, with a projected 30–40 million surplus of men expected by 2020. Because of this skewed sex ratio, teen-age girls in some parts of rural China are being kidnapped and sold as brides for single men in other parts of the country.

With fewer children, the average age of China's population is increasing rapidly. By 2020, 31% of China's population will be over 60 years old compared to 8% in 2007. This graying of the Chinese population could lead to a declining work force, higher wages for younger workers, lack of funds for supporting continuing economic development, and fewer children and grandchildren to care for the growing number of elderly people. These and other factors may slow economic growth and lead to some relaxation of China's one-child population control policy. Some middle-class couples now have more than one child and pay the fines.

China also faces serious resource and environmental problems. It has 20% of the world's population, but only 7% of the world's freshwater and cropland, 4% of its forests, and 2% of its oil. In 2005, China's deputy minister of the environment summarized the country's environmental problems: "Our raw materials are scarce, we don't have enough land, and our population is constantly growing. Half of the water in our seven largest rivers is completely useless. One-third of the urban population is breathing polluted air."

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. 13) will consume more resources per person, increasing China's ecological footprint (Figure 1-8, p. 13) within its own borders and in other parts of the world that provide it with resources. This will put a strain on the earth's natural capital unless China steers a course toward more sustainable economic development.

■ CASE STUDY
Slowing Population Growth in India

For more than five decades, India has tried to control its population growth with only modest success. The world's first national family planning program began in India in 1952, when its population was nearly 400 million. In 2007, after 55 years of population control efforts, India had 1.1 billion people.

In 1952, India added 5 million people to its population. In 2007, it added 18.3 million—more than any other country. By 2015, India is projected to be the world's most populous country, with its population projected to peak at 1.6 billion around 2065.

India faces a number of serious poverty, malnutrition, and environmental problems that could worsen as its population continues to grow rapidly. India has a thriving and rapidly growing middle class of more than 300 million people—roughly equal to the entire U.S. population—many of them highly skilled software developers and entrepreneurs. By global standards, however, one of every four people in India is poor. Nearly half of the country's labor force is unemployed or can find only occasional work. Although India currently is self-sufficient in food grain production, about 40% of its population and more than half of its children suffer from malnutrition, mostly because of poverty. In 2007, an estimated 2.5 million people in India were infected with HIV, the third largest number after Nigeria and South Africa.

The Indian government has provided information about the advantages of small families for years and has also made family planning available throughout the country. Even so, Indian women have an average of 2.9 children. Most poor couples still believe they need many children to work and care for them in old age. As in China, the strong cultural preference for male children means some couples keep having children until they produce one or more boys. The result: Even though 90% of Indian couples know of at least one modern birth control method, only 48% actually use one.

Like China, India also faces critical resource and environmental problems. With 17% of the world's people, India has just 2.3% of the world's land resources and 2% of the forests. About half the country's cropland is degraded as a result of soil erosion and overgrazing. In addition, more than two-thirds of its water is seriously polluted, sanitation services often are inadequate, and many of its major cities suffer from serious air pollution (see photo 2, p. vi, and photo 13, p. xii).

India is undergoing rapid economic growth, which is expected to accelerate. As members of its huge and growing middle class increase their resource use per person, India's ecological footprint (Figure 1-8, p. 13) will expand and increase the pressure on the country's and the earth's natural capital.

On the other hand, economic growth may help slow population growth by accelerating India's demographic transition. By 2050, India—the largest democracy the world has ever seen—could become the world's leading economic power.

THINKING ABOUT

China, India, the United States, and Overpopulation

Based on population size and resource use per person (Figure 1-8, p. 13) is the United States more overpopulated than China? Explain. Answer the same question for the U.S. vs. India.

7-5 What Are the Major Population and Environmental Problems of Urban Areas?

CONCEPT 7-5 Cities can improve individual lives, but 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, with 80% of Americans living in urban areas and 50% of the world's people living in cities. 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, entertainment, and freedom from religious, racial, and political conflicts. Some are also *pushed* from rural to urban areas by factors such as poverty, lack of land for growing food, declining agricultural jobs, famine, and war.

Five 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 2007, the percentage of people living in urban areas increased from 2% to almost 50% and could reach 60% by 2030. Almost all of this growth will occur in already overcrowded and stressed cities in developing countries.

Second, *the number and sizes of urban areas is mushrooming.* Each week 1 million people are added to the world's urban areas. Between 2006 and 2015, the number of urban areas with a million or more people is projected to increase from 400 to 564. Also, there are 18 *megacities* or *megalopolises* (up from 8 in 1985), each with 10 million or more people—15 of them in developing countries (Figure 7-13, p. 138). Such megacities will soon be eclipsed by *hypercities* with more than 20 million people. So far, Tokyo, Japan, with 26.5 million people, is the only city in this category. But according to U.N. projections, by 2015 Mumbai (formerly Bombay) in India, Lagos in Nigeria, Dakar in Bangladesh, and São Paulo in Brazil will become hypercities.

A third trend is the *rapid increase in urban populations in developing countries.* Between 2007 and 2030, the percentage of people living in urban areas in developing countries is expected to increase from 43% to 56%. In South America, about 80% of the people already live in cities, mostly along the coasts.

Fourth, *urban growth is much slower in developed countries than in developing countries.* Still, developed countries, now with 75% urbanization, are projected to reach 84% urbanization by 2030.

Fifth, *poverty is becoming increasingly urbanized as more poor people migrate from rural to urban areas, mostly in developing countries.* The United Nations estimates that at least 1 billion people live in crowded and unsanitary slums and shantytowns in or on the outskirts of most cities in developing countries; within 30 years this number may double. At the same time, some cities in developing countries have undergone phenomenal economic growth. Examples include Singapore (with the highest standard of living in Asia), Hong Kong in China, Taipei in Taiwan, Kuala Lumpur in Malaysia, and Bangalore, India.

THINKING ABOUT

Urban Trends

CORE CASE STUDY

If you could reverse one of the five urban trends discussed here, which one would it be? Why? Which of these trends has Curitiba, Brazil (**Core Case Study**), reversed?

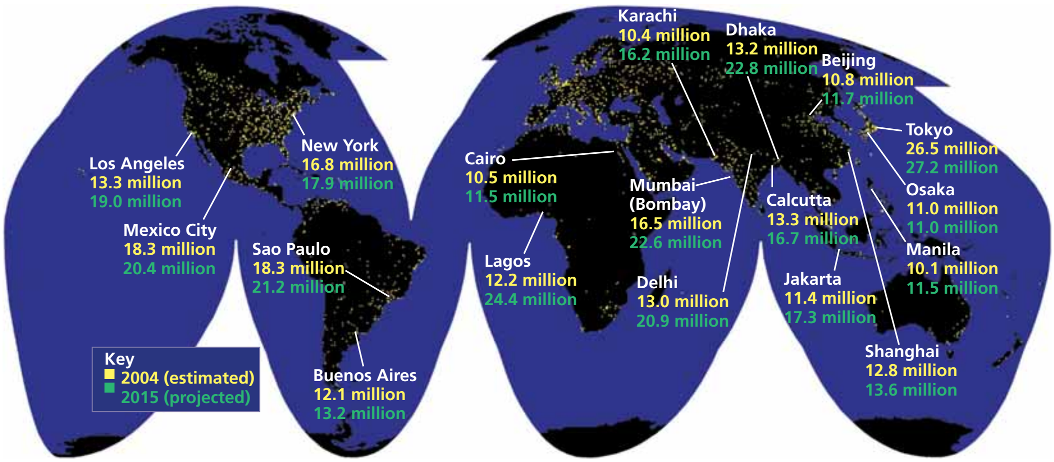


Figure 7-13 *Global outlook:* major urban areas throughout the world revealed in satellite images of the earth at night showing city lights. Currently, almost 50% of the world's people living in urban areas occupy about 2% of the earth's land area. Note that most of the urban areas are found along the coasts of continents, explaining 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 2004 (the latest year for which U.N. data is available) 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 2004 and the five most populous ones projected for 2015? (Data from National Geophysics Data Center, National Oceanic and Atmospheric Administration, and United Nations)

■ **CASE STUDY**

Urbanization in the United States

Between 1800 and 2007, 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, 75% of Americans live in cities with at least 50,000 people, and nearly half live in urban areas with 1 million or more residents (Figure 7-14).

Second, *many people migrated from large central cities to suburbs and smaller cities.* Currently, about 51% of Americans live in the suburbs, 30% in central cities, and 19% in rural areas and *exurbs,* developments beyond suburbs but still within commuting distance of cities.

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 2007 and 2043, demographers project that the fastest growing U.S. states will continue to be Nevada, Arizona, and Florida. According to a 2006 study by the Center for Environment and Population, the southern and western United States lead the country in population size and growth and in per capita energy and water use. As a result, they are hotspots where biodiversity is being threatened.

Fourth, since the 1970s, and especially since 1990, *some people have fled both cities and suburbs and migrated to rural areas* and to vast sprawling exurbs that have no centers and are further from central cities than are suburbs.

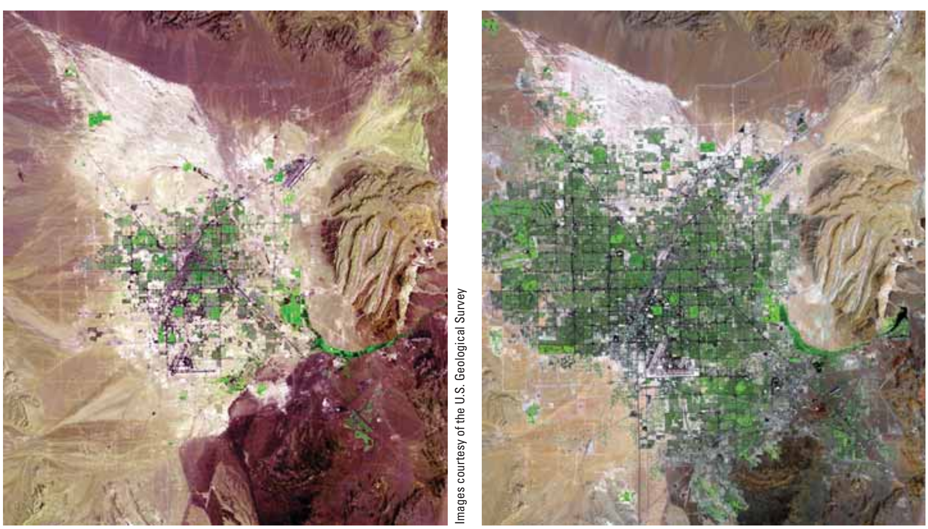
Since 1920, many of the worst urban environmental problems in the United States have been reduced significantly. Most people have better working and housing conditions, and air and water quality have improved. Better sanitation, public water supplies, and medical care have slashed death rates and incidences of sickness from malnutrition and infectious diseases (Figure 7-6). 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, but urban sprawl can reduce this benefit.

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

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 gobbling up the surrounding countryside (Figure 7-15)—is a major problem.

Figure 7-14 Major urban areas in the United States revealed in satellite images of the earth at night showing city lights (top). About 8 of 10 Americans live in urban areas that occupy about 1.7% of the land area of the lower 48 states. 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. **Question:** Why are most of the largest urban areas located near water? (Data from National Geophysical Data Center/National Oceanic and Atmospheric Administration, U.S. Census Bureau)



Images courtesy of the U.S. Geological Survey

Images courtesy of the U.S. Geological Survey

1973

2000

Figure 7-15 *Urban sprawl* in and around Las Vegas, Nevada, between 1973 and 2000—a process that has continued. Between 1970 and 2006, the population of water-short Clark County, which includes Las Vegas, more than quadrupled from 463,000 to around 2 million. And the growth is expected to continue. **Question:** What might be a limiting factor on population growth in the Las Vegas area?

Figure 7-16 Some undesirable impacts of urban sprawl, or car-dependent development. **Question:** Which five of these effects do you think are the most harmful? Why?

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 increased prosperity, ample and affordable land, automobiles, cheap gasoline, and poor urban planning. Figure 7-16 shows some of the undesirable consequences of urban sprawl. Because of nonexistent or inadequate mass transportation in most such areas, sprawl forces people to drive everywhere. Sprawl has decreased energy efficiency, increased traffic congestion, and destroyed prime cropland, forests, and wetlands. It has also led to the economic death of many central cities as people and businesses move out of these areas.

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. Often they also have newer public schools and lower crime rates.

As they grow and sprawl outward, separate urban areas sometimes merge to form a *megalopolis*. For example, the remaining open spaces between the U.S. cities of Boston, Massachusetts, and Washington, D.C. are rapidly urbanizing and coalescing. The result is an almost 800-kilometer-long (500-mile-long) urban area that contains about 35 million people and is sometimes called *Bowash* (Figure 7-17 and Figure 7-14).

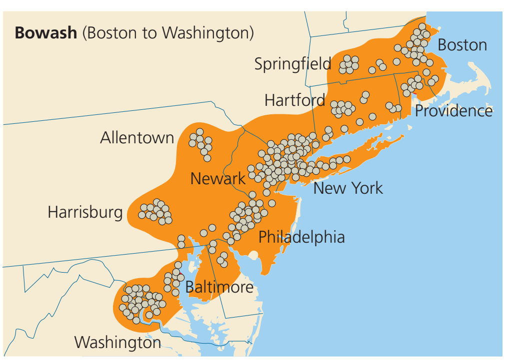


Figure 7-17 U.S. megalopolis: *Bowash,* consists of urban sprawl and coalescence between Boston, Massachusetts, and Washington, D.C. **Question:** What are two ways in which this development might be harming ecosystems along the Atlantic Coast?

THINKING ABOUT
Where You Live

CORE CASE STUDY

If you had a choice, would you prefer to live in a rural area, an exurb, a suburb, a small town, a medium-size city (200,000 or more), a large city (1 million or more), an ecocity such as Curitiba, Brazil (**Core Case Study**), or a megalopolis (10 million or more)? Explain.

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

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 live longer than do rural residents and have lower infant mortality rates and fertility rates. Most urban dwellers also have better access to medical care, family planning, education, and social services than do their rural counterparts.

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 also helps preserve biodiversity by reducing the stress on wildlife habitats.

Urbanization Has Disadvantages

Unsustainable Systems. Although urban populations occupy only about 2% of the earth's land area, they consume 75% of its resources. Because of this high resource input and high waste output (Figure 7-18), *most of the world's cities are not self-sustaining systems* (**Concept 7-5**).

Urbanization can help preserve biodiversity in some areas. On the other hand, large areas of land must be disturbed and degraded to provide urban dwellers with food, water, energy, minerals, and other resources. This decreases and degrades the earth's overall biodiversity (**Concept 3-4A**, p. 48).

CONCEPT LINKS

Thus, urban areas have huge ecological footprints (**Concept 1-3**, p. 11) that extend far beyond their boundaries. If you live in a city, you can calculate its ecological footprint by going to the website **www.redefiningprogress.org/**. Also, see the Guest Essay on this topic by Michael Cain at ThomsonNOW.

Lack of Vegetation. In urban areas, most trees, shrubs, or other plants are destroyed to make way for buildings, roads, and parking lots. So most cities do not benefit from vegetation that might otherwise absorb air pollutants, give off oxygen, help cool the air through transpiration, provide shade and wildlife habitats, reduce soil erosion, and muffle noise. As one observer remarked, "Most cities are places where they cut down most of the trees and then name the streets after them."

Water Problems. As cities grow and water demands increase, expensive reservoirs and canals must be built

Figure 7-18 Urban areas rarely are sustainable systems (**Concept 7-5**). 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 meeting the needs of all the world's people at the same rate of resource use as that of London would take at least three more planet earths. **Question:** How would you apply the four scientific **principles of sustainability** (see back cover) to lessen some of these impacts?

and deeper wells must be drilled. This can deprive rural and wild areas of surface water and deplete groundwater faster than it is replenished.

Flooding also tends to be greater in some cities, because they are built on floodplains or along low-lying coastal areas subject to natural flooding. Covering land with buildings, asphalt, and concrete causes precipitation to run off quickly and overload storm drains. In addition, urban development often destroys or degrades wetlands that act as natural sponges to help absorb excess water. Many of the world's largest cities face another threat because they are located in coastal areas (Figure 7-13) that could be partially flooded sometime in this century as sea levels rise due to projected global warming.

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. 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 7-19) is another problem.

Climate and Artificial Light. Cities generally are warmer, rainier, foggier, and cloudier than suburbs and nearby rural areas. The enormous amounts of heat generated by cars, factories, furnaces, lights, air conditioners, and heat-absorbing dark roofs and streets in cities create an *urban heat island* that is surrounded by cooler suburban and rural areas. As cities grow and merge (Figure 7-17), their heat islands merge, which can reduce the natural dilution and cleansing of polluted air.

Also, the artificial light created by cities hinders astronomers from conducting their research and makes it difficult for casual observers to enjoy the night sky. *Light pollution* also affects some plant and animal species. For example, endangered sea turtles lay their eggs on beaches at night and require darkness. In addition, each year millions of migrating birds, lured off course by the lights of high-rise buildings, often fatally collide with the buildings.

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. About 1 billion people live in such cities under crowded and unsanitary conditions, and according to a 2006 UN study, that number could reach 1.4 billion by 2020 (Figure 7-20). Some live in *slums*—tenements and rooming houses where 3–10 people live in a single room. Others live in *squatter settlements* and *shantytowns* on the outskirts of these cities, some perched precariously on steep hillsides subject to landslides. They build shacks from corrugated metal, plastic sheets, scrap wood, and other scavenged building materials or live in rusted shipping containers and junked cars. Still others live or sleep on the streets. When it rains, the usually unpaved alleys become clogged with dead rats, garbage, and sewage. In some shantytowns, 40% of the children are born HIV-positive and murder is a leading cause of death for children.

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, and earthquakes.

Most cities cannot afford to provide squatter settlements and shantytowns with basic services, and their officials fear that improving services will attract even

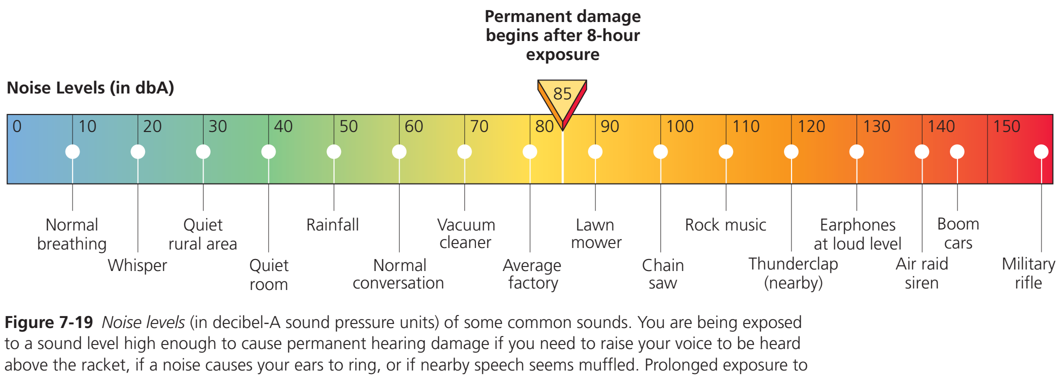
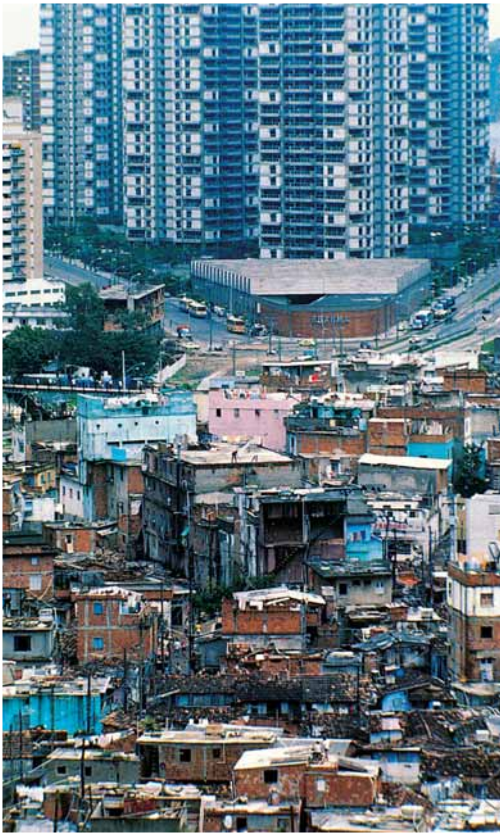


Figure 7-19 *Noise levels* (in decibel-A sound pressure units) of some common sounds. You are being exposed to a sound level high enough to cause permanent hearing damage if you need to raise your voice to be heard above the racket, if a noise causes your ears to ring, or if nearby speech seems muffled. Prolonged exposure to lower noise levels and occasional loud sounds may not damage your hearing but 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 7-20 *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.

more of the rural poor. Many city governments regularly bulldoze squatter shacks and send police to drive illegal settlers out. The people usually move back in or develop another shantytown somewhere else.

Governments can slow the migration from rural to urban areas by improving conditions in the countryside. They can provide social services, such as basic education and health care, and encourage investment in small towns throughout their countries. In addition, they can designate land for squatter settlements and supply them with clean water. However, implementing such policies in many of the poorest nations is hindered by extensive government corruption.

HOW WOULD YOU VOTE? ✓

Should squatters around cities of developing countries be given title to land they live on? Cast your vote online at **www.thomsonedu.com/biology/miller**.

Despite joblessness, squalor, overcrowding, and environmental and health hazards, most poor urban residents are better off than their rural counterparts. Thanks to the greater availability of family planning programs, they tend to have fewer children and better access to schools. Many squatter settlements provide people with a sense of community and a vital safety net of neighbors, friends, and relatives.

■ CASE STUDY
Mexico City

Mexico City—the world's second most populous city—is an urban area in crisis. About 19 million people live there and 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 consequence, 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 too many cars, polluting factories, a sunny climate and thus more smog (see photo 13 on p. xii), and topographical bad luck. The city sits in a 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.

The city's air and water pollution cause an estimated 100,000 premature deaths per year. Writer Carlos Fuentes has nicknamed it "Makesicko City."

Some progress has been made. 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 catalytic converters 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.

THINKING ABOUT
Mexico City and Curitiba

CORE CASE STUDY

What are two sustainability strategies used in Curitiba, Brazil (**Core Case Study**), that might be helpful in Mexico City?

7-6 How Does Transportation Affect Urban Development?

CONCEPT 7-6 A combination of plentiful land, inexpensive fuel, and an expanding network of highways results in dispersed cities that depend on motor vehicles for most 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* like Hong Kong, China, and Tokyo, Japan, walk, ride bicycles, or use energy-efficient mass transit.

On the other hand, a combination of plentiful land, cheap gasoline, and a network of highways have produced *dispersed cities* that depend on the automobile for most travel (**Concept 7-6**). 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 can have a number of undesirable effects (Figure 7-16).

The United States is a prime example of a car-centered nation. With 4.6% of the world's people, the United States has almost one-third of the world's 900 million passenger cars and commercial vehicles. More than half of all American passenger vehicles are gas-guzzling sport utility vehicles, pickup trucks, and vans.

Mostly because of urban sprawl and convenience, passenger vehicles are used for 98% of all urban transportation and 91% of travel to work in the United States. About 75% of Americans drive to work alone, 5% use public transit, and 0.4% bicycle to work. Each year, Americans drive about the same distance driven by all other drivers in the world. According to the American Public Transit Association, if Americans increased their use of mass transit from the current rate of 5% to 10%, it would reduce U.S. dependence on oil (at least half of it imported) by 40%.

THINKING ABOUT
Mass Transit

Why is there less emphasis on mass transit in the United States than in many European and Asian countries?

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. In addition, 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 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.

Motor vehicles have helped create urban sprawl. At least a third of urban land worldwide and half 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 two years of their lives in traffic jams, as streets and freeways in effect become parking lots. Commuter distances increase as cities sprawl out. 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."

It Is Difficult to Reduce Automobile Use

Some environmental scientists and economists suggest that one way to reduce the harmful effects of automobile use is to make drivers pay directly for most environmental and health costs of their automobile use—a *user-pays* approach.

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 $2.90 per liter ($11 per gallon) of gasoline in the United States. This 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, and reduce pollution and environmental degradation.

RESEARCH FRONTIER

Determining the harmful costs of motor vehicles

Proponents of this approach urge governments to use gasoline tax revenues to help finance mass transit systems, bike paths, and sidewalks as alternatives to cars. They suggest reducing 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.

Most analysts doubt that heavily taxing gasoline would be feasible in the United States, for four reasons. *First,* it faces strong political opposition from two groups: the public, which is largely unaware of the huge hidden costs they are already paying; and powerful transportation-related industries such as oil and tire companies, road builders, car makers, and many real estate developers. However, taxpayers might accept sharp increases in gasoline taxes if a tax shift were employed, as mentioned above.

Second, fast, efficient, reliable, and affordable mass transit options and bike paths are not widely available in most of 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.

Another way to reduce automobile use and urban congestion is to raise parking fees and charge tolls on roads, tunnels, and bridges—especially during peak traffic times. 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% and car commuting by nearly 90%.

There Are Alternatives to Using a Car

Some *good news* is that mayors and urban planners in many parts of the world are beginning to rethink the role of the car in urban transportation systems and are providing a mix of other options, as they have in Curitiba, Brazil (**Core Case Study**). CORE CASE STUDY

There are several alternatives to motor vehicles, each with its own advantages and disadvantages. They include *bicycles* (Figure 7-21), *mass transit rail systems in urban areas* (Figure 7-22), *bus systems in urban areas* (Figure 7-23, p. 146), and *rapid rail systems between urban areas* (Figure 7-24, p. 146).

HOW WOULD YOU VOTE?

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

Figure 7-21 Advantages and disadvantages of *bicycles.* **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

Figure 7-22 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? Why?

TRADE-OFFS
Buses

Advantages	Disadvantages
Can be rerouted as needed	Can lose money because they need low fares to attract riders
Cost less to develop and maintain than heavy-rail system	Can get caught in traffic and add to pollution
	Commits riders to transportation schedules
Can greatly reduce car use and air pollution	Noisy

Figure 7-23 Advantages and disadvantages of *bus systems in urban areas.* **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

TRADE-OFFS
Rapid Rail

Advantages	Disadvantages
Can reduce travel by car or plane	Expensive to run and maintain
Ideal for trips of 200–1,000 kilometers (120–620 miles)	Must operate along heavily used routes to be profitable
Much more energy efficient per rider than a car or plane	Causes noise and vibration for nearby residents

Figure 7-24 Advantages and disadvantages of *rapid-rail systems between urban areas.* **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

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

CONCEPT 7-7 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 Build More Environmentally Sustainable Cities

Most environmental scientists and urban planners argue for making new and existing urban areas more self-reliant, sustainable, and enjoyable places to live through good ecological design. (See the Guest Essay on this topic by David Orr at ThomsonNOW.)

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 7-25 lists popular smart growth tools used to prevent, slow, and control urban growth and sprawl.

A more environmentally sustainable city, called an *ecocity* or *green city* (**Concept 7-7**), emphasizes the following goals built around the four **scientific principles of sustainability** (see back cover):

- Build and redesign cities for people not cars
- Use solar and other locally available, renewable energy resources and design buildings to be heated and cooled as much as possible by nature
- 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

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 to provide shade and beauty, supply wildlife habitats, and reduce pollution, noise, and soil erosion. Small organic gardens and a variety of plants adapted to local climate conditions often replace monoculture grass lawns. Parks are easily available to everyone.

In an ecocity, abandoned lots, industrial sites, and polluted creeks and rivers are cleaned up and restored. Nearby forests, grasslands, wetlands, and farms are 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. People designing and living in ecocities take seriously the advice that U.S. urban planner Lewis Mumford gave more than three decades ago: "Forget the damned motor car and build cities for lovers and friends."

The ecocity is not a futuristic dream. Examples of cities that have attempted to become more environmentally sustainable and livable include Curitiba, Brazil (**Core Case Study**); 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 (Case Study, p. 18).

CORE CASE STUDY

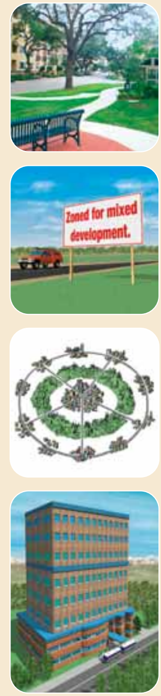
RESEARCH FRONTIER

Evaluating and improving the design and expansion of ecocities

Figure 7-25 *Smart growth* or *new urbanism tools* used to prevent, slow, and 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? Why? Which, if any, of these tools are being used in your community?

SOLUTIONS

Smart Growth Tools



Limits and Regulations

Limit building permits

Urban growth boundaries

Greenbelts around cities

Public review of new development

Zoning

Encourage mixed use of housing and small businesses

Concentrate development along mass transportation routes

Promote high-density cluster housing developments

Planning

Ecological land-use planning

Environmental impact analysis

Integrated regional planning

State and national planning

Protection

Preserve existing open space

Buy new open space

Buy development rights that prohibit certain types of development on land parcels

Taxes

Tax land, not buildings

Tax land on value of actual use (such as forest and agriculture) instead of on highest value as developed land

Tax Breaks

For owners agreeing not to allow certain types of development (conservation easements)

For cleaning up and developing abandoned urban sites (brownfields)

Revitalization and New Growth

Revitalize existing towns and cities

Build well-planned new towns and villages within cities

REVISITING Curitiba, Population Growth, and Sustainability

CORE CASE STUDY

SUSTAINABILITY

This chapter explored issues related to human population growth and its distribution. As elsewhere in this text, we focused on *sustainability* in discussing the issues. For example, we know that, each week, 1 million people are added to urban areas, just in developing countries. For the human population to live more sustainably, cities will have to accommodate this sort of growth without seriously depleting or degrading the natural capital available to them locally and throughout the world.

Curitiba, Brazil (**Core Case Study**), is one city in a developing country that has made great strides toward becoming environmentally sustainable. Its 2 million people have opportunities for living well or improving their lives, and its ecological footprint is considerably smaller than that of most cities its size. Curitiba's story gives us hope for managing human population growth in many of the world's urban areas more sustainably in the short run. However, rapid population growth has hindered such efforts. The most difficult challenge is to convert the little- or no-hope cities in the world's poorest countries to cities full of hope.

For the long run, some experts say, we ought to ask what is the optimal level of human population that the planet can support *sustainably?* That is, at what level could the maximum number of people live comfortably and freely without jeopardizing the earth's ability to provide the same comforts and freedoms for future generations?

In the first six chapters of this book, you have learned how ecosystems and species have sustained themselves throughout history by use of four **scientific principles of sustainability**—relying on solar energy, biodiversity, population control, and nutrient recycling (see back cover). In this chapter, you may have gained a feel for the need for humans to apply these sustainability principles to their lifestyles and economies.

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

Our numbers expand but Earth's natural systems do not.

LESTER R. BROWN

REVIEW QUESTIONS

1. Explain why the city of Curitiba, Brazil is regarded as a model for urban planning and sustainability.
2. Describe the three major factors that have caused the human population to grow exponentially.
3. Explain how the interplay between births, deaths, and migration affect changes in population. Describe how two types of fertility rates affect a country's population size and growth rate.
4. Describe population and immigration trends in the United States since 1900.
5. Explain the role that age structure plays in determining the population of each country.
6. How does the population structure differ in developing and developed countries? How can these age structure diagrams be used to make future population and economic projections?
7. With reference to the demographic transition, discuss the most effective ways to slow population growth.
8. Compare and contrast the success of the policies utilized by China and India in slowing their population growth.
9. What are five major trends in urban growth? Explain the role that motor vehicles have played in urbanization.
10. Describe how smart growth and ecocities can help prevent and control urban growth and sprawl.

CRITICAL THINKING

1. List three ways in which you could apply **Concepts 7-1** and **7-7** to make your lifestyle, and that of any children and grandchildren you might have, more environmentally sustainable.
2. Curitiba, Brazil (**Core Case Study**), has made significant progress in becoming a more environmentally sustainable and desirable place to live. What steps, if any, has the urban area in or near where you live taken toward becoming more environmentally sustainable? List five ways to make it more environmentally sustainable. CORE CASE STUDY
3. Identify a major local, national, or global environmental problem, and describe the role of population growth in this problem.
4. Why is it rational for a poor couple in a developing country such as India to have four or five children? What changes might induce such a couple to consider their behavior irrational?
5. Do you believe that the population is too high in **(a)** the world (Case Study, p. 126), **(b)** your own country, and **(c)** the area where you live? Explain.
6. Should everyone have the right to have as many children as they want? Explain.
7. Some people believe the most important goal is 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 1-8, p. 13). What is your view on this issue? Explain.
8. Do you believe the United States or the country where you live should develop a comprehensive and integrated mass transit system over the next 20 years, including building an efficient rapid-rail network for travel within and between its major cities? How would you pay for such a system?
9. Congratulations! You are in charge of the world. List the three most important features of your **(a)** population policy and **(b)** urban policy.
10. List two questions that you would like to have answered as a result of reading this chapter.

LEARNING ONLINE

Log on to the Student Companion Site for this book at www.thomsonedu.com/biology/miller and choose Chapter 7 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Web links, information on Green Careers, and InfoTrac® College Edition articles.

For access to animations and additional quizzing, register and log on to Thomson NOW! at **www.thomsonedu.com/thomsonnow** using the access code card in the front of your book. You can also explore the **Active Graphing** exercises that your instructor may assign.

Sustaining Biodiversity: The Ecosystem Approach

8

Reintroducing Wolves to Yellowstone

CORE CASE STUDY

At one time, the gray wolf, also known as the eastern timber wolf (Figure 8-1), roamed over most of North America. But between 1850 and 1900, an estimated 2 million wolves were shot, trapped, and poisoned by ranchers, hunters, and government employees. The idea was to make the West and the Great Plains safe for livestock and for big-game animals prized by hunters.

It worked. 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.

Ecologists recognize the important role this keystone predator species once played in parts of the West and the Great Plains. These wolves culled herds of bison, elk, caribou, 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.

In recent years, herds of elk, moose, deer, and antelope have expanded. Their larger numbers have devastated some vegetation such as willow and aspen trees, increased erosion, and threatened the niches of other wildlife species such as beavers that help create wetlands.

In 1987, the U.S. Fish and Wildlife Service (USFWS) proposed reintroducing gray wolves as a keystone species into the Yellowstone National Park ecosystem as one way to help sustain the biodiversity of the ecosystem and prevent further environmental degradation. The proposal brought angry protests, some from 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.

Since 1995, federal wildlife officials have caught gray wolves in Canada and relocated them in Yellowstone National Park and northern Idaho. Scientists estimate that the long-term carrying capacity of the park is 110 to 150 gray wolves. In 2007, the park had 136 gray wolves.

Reintroducing this keystone species has sent ecological ripples through the park's ecosystem. With wolves around, elk are gathering less near streams and rivers and their population growth has slowed. This has spurred the growth of aspen, cottonwoods, and willow trees. This in turn helped stabilize stream banks, which lowered the water temperatures and made the habitat better for trout. Beavers seeking willow and aspen have returned. In addition, leftovers of elk killed by wolves are an important food source for grizzly bears and other scavengers such bald eagles and ravens.

The wolves have also cut the population of coyotes—the top predators in the absence of wolves—in half. This has reduced coyote attacks on cattle in surrounding ranches. It has also increased populations of smaller animals such as ground squirrels, mice, and gophers hunted by coyotes, eagles, and hawks.

Since 1980, *biodiversity* (Figure 3-12, p. 48) has emerged as one of the most important integrative principles of biology. It is one of the four **scientific principles of sustainability**. This chapter and the one that follows are devoted to helping us understand and sustain the earth's terrestrial and aquatic biodiversity.

SUSTAINABILITY

Tom Kitchin/Tom Stack & Associates.

Figure 8-1 **Natural capital restoration:** the *gray wolf.* Ranchers, hunters, miners, and loggers have vigorously opposed efforts to return this keystone species to its former habitat in the Yellowstone National Park. Wolves were reintroduced beginning in 1995 and in 2007 numbered around 136.

Key Questions and Concepts

8-1 How are we affecting the earth's biodiversity and why should we protect it?

CONCEPT 8-1A We are degrading and destroying biodiversity in many parts of the world and these threats are increasing.

CONCEPT 8-1B We should protect biodiversity because it exists and because of its usefulness to us and other species.

8-2 How should we manage and sustain forests?

CONCEPT 8-2 We can sustain forests by recognizing the economic value of their ecological services, protecting old-growth forests, harvesting trees no faster than they are replenished, and making most paper from fast-growing plants and agricultural residues instead of trees.

8-3 How serious is tropical deforestation and how can it be reduced?

CONCEPT 8-3 We can reduce tropical deforestation by protecting large forest areas, teaching settlers about sustainable agriculture and forestry, using government subsidies that encourage sustainable forest use, reducing poverty, and slowing population growth.

8-4 How should we manage and sustain grasslands?

CONCEPT 8-4 We can sustain the productivity of rangeland by controlling the number and distribution of livestock and by restoring degraded rangeland.

8-5 How should we manage and sustain parks and nature reserves?

CONCEPT 8-5 Sustaining biodiversity will require protecting much more of the earth's remaining undisturbed land area, starting with the most endangered biodiversity hot spots.

8-6 What is the importance of restoration ecology?

CONCEPT 8-6 Sustaining biodiversity will require a global effort to rehabilitate and restore damaged ecosystems.

8-7 How can we help sustain aquatic biodiversity?

CONCEPT 8-7 We can sustain aquatic biodiversity by establishing protected sanctuaries, managing coastal development, reducing water pollution, and preventing overfishing.

8-8 What should be our priorities for protecting biodiversity?

CONCEPT 8-8 Sustaining the world's biodiversity requires mapping terrestrial and aquatic biodiversity, protecting terrestrial and aquatic hotspots and old-growth forests, initiating ecological restoration projects worldwide, and making conservation profitable.

Note: Supplements 3, 4, 5, 6, 11, and 13 can be used with this chapter.

Forests precede civilizations,
deserts follow them.

FRANCOIS-AUGUSTE-RENÉ DE CHATEAUBRIAND

8-1 How Are We Affecting the Earth's Biodiversity and Why Should We Protect It?

CONCEPT 8-1A We are degrading and destroying biodiversity in many parts of the world and these threats are increasing.

CONCEPT 8-1B We should protect biodiversity because it exists and because of its usefulness to us and other species.

Human Activities Are Destroying and Degrading Biodiversity

We have depleted and degraded some of the earth's biodiversity, and these threats are expected to increase (**Concept 8-1A**). You can get an idea of our impact on the earth's natural systems by comparing a map of those systems (Figure 1 on pp. S12–S13 in Supplement 4 and Figure 5-8, p. 81) with maps showing our large and growing ecological footprints (Figures 3 on pp. S16–S17 and Figure 7 on pp. S20–S21 in Supplement 4) (**Concept 1-3**, p. 11). 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."

CONCEPT LINK

According the 2005 Millennium Ecosystem Assessment and other studies, humans have disturbed to

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.

some extent at least half and probably about 83% of the earth's land surface (excluding Antarctica and Greenland). Most of this disturbance involves filling in wetlands or converting grasslands and forests to crop fields and urban areas.

The global area of temperate forests increased by 1% during the 1990s. But the area of tropical forests decreased by 7%. As grasslands were converted to cropland between 1970 and 2000, the populations of wild species in temperate grasslands dropped by 7% while those in tropical grasslands declined by a staggering 80%.

Human activities are also degrading the earth's *aquatic biodiversity.* About half of the world's wetlands (including half of U.S. wetlands) were lost during the last century. An estimated 15% of the world's biologically rich coral reefs—the "rain forests of the sea"—have been destroyed, and another 20% have been damaged, mostly by human activities (Figure 5-27, right, p. 99). According to a 2006 report by NOAA's U.S. Coral Reef Task Force, 60% of the world's coral reefs may be severely damaged or destroyed in less than 25 years due to pollutants and global warming—a major loss of the world's aquatic biodiversity.

Three-fourths of the world's 200 commercially valuable marine fish species are either overfished or fished to their estimated sustainable yield, and 29% have collapsed, with a resulting 90% decline in their catch. According to a 2006 report by Redefining Progress, the Ocean Project, and the Center for Sustainable Economy, the world's *ecological fishprint* is unsustainable. The study estimated that to sustain 2003 levels of seafood consumption, humans would need more than 2.5 times the area of all of the earth's oceans. Some 91 countries have exceeded the biological capacity of the waters under their control, with Japan, Indonesia, and China leading the pack.

The ocean is a great recycler. It converts sewage into nutrients, removes some toxins from water, produces food, adds oxygen to water and the atmosphere, and reduces the threat of global warming by removing carbon dioxide from the atmosphere. But these vital ecological and economic services (Figure 5-21, p. 94) depend on maintaining, not depleting, the millions of marine plants and animals whose biodiversity and interactions supply such natural capital.

Freshwater streams and rivers, which make up only about 2.5% of the earth's water, face intense environmental pressures as we dam and pollute them and withdraw more than half of the their runoff to grow crops and support cities.

Human activities also contribute to the *premature extinction of species.* Biologists estimate that the current global extinction rate of species is at least 100 times and probably 1,000–10,000 times what it was before humans existed. Mostly because of their small volume, freshwater ecosystems have a higher rate of endangered species per unit of area than terrestrial ecosystems have. These threats to the world's species are projected to increase sharply during the next few decades, as discussed in Chapter 9.

From this brief overview, you can see why protecting and sustaining the genes, species, ecosystems, and ecological functions that make up the world's biodiversity is such an important and urgent environmental issue. Let's explore these reasons more fully.

Why Should We Protect Biodiversity?

Biodiversity researchers contend that we should act to preserve the earth's overall biodiversity, which includes genes, species, ecosystems, and ecological processes, because it has two types of value. One is **intrinsic value**—the fact that these components of biodiversity exist, regardless of their use to us (**Concept 8-1B**). Protecting biodiversity on this basis is essentially an ethical decision.

The other is **instrumental value**—their usefulness to us in the form of economic and ecological services (Figure 1-3, p. 8) (**Concept 8-1B**). For example, more than half the world's people depend directly on forests, rangelands, croplands, and fisheries for their livelihoods.

Biodiversity provides economic benefits and pleasure from recreation and tourism. It also helps maintain the structure and function of ecosystems (Figure 3-11, p. 47) and plays a role in controlling the populations of the earth's species. Biodiversity also helps nature to adapt to environmental change through natural selection (**Concept 4-1B**, p. 64) and supplies us with food and a variety of medicines and drugs. In other words, biodiversity is one of the most important forms of natural capital (Figure 1-3, p. 8).

CONCEPT LINK

The other form of instrumental values is *nonuse values.* For example, there is *existence value*—the satisfaction of knowing that a redwood forest, a wilderness, orangutans (Figure 8-2, p. 152), and wolf packs (**Core Case Study**) exist, even if we will never see them or get direct use from them. *Aesthetic value* is another nonuse value. Many people, for example, appreciate a tree, a forest, a wild species such as a parrot (see photo 3, p. vii), or a vista because of its beauty. *Bequest value,* a third type of nonuse value, is based on the willingness of some people to pay to protect some forms of natural capital for use by future generations.

CORE CASE STUDY

THINKING ABOUT
Orangutans

If orangutans become extinct, mostly because of human activities, what difference might this make to you and to any children you may have?

RESEARCH FRONTIER

Improving estimates of the economic values of the ecological services provided by ecosystems

Figure 8-2 Endangered orangutans in a tropical forest. In 1900, there were over 315,000 wild orangutans. Now there are less than 20,000 and they are disappearing at a rate of over 2,000 per year. An illegally smuggled orangutan typically sells for a street price of $10,000. **Question:** How would you go about trying to set a price on the ecological value of an orangutan?

SuperStock

8-2 How Should We Manage and Sustain Forests?

CONCEPT 8-2 We can sustain forests by emphasizing the economic value of their ecological services, protecting old-growth forests, harvesting trees no faster than they are replenished, and making most paper from fast-growing plants and agricultural residues instead of trees.

Forests Provide Important Economic and Ecological Services

Figure 5-8 (p. 81) shows the distribution of the world's boreal, temperate, and tropical forests, which occupy about 30% of the earth's land surface (excluding Greenland and Antarctica). They provide many important ecological and economic services (Figure 8-3). 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 stabilize the earth's temperature and slow global warming as a part of the global carbon cycle (Figure 3-19, 56).

There have been efforts to estimate the economic value of the ecological services provided by the world's forests and other ecosystems (Science Focus, at right).

We Have Old-Growth and Second-Growth Forests and Tree Plantations

Forest managers and ecologists classify forests into two major types based on their age and structure. The first type is an **old-growth forest:** an uncut or regenerated forest that has not been seriously disturbed by human activities or natural disasters for a hundred years or more (Figure 8-4, p. 154, and Figure 5-14, top photo, p. 87). Old-growth forests are storehouses of biodiversity because they provide ecological niches for a multitude of wildlife species (Figure 5-15, p. 88, and Figure 5-16, p. 89).

The second type is a **second-growth forest:** a stand of trees resulting from secondary ecological succession (**Concept 6-4A**, p. 115; Figure 6-9, p. 116; and Figure 5-14, middle photo, p. 87). These forests develop after the trees in an area have been removed by human activities (such as clear-cutting for timber or conversion to cropland) or by natural forces (such as fire, hurricanes, or volcanic eruption).

CONCEPT LINKS

A **tree plantation,** also called a **tree farm** (Figure 8-5, p. 154, and photo 1, p. vi), is a managed tract with uniformly aged trees of one or two genetically uniform species that 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 increase profits, but they are much less biologically diverse and sustainable than old-growth and second-growth forests. In addition, repeated cycles of cutting and replanting can eventually deplete the soil of nutrients and hinder the growth of any type of forest on the land.

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 or other uses. Surveys by the World Resources Institute (WRI) indicate that over the past 8,000 years, human activities have reduced the earth's original forest cover by about 46%, with most of this loss taking place since 1950.

Deforestation is continuing at a rapid rate in many parts of the world. The FAO and WRI surveys indicate that the global rate of forest cover loss between 1990 and 2005 was between 0.2% and 0.5% per year, and that at least another 0.1–0.3% of the world's forests were degraded annually, mostly to grow crops and graze cattle.

If these estimates are correct, the world's forests are being cleared or degraded exponentially at a rate of 0.3–0.8% per year, with much higher rates in some areas. These losses are concentrated in developing countries, especially those in the tropical areas of Latin America, Indonesia, and Africa. 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 two decades, if not sooner.

Cutting down large areas of forests, especially old-growth forests, has important short-term economic

Figure 8-3 Major ecological and economic services provided by forests (**Concept 8-1B**). **Question:** Which two ecological services and which two economic services do you think are the most important? Why?

SCIENCE FOCUS

Putting a Price Tag on Nature's Ecological Services

The long-term health of an economy cannot be separated from the health of the natural systems that support it. Currently, forests and other ecosystems are valued mostly for their economic services (Figure 8-3, right). But suppose we took into account the monetary value of the ecological services provided by forests (Figure 8-3, 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. To provide this income, the world's natural capital would have a value of at least $500 trillion—an average of about $82,000 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.

The authors of such studies warn that unless we include the financial value of ecological services in deciding how to use forests and other natural resources, they will be destroyed or degraded for short-term economic gain. 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.

According to Costanza, "We have been cooking the books for a long time by leaving out the worth of nature." Biologist David Suzuki warns, "Our economic system has been constructed under the premise that natural services are free. We can't afford that luxury anymore."

Why haven't we changed our accounting systems to reflect the values of these resources and the losses that result from destroying or degrading these ecological services? One reason is that economic savings provided by conserving natural resources benefit everyone now and in the future, whereas the profits made by exploiting these resources are immediate, and they benefit a relatively small group of people who have the motivation and means to develop them.

A second reason is that many government subsidies and tax incentives support unsustainable use of forests and other ecosystems for short-term economic gain. Finally, most people are unaware of the value of the ecological services and biological income provided by forests and other ecosystems.

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 8-4 **Natural capital:** old-growth forest in the U.S. state of Washington's Olympic National Forest.

benefits (Figure 8-3, right), but it also has a number of harmful environmental effects (Figure 8-6).

HOW WOULD YOU VOTE?

Should there be a global effort to sharply reduce the cutting of old-growth forests? Cast your vote online at **www.thomsonedu.com/biology/miller**.

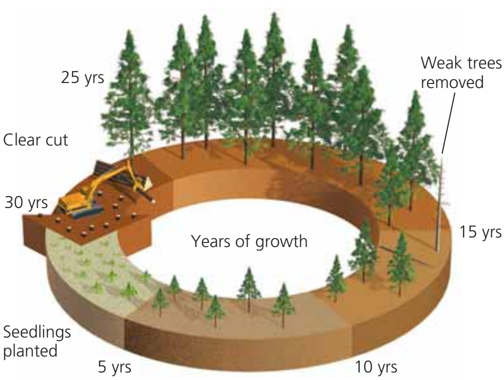


Figure 8-5 Short (25- to 30-year) rotation cycle of cutting and regrowth of a monoculture tree plantation in modern industrial forestry. In tropical countries, where trees can grow more rapidly year-round, the rotation cycle can be 6–10 years. Old-growth or secondary forests are clear-cut to provide land for growing most tree plantations. **Question:** What are two ways in which this process can degrade an ecosystem?

Good news. According to the 2005 Global Forest Resources Assessment by the FAO, the net total area occupied by forests in North America, Europe, India, China, Turkey, and Vietnam changed very little or increased between 2000 and 2005. This was because of the spread of commercial tree plantations and natural reforestation from secondary ecological succession on cleared forest areas and abandoned croplands.

Some analysts believe that establishing tree plantations on much of the earth's deforested and degraded land could conceivably meet most of the world's future needs for wood, help reduce soil erosion, and slow global warming by removing more CO_2 from the atmosphere. But biodiversity researchers warn that replacing old-growth and second-growth forests with much simpler tree plantations represents a net loss of terrestrial biodiversity and can eventually deplete forest soils of key nutrients. Many of them favor establishing tree plantations only on land that has already been degraded. And these analysts argue against cutting old-growth and second-growth forests to plant tree plantations.

THINKING ABOUT
Tree Farms

Do you support establishing tree plantations only on land that has already been degraded? What are three things you would do to implement such a policy?

ThomsonNOW™ Learn more about how deforestation can affect the drainage of a watershed and disturb its ecosystem at ThomsonNOW.

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.

Forests in the United States (including tree plantations) cover more area than they did in 1920. Many of the old-growth forests that were cleared or partially cleared between 1620 and 1960 have grown back naturally through secondary ecological succession (Figure 6-9, p. 116). There are 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 contains 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 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. Some environmentally concerned citizens have protested the cutting down of ancient trees and forests (Individuals Matter, below).

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 8-6 Harmful environmental effects of deforestation that can reduce biodiversity and the ecological services provided by forests (Figure 8-3, left). **Question:** What are two ways in which your lifestyle contributes directly and two ways in which it contributes indirectly to deforestation?

There Is Controversy Over Logging in U.S. National Forests

According to federal law, U.S. national forests are supposed to be managed by using two principles: the *principle of sustainable yield,* which states that trees in national forests should not be harvested faster than they are replenished; and the *principle of multiple use,* which calls for a variety of uses on the same forest land at the same time.

These government regulations have been difficult to monitor and enforce. For decades, there has been controversy over the principle of multiple use. Timber companies push to make timber cutting the primary use by cutting as much timber in national forests as possible at low prices and with taxpayer subsidies. Biodiversity experts and many environmental scientists argue that national forests should be managed primarily

INDIVIDUALS MATTER

Butterfly in a Redwood Tree

"Butterfly" is the nickname given to Julia Hill. This young woman spent two years of her life on a small platform near the top of a giant redwood tree in California to protest the clear-cutting of 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,* similar to that used decades ago by Mahatma Gandhi in his efforts to end the British occupation of India and by Martin Luther King, Jr., in the U.S. civil rights movement.

Butterfly had never participated in any 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, even if you own them. 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 two years to publicize what was happening and help save the surrounding trees. She became a symbol of the protest and, during her stay, used a cell phone to communicate with members of the mass media throughout the world to help develop public support for saving the trees.

Can you imagine spending two 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 trying to scare her into returning to the ground.

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.

Maybe Butterfly and the earth did not lose. 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 other environmental causes.

Butterfly led others by following in the tradition of Gandhi, who said, "My life is my message." Would you spend a day or a week of your life protesting something that you believed to be wrong?

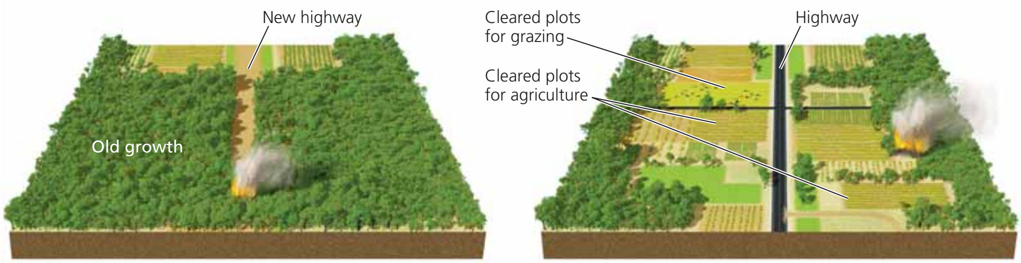


Figure 8-7 Natural capital degradation: Building roads into previously inaccessible forests paves the way to fragmentation, destruction, and degradation.

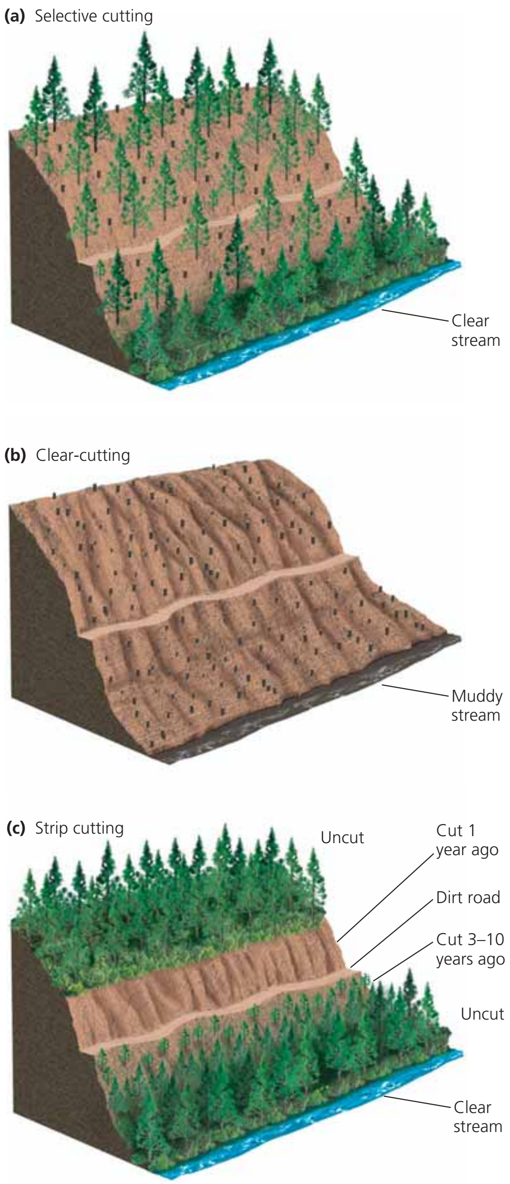


Figure 8-8 Major tree harvesting methods. **Question:** If you were cutting trees in a forest you owned, which method would you choose and why?

to provide recreation and to sustain biodiversity, water resources, and other ecological services.

By law, the USFS must sell timber for no less than the cost of reforesting the land. However, the USFS timber-cutting program loses money because the revenues from timber sales do not cover the expenses of road building, timber sale preparation, administration, and other overhead costs provided by the nation's citizens who jointly own these forests. More than 644,000 kilometers (400,000 miles) of roads have been cut through the national forests at taxpayers' expense, primarily to facilitate logging.

Because of such government subsidies, a 2005 study by the Earth Island Institute found, timber sales from U.S. federal lands have lost money in 97 of the last 100 years. According to a 2000 study by the accounting firm ECONorthwest, recreation, hunting, and fishing in national forests add ten times more money to the national economy and provide seven times more jobs than does extraction of timber and other resources.

HOW WOULD YOU VOTE?

Should the U.S. Congress ban logging in U.S. national forests? Cast your vote online at **www.thomsonedu.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 (Figure 8-7)—namely, increased erosion and sediment runoff into waterways, habitat fragmentation, and biodiversity loss. Logging roads also expose forests to invasion by nonnative pests, diseases, and wildlife species. In addition, they open once-inaccessible forests to farmers, miners, ranchers, hunters, and off-road vehicle users. Logging roads on public lands in the United States also disqualify the land for protection as wilderness.

Once loggers reach a forest area, they use a variety of methods to harvest the trees (Figure 8-8). With *selective cutting,* intermediate-aged or mature trees in an un-

Daniel Dancer/Peter Arnold, Inc.

Figure 8-9 Clear-cut logging in the U.S. state of Washington

even-aged forest are cut singly or in small groups (Figure 8-8a).

Some tree species that grow best in full or moderate sunlight are sometimes all removed in a single *clear-cut* (Figures 8-8b and 8-9). Figure 8-10 lists the advantages and disadvantages of clear-cutting.

TRADE-OFFS

Clear-Cutting Forests

Advantages	Disadvantages
Higher timber yields	Reduces biodiversity
Maximum profits in shortest time	Destroys and fragments wildlife habitats
Can reforest with fast-growing trees	Increases water pollution, flooding, and erosion on steep slopes
Good for tree species needing full or moderate sunlight	Eliminates most recreational value

Figure 8-10 Advantages and disadvantages of clear-cutting forests. **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

A clear-cutting variation that can allow a more sustainable timber yield without widespread destruction is *strip cutting* (Figure 8-8c). 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 above the first, and so on.

Some Forest Fires Are Beneficial

Two types of fires can affect forest ecosystems. *Surface fires* (Figure 8-11, left, p. 158) usually burn only undergrowth and leaf litter on the forest floor. They may kill seedlings and small trees but 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 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 control pathogens and insects. In addition, wildlife species such as deer, moose, elk, muskrat, woodcock, and quail depend on occasional surface fires to maintain their habitats and provide food in the form of vegetation that sprouts after fires.

Some extremely hot fires, called *crown fires* (Figure 8-11, right), may start on the ground but eventually burn whole trees and leap from treetop to treetop. They usually occur in forests that have not experienced surface fires for several decades, which 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.

We Can Improve the Management of Forest Fires

In the United States, the Smokey Bear educational campaign undertaken by the Forest Service and the National Advertising Council has prevented countless forest fires. It has also saved many lives and prevented billions of dollars in losses of trees, wildlife, and human structures.

At the same time, this educational program has convinced much of the public that all forest fires are bad and should be prevented or put out. Ecologists warn that trying to prevent all forest fires increases the likelihood of destructive crown fires by allowing accumulation of highly flammable underbrush and smaller trees in some forests.

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*

David J. Moorhead/The University of Georgia

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Figure 8-11 Surface fires (left) usually burn undergrowth and leaf litter on a forest floor. They can help prevent more destructive crown fires (right) by removing flammable ground material. They also recycle nutrients and thus help maintain the productivity of a variety of forest ecosystems. Sometimes carefully controlled surface fires are deliberately set to prevent buildup of flammable ground material in forests. **Question:** What is another way in which a surface fire might benefit a forest?

fires require careful planning and monitoring to keep them from getting out of control.

A second 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. In addition, a 2006 study by U.S. forest researchers found that thinning forests without using prescribed burning to remove the accumulated brush and deadwood from the thinning can greatly increase fire damage.

Despite such warnings from scientists, the U.S. Congress under lobbying pressure from timber companies passed the 2003 *Healthy Forests Restoration Act.* It allows timber companies to cut down economically valuable medium-size and large trees in 71% of the country's national forests in return for clearing away smaller, more fire-prone trees and underbrush and

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, economic, and social 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 cutting has not exceeded long-term forest regeneration; roads and harvesting systems have not caused unreasonable ecological damage; soils are not damaged; downed wood (boles) and standing dead trees (snags) are left to provide wildlife habitat; and the company is a good employer and a good steward of its land and water resources.

According to the FSC, between 1995 and 2005, the area of forests that meets its international certification standards grew tenfold. Of the 65 countries with FSC-certified forests, those with the largest areas of such forests are, in order, Sweden, Poland, the United States, and Canada. Despite this progress, by 2005 only about 6% of the world's forested area was certified.

Critical Thinking

Should governments provide tax breaks for sustainably grown timber to encourage this practice? Explain.

without conducting prescribed burns after completing the thinning process. This law also exempts most thinning projects from environmental reviews currently required by forest protection laws in the national forests. According to many ecologists and forest experts, this program paid for by taxpayers will significantly increase fire damage.

Another fire management 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 fourth approach is to protect houses or 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.

Forest fires in the United States have increased significantly over the past 15 years, and according to a 2006 evaluation by about 1,000 scientists and forestry officials, are likely to get much worse because of drying caused by global warming. Such burning in turn will lead to greater warming and more wildfires in a runaway positive feedback cycle.

We Can Manage Forests More Sustainably

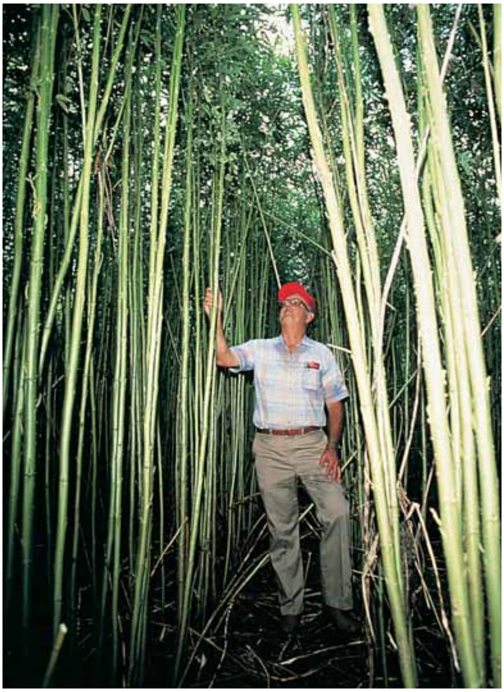
Biodiversity researchers and a growing number of foresters have called for more sustainable forest management. Figure 8-12 lists ways to achieve this goal.

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 8-12 Ways to manage forests more sustainably (**Concept 8-2**). **Question:** Which three of these solutions do you think are the most important? Why?



U.S. Department of Agriculture

Figure 8-13 **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.

One way is to certify sustainably grown timber (Science Focus, at left). Another way to sustain forests is to require that trees are harvested no faster than they are replenished (**Concept 8-2**). **GREEN CAREER:** Sustainable forestry

THINKING ABOUT

Gray Wolves and More Sustainable Forests

CORE CASE STUDY

What is the connection between introducing gray wolves into the Yellowstone ecosystem (**Core Case Study**) and the sustainability of some of its forests?

One reason for cutting trees is to provide pulp for making paper. We could reduce the pressure to harvest trees for this purpose by making paper out of fiber that does not come from trees. China uses tree-free pulp from rice straw and other agricultural residues to make almost two-thirds 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 8-13). Kenaf and many other non-tree fibers yield more paper pulp per unit of land area than tree farms and require fewer pesticides and herbicides.

It is estimated, that within two to three decades we could essentially eliminate the need to use trees to make paper. However, while timber companies successfully lobby for government subsidies to grow and harvest trees to make paper, there are no major lobbying efforts or subsidies for producing paper from kenaf.

8-3 How Serious Is Tropical Deforestation and How Can It Be Reduced?

CONCEPT 8-3 We can reduce tropical deforestation by protecting large forest areas, teaching settlers about sustainable agriculture and forestry, using government subsidies that encourage sustainable forest use, reducing poverty, and slowing population growth.

Tropical Forests Are Disappearing Rapidly

Tropical forests 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, with most of these losses taking place since 1950.

Herbert Giradet/Peter Arnold, Inc.

Figure 8-14 **Natural capital degradation:** each year, large areas of tropical forest in Brazil's Amazon basin are burned to make way for cattle ranches, small-scale farms, and plantation crops. According to a 2003 study by NASA, the Amazon is slowly getting drier due to this practice. If this trend continues, it will prevent the restoration of forest by secondary ecological succession and convert a large area of these tropical forests to grasslands (savanna). **Questions:** What are three ways in which your lifestyle probably contributes to this process? How, in turn, might this process affect your life?

Studies indicate that at least half of the world's known species of terrestrial plants and animals live in tropical rain forests. Because of their specialized niches (**Concept 4-3**, p. 68 and Figure 5-16, p. 89) these species are highly vulnerable to extinction when their forest habitats are cleared or degraded.

CONCEPT LINK

A 2006 study by the U.S. National Academy of Sciences found that between 1990 and 2005 Brazil and Indonesia led the world in tropical forest loss. Brazil has about 40% of the world's remaining tropical rain forest and an estimated 30% of the world's terrestrial plant and animal species in its vast Amazon basin, which covers an area larger than India. According to Brazil's government and forest experts, the percentage of its basin that had been deforested or degraded increased from 1% in 1970 to 16–20% by 2005.

However, in 2004 a leading Brazilian environmental group, Imazon, reported that satellite photos show that land occupation and deforestation covers some 47% of Brazil's Amazon basin. Large-scale burning of the forests (Figure 8-14) to clear large tracts for agriculture destroys and degrades their astounding biodiversity and accounts for three-fourths of Brazil's greenhouse gas emissions.

Estimates of global tropical forest loss vary because of the difficulty of interpreting satellite images and because of different definitions of forest and deforestation. Also, some countries hide or exaggerate deforestation rates for political and economic reasons.

Because of these factors, estimates of global tropical forest loss vary widely from 50,000 square kilometers (19,300 square miles) to 170,000 square kilometers (65,600 square miles) per year. This rate is high enough to represent loss or degradation of half of the world's remaining tropical forests in 35–117 years. A 2005 survey found that less than 5% of the world's tropical forests are managed sustainably. Most of the world's tropical forests are likely to disappear within your lifetime, unless immediate and sustained action is taken by governments, businesses, conservation organizations, and individuals to slow this serious loss of biodiversity.

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

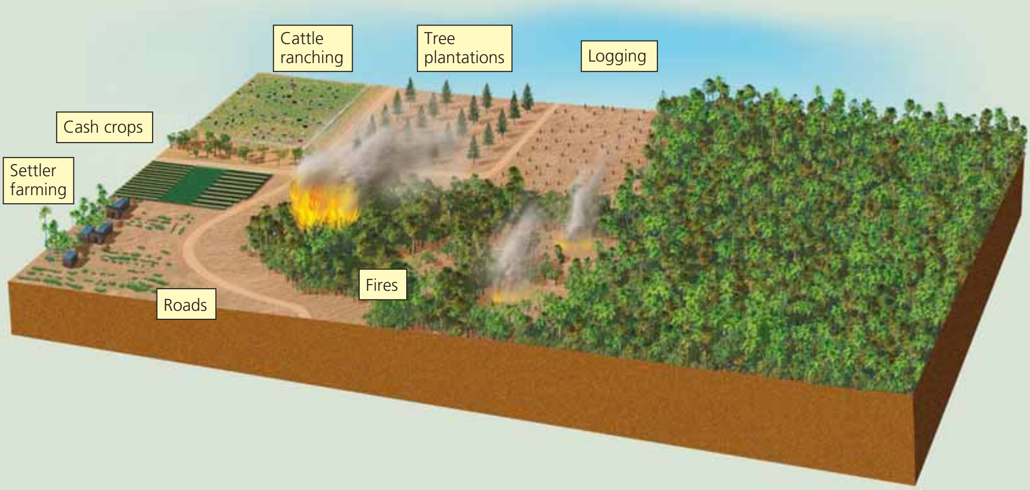


Figure 8-15 Major interconnected causes of the destruction and degradation of tropical forests. The importance of specific secondary causes varies in different parts of the world. **Question:** If we could eliminate the basic causes, which if any of the secondary causes might automatically be eliminated? Why?

RESEARCH FRONTIER

Refining estimates of rates of deforestation

There Are Many Causes of Tropical Deforestation and Degradation

Tropical deforestation results from a number of interconnected primary and secondary causes (Figure 8-15). Population growth and poverty combine to drive subsistence farmers and the landless poor to tropical forests, where they try to grow enough food to survive. Government subsidies can accelerate deforestation by reducing the costs of timber harvesting and cattle grazing.

Governments in Indonesia, Mexico, and Brazil encourage the poor to colonize tropical forests by giving them title to land they clear. This practice can help reduce poverty, but it can also lead to environmental degradation unless the new settlers are taught how to use the forests more sustainably, which is rarely done.

In addition, international lending agencies encourage developing countries to borrow huge sums of money from developed countries to finance projects such as roads, soybean and coffee plantations, mines, logging operations, oil drilling, and dams in tropical forests. Most countries also fail to value the ecological services provided by their forests (Figure 8-3, left).

In some areas—especially in Africa and in Latin America—large sections of tropical forest are cleared

SOLUTIONS

Sustaining Tropical Forests

Prevention	Restoration
Protect the most diverse and endangered areas	Encourage regrowth through secondary succession
Educate settlers about sustainable agriculture and forestry	Rehabilitate degraded areas
Subsidize only sustainable forest use	Concentrate farming and ranching in already-cleared areas
Protect forests with debt-for-nature swaps and conservation easements	
Certify sustainably grown timber	
Reduce poverty	
Slow population growth	

Figure 8-16 Ways to protect tropical forests and use them more sustainably (**Concept 8-3**). **Question:** Which three of these solutions do you think are the most important? Why?

for raising cash crops such as sugarcane, bananas, pineapples, strawberries, soybeans, palm oil for use as a cooking oil and as biodiesel fuel, and coffee mostly for export to developed countries. Tropical forests are also cleared for mining and oil drilling and to build dams on rivers that flood large areas of the forest.

The depletion and degradation of a tropical forest begin when a road is cut deep into the forest interior for logging and settlement (Figure 8-7). Loggers then use selective cutting (Figure 8-8, top) to remove the best timber. This topples many other trees because of their shallow roots and the network of vines connecting trees in the forest's canopy.

After the best timber has been removed, timber companies or the government often sell the land to ranchers. Between 1990 and 2002, for example, the cattle population in Brazil's Amazon more than doubled, according to a 2004 study by the Center for International Forestry Research.

Within a few years, the cattle typically overgraze the land and ranchers sell it to settlers who have migrated to tropical forests hoping to grow enough food to survive. Then the ranchers move their land-degrading operations to another forest area. After a few years of crop growing and erosion from rain, the nutrient-poor tropical soil is depleted of any nutrients. Then the settlers move on to newly cleared land to repeat this environmentally destructive process.

Healthy rain forests do not burn. But increased burning (Figure 8-14), logging, settlements, grazing, and farming along roads built in these forests results in patchy fragments of forest (Figure 8-7, right), which dry out and are readily ignited and burned by farmers and ranchers. Burning forests destroys and degrades biodiversity and reduces the ability of forests to remove carbon dioxide from the air. Even worse, burning forests *adds* large amounts of carbon dioxide to the atmosphere, further accelerating climate change from global warming.

A 2005 study by forest scientists found that widespread burning of tropical forest areas in the Amazon is changing weather patterns by raising temperatures and reducing rainfall. This is converting deforested areas into tropical grassland (savanna). Models project that if current burning and deforestation rates continue, 20–30% of the Amazon will turn into savanna in the next 50 years.

THINKING ABOUT
Tropical Forests

Why should you care if most of the world's remaining tropical forests are cleared and converted to savanna within your lifetime? What are three things you could do help slow this process?

We Can Reduce Tropical Deforestation and Degradation

Analysts have suggested various ways to protect tropical forests and use them more sustainably (Figure 8-16).

One way is to help new settlers in tropical forests learn how to practice small-scale sustainable agriculture and forestry. Another is to harvest some of the renewable resources such as fruits and nuts in rain forests on a sustainable basis. Strip-cutting (Figure 8-8c) can also be used to harvest tropical trees for lumber.

Debt-for-nature swaps can make it financially attractive for countries to protect their tropical forests. In such swaps, participating countries act as custodians of protected forest reserves in return for foreign aid or debt relief. In a similar newer strategy called *conservation concession,* a government or a private conservation organization pays nations for concessions that preserve their natural resources.

Loggers can also use gentler methods for harvesting 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. In addition, governments and individuals can mount efforts to reforest and rehabilitate degraded tropical forests and watersheds (see Individuals Matter, at right) and clamp down on illegal logging.

INDIVIDUALS MATTER

Wangari Maathai and Kenya's Green Belt Movement

Starting with a small tree nursery in her backyard, Wangari Maathai (Figure 8-A) founded the Green Belt Movement in the African country of Kenya in 1977.

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 to combat deforestation and provide fuelwood. By 2004, the 50,000 members of this grassroots group had 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 break the cycle of poverty. It also improves the environment because trees reduce soil erosion and provide fuel, building materials, fruits, fodder for livestock, shade, and beauty. Such environmental improvement can reduce the distances women and children have to walk to get fuelwood for cooking and heating. The success of this project has sparked the creation of similar programs in more than 30 other African countries.

Figure 8-A 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. For her work in protecting the environment, she has received many honors, including the Goldman Prize, the Right Livelihood Award, the UN Africa Prize for Leadership, and the 2004 Nobel Peace Prize. 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. In 2003, she was appointed Assistant Minister for Environment, Natural Resources, and Wildlife.

This inspiring leader has said,

I don't really know why I care so much. I just have something inside me that tells me that there is a problem and I have got to do something about it. And I'm sure it's the same voice that is speaking to everyone on this planet, at least everybody who seems to be concerned about the fate of the world, the fate of this planet.

In 2004, she 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, Maathai planted a tree. In her speech accepting the award she urged everyone in the world to plant a tree as a symbol of commitment and hope. In 2006, she launched a project to plant a billion trees worldwide to help fight poverty and climate change.

8-4 How Should We Manage and Sustain Grasslands?

CONCEPT 8-4 We can sustain the productivity of rangeland by controlling the number and distribution of livestock and by restoring degraded rangeland.

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 maintaining biodiversity.

After forests, grasslands are the ecosystems most widely used and altered by human activities. **Rangelands** are unfenced grasslands in temperate and tropical climates that supply *forage,* or vegetation, for grazing (grass-eating) and browsing (shrub-eating) animals. Cattle, sheep, and goats graze on about 42% of the world's rangeland. The 2005 Millennium Ecosystem Assessment estimated that continuing on our present course will increase that percentage to 70% by 2050. Livestock also graze in **pastures**—managed grasslands or enclosed meadows usually planted with domesticated grasses or other forage.

Blades of rangeland grass grow from the base, not the tip. Thus, as long as only its upper half is eaten and its lower half remains, rangeland grass is a renewable resource that can be grazed again and again.

Overgrazing occurs when too many animals graze for too long and exceed the carrying capacity of a grassland area (See photo 10, p. x). 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 or cannot eat. Limited data from U.N. surveys in various countries indicate that overgrazing by livestock has caused as much as a fifth of the world's rangeland to lose productivity.

U.S. Bureau of Land Management

U.S. Bureau of Land Management

Figure 8-17 **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 the banning of grazing and off-road vehicles (**Concept 8-4**).

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 8-4**). One way of doing this is *rotational grazing* in which cattle are confined by portable fencing to one area for a short time (often only 1–2 days) and then moved to a new location.

Livestock tend to aggregate around natural water sources, especially thin strips of lush vegetation along streams or rivers known as *riparian zones,* and around ponds established to provide water for livestock. Overgrazing by cattle can destroy the vegetation in such areas (Figure 8-17, left). Protecting overgrazed land from further grazing by moving livestock around and by fencing off these areas can eventually lead to its natural ecological restoration (Figure 8-17, right).

A more expensive and less widely used method of rangeland management is to suppress the growth of unwanted invader plants by herbicide spraying, mechanical removal, or controlled burning. A cheaper way to discourage unwanted vegetation in some areas is controlled, short-term trampling by large numbers of livestock.

Replanting barren areas with native grass seeds and applying fertilizer can increase growth of desirable vegetation and reduce soil erosion. But this is an expensive way to restore severely degraded rangeland.

8-5 How Should We Manage and Sustain Parks and Nature Reserves?

CONCEPT 8-5 Sustaining biodiversity will require protecting much more of the earth's remaining undisturbed land area, starting with the most endangered biodiversity hot spots.

National Parks Face Many Environmental Threats

Today, more than 1,100 national parks, each larger than 10 square kilometers (4 square miles), are located in more than 120 countries (see Figure 5-17, p. 90). However, according to a 1999 study by the World Bank and the Worldwide Fund for Nature, only 1% of the parks in developing countries are protected.

Local people invade most parks in developing countries in search of wood, cropland, game animals, and other natural products for their daily survival. Loggers, miners, and wildlife poachers (who kill animals to obtain and sell items such as rhino horns, elephant tusks, and furs) also operate in many of these parks. Park services in these countries typically have too little money and too few personnel to fight these invasions, either by force or through education.

Another problem is that most national parks are too small to sustain many large animal species. Also, many parks suffer ecological disruption from invasion by nonnative species.

There Are Heavy Stresses on U.S. National Parks

The U.S. national park system, established in 1912, includes 58 national parks, sometimes called the country's crown jewels. State, county, and city parks supplement these national parks.

Popularity is one of the biggest problems of many national and state parks and other nature reserves in the United States. In some parks and other public lands, noisy and polluting dirt bikes, dune buggies, jet skis, snowmobiles, and other off-road vehicles degrade the aesthetic experience for many visitors, destroy or damage fragile vegetation (Figure 8-18), and disturb wildlife. There is controversy over whether these machines should be allowed in national parks.

Photo courtesy of Kevin Walker

Figure 8-18 **Natural capital degradation:** damage from off-road vehicles in a proposed wilderness area near the U.S. city of Moab, Utah. Such vehicles pollute the air, damage soils and vegetation, threaten wildlife, and degrade wetlands and streams.

> **THINKING ABOUT**
> **National Parks and Off-Road Vehicles**
> Do you support allowing off-road vehicles in national parks? Explain. If you do, what restrictions, if any, would you put on their use?

Many parks suffer damage from the migration or deliberate introduction of nonnative species. European wild boars (imported to the U.S. state of North Carolina in 1912 for hunting) threaten vegetation in parts of the heavily visited Great Smoky Mountains National Park. Nonnative mountain goats in Washington State's Olympic National Park trample native vegetation and accelerate soil erosion.

While nonnative species have moved into parks, many economically valuable native species—some of them threatened or endangered—are killed or removed illegally in almost half of U.S. national parks. On the other hand, an important keystone species, the gray wolf, has been reintroduced into the Yellowstone National Park ecosystem (**Core Case Study**). CORE CASE STUDY

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 affects scenic views in U.S. national parks more than 90% of the time. The country's most frequently visited park, the Great Smoky Mountains National Park in the states of Tennessee and North Carolina, has air quality similar to that of Los Angeles, California. The U.S. General Accounting Office reports that the national parks need at least \$6 billion for long overdue repair of trails, buildings, and other infrastructure.

Figure 8-19 (p. 166) lists suggestions made by various analysts for sustaining and expanding the national park system in the United States.

Nature Reserves Occupy Only a Small Part of the Earth's Land

Currently, 12% of the earth's land area is protected strictly or partially in nature reserves, parks, wildlife refuges, wilderness, and other areas. The 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 us,* and most of the remaining area consists of ice, tundra, or desert—places where we do not want to live. (See the maps in Figure 3 on pp. S16–S17 and Figure 6 on p. S20 in Supplement 4.)

Conservation biologists call for full protection of at least 20% of the earth's land area in a global system of biodiversity reserves that includes multiple examples of all the earth's biomes (**Concept 8-5**). But powerful economic and political interests oppose doing this.

SOLUTIONS

National Parks

- Integrate plans for managing parks and nearby federal lands
- Add new parkland near threatened parks
- Buy private land inside parks
- Locate visitor parking outside parks and use shuttle buses for entering and touring heavily used parks
- Increase federal funds for park maintenance and repairs
- Raise entry fees for visitors and use funds for park management and maintenance
- Seek private donations for park maintenance and repairs
- Limit the number of visitors to crowded park areas
- Increase the number of park rangers and their pay
- Encourage volunteers to give visitor lectures and tours

Figure 8-19 Suggestions for sustaining and expanding the national park system in the United States. **Question:** Which two of these solutions do you think are the most important? Why? (Based on data from Wilderness Society and National Parks and Conservation Association)

Protecting more of the earth's land from unsustainable use will require action and funding by national governments and private groups, bottom-up political pressure by concerned individuals, and cooperative ventures involving governments, businesses, and private conservation groups. Private groups play an important role in establishing wildlife refuges and other reserves to protect biological diversity. For example, since its founding by a group of professional ecologists in 1951, the *Nature Conservancy*—with more than 1 million members worldwide—has created the world's largest system of private natural areas and wildlife sanctuaries in 30 countries.

In the United States, efforts by the Nature Conservancy and private landowners have protected land, waterways, and wetlands in local and state trusts totaling roughly the same size as the U.S. state of Georgia. Between 2000 and 2005, there was a 54% increase in the area of land protected by such private trusts.

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 economic growth. Ecologists and conservation biologists disagree. They view protected areas as islands of biodiversity that help sustain all life and economies and serve as centers of future evolution and that provide ecological services whose value greatly exceeds their short-term economic value (Science Focus, p. 153). See the Guest Essay on this topic by Norman Myers at ThomsonNOW™.

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.thomsonedu.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 by establishing two buffer zones in which local people can extract resources sustainably without harming the inner core. This includes enlisting local people as partners in protecting a reserve from unsustainable uses. The United Nations has used this principle in creating its global network of 425 biosphere reserves in 95 countries (Figure 8-20).

So far, most biosphere reserves fall short of the ideal and receive too little funding for their protection and management. An international fund to help make up the shortfall would cost about what the world's nations spend on weapons every 90 minutes.

CASE STUDY

Costa Rica—A Global Conservation Leader

Tropical forests once completely covered Central America's Costa Rica, which is smaller in area than the U.S. state of West Virginia and about one-tenth the size of France. Between 1963 and 1983, politically powerful ranching families cleared much of the country's forests to graze cattle.

Despite such widespread forest loss, tiny Costa Rica is a superpower of biodiversity. 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 2006 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 8-21). Each reserve contains a protected inner core surrounded by two buffer zones that local and indigenous people can use for sustainable logging, food growing, cattle grazing, hunting, fishing, and eco-tourism.

Costa Rica's biodiversity conservation strategy has paid off. Today, the country's largest source of income is its $1-billion-a-year tourism business, almost two-thirds of which involves eco-tourism. **GREEN CAREER:** Eco-tourism guide

To reduce deforestation, the government has eliminated subsidies for converting forest to cattle grazing land. It also pays landowners to maintain or restore tree coverage. The goal is to make sustaining forests profitable. This economic strategy has worked: Costa

Biosphere Reserve

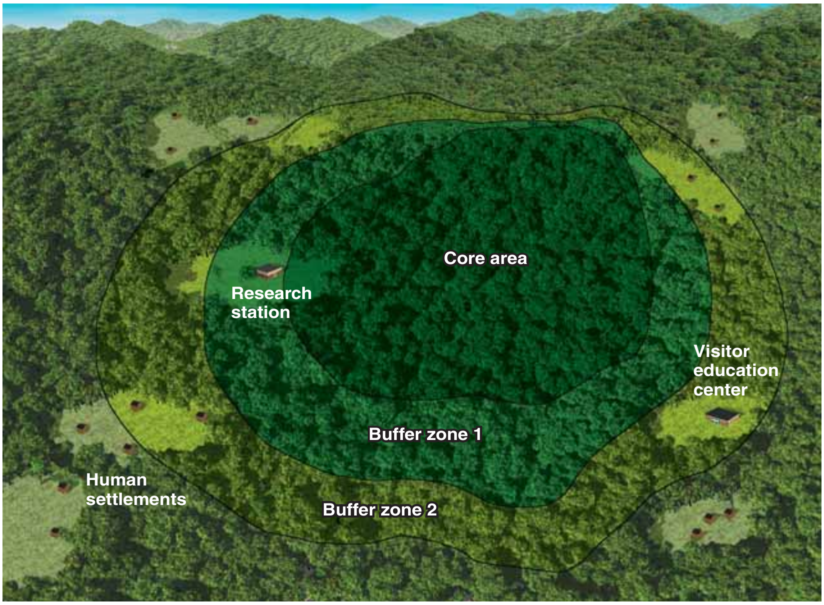


Figure 8-20 A model *biosphere reserve.* Each reserve contains a protected inner core surrounded by two buffer zones that local and indigenous people can use for sustainable logging, food growing, cattle grazing, hunting, fishing, and eco-tourism. **Question:** Do you think some of these reserves should be free of all human activity, including eco-tourism? Why or why not?

Rica has gone from having one of the world's highest deforestation rates to having one of the lowest.

Protecting Wilderness Is an Important Way to Preserve Biodiversity

One way to protect undeveloped lands from human exploitation is by setting them aside legally as undeveloped land called **wilderness** (**Concept 8-5**). Hikers and campers can visit such areas but they cannot stay. U.S. President Theodore Roosevelt (Figure 4 on p. S25 in Supplement 5) summarized what we should do with wilderness: "Leave it as it is. You cannot improve it."

The U.S. Wilderness Society estimates that a wilderness area should contain at least 4,000 square kilometers (1,500 square miles). Otherwise, it can be affected by air, water, and noise pollution from nearby human activities.

In such wild areas, people can experience the beauty of nature and observe natural biological diversity. They can also enhance their mental and physical health by getting away from noise, stress, developed areas, and large numbers of people. Even those who never use the wilderness areas may want to know they are there, a feeling expressed by U.S. novelist Wallace Stegner:

> *Save a piece of country . . . and it does not matter in the slightest that only a few people every year will go into it. This is precisely its value. . . . We simply need that wild country available to us, even if we never do more than drive to its edge and look in. For it can be a means of reassuring ourselves of our sanity as creatures, a part of the geography of hope.*

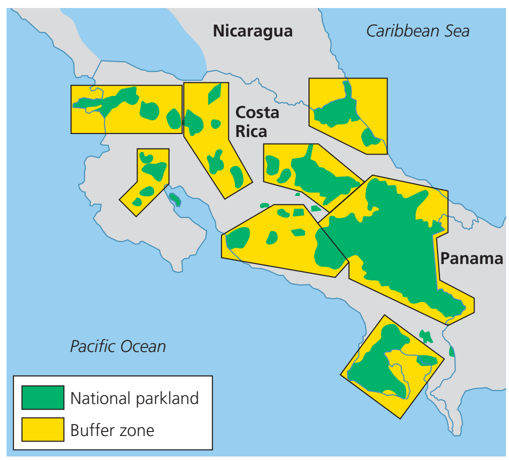


Figure 8-21 **Solutions:** Costa Rica has consolidated its parks and reserves into eight zoned *megareserves* designed to sustain about 80% of the country's rich biodiversity. Green areas are protected reserves and yellow areas are nearby buffer zones, which can be used for sustainable forms of forestry, agriculture, hydropower, hunting, and other human activities.

Some critics oppose protecting wilderness for its scenic and recreational value for a small number of people. They believe this is an ideal that keeps some areas of the planet from being economically useful to people here today.

To most biologists, the most important reasons for protecting wilderness and other areas from exploitation and degradation are to *preserve their biodiversity* as a vital part of the earth's natural capital and to *protect them as centers for evolution* in response to mostly unpredictable changes in environmental conditions. In other words, wilderness serves as a biodiversity bank and an eco-insurance policy.

Some analysts also believe wilderness should be preserved because the wild species it contains have a right to exist and play their roles in the earth's ongoing saga of biological evolution and ecological processes, without human interference.

■ **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 (Figure 6 on p. S27 in Supplement 5). 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 2000. 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 have protected only 2% as wilderness. According to a 1999 study by the World Conservation Union, the United States ranks 42nd among nations in terms of terrestrial area protected as wilderness, and Canada is in 36th place.

In addition, only 4 of the 413 wilderness areas in the lower 48 states are larger than 4,000 square kilometers (1,500 square miles). Also, the system includes only 81 of the country's 233 distinct ecosystems. Most wilderness areas in the lower 48 states are threatened habitat islands in a sea of development.

Almost 400,000 square kilometers (150,000 square miles) in scattered blocks of public lands could qualify for designation as wilderness—about 60% of it in the national forests. For over 20 years, these areas have been temporarily protected under the Roadless Rule while they were evaluated for wilderness protection.

For decades, politically powerful oil, gas, mining, and timber industries have sought entry to these areas, owned jointly by all citizens of the United States, to develop resources for increased profits and short-term economic growth. Their efforts paid off in 2005 when the Secretary of the Interior ceased protecting roadless areas under consideration for classification as wilderness within the national forest system. The Secretary of the Interior also began allowing states to classify old cow paths and off-road vehicle trails as roads, which would disqualify their surrounding areas from protection as wilderness.

Protecting Global Biodiversity Hot Spots Is an Urgent Priority

The earth's species are not evenly distributed. In fact, 17 megadiversity countries (see the map in Figure 2 on p. S14–S15 in Supplement 4), most of them with large areas of tropical forests, contain more than two-thirds of all species. The leading megadiversity country is Indonesia, followed by Colombia, Mexico, Brazil, and Ecuador. Most of the rich developed countries (except Australia) are biodiversity poor, while many of the poor developing countries are biodiversity rich.

To protect as much of the earth's remaining biodiversity as possible, conservation biologists have used an *emergency action* strategy to identify and quickly protect *biodiversity hot spots* (**Concept 8-5**)—an idea first proposed by environmental scientist Norman Myers. (See his Guest Essay on this topic at ThomsonNOW.) These "ecological arks" are areas especially rich in plant and animal species that are found nowhere else and are in great danger of extinction or serious ecological disruption, mostly because of rapid human population growth and the resulting pressure on natural resources.

Figure 8-22 shows 34 global terrestrial hot spots and Figure 8-23 shows such hotspots in the United States. They cover only a little over 2% of the earth's land surface but contain 50% of the world's flowering plant species and 42% of all terrestrial vertebrates (mammals, birds, reptiles, and amphibians). These areas are also the only homes for more than one-third of the planet's known terrestrial plant and animal species. According to the International Union for the Conservation of Nature, they are also home for a large majority of the world's endangered or critically endangered species, including 92% of the earth's amphibians, 86% of the birds, and 72% of the mammals. Says Norman Myers, "I can think of no other biodiversity initiative that could achieve so much at a comparatively small cost, as the hot spots strategy."

Identifying and protecting hotspots is very important. But conservation biologists warn that it will not be enough for the long run if we do not work to sustain much more of the world's entire fabric of biodiversity.

ThomsonNOW™ Learn more about hot spots around the world, what is at stake there, and how they are threatened at ThomsonNOW.

RESEARCH FRONTIER

Identifying and preserving all of the world's terrestrial and aquatic biodiversity hotspots

ThomsonNOW™ Active Figure 8-22 Endangered natural capital: 34 *hot spots* identified by ecologists as important and endangered centers of terrestrial biodiversity that contain a large number of endemic plant and animal species found nowhere else. Identifying and saving these critical habitats is a vital emergency response (**Concept 8-5**). *See an animation based on this figure at* ThomsonNOW. **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)

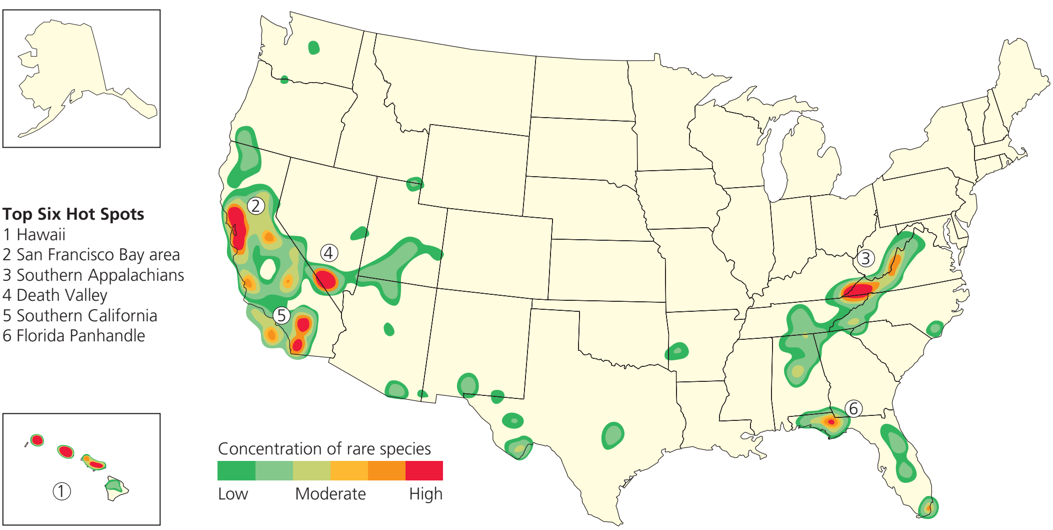


Figure 8-23 Endangered natural capital: biodiversity hot spots in the United States that need emergency protection. The shaded areas contain the largest concentrations of rare and potentially endangered species. Compare these areas with those on the map of the human ecological footprint in North America shown in Figure 7 on p. S20–S21 in Supplement 4. **Question:** Do you think that hotspots near urban areas would be harder to protect than those in rural areas? Explain. (Data from State Natural Heritage Programs, the Nature Conservancy, and Association for Biodiversity Information)

8-6 What Is the Importance of Restoration Ecology?

CONCEPT 8-6 Sustaining biodiversity will require a global effort to rehabilitate and restore damaged ecosystems.

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. Much of the harm we have inflicted on nature is at least partially reversible through **ecological restoration:** the process of repairing damage caused by humans to the biodiversity and dynamics of natural ecosystems. Examples include replanting forests, restoring grasslands, restoring wetlands and stream banks, reclaiming urban industrial areas (brownfields), reintroducing native species (**Core Case Study**), removing invasive species, and freeing river flows by removing dams.

CORE CASE STUDY

Evidence indicates that in order to sustain biodiversity, we must make a global effort, on as much land area as possible, to rehabilitate and restore ecosystems we have damaged (**Concept 8-6**). An important strategy is to mimic nature and natural processes and ideally let nature do most of the work, usually through secondary ecological succession (Figure 6-9, p. 116).

Scientists are learning how to speed up repair operations using a variety of approaches. They include the following measures:

- *Restoration:* returning a particular degraded habitat or ecosystem to a condition as similar as possible to its natural state.
- *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 areas such as mining sites, landfills, and clear-cut forests.
- *Replacement:* replacing a degraded ecosystem with another type of ecosystem. For example, a productive pasture or tree farm may replace a degraded forest.
- *Creating artificial ecosystems:* for example, creating artificial wetlands to help reduce flooding or to treat sewage.

Researchers have suggested four science-based principles for carrying out most forms of ecological restoration and rehabilitation.

- Identify what caused the degradation (such as pollution, farming, overgrazing, mining, or invading species).
- Stop the abuse by eliminating or sharply reducing these factors. For example, remove toxic soil pollutants or eliminate disruptive nonnative species.
- If necessary, reintroduce species—especially pioneer, keystone, and foundation species—to help restore natural ecological processes, as was done with wolves in the Yellowstone area (**Core Case Study**).
- Protect the area from further degradation (Figure 8-17, right).

CORE CASE STUDY

■ CASE STUDY
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 8-21), a small tropical dry forest has been burned, degraded, and fragmented by large-scale conversion to cattle ranches and farms.

Now it is being restored and relinked to the rain forest on adjacent mountain slopes. The goal is to eliminate damaging nonnative grass and reestablish a tropical dry tropical forest ecosystem over the next 100–300 years.

Daniel Janzen, professor of biology at the University of Pennsylvania and a leader in the field of restoration ecology, helped galvanize international support for this restoration project. He used his own MacArthur grant money to purchase this Costa Rican land to be set aside as a national park. He also raised more than $10 million for restoring the park.

Janzen realized that large native animals that ate the fruit of the Guanacaste tree and spread its seeds in their droppings maintained the original forests. But these animals disappeared about 10,000 years ago. About 500 years ago, horses and cattle introduced by Europeans spread the seeds, but farming and ranching took their toll on the forest's trees. Janzen decided to speed up restoration of this tropical dry forest by incorporating limited numbers of horses and cattle as seed dispersers in his recovery plan.

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 have the nearly 40,000 people who live near the park play an essential role in the restoration of the degraded forest, a concept he calls *biocultural restoration.*

By actively participating in the project, local residents reap educational, economic, and environmental benefits. Local farmers 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.

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 are 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 protect largely intact ecosystems from unsustainable use.

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 sustainable 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 8-24 **Individuals matter:** ways to help sustain terrestrial biodiversity. **Questions:** Which two of these actions do you think are the most important? Why? Which of these things do you do?

Will Restoration Encourage Further Destruction?

Some analysts worry that ecological restoration could encourage continuing environmental destruction and degradation by suggesting that any ecological harm we do can be undone. Restoration ecologists disagree. They point out that the suggestion is not accurate and that preventing ecosystem damage in the first place is cheaper and more effective than any form of ecological restoration.

Restoration scientists point out that so far we have been able to protect or preserve only about 5% of the earth's land from the effects of human activities, so ecological restoration is badly needed for many of the world's ecosystems. They also point out that if a restored ecosystem differs from the original system, it is better than no restoration at all.

HOW WOULD YOU VOTE?

Should we mount a massive effort to restore ecosystems we have degraded even though this will be quite costly? Cast your vote online at **www.thomsonedu.com/biology/miller**.

Figure 8-24 lists some ways you can help sustain the earth's terrestrial biodiversity.

8-7 How Can We Help Sustain Aquatic Biodiversity?

CONCEPT 8-7 We can sustain aquatic biodiversity by establishing protected sanctuaries, managing coastal development, reducing water pollution, and preventing overfishing.

We Need to Learn Much More about Aquatic Biodiversity

Although we live on a watery planet (Figure 5-19, p. 92), we have explored only about 5% of the earth's global ocean and know relatively little about its biodiversity and how it works. We also have limited knowledge about freshwater biodiversity.

However, scientists have established three general patterns of marine biodiversity. *First,* the greatest marine biodiversity occurs in coral reefs, estuaries, and the deep-ocean floor. *Second,* biodiversity is higher near coasts than in the open sea because of the greater variety of producers and habitats in coastal areas. *Third,* biodiversity is higher in the bottom region of the ocean than in the surface region because of the greater variety of habitats and food sources on the ocean bottom.

Intensive scientific investigation of marine and freshwater aquatic systems could result in immense ecological and economic benefits. Marine systems provide a variety of important ecological and economic services (Figure 5-21, p. 94). Freshwater systems also provide important ecological and economic services (Figure 5-28, p. 100). A very conservative estimate of the value of their ecological services is $1.7 trillion a year—an average of $3.2 million a minute—which is rarely included in the market prices of goods and services derived from or dependent on aquatic biodiversity.

Human Activities Are Destroying and Degrading Aquatic Biodiversity

Human activities have destroyed or degraded a large proportion of the world's coastal wetlands, coral reefs, mangroves, and ocean bottom, and disrupted many of the world's freshwater ecosystems.

Also, since 1989, we have removed more than a third of the world's ecologically important mangrove forests (Figure 5-20, p. 93) to make way for shrimp farms and other uses. More mangrove forests will be flooded and lost as sea levels rise from global warming. In addition, more than half of the world's coastal wetlands (Figure 5-23, p. 95), which serve as key nurseries for commercially important fish and shellfish, have disappeared primarily because of human development.

Many sea-bottom habitats are being degraded and destroyed by dredging operations and trawler fishing boats, which, like giant submerged bulldozers, drag huge nets weighted down with heavy chains and steel plates over ocean bottoms to harvest bottom fish and shellfish (Figure 8-25). 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 scientists 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. The 2005 Millennium Ecosystem Assessment reported that the amount of water held behind dams is currently three to six times the amount that flows in natural rivers. In addition, we have greatly increased the amount of water we withdraw each year from rivers and lakes (mostly for agriculture). Dams and excessive water withdrawal destroy aquatic habitats and water flows and disrupt freshwater biodiversity.

According to ocean experts at the 2006 Third Global conference on Oceans, Coasts, and Islands, about 75% of the world's 200 commercially valuable marine fish species (40% in U.S. waters) are either overfished or fished to their estimated sustainable yield. 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 extinction within your lifetime. Indeed, *marine and freshwater fish are threatened with extinction by human activities more than any other group of species.*

RESEARCH FRONTIER

Learning more about how aquatic systems work and how human activities affect aquatic biodiversity

We Can Protect and Sustain Marine Biodiversity

Protecting marine biodiversity is difficult for several reasons. *First,* the human ecological footprint (Figure 1-8, p. 13) is 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 re-

Figure 8-25 **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?

source that can absorb an almost infinite amount of waste and pollution.

Finally, most of the world's ocean area lies outside the legal jurisdiction of any country. Thus, it is an open-access resource, subject to overexploitation.

Nevertheless, there are several ways to protect and sustain marine biodiversity (**Concept 8-7**). For example, we can *protect endangered and threatened aquatic species,* as discussed in Chapter 9. We can also *establish protected marine sanctuaries.* Since 1986, the IUCN has helped establish a global system of *marine protected areas* (MPAs)—areas of ocean partially protected from human activities. There are 1,300 MPAs, almost 200 of them in U.S. waters. However, nearly all MPAs allow dredging, trawler fishing, and other potentially harmful resource extraction activities.

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 two to four years after strict protection begins.

We can also establish *integrated coastal management* in which fishers, scientists, conservationists, citizens, business interests, developers, and politicians collaborate to identify shared problems and goals. Then they attempt to build social capital (p. 18) by developing workable and cost-effective solutions that preserve biodiversity and environmental quality while meeting economic and social needs. 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.

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 8-26 Ways to manage fisheries more sustainably and protect marine biodiversity (**Concept 8-7**). **Question:** Which four of these solutions do you think are the most important? Why?

Figure 8-26 lists some ways to manage global fisheries more sustainably and to protect marine biodiversity (**Concept 8-7**). Most of these approaches rely on some sort of government regulation.

8-8 What Should Be Our Priorities for Protecting Biodiversity?

CONCEPT 8-8 Sustaining the world's biodiversity requires mapping terrestrial and aquatic biodiversity, protecting terrestrial and aquatic hotspots and old-growth forests, initiating ecological restoration projects worldwide, and making conservation profitable.

We Need to Establish Priorities for Protecting Biodiversity

In 2002, Edward O. Wilson, considered to be one of the world's foremost experts on biodiversity, proposed the following priorities for protecting most of the world's remaining ecosystems and species (**Concept 8-8**):

- Complete the mapping of the world's terrestrial and aquatic biodiversity so we know what we have and can make conservation efforts more precise and cost-effective.
- Take immediate action to identify and preserve the world's terrestrial (Figures 8-22 and 8-23) and aquatic biological hot spots.

- Keep intact the world's remaining old-growth forests and cease all logging of such forests.
- Protect and restore the world's lakes and river systems, which are the world's most threatened ecosystems.
- Initiate ecological restoration projects worldwide to heal some of the damage we have done.
- Make conservation profitable by finding ways to raise the incomes of people who live in or near nature reserves so they can become partners in the protection and sustainable use of the reserves.

According to 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.

This 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 require cooperation among key people in government, the private sector, science, and engineering.

REVISITING Wolves in Yellowstone National Park and Sustainability

CORE CASE STUDY

SUSTAINABILITY

In this chapter we have seen how terrestrial biodiversity is being destroyed and degraded and how threats to aquatic biodiversity are growing and are even greater than threats to terrestrial biodiversity. We know that we could reduce these threats by using terrestrial and aquatic ecosystems more sustainably and by protecting species and ecosystems in a greatly increased network of terrestrial and aquatic nature reserves.

We have also learned the importance of restoring or rehabilitating some of the ecosystems we have degraded. Reintroducing keystone species such as the gray wolf into ecosystems they once inhabited (**Core Case Study**) is a form of ecological restoration that can reestablish some of the ecological functions and interactions in such systems.

Preserving biodiversity involves applying the four scientific **principles of sustainability**, one of which concerns biodiversity itself (see back cover). This means learning about the flows of energy from the sun through food webs, the cycling of nutrients in ecosystems, the species interactions in food webs that help prevent excessive population growth of any one species, and the importance of not disrupting these vital processes.

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 QUESTIONS

1. What have been the consequences of reintroducing wolves into Yellowstone National Park?
2. Discuss how human activities are degrading terrestrial and aquatic biodiversity. Describe the two types of values that researchers assign to the earth's biodiversity.
3. Summarize the ecological and economic services provided by forests. How can forests be managed more sustainably? Explain the role of fires in forest management.
4. Identify the major interconnected causes of the destruction and degradation of tropical forests. Describe ways to protect tropical forests and use them more sustainably.
5. What is the Green Belt Movement and how has it improved the environment and protected Kenya's forests?
6. What are the important ecological services that are provided by grasslands and rangelands? How can these areas be managed more sustainably?
7. Describe the options for sustaining and expanding the national parks system in the United States. Explain why Costa Rica is considered to be a leader in global conservation and protection of biodiversity.
8. Identify seven examples of ecological restoration projects. Describe four measures that can be taken to speed up ecosystem recovery. Explain four science-based principles for carrying out most forms of ecological restoration.
9. How can we protect and sustain aquatic biodiversity? Describe ways to manage fisheries more sustainably and protect marine biodiversity.
10. Discuss the priorities put forward by E.O. Wilson in 2002 for protecting most of the world's remaining ecosystems and species.

CRITICAL THINKING

1. List three ways you could apply **Concept 8-8** to make your lifestyle and that of any children and grandchildren you might have more environmentally sustainable.

2. Do you support the program that reintroduced populations of the gray wolf in the Yellowstone ecosystem in the United States (**Core Case Study**)? Explain. CORE CASE STUDY

3. Explain why you agree or disagree with each of the proposals for providing more sustainable use of forests throughout the world, listed in Figure 8-12, p. 159.

4. 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 his position? Explain your decision.

5. There is controversy over whether Yellowstone National Park in the United States should be accessible by snowmobile during winter. Conservationists and backpackers who use cross-country skis or snowshoes for excursions in the park during winter say no. They contend that snowmobiles are noisy, pollute the air, and can destroy vegetation and disrupt some of the park's wildlife. Proponents who want to use the park say that the snowmobile should be allowed so they can enjoy the park during winter when cars are largely banned. They point out that new snowmobiles with four-stroke engines cut most pollution by 90% and noise by 50%. A compromise would be to allow no more than 950 new four-stroke machines into the park per day, only on roads, and primarily on guided tours. What is your view on this issue? Explain.

6. In 2006, 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. What other part or parts of the federal budget would you decrease to come up with these funds?

7. What do you think are the three greatest threats to aquatic biodiversity? Why are aquatic species overall more vulnerable to premature extinction from human activities than terrestrial species are?

8. If ecosystems are undergoing constant change, why should we **(a)** establish and protect nature reserves and **(b)** carry out ecological restoration?

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)** parks and other nature reserves, and **(c)** aquatic biodiversity.

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

LEARNING ONLINE

Log on to the Student Companion Site for this book at **www.thomsonedu.com/biology/miller** and choose Chapter 8 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Web links, information on Green Careers, and InfoTrac® College Edition articles.

For access to animations and additional quizzing, register and log on to ThomsonNOW! at **www.thomsonedu.com/thomsonnow** using the access code card in the front of your book. You can also explore the **Active Graphing** exercises that your instructor may assign.

9 Sustaining Biodiversity: The Species Approach

CORE CASE STUDY A Disturbing Message from the Birds

Approximately 70% of the world's 9,775 known bird species are declining in numbers. A 2006 review of more than 200 scientific articles by the World Wildlife Fund projected that climate change during this century could drive up to 72% of world's bird species into extinction. The report found that groups of birds with the highest risk from climate change are migratory, mountain, island, wetland, Arctic, Antarctic, and sea birds.

The numbers and distribution of North American bird species that can prosper around humans year-round, such as robins, blackbirds, and starlings, have increased over the last 30 years. At the same time, populations of many forest songbirds have decreased. The greatest decline has occurred among long-distance migrant species such as tanagers, orioles, thrushes, vireos, and warblers that nest in northern forests in the summer and spend their winters in Central or South America or the Caribbean Islands (Figure 9-1).

The primary culprit for these declines appears 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 (Figure 8-7, p. 156) are suffering the same fate.

Conservation biologists view this decline of bird species with alarm. One reason is that birds are excellent *environmental indicators* because they live in every climate and biome, respond quickly to environmental changes in their habitats, and are fairly easy to track and count.

In addition, birds perform a number of important economic and ecological services in ecosystems throughout the world. They help 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 key and 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 become extinct.

Conservation biologists 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.

Figure 9-1 **Threatened natural capital:** Some of the many threatened species of U.S. songbirds are (left to right) the Florida scrub jay, Kirtland's warbler, the black-capped vireo, Bachman's warbler, and Henslow's sparrow.

Key Questions and Concepts

9-1 **What role do humans play in the premature extinction of species?**

CONCEPT 9-1 The current rate of species extinction is at least 100 times the rate that existed before modern humans arrived on earth, and is expected to increase to between 1,000 and 10,000 times the earlier rate during this century.

9-2 **Why should we care about preventing species extinction?**

CONCEPT 9-2 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.

9-3 **How do humans accelerate species extinction?**

CONCEPT 9-3 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.

9-4 **How can we protect wild species from premature extinction resulting from our activities?**

CONCEPT 9-4A We can use existing environmental laws and treaties and work to enact new laws designed to prevent species extinction and to protect overall biodiversity.

CONCEPT 9-4B We can help prevent species extinction by creating and maintaining wildlife refuges, gene banks, botanical gardens, zoos, and aquariums.

9-5 **What is reconciliation ecology?**

CONCEPT 9-5 We can help protect some species from premature extinction by finding ways to share the places we dominate with them.

Note: Supplements 4 and 11 can be used with this chapter.

The last word in ignorance is the person who says of an animal or plant:
"What good is it?" . . . If the land mechanism as a whole is good,
then every part of it is good, whether we understand it or not. . . .
Harmony with land is like harmony with a friend;
you cannot cherish his right hand and chop off his left.

ALDO LEOPOLD

9-1 What Role Do Humans Play in the Premature Extinction of Species?

CONCEPT 9-1 The current rate of species extinction is at least 100 times the rate that existed before modern humans arrived on earth, and is expected to increase to between 1,000 and 10,000 times the earlier rate during this century.

There Are Three Types of Species Extinction

Biologists distinguish among three levels of species extinction. *Local extinction* occurs when a species is no longer found in an area it once inhabited but is still found elsewhere in the world. Most local extinctions involve losses of one or more populations of species.

Ecological extinction occurs when so few members of a species are left that it can no longer play its ecological roles in the biological communities where it is found.

In *biological extinction,* a species is no longer found anywhere on the earth (Figure 9-2, p. 178). Biological extinction is forever and represents a loss of natural capital (**Concept 1-1A**, p. 6). CONCEPT LINK

Endangered and Threatened Species Are Ecological Smoke Alarms

Biologists classify species heading toward biological extinction as either *endangered* or *threatened* (Figure 9-3, p. 179). 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 where it is normally found). A **threatened species** (also known as a vulnerable species) is still abundant in its natural

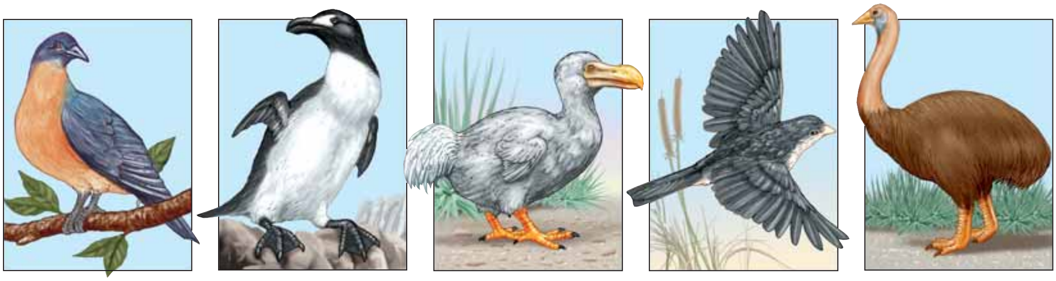


Figure 9-2 **Lost natural capital:** some animal species that have become prematurely extinct largely because of human activities, mostly habitat destruction and overhunting. **Question:** Why do you think birds top the list of extinct species?

range but, because of declining numbers, is likely to become endangered in the near future. Examples are some of the world's bird species (**Core Case Study**, Figure 9-1).

Some species have characteristics that make them especially vulnerable to ecological and biological extinction (Figure 9-4, p. 180). 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 and the Carolina parakeet nested in large flocks that made them easy to kill. Key deer are "nicotine addicts" that get killed by cars because they forage for cigarette butts along highways.

According to the 2005 Millennium Ecosystem Assessment, the current rate of species extinction is at least 100 times the rate that existed before modern humans appeared about 150,000 years ago (**Concept 9-1**). This study and several others found that some types of species were more threatened with premature extinction than others were (Figure 9-5, p. 180).

Estimating Extinction Rates Is Not Easy

An **extinction rate** is expressed as a percentage or number of species that go extinct within a certain time, typically a year. Biologists trying to catalog extinctions and estimate extinction rates have three problems. *First,* the extinction of a species usually takes such a long time that it is not easy to document. *Second,* we have identified only about 1.8 million of the world's estimated 4 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 is to study records documenting the rates at which mammals and birds 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 help track how long a species typically lasts before becoming extinct. Such evidence indicates that under normal circumstances, species survive for 1 million to 10 million years before becoming extinct.

Another way in which biologists project future extinction rates is to observe how the number of species present increases with the size of an area. This *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 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 incomplete models. They are continually striving to get better data and to improve the models used to estimate extinction rates.

RESEARCH FRONTIER

Identifying and cataloguing the millions of unknown species and improving models for estimating extinction rates

Human Activities Cause Many Premature Extinctions

In due time, all species become extinct. Evidence indicates that before humans came on the scene, the earth's estimated natural or *background extinction rate* was roughly one extinct species per million species per year. This amounted to an extinction rate of about 0.0001% per year.

Using the methods just described, biologists conservatively estimate that the current rate of extinction is at least 100 times the background extinction rate, or

Figure 9-3 **Endangered natural capital:** species that are endangered or threatened with premature extinction largely because of human activities. Almost 30,000 of the world's species and 1,260 of those in the United States are officially listed as being in danger of becoming extinct. Most biologists believe the actual number of species at risk is much larger.

0.01% a year. Conservation biologists project that the extinction rate caused by habitat loss, global warming, and other effects of human activities will increase to 1,000–10,000 times the natural rate during this century (**Concept 9-1**). This amounts to an annual extinction rate of 0.1% to 1% per year.

How many species are we likely to lose each year? The answer depends on how many species are on the

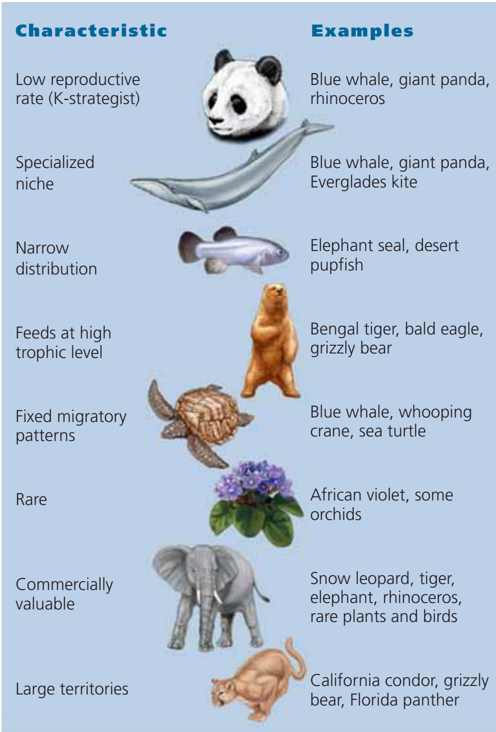


Figure 9-4 Characteristics of species that are prone to ecological and biological extinction.

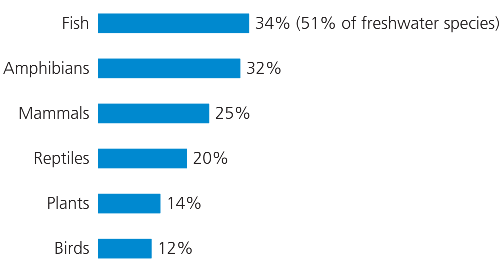


Figure 9-5 **Endangered natural capital:** percentage of various types of species threatened with premature extinction because of human activities (**Concept 9-1**). **Question:** Why do you think fish top this list? (Data from World Conservation Union, Conservation International, World Wide Fund for Nature, 2005 Millennium Ecosystem Assessment, and the Intergovernmental Panel on Climate Change)

earth and the rate of species extinction. Assuming that the extinction rate is 0.1%, we lose 5,000 species per year if there are 5 million species on earth. We lose 14,000 species per year if there are 14 million species—biologists' current best guess. Most biologists would consider the premature loss of 1 million species over 100–200 years to be an extinction crisis that, if it continued, would lead to a mass extinction.

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 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

CORE CASE STUDY

How might your lifestyle change if human activities cause the premature extinction of a third to half of the world's species, such as the bird species in Figure 9-1, in your lifetime? List three aspects of your lifestyle that contribute to this threat to the earth's natural capital.

Most biologists in this field consider extinction rates of 0.01%–1% to be conservative estimates for several reasons. *First,* both the rate of species loss and the extent of biodiversity loss are likely to increase during the next 50–100 years because of the projected growth of the world's human population resource use per person (Figure 1-8, p. 13, and Figure 3 in Supplement 4, pp. S16–S17) and global warming.

Second, current and projected extinction rates are much higher than the global average in parts of the world that are hot spots or highly endangered centers of biodiversity. Conservation biologists urge us to focus our efforts on slowing the much higher rates of extinction in such *hot spots* (Figure 8-22, p. 169, and **Concept 8-5**, p. 164) as the best and quickest way to protect much of the earth's biodiversity from being lost prematurely.

CONCEPT LINK

Third, we are eliminating, degrading, 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 5-3**, p. 91, and **Concept 5-5**, p. 94). Thus, in addition to increasing the rate of extinction, we appear to be limiting the long-term recovery of biodiversity by reducing the rate of speciation for some types of species. In other words, we are creating a *speciation crisis.* (See the Guest Essay on this topic by Normal Myers at ThomsonNOW™.)

CONCEPT LINKS

Philip Levin, Donald Levin, and other biologists also 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. Thus, the real threat to biodiversity from current human activities may be a long-term erosion in the earth's variety of species and habitats. Such a loss of biodiversity would reduce the ability of life to adapt to changing conditions by creating new species.

9-2 Why Should We Care about Preventing Species Extinction?

CONCEPT 9-2 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 losing a few more because of our activities? Does it matter that the bird species in Figure 9-1 (**Core Case Study**), the remaining orangutans (Figure 8-2, p. 152), or some unknown plant or insect in a tropical forest becomes prematurely extinct because of human activities?

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 is: because it will take 5–10 million years for natural speciation to rebuild the biodiversity we are likely to destroy during your lifetime.

Conservation biologists and ecologists say we should act now to prevent premature extinction of species because of their *instrumental value*—their usefulness to us in the form of their economic and ecological services (**Concept 9-2**). For example, some plant species provide economic value in the form of food crops, fuelwood and lumber, paper, and medicine (Figure 9-6). About one of every seven of the world's plant species is in danger of becoming extinct (Figure 9-5), and this percentage is expected to increase.

Another instrumental value is the *genetic information* that allows species to adapt to changing environmental conditions and to form genetically modified species. Genetic engineers use this information to produce new types of crops and foods. Scientists warn of the alarming loss of genetic diversity in the small number of crop plants that feed the world and from the premature extinction of wild plants whose genes are used by genetic engineers to develop improved crop varieties (Figure 4-8, p. 72).

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 named many of the species that are becoming extinct. To make matters worse, we have no clue about their genetic makeup and their roles in sustaining ecosystems and in improving human welfare.

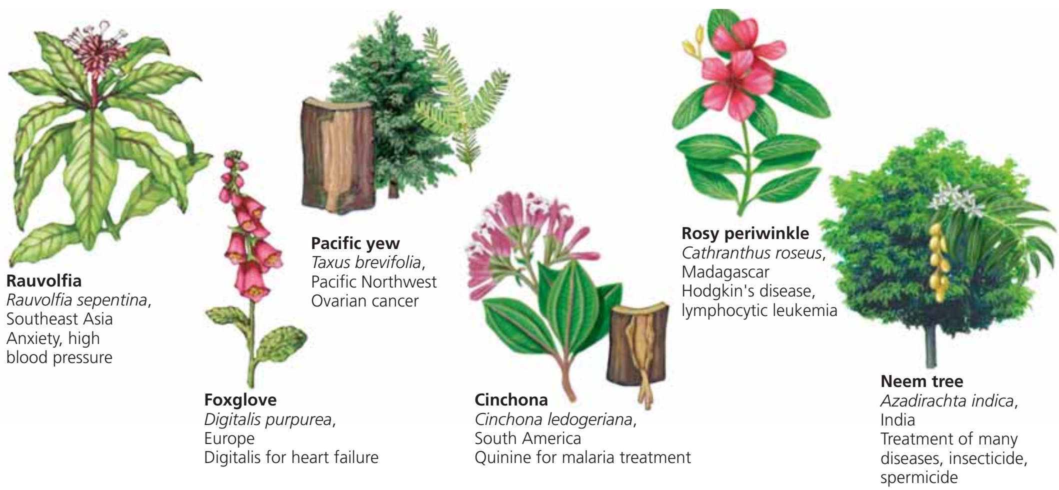


Figure 9-6 **Natural capital:** *nature's pharmacy.* Parts of these and a number of other plants and animals (many of them found in tropical forests) are used to treat a variety of human ailments and diseases. Nine of the ten leading prescription drugs originally came from wild organisms. About 2,100 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 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:** What are two aspects of your lifestyle that might contribute to this loss of some of the world's plant species?

Carelessly eliminating many of the species making up the world's vast genetic library is like burning books that we have never read.

Wild species also provide a way for us to learn how nature works and sustains itself. In addition, wild plants and animals provide us with *recreational pleasure.* Each year, Americans, as a whole, spend more than three times as many hours watching wildlife—doing nature photography and bird watching, for example—as they spend watching movies or professional sporting events.

Wildlife tourism, or *eco-tourism,* generates at least $500 billion per year worldwide, and perhaps twice that much. This amounts to an average economic input between $951,000 and $1.8 million per minute. 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. Similarly, over a lifetime of 60 years, a Kenyan elephant is worth about $1 million in eco-tourist revenue—many times more than its tusks are worth when they are sold illegally for their ivory. Eco-tourism should not cause ecological damage but some of it does. The website for this chapter lists some guidelines for evaluating eco-tours.

Are We Ethically Obligated to Prevent Premature Extinction?

Many people believe that each wild species has *intrinsic* or *existence* value based on its inherent right to exist and play its ecological roles, regardless of its usefulness to us (**Concept 9-2**). According to this 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.

Each species in the encyclopedia of life is a masterpiece of evolution that possesses a unique combination of genetic traits that adapt it to its natural environment. These genes have been tested through countless generations in the crucible of natural selection. They also provide mechanisms for changes in its genetic makeup through further natural selection when environmental conditions change. Many analysts believe that we have no right to erase these unique parts of nature.

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.

Some biologists caution us not to focus primarily on protecting relatively large organisms—the plants and animals we can see and are familiar with. They remind us that the true foundation of the earth's ecosystems and ecological processes are invisible bacteria and the algae, fungi, and other microorganisms that decompose the bodies of larger organisms and recycle the nutrients needed by all life.

9-3 How Do Humans Accelerate Species Extinction?

CONCEPT 9-3 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 9-7 shows the basic and secondary causes of the endangerment and premature extinction of wild species. Conservation biologists summarize the most important secondary causes of premature extinction using the acronym **HIPPCO: 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 (**Concept 9-3**).

According to biodiversity researchers, the greatest threat to wild species is habitat loss (Figure 9-8, p. 184), degradation, and fragmentation. The bird species shown in Figure 9-1 (**Core Case Study**) are just a few of many species whose extinctions are being hastened by loss and fragmentation of habitat from forest clearing and degradation.

CORE CASE STUDY

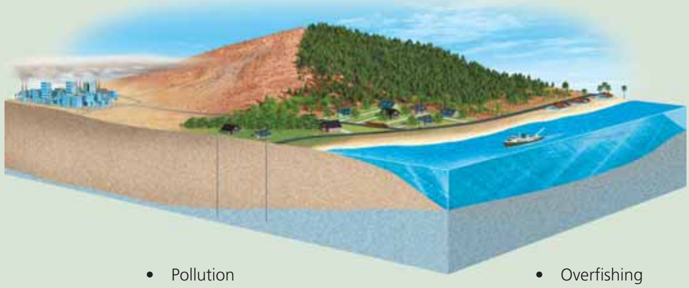
Deforestation in tropical areas is the greatest eliminator of species, followed by the destruction and degradation of coral reefs and wetlands, plowing of grasslands, and pollution of streams, lakes, and oceans. Globally, temperate biomes have been affected more by habitat loss and degradation than have tropical biomes

NATURAL CAPITAL DEGRADATION

Causes of Depletion and Premature Extinction of Wild Species

Basic Causes

- Population growth
- Rising resource use
- Undervaluing natural capital
- Poverty



Secondary Causes

- Habitat loss
- Habitat degradation and fragmentation
- Introduction of nonnative species
- Pollution
- Commercial hunting and poaching
- Sale of exotic pets and decorative plants
- Overfishing
- Climate change
- Predator and pest control

Figure 9-7 Underlying and direct causes of depletion and premature extinction of wild species (**Concept 9-3**). 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 secondary causes that are directly related to each of the basic causes?

because of widespread economic development in temperate countries over 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 state of Hawaii—with 63% of its species at risk—is America's "extinction capital." 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, energy extraction, and industrial activities. Freshwater lakes are also habitat islands that are especially vulnerable to the introduction of nonnative species and pollution.

Habitat fragmentation—by roads, logging, agriculture, and urban development—occurs when a large, continuous area of habitat is reduced in area and divided into smaller, more scattered, and isolated patches or "habitat islands" (Figure 8-7, p. 156). This process can block migration routes and 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. Also, it creates barriers that limit the abilities of some species to disperse and colonize new areas, to get enough to eat, and to find mates.

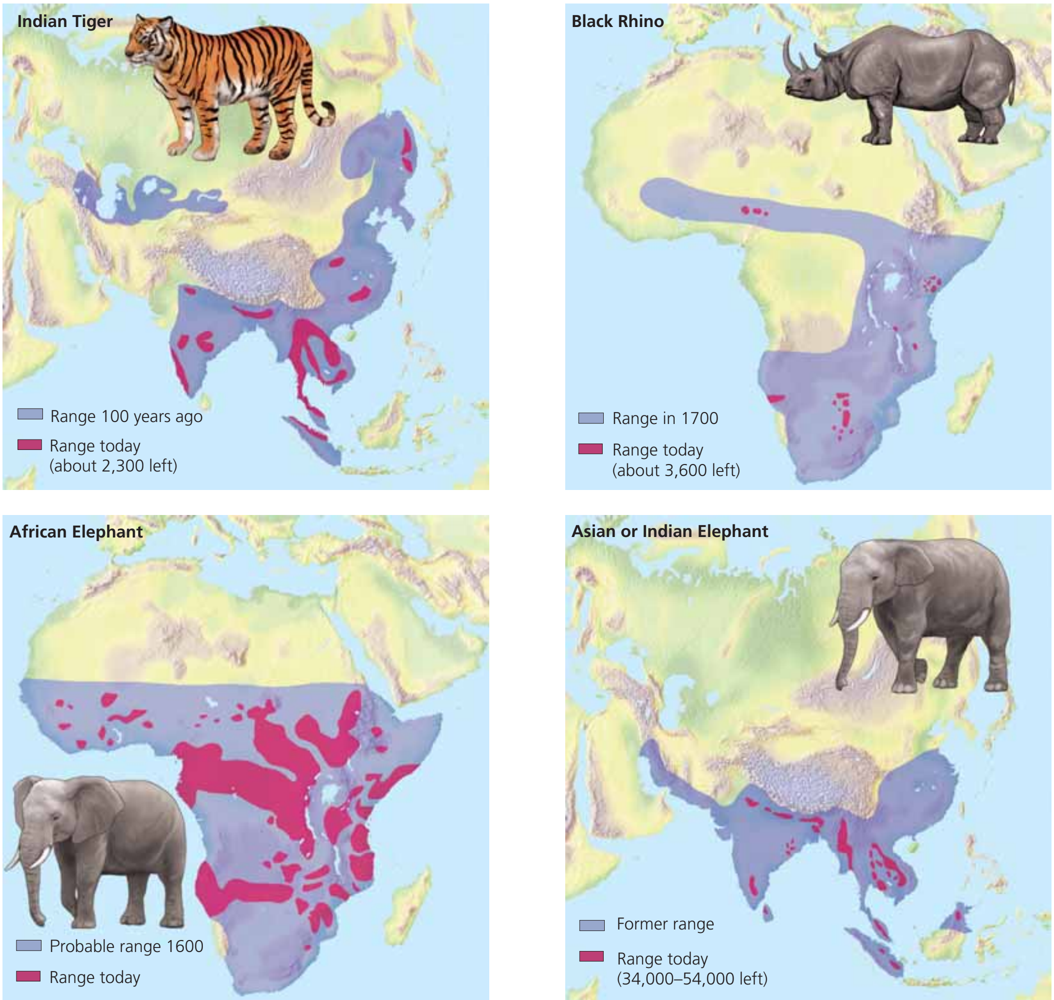
ThomsonNOW™ See how serious the habitat fragmentation problem is for elephants, tigers, and rhinos at ThomsonNOW.

Some Deliberately Introduced Species Can Disrupt Ecosystems

After habitat loss and degradation, the deliberate or accidental introduction of harmful invasive species into ecosystems is the biggest cause of animal and plant extinctions (**Concept 9-3**).

Most species introductions are beneficial. According to a 2000 study by ecologist David Pimentel, introduced species such as corn, wheat, rice, other food crops, 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 control pests.

On the other hand, Pimentel estimates that there are now about 500,000 alien invader species known to science. Jeffrey McNeely, chief scientist for the World Conservation Union calls the global genetic upheaval "the great reshuffling." About 50,000 nonnative species now live in the United States and about one in seven of them are harmful invasive species. The problem is that when introduced, some species have no natural predators, competitors, parasites, or pathogens to help control



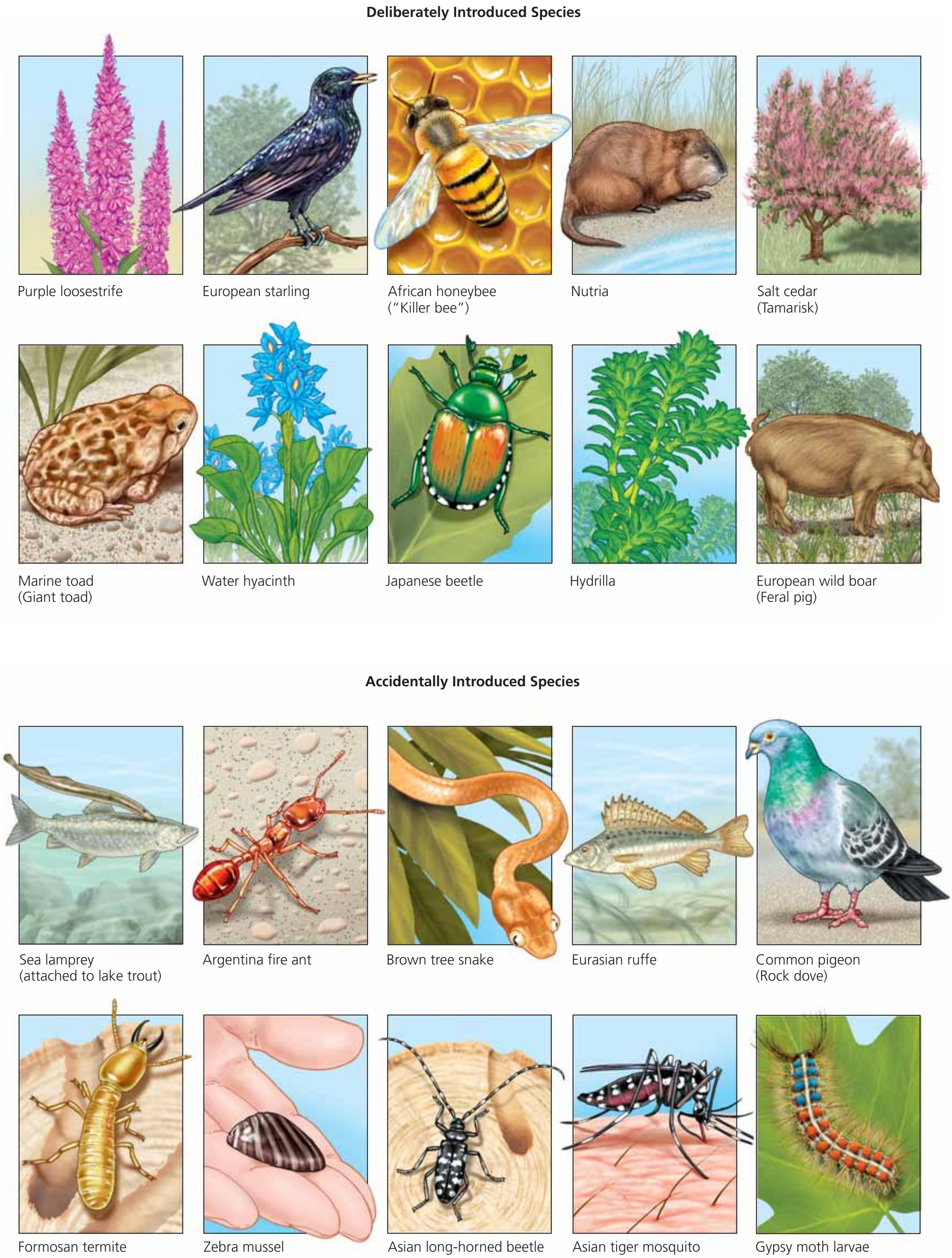
ThomsonNOW™ **Active Figure 9-8 Natural capital degradation:** reductions in the ranges of four wildlife species, mostly as the result of habitat loss and hunting. What will happen to these and millions of other species when the world's human population doubles and per capita resource consumption rises sharply in the next few decades? *See an animation based on this figure at* ThomsonNOW. **Question:** What are two specific things that could be done to expand these ranges? (Data from International Union for the Conservation of Nature and World Wildlife Fund)

their numbers in their new habitats. Such species can reduce or wipe out populations of many native species and trigger ecological disruptions.

Figure 9-9 shows some of the estimated 7,100 harmful 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 more than $137 billion each year—an average of $261,000 per minute!

Nonnative species threaten almost half of the more than 1,180 endangered and threatened species in the United States and 95% of those in the state of Hawaii, according to the U.S. Fish and Wildlife Service.

Figure 9-9 (facing page) Some of the more than 7,100 harmful invasive (nonnative) species that have been deliberately or accidentally introduced into the United States (**Concept 9-3**).


Deliberately Introduced Species
Purple loosestrife
European starling
African honeybee
("Killer bee")
Nutria
Salt cedar
(Tamarisk)
Marine toad
(Giant toad)
Water hyacinth
Japanese beetle
Hydrilla
European wild boar
(Feral pig)
Accidentally Introduced Species
Sea lamprey
(attached to lake trout)
Argentina fire ant
Brown tree snake
Eurasian ruffe
Common pigeon
(Rock dove)
Formosan termite
Zebra mussel
Asian long-horned beetle
Asian tiger mosquito
Gypsy moth larvae

Bruce Coleman USA

Figure 9-10 *Deliberately introduced invasive species:* Kudzu taking over the U.S. state of Mississippi. This vine, which can grow 5 centimeters (2 inches) per hour, was deliberately introduced into the United States for erosion control. It cannot be stopped by digging it up or burning it. Grazing by goats and repeated doses of herbicides can destroy it, but goats and herbicides also destroy other plants, and herbicides can contaminate water supplies. Scientists have found a common fungus that can kill kudzu within a few hours, apparently without harming other plants. Stay tuned.

■ **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 9-10).

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 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. And 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?

Although kudzu can engulf and kill trees, it might eventually help save trees from loggers. Researchers at the Georgia Institute of Technology indicate that it could be used as a source of tree-free paper. And a preliminary 2005 study indicated that kudzu powder could reduce alcoholism and binge drinking. Ingesting small amounts of the powder can lessen one's desire for alcohol.

THINKING ABOUT
Kudzu

Do you think the advantages of the kudzu plant outweigh its disadvantages? Explain.

Some Accidentally Introduced Species Can Also Disrupt Ecosystems

Welcome to one of the downsides of global trade. 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 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 late 1930s, the extremely aggressive Argentina fire ant (Figure 9-11) was introduced accidentally into the United States in Mobile, Alabama. The

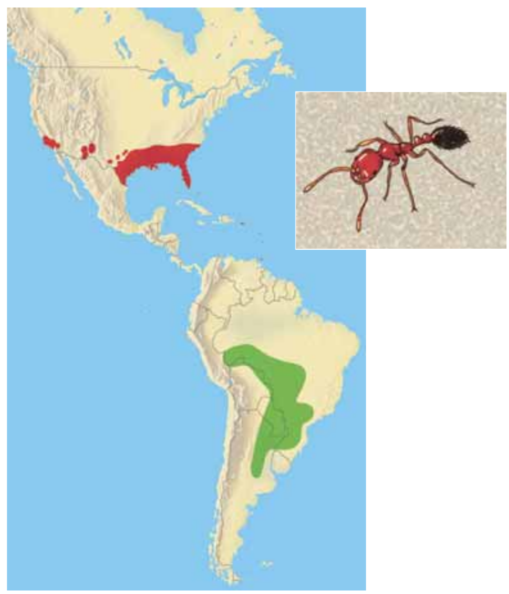


Figure 9-11 *Accidentally introduced invasive species:* the *Argentina fire ant,* introduced accidentally into Mobile, Alabama, in 1932 from South America (green area), has spread over much of the southern United States (red area). This invader is also found in Puerto Rico, New Mexico, and California. **Question:** How might this accidental introduction of fire ants have been prevented? (Data from S.D. Porter, Agricultural Research Service, U.S. Department of Agriculture)

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) throughout the South, from Texas to Florida and as far north as Tennessee and Virginia.

When these ants invade an area, they can wipe out as much as 90% of native ant populations. Bother them, and 100,000 ants may swarm out of their nest mounds 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—some of them fragile nursing home residents. 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 4-1B**, p. 64). In other words, we helped wipe out their competitors and made them genetically stronger.

CONCEPT LINK

In the Everglades in the U.S. state of Florida, the population of the huge *Burmese python* snake is increasing. This native of Southeast Asia was imported as a pet and ended up being dumped in the Everglades by people who learned that pythons do not make great pets. They can live 25 years, reach 6 meters (20 feet) in length, have the girth of a telephone pole, and with their razor-sharp teeth can eat practically anything that moves, including a full-grown deer.

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 get smoke back into a chimney. Thus, 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 9-12).
- Greatly increase ground surveys and satellite observations to detect and monitor species invasions and develop better models for predicting how they will spread.
- Step up inspection of imported goods and goods carried by travelers that are likely to contain invader species.
- Identify major harmful invader species and pass international laws banning their transfer from one country to another, as is now done for endangered species.
- Require cargo ships to discharge their ballast water and replace it with saltwater at sea before entering ports, or require them to sterilize such water or pump nitrogen into the water to displace dissolved oxygen and 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 (r-selected species)	■ 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 9-12 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 invasive species, why they thrive, and how to control them.

Figure 9-13 (p. 188) shows some of the things you can do to help prevent or slow the spread of these harmful invaders.

Population Growth, Overconsumption, Pollution, and Climate Change Can Cause Species Extinctions

Past and projected human population growth (Figure 7-3, p. 126) and excessive and wasteful consumption of resources have caused premature extinction of some species (**Concept 9-3**). Acting together, these two factors have greatly expanded the human ecological footprint (Figure 1-8, p. 13, and Figure 3 on pp. S16–S17 and Figure 7 on pp. S20–S21 in Supplement 4).

An unintended effect of pesticides illustrates how pollution can threaten some species with extinction. According to the U.S. Fish and Wildlife Service, each

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 9-13 **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?

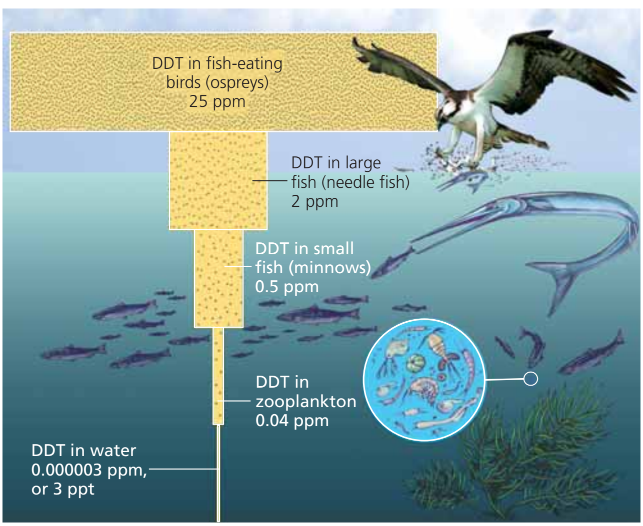


Figure 9-14 *Bioaccumulation* and *biomagnification.* DDT is a fat-soluble chemical that can accumulate in the fatty tissues of animals. In a food chain or web, the accumulated DDT can be biologically magnified in the bodies of animals at each higher trophic level. The concentration of DDT in the fatty tissues of organisms was biomagnified about 10 million times in this food chain in an estuary near Long Island Sound in the U.S. state of New York. If each phytoplankton organism takes up and retains one unit of DDT from the water, 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 10 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?

year pesticides kill about one-fifth of the beneficial honeybee colonies in United States, more than 67 million birds, and 6–14 million fish. They also threaten about one-fifth of the country's endangered and threatened species.

During the 1950s and 1960s, populations of fish-eating birds such as ospreys, brown pelicans, and bald eagles plummeted. A chemical derived from the pesticide DDT, when biologically magnified in food webs (Figure 9-14), 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 control rabbits, ground squirrels, and other crop eaters. Since the U.S. ban on DDT in 1972, most of these species have made a comeback. For example, after eliminating DDT and crackdowns on hunting and habitat destruction, the American bald eagle has rebounded from 417 nesting pairs in the lower 48 states in the early 1960s to more than 7,000 in 2006.

In the past, most natural climate changes have taken place over long periods—giving species more time to adapt, move, or evolve to cope with the change. Considerable evidence indicates that human activities such as greenhouse gas emissions and deforestation are likely to bring about rapid climate change during this century, as discussed in Chapter 15.

A 2004 study by Conservation International predicted that climate change could drive more than a quarter of all land animals and plants to extinction by the end of this century. Some scientific studies indicate that polar bears (see front cover) and 10 of the world's 17 penguin species are threatened because of higher temperatures and melting sea ice in their polar habitats.

Illegally Killing or Capturing and Selling Wild Species Can Threaten Them

Some protected species are illegally killed for their valuable parts or are sold live to collectors (**Concept 9-3**). Such *poaching* endangers many larger animals and some rare plants. This illegal trade in wildlife earns smugglers $6–10 billion a year—an average of $685,000 to $1.1 billion a minute. 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. At least two-thirds of all live animals smuggled around the world die in transit.

Poor people in areas rich with wildlife may kill or trap such species in an effort to make enough money to survive and feed their families. Professional poachers also prey on these species. 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 9-15) can be worth as much as $28,600 per kilogram ($13,000 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 1950, an estimated 100,000 tigers roamed free in the world. Despite international protection, only about 5,000 tigers remain in the wild, on an ever-shrinking range (Figure 9-8, top left). Today all five tiger subspecies are endangered. 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. Wealthy collectors have paid $10,000 or more for a Bengal tiger rug. With the body parts of a single tiger worth as much as $25,000, 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 may be left in the wild within 20 years.

THINKING ABOUT
Tigers

What difference would it make if all the world's tigers disappeared? What are three things you would do to help protect the world's remaining tigers from premature extinction?


Martin Harvey/Peter Arnold, Inc

Figure 9-15 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. Most people are also unaware that some imported exotic animals can carry dangerous infectious diseases.

About 25 million U.S. households have exotic birds as pets, 85% of them imported. More than 60 bird species, mostly parrots, (see photo 3, p. vii), are endangered or threatened because of this wild bird trade. Ironically, keeping birds as pets can also be dangerous for people. 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 wild species whose populations are depleted because of the pet trade include amphibians, reptiles, mammals (Figure 8-2, p. 152), and tropical fish (taken mostly from the coral reefs of Indonesia and the Philippines). Divers catch tropical fish by using plastic squeeze bottles of poisonous cyanide to stun them. For each fish caught alive, many more die. In addition, the cyanide solution kills the coral animals that create the reef.

Some exotic plants, especially orchids and cacti, are endangered because 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.

As commercially valuable species become endangered, their black market demand soars. This increases their chances of premature extinction from poaching. Most poachers are not caught and the money they can make far outweighs the small risk of being caught, fined, or imprisoned.

On the other hand, species also hold great value by surviving in the wild. According to the U.S. Fish and Wildlife Service, collectors of exotic birds may pay $10,000 for a threatened hyacinth macaw smuggled out of Brazil. But during its lifetime, a single macaw left in the wild might yield as much as $165,000 in tourist income.

In Thailand, Pilai Poonswad decided to do something about poachers taking hornbills—large, beautiful, and rare birds—from a rain forest. She visited the poachers in their villages and showed them why the birds are worth more alive than dead. Today, some ex-poachers earn money by taking eco-tourists into the forest to see these magnificent birds. Because of their vested financial interest in preserving the hornbills, they now help protect the birds from poachers. Individuals matter.

Jacques Fretey/Peter Arnold, Inc.

Figure 9-16 *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 (**Concept 9-3**). **Question:** How, if at all, is this different from killing a cow for food?

The 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 two decades, bush meat hunting in some areas has skyrocketed as local people try to provide food for a rapidly growing population and to make a living by supplying restaurants with exotic meat (Figure 9-16). Killing animals for bush meat has also increased because logging roads have allowed miners, ranchers, and settlers to move into once inaccessible forests (Figure 8-7, p. 155).

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 is that bush meat hunting has caused the local extinction of many 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 8-2, p. 152), chimpanzee, elephant, and hippo populations. This practice also threatens forest carnivores such as crowned eagles and leopards by depleting their main prey species. Another problem is that butchering and eating some forms of bush meat has helped 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.

9-4 How Can We Protect Wild Species from Premature Extinction?

CONCEPT 9-4A We can use existing environmental laws and treaties and work to enact new laws designed to prevent species extinction and to protect overall biodiversity.

CONCEPT 9-4B We can help prevent species extinction by creating and maintaining wildlife refuges, gene banks, botanical gardens, zoos, and aquariums.

International Treaties Can Help Protect Species

Several international treaties and conventions help protect endangered or threatened wild species (**Concept 9-4A**). One of the most far reaching is the 1975 *Convention on International Trade in Endangered Species* (CITES). This treaty, now signed by 171 countries, 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 in 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 188 countries (but not the United States), legally commits participating governments to reversing the global decline of biodiversity and 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 such as the United States have not ratified it, implementation has been slow. Also, the law contains no severe penalties or other enforcement mechanisms.

■ **CASE STUDY**

Controversy over the U.S. Endangered Species Act

The *Endangered Species Act of 1973* (ESA; amended in 1982, 1985, and 1988) was designed to identify and legally protect endangered species in the United States and abroad (**Concept 9-4A**). This act is probably the most far-reaching environmental law ever adopted by any nation, which has made it controversial. Canada and a number of other countries have similar laws.

According to the ESA, the National Marine Fisheries Service (NMFS) is responsible for identifying and listing endangered and threatened ocean species. The U.S. Fish and Wildlife Services (USFWS) identifies and lists all other endangered and threatened species. Any decision by either agency to add a species to, or remove it 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 the critical habitat it needs to survive. For such offenses committed on private lands, fines as high as $100,000 and one year in prison can be imposed to ensure protection of the habitats of endangered species. 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 2007, the number of U.S. species on the official endangered and threatened lists increased from 92 to about 1,180 species—60% of them plants and 40% animals. 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 1,180 species on the ESA list. The study also found that many of the country's rarest and most imperiled species are concentrated in a few hot spots (Figure 8-23, p. 169).

The USFWS or the NMFS is supposed to prepare a plan to help each listed species recover, including designating and protecting its critical habitat. By 2007, only one-fourth of the species on the protected list had active plans and only one-third had designated critical habitats—mostly because of political opposition and limited funds. Examples of successful recovery plans include those for the American alligator (**Core Case Study**, p. 105), the gray wolf (**Core Case Study**, p. 149), the bald eagle, and the peregrine falcon.

Only 120 full-time USFWS inspectors examine shipments of wild animals that enter the United States through ports, airports, and border crossings. They can inspect only a small fraction of the more than 200 million wild animals brought legally into the United States each year, plus the tens of millions of such animals that enter illegally. Few illegal shipments of endangered or threatened animals or plants are confiscated (see photo 8, p. ix). Even if caught, many violators are not prosecuted, and convicted violators often pay only a small fine.

In addition, people who smuggle or buy imported exotic animals are rarely aware that many of them can carry dangerous infectious diseases such as hantavirus, Ebola virus, Asian bird flu, herpes B virus (carried by most adult macaques), and salmonella (from pets such as hamsters, turtles, and iguanas) that can jump from pets to humans. The country's small number of wildlife inspectors does not have the capability or budget to detect such diseases.

The ESA has also 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.

The ESA has also been used to protect endangered and threatened marine reptiles (turtles) and mammals (especially whales, seals, and sea lions). Each year plastic items dumped from ships and left as litter on beaches threaten the lives of millions of marine mammals, turtles, and seabirds that ingest, become entangled in, choke on, or are poisoned by such debris (Figure 9-17, p. 192).

The world's eight major sea turtle species are endangered or threatened (Figure 9-18, p. 192). Two major threats to these turtles are loss or degradation of beach habitat (where they come ashore to lay their eggs) and legal and illegal taking of their eggs. Other

Doris Alcorn/U.S. National Maritime Fisheries

Figure 9-17 *A threat to marine animals:* before this discarded piece of plastic was removed by the photographer, this Hawaiian monk seal was slowly starving to death. Each year plastic items dumped from ships and left as litter on beaches threaten the lives of millions of marine mammals, turtles, and seabirds that ingest, become entangled in, or are poisoned by such debris. **Question:** Do you think most of the people you know are aware of this problem?

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. In China, for example, some sea turtles sell for as much as $1,500.

Two major problems hinder efforts to protect marine biodiversity by protecting endangered species. One is lack of knowledge about marine species. The other is the difficulty of monitoring and enforcing treaties to protect marine species, especially in the open ocean.

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 ESA contend that it puts the rights and welfare of endangered plants and animals above those of people. They argue it has not been effective in protecting endangered species and has caused severe economic losses by hindering development on private lands. Since 1995, efforts to weaken the ESA have included the following suggested changes:

- Make protection of endangered species on private land voluntary.
- Have the government compensate landowners if they are forced to stop using part of their land to protect endangered species.
- Make it harder and more expensive to list newly endangered species by requiring government wildlife officials to navigate through a series of hearings and peer-review panels and requiring hard data instead of computer-based models.
- Eliminate the need to designate critical habitats.
- Allow the secretary of the interior to permit a listed species to become extinct without trying to save it.
- Allow the secretary of the interior to give any state, county, or landowner permanent exemption from the law, with no requirement for public notification or comment.

Other critics would go further and do away with this act. Because this step is politically unpopular with the American public, most efforts are designed to weaken the act and reduce its meager funding.

Most conservation biologists and wildlife scientists agree that the ESA needs to be simplified and streamlined. But they contend that it has not been a failure (Science Focus, at right).

Biologist Edward O. Wilson says that "Humanity must make a decision, and make it now: conserve Earth's natural heritage, or let future generations adjust to a biologically impoverished world. There is no way to weasel out of this choice."

This is why most biologists and wildlife conservationists believe that the United States needs a new law that emphasizes protecting and sustaining biological diversity and ecosystem functioning (**Concept 9-4A** and **Concept 8-8**, p. 173) rather than focusing mostly on saving individual species. The idea is to prevent species from becoming extinct in the first place by protecting their habitats. This new *ecosystems approach* would follow three principles:

CONCEPT LINK

- Find out what species and ecosystems the country has.
- Locate and protect the most endangered ecosystems (Figure 8-23, p. 169) and species.
- Make development *biodiversity-friendly* by providing significant financial incentives (tax breaks and write-offs) and technical help to private landowners who agree to help protect specific endangered ecosystems.

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Figure 9-18 Endangered green sea turtle.

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.

Fourth, the ESA budget was only $58 million in 2005—about what the Department of Defense spends in a little more than an hour—or 20¢ per year per U.S. citizen. To its supporters, it is amazing that the ESA has managed to stabilize or improve the conditions of more than half of the listed species on a shoestring budget.

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.
- 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.

Critical Thinking

Should the budget for the Endangered Species Act be significantly increased? Explain.

HOW WOULD YOU VOTE?

Should the U.S. Endangered Species Act be modified to protect and sustain the nation's overall biodiversity? Cast your vote online at **www.thomsonedu.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 from extinction. Since then, the National Wildlife Refuge System has grown to include 544 refuges. More than 35 million Americans visit these refuges each year to hunt, fish, hike, or watch birds and other wildlife.

More than three-fourths of the refuges serve as wetland sanctuaries 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 9-4B**). 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 occur in nearly 60% of the nation's wildlife refuges.

Conservation biologists call for setting aside more refuges for endangered plants. 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 Protect Species

Gene or *seed banks* preserve genetic information and endangered plant species by storing their seeds in refrigerated, low-humidity environments (**Concept 9-4B**). More than 100 seed banks around the world collectively hold about 3 million samples.

Scientists urge the establishment of many more such banks, especially in developing countries. But some species cannot be preserved in gene banks. The banks are also expensive to operate and can be destroyed by fires and other mishaps.

The world's 1,600 *botanical gardens* and *arboreta* contain living plants, representing almost one-third of the world's known plant species. However, 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 the world's rare and threatened plants.

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.

WHAT CAN YOU DO?

Protecting Species

- Do not buy furs, ivory products, or other items made from endangered or threatened animal species.
- Do not buy wood or paper products produced by cutting old-growth forests in the tropics.
- Do not buy birds, snakes, turtles, tropical fish, and other animals that are taken from the wild.
- Do not buy orchids, cacti, or other plants that are taken from the wild.
- Spread the word. Talk to your friends and relatives about this problem and what they can do about it.

Figure 9-19 **Individuals matter:** ways to help prevent premature extinction of species. **Question:** Which two of these actions do you believe are the most important? Why?

Zoos and Aquariums Can Help 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 (**Concept 9-4B**).

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 (Figure 9-3).

Lack of space and money limits 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 to avoid extinction through accidents, 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.

Public aquariums that exhibit unusual and attractive fishes and some marine animals such as seals and dolphins also help educate the public about the need to protect such species. But public aquariums have not served as effective gene banks for endangered marine species, especially marine mammals that need large volumes of water.

Instead of seeing zoos and aquariums as sanctuaries, some critics claim that most of them imprison once-wild animals. They also contend that zoos and aquariums can foster the notion that we do not need to preserve large numbers of wild species in their natural habitats. Proponents counter that these facilities play an important role in educating the public about wildlife and the need to protect biodiversity.

Regardless of their benefits and drawbacks, zoos, aquariums, and botanical gardens are not biologically or economically feasible solutions for the growing problem of premature extinction of species. Figure 9-19 lists some things you can do to help deal with this problem.

Bottom line: Protecting species is important but not enough to protect the biodiversity needed for a more sustainable world. According to biodiversity expert Edward O. Wilson, "There is no solution, I assure you, to save Earth's biodiversity other than preservation on natural environments in reserves large enough to maintain wild populations sustainably."

9-5 What Is Reconciliation Ecology?

CONCEPT 9-5 We can help protect some species from premature extinction by finding ways to share the places we dominate with them.

We Can Share Places We Dominate with Other Species

In 2003, ecologist Michael L. Rosenzweig wrote a book entitled *Win–Win Ecology: How Earth's Species Can Survive in the Midst of Human Enterprise.* Rosenzweig strongly supports Edward O. Wilson's proposals to help sustain the earth's biodiversity (pp. 173–174). He also supports the species protection strategies discussed in this chapter.

But Rosenzweig contends that, in the long run, these approaches will fail for two reasons. *First,* current fully protected reserves are devoted to saving only about 5% of the world's terrestrial area, excluding polar and other uninhabitable areas. To Rosenzweig, the real challenge is to help sustain wild species in the human-dominated portion of nature that makes up 95% of the planet's terrestrial area.

Second, setting aside funds and refuges and passing laws to protect endangered and threatened species are essentially desperate attempts to save species that are in deep trouble. They can help a few species, but the real challenge is in learning how to keep more species away from the brink of extinction. This is a prevention approach.

Rosenzweig suggests that we develop a new form of conservation biology, called **reconciliation ecology.** This science focuses on inventing, establishing, and maintaining new habitats to conserve species diversity in places where people live, work, or play. In other words, we need to learn how to share the spaces we dominate with other species (**Concept 9-5**).

There Are Many Ways to Implement Reconciliation Ecology

Here are a few examples of reconciliation ecology. People are learning how to protect vital insect pollinators such as native butterflies and bees that are vulnerable to insecticides and habitat loss. Neighbors 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 in planting gardens of flowering plants as a source of food for pollinating insect species.

In 1979, populations of bluebirds in the eastern United States had been declining because timber companies and some homeowners had removed dead and dying trees whose holes served as nesting sites for the birds. In addition, nonnative bird species such as house sparrows and starlings took away tree nest holes from the bluebirds. But since 1979, the North American Bluebird Society has reduced the decline of bluebirds in the eastern United States by encouraging people to use bluebird nest boxes. The boxes are not deep enough to attract sparrows, and their holes are too small for starlings.

In Berlin, Germany, people have planted gardens on many large rooftops. These can be designed to support a variety of wild species by varying the depth and type of soil and their exposure to sun. Such roofs also save energy by providing insulation, and they help to cool cities and conserve water by reducing evapotranspiration. 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 humans who transformed it from a system of sand dunes. There are other examples of where individuals and groups have worked together on projects to restore grasslands, wetlands, streams, and other degraded areas (see Case Study at right).

There are plenty of possibilities for neighborhood reconciliation ecology projects. Some monoculture grass yards could be replaced with diverse yards using plant species adapted to local climates. This would keep down insect pests, save water, require less use of noisy and polluting lawnmowers, and save money.

Communities could have contests and awards for people who design the most biologically diverse and species-friendly yards and gardens. Signs could describe the types of ecosystems being mimicked and the species being protected as a way to educate people and encourage experimentation. Some college campuses and schools could also serve as reconciliation ecology laboratories. How about yours? **GREEN CAREER:** Reconciliation ecology specialist

These are all examples of people building *social capital*—working together and finding trade-offs to arrive at solutions to problems—in order to protect natural capital.

■ **CASE STUDY**

The Blackfoot Challenge—Reconciliation Ecology in Action

The Blackfoot River flows among beautiful mountain ranges in the west central part of the U.S. state of Montana. This large watershed is home to more than 600 species of plants, 21 species of waterfowl, bald eagles, peregrine falcons, grizzly bears, and rare species of trout. Some species, such as the Howell's gumweed and the bull trout, are threatened with extinction.

The Blackfoot River Valley is also home to people who live in seven communities and 2,500 rural households. A book and movie, both titled "A River Runs Through It," tell of how residents of the valley cherish their lifestyles.

In the 1970s, many of these people recognized that their beloved valley was threatened by destructive mining, logging, and grazing practices, water and air pollution, and unsustainable commercial and residential development. They also understood that their way of life depended on wildlife and wild ecosystems located on private as well as on public land. They began meeting informally over kitchen tables to discuss how to maintain their way of life while sustaining the other species living in the valley. These small gatherings spawned community meetings attended by individual and corporate landowners, state and federal land managers, scientists, and local government officials.

Out of these meetings came action. Teams of residents organized weed-pulling parties, built nesting structures for waterfowl, and developed sustainable grazing systems. Landowners agreed to create perpetual conservation easements, setting land aside only for conservation and sustainable uses such as hunting and fishing. They created corridors between large tracts of undeveloped land. In 1993, these efforts were organized under a charter called The Blackfoot Challenge.

The results were dramatic. Blackfoot Challenge members have restored and enhanced more than 6,070 hectares (15,000 acres) of wetlands, 322 kilometers (200 miles) of streams, and 6,070 hectares (15,000 acres) of native grasslands. They have reserved 36,000 hectares (89,000 acres) of private land under perpetual conservation easements.

The pioneers in this project might not have known it, but they were initiating what has become a classic example of *reconciliation ecology*. They worked together, respected each other's views, accepted compromises, and found ways to share their land with the plants and animals that make it such a beautiful place to live.

RESEARCH FRONTIER

Determining where and how reconciliation ecology can work best

REVISITING Declining Bird Populations and Sustainability

CORE CASE STUDY

SUSTAINABILITY

This chapter opened with a **Core Case Study** about the decline of various bird species (Figure 9-1, p. 176), mostly due to habitat loss and fragmentation, and the harmful ecological effects of this decline.

We have learned a lot about how to help protect birds and other species from premature extinction resulting from our activities. 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. Ecological ignorance accounts for some of failure to deal with this problem. But to many, the most serious problem is our lack of political and ethical will to act on what we know.

Acting to prevent the premature extinction of species, primarily by preserving their habitats (Chapter 8), is a key to sustainability. In keeping with the four **scientific principles of sustainability** (see back cover), such action helps to preserve the earth's biodiversity and to maintain species interactions that help control population sizes, energy flow, and matter cycling in ecosystems.

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 that will affect many species and their habitats. And it will require reducing the size and impact of our ecological footprints (Figure 1-8, p. 13). Part of the solution also involves getting people to work together to preserve biodiversity within the areas where humans dominate, through reconciliation ecology. This begins in one's local neighborhood.

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. Why do conservation biologists consider birds to be excellent environmental indicators?
2. Describe the three types of species extinction. Define the terms *endangered species* and *threatened species*.
3. How do biologists estimate extinction rates, and how do humans affect these rates?
4. Provide an argument for preventing the premature extinction of wild species.
5. Summarize the basic and secondary causes of the endangerment and premature extinction of wild species. What do conservation biologists consider to be the most important secondary causes of premature extinction?
6. What could you do to prevent or slow the spread of harmful invasive species? What role does the bioaccumulation and biomagnification of DDT play in the decline of fish-eating birds?
7. Discuss the impact that the Convention on International Trade in Endangered Species (CITES), and the Endangered Species Act (ESA) has had on protecting biodiversity. Why is the ESA controversial?
8. In addition to national and international laws and treaties, describe other ways that can be used to prevent species extinction.
9. What actions could you tell an individual to take in order to personally help prevent the premature extinction of species?
10. What is reconciliation ecology? How can it help prevent premature extinction of species?

CRITICAL THINKING

1. List three ways in which you could apply **Concept 9-3** (p. 182) to make your lifestyle and that of any children and grandchildren you might have more environmentally sustainable.

2. What are three aspects of your lifestyle that directly or indirectly contribute to the premature extinction of some bird species (**Core Case Study**)? What are three things that you think should be done to reduce the premature extinction of birds? CORE CASE STUDY

3. Discuss your gut-level reaction to the following statement: "Eventually, all species become extinct. Thus, it does not really matter that the passenger pigeon is extinct, and that the whooping crane and the world's remaining tiger species are endangered mostly because of human activities." Be honest about your reaction, and give arguments for your position.

4. Make a log of your own consumption of all products for a single day. Relate your level and types of consumption to the decline of wildlife species and the increased destruction and degradation of wildlife habitats in the United States (or the country where you live), in tropical forests, and in aquatic ecosystems. Compare your results with those of your classmates.

5. 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.

6. 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.

7. What would you do if **(a)** fire ants invaded your yard and house and **(b)** deer invaded your yard and ate your shrubs, flowers, and vegetables?

8. 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.

9. 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?

10. Congratulations! You are in charge of preventing the premature extinction, caused by human activities, of the world's existing species. What would you do to accomplish this goal?

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

LEARNING ONLINE

Log on to the Student Companion Site for this book at **www.thomsonedu.com/biology/miller** and choose Chapter 9 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Web links, information on Green Careers, and InfoTrac® College Edition articles.

For access to animations and additional quizzing, register and log on to ThomsonNOW! at **www.thomsonedu.com/thomsonnow** using the access code card in the front of your book. You can also explore the **Active Graphing** exercises that your instructor may assign.

10 Food, Soil, and Pest Management

CORE CASE STUDY Golden Rice: Grains of Hope or an Illusion?

Many of the world's poor do not have enough land or money to obtain foods that give them enough protein and essential vitamins and minerals to prevent malnutrition. For example, according to the World Health Organization (WHO), 120–140 million children in developing countries, mostly in Africa and Southeast Asia, do not get enough vitamin A. This makes them more susceptible to common childhood infectious diseases. Some 250,000 to 500,000 children younger than age 6 go blind each year from a lack of vitamin A. More than half of them die within a year after becoming blind.

SuperStock

Jongky Kurniawan

Figure 10-1 *Golden rice* is a new genetically engineered strain of rice containing beta-carotene (giving it its yellow color), which the body can convert to vitamin A. Some farmers in countries such as India, Bangladesh, and China may begin replacing some conventional strains of rice, planted in terraces to help reduce soil erosion (left), with this new golden rice strain.

In 1999, scientists Ingo Potrykus and Peter Beyer decided to tackle this problem by genetically engineering (Figure 4-8, p. 72) a form of rice that contained beta-carotene, a substance that the body can convert to vitamin A. They transferred snippets of DNA in genes taken from common daffodils (Figure 10-1, right) and from a soil bacterium into conventional rice strains to produce a strain of rice containing beta-carotene.

Pre-school children can get their daily requirement for vitamin A by eating small amounts of mango, yellow sweet potatoes, or coriander. But these foods are too expensive to grow or buy for most of the poor. Children can also be given two vitamin A capsules each year, but so far the United Nations, global health organizations, and governments have not provided enough money to do this.

Potrykus and Beyer estimate that eating 200–300 grams of their latest golden rice strain per day should provide enough vitamin A to prevent blindness and susceptibility to common childhood infections. They also worked out agreements for poor subsistence farmers in several developing countries to get the new strain free of charge.

Critics view golden rice mostly as a seed industry–financed public relations ploy to soften up widespread consumer opposition to genetically engineered crops in parts of the world such as India and Europe. They also contend that golden rice is drawing funding and attention away from a quicker and cheaper program for getting vitamin A capsules to the millions of children who need them. Also, there is concern over whether the poor can afford to buy yellow rice.

In addition, scientists want more evidence on how much of the beta-carotene in the golden rice will actually be converted to vitamin A in the body. They also want evidence that golden rice strains that perform well in the laboratory will perform as well in nature where many more factors come into play.

The world faces three major food challenges: reducing poverty, which blocks access to enough resources to avoid malnutrition for hundreds of millions of people; providing and distributing enough food for the 8.9 billion people projected to be living on the earth by 2050; and doing both in an environmentally sustainable manner that does not deplete or degrade the soil and water resources needed to produce food.

Key Questions and Concepts

10-1 How can we improve food security?

CONCEPT 10-1 Meeting the nutritional needs of the world's people requires reducing poverty and the harmful environmental impacts of agriculture.

10-2 How is food produced and how might food production change?

CONCEPT 10-2 Producing enough food to feed the rapidly growing human population will require growing food in a mix of monocultures and polycultures and decreasing the enormous environmental impact of industrialized agriculture.

10-3 How serious are soil erosion and degradation and how can they be reduced?

CONCEPT 10-3 We can reduce soil erosion and degradation by using proven agricultural techniques and restoring depleted soil nutrients.

10-4 What have the green and gene revolutions done for food security?

CONCEPT 10-4 Industrialized agriculture has increased global food production dramatically, but its harmful environmental impacts may limit future food production.

10-5 Are there limits to providing more meat and seafood?

CONCEPT 10-5A Rangeland overgrazing and the harmful environmental impacts of industrial livestock production may limit meat production.

CONCEPT 10-5B We can harvest fish more sustainably to prevent overfishing and use improved types of aquaculture.

10-6 How can we protect crops from pests?

CONCEPT 10-6 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).

10-7 How can we produce food more sustainably?

CONCEPT 10-7 Sustainable agriculture involves reducing topsoil erosion, eliminating overgrazing and overfishing, irrigating more efficiently, using integrated pest management, providing government subsidies for sustainable farming and fishing, and promoting agrobiodiversity.

Note: Supplements 3, 4, 5, and 6 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 How Can We Improve Food Security?

CONCEPT 10-1 Meeting the nutritional needs of the world's people requires reducing poverty and the harmful environmental impacts of agriculture.

Many Poor People Have Health Problems Because They Do Not Get Enough to Eat

Today we produce more than enough food to meet the basic nutritional needs of every person on the earth. Even with this surplus of food, one of every six people in developing countries is not getting enough to eat. They face **food insecurity,** living with chronic hunger and malnutrition that threatens their ability to lead healthy and productive lives.

Most agricultural experts agree that *the root cause of food insecurity is poverty,* which prevents poor people from growing or buying enough food. (See Figure 2 on p. S8 in Supplement 3 for a map showing the world's low-income countries.) War and corruption can also deny poor people access to food.

Food security means that every person in a given area has daily access to enough nutritious food to have an active and healthy life. At the national level, government programs that reduce poverty by helping the poor to help themselves can improve food security. Such programs promote family planning, education and jobs (especially for women), and small loans to poor people to help them start businesses or buy land to grow their own food.

Many less-developed countries do not produce enough food to feed their people, and are too poor to import enough food, to provide national food security. One solution is for developed nations and international lending institutions such as the World Bank to provide technical advice and funding to help such countries become more self-sufficient in meeting their food security needs. This would require governments of those countries to spend more of their funds on helping the rural poor to help themselves.

Food security also depends on greatly reducing the harmful environmental effects of agriculture—such as soil erosion and aquifer depletion—at the local, national, and global levels (**Concept 10-1**).

To maintain good health and resist disease, individuals need fairly large amounts of *macronutrients* (such as protein, carbohydrates, and fats), 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.** Most chronically undernourished children live in developing countries. Because of lack of access to adequate health care, they are likely to suffer from mental retardation and stunted growth and to die 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 of grains such as wheat, rice, or corn. They often suffer from **malnutrition** resulting from diet deficiencies of protein and other key nutrients. This weakens them, makes them more susceptible to disease, and hinders the normal physical and mental development of children (Figure 1-12, p. 16).

Good news. According to the U.N. Food and Agriculture Organization (FAO), the average daily food intake in calories per person in the world and in developing countries rose sharply between 1961 and 2007, and is projected to continue rising through 2030. Also, the estimated number of chronically undernourished or malnourished people fell from 918 million in 1970 to 852 million in 2005. (See Figure 7 on p. S11 in Supplement 3 for a map of the countries with the most undernourished people.) This is a good start but it is far from the Millennium Development Goal of reducing the number of hungry and malnourished people to 400 million by 2015.

Despite such progress, one of every six people in developing countries (including about one of every three children younger than age 5) is chronically undernourished or malnourished. In 2005, the FAO estimated that each year, nearly 6 million children die prematurely from undernutrition, malnutrition, and increased susceptibility to normally nonfatal infectious diseases because of their weakened condition. This means that each day, an average of 16,400 children die prematurely from these poverty-related causes. How many people 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, most often in developing countries and involving *vitamin A, iron,* and *iodine.*

Too little *iron*—a component of the hemoglobin that transports oxygen in the blood—causes *anemia.* According to a 1999 survey by the WHO, one of every three people in the world—mostly women and children in tropical developing countries—suffers from iron deficiency. It causes fatigue, makes infection more likely, and increases a woman's chances of dying from hemorrhage in childbirth. New strains of golden rice (**Core Case Study**) contain more iron than conventional strains and could help reduce the severity of this nutritional deficiency.

CORE CASE STUDY

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 10-2). According to the United Nations, some 600 million people—mostly in south and Southeast Asia—suffer from goiter, and

John Paul Kay/Peter Arnold, Inc.

Figure 10-2 Woman with goiter in Bangladesh. A diet with insufficient iodine can cause this enlargement of the thyroid gland. Adding traces of iodine to salt has largely eliminated this problem in developed countries.

26 million children suffer brain damage each year from lack of iodine.

We Can Reduce Childhood Deaths from Hunger and Malnutrition

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 a cost of about 10¢ per child annually and widespread planting of golden rice in developing countries (**Core Case Study**). CORE CASE STUDY
- 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.

THINKING ABOUT
Golden Rice and Children CORE CASE STUDY

What do you think is the best way to deal with vitamin A deficiencies in many of the world's poor children? Explain.

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.*

We live in a world where 1 billion people have health problems because they do not get enough to eat and another 1.2 billion face health problems from eating too much. According to a 2004 study by the International Obesity Task Force, one of every four people in the world is overweight and one of every twenty is obese.

A 2005 study at Boston University found that about 60% of American adults are overweight and 33% are obese, for a total of 93%—the highest overnutrition rate in any developed country. The $40–100 billion that Americans spend each year trying to lose weight is about two to four times as much as the $24 billion per year needed to eliminate undernutrition and malnutrition in the world.

10-2 How Is Food Produced and How Might Food Production Change?

CONCEPT 10-2 Producing enough food to feed the rapidly growing human population will require growing food in a mix of monocultures and polycultures and decreasing the enormous environmental impact of industrialized agriculture.

Industrialized Agriculture Has Greatly Increased Food Production

Three systems supply most of our food. *Croplands* produce mostly grains and provide about 77% of the world's food using 11% of its land area. *Rangelands* and *pastures* produce meat, mostly from grazing livestock, and supply about 16% of the world's food using about 29% the world's land area. *Oceanic fisheries,* and more recently *aquaculture,* supply about 7% of the world's food.

Since 1960, there has been a staggering increase in global food production from all three systems. This occurred because of technological advances such as increased use of tractors and farm machinery and high-tech fishing fleets. Other technological developments include inorganic chemical fertilizers, irrigation, pesticides, high-yield grain varieties, and raising large numbers of livestock, poultry, and fish in factory-like conditions.

We face important challenges to increase food production without causing serious environmental harm. Each day, there are about 225,000 more mouths to feed. Between 2007 and 2050, the world's population is projected to increase by 2.2 billion people. To provide food security for these individuals, we will have to grow and distribute more food than has been produced since agriculture began about 10,000 years ago, and do so in an environmentally sustainable manner (**Concept 10-2**).

Can we achieve this goal? Some analysts say we can, mostly by using genetic engineering (Figure 4-8, p. 72, and **Concept 4-5**, p. 71). Others have doubts. They point out that agriculture, the world's largest industry, is increasing pressure on the earth's natural capital (**Concept 1-1A**, p. 6). They are concerned that environmental degradation, pollution, lack of water for irrigation, overgrazing by livestock (see photo 10, p. x), overfishing, rising temperatures, increasing fuel costs, and loss of vital ecological services may limit future food production.

CONCEPT LINKS

A Small Number of Plant and Animal Species Feed the World

Of the estimated 50,000 wild plant species that people can eat, only 14 of them supply an estimated 90% of the world's food calories. Just three types of grain crops—*wheat, rice,* and *corn*—provide about 47% of the calories and 42% of the protein people consume.

Such food specialization puts us in a vulnerable position should the small number of crops we depend on fail from disease or climate change. This violates the **biodiversity principle of sustainability** (Figure 1-13, p. 20), which calls for depending on a variety of food crops as an ecological insurance policy for dealing with environmental change.

SUSTAINABILITY

Two-thirds of the world's people survive primarily on rice, wheat, and corn, mostly because they cannot afford meat. As incomes rise, most people consume more meat, milk, cheese, and other products of domesticated livestock. *Fish and shellfish* are an important source of food for about 1 billion people, mostly in Asia and in coastal areas of developing countries.

Industrialized Agriculture Relies on High-Input Monocultures

Agriculture can be divided roughly into two types: industrialized agriculture and subsistence agriculture. **Industrialized agriculture,** or **high-input agriculture,** uses large amounts of financial capital, fossil fuel, water, commercial fertilizers, and pesticides to produce high yields (the amount of food per unit of land) of single crops (*monocultures*) or livestock animals for sale. Practiced on one-fourth of all cropland, mostly in developed countries, this form of agriculture has spread since the mid-1960s to some developing countries and now produces about 80% of the world's food.

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 (for sugar and to produce ethanol fuel for cars), coffee, and vegetables on large monoculture plantations, mostly for sale in developed countries. Producing such monoculture crops in the tropics increases yields but decreases biodiversity when tropical forests are cleared for the plantations. A new form of industrialized agriculture involves widespread use of greenhouses to raise food (Figure 10-3).

An increasing amount of livestock production in developed and developing countries is industrialized. Large numbers of cattle are brought to densely populated *feedlots,* or *animal factories,* where they are fattened up for about 4 months before slaughter. Most pigs and chickens in developed countries spend their lives in densely populated pens and cages, often in huge buildings, and eat mostly grain grown on cropland. Such systems use large amounts of energy and water and produce huge amounts of animal waste that can pollute surface and groundwater and saturate the air with unpleasant odors.

■ CASE STUDY
Industrialized Food Production in the United States

In the United States, industrialized farming has evolved into *agribusiness,* as giant multinational corporations increasingly control the growing, processing, distribution, and sale of food in the United States and in the global marketplace.

Agriculture generates almost one-fifth of the nation's gross domestic product. Although agriculture employs more people than any other industry, U.S. farms use industrialized agriculture to produce about 17% of the world's grain with only 0.3% of the world's farm labor force.

Since 1950, U.S. industrialized agriculture has more than doubled the yield of key crops such as wheat, corn, and soybeans without cultivating more land. Such yield increases have kept large areas of forests, grasslands, and wetlands from being converted to farmland.

U.S. consumers now spend about 2% of their disposable income on food, compared to about 11% in 1948. People in developing countries typically spend up to 40% of their income on food. And the 1.2 billion of the world's poor, struggling to live on less than $1 a day, typically spend about 70% of their meager income on food.

However, the actual prices consumers in the U.S. and other developed countries pay for food are much higher than what they pay at grocery stores. In addition to the direct market prices, consumers pay taxes to give subsidies to food producers and distributors and to help deal with the massive pollution and environmental degradation caused by agriculture. They also face higher health costs and higher insurance bills related to the harmful environmental effects of agriculture. Including these harmful costs in the market prices for food could help to bring about a shift to more sustainable and less harmful agriculture.

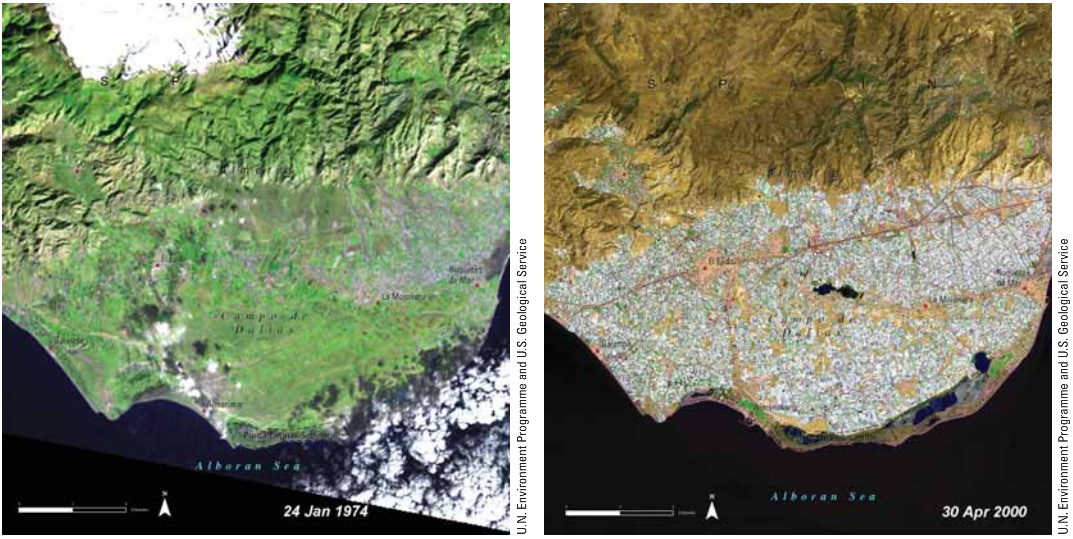


Figure 10-3 Satellite images of massive and rapid development of greenhouse food production and human settlements in the Almeria province along Spain's southern coast between 1974 and 2000. Greenhouse-dominated land appears as whitish gray patches. To provide the water needed to grow these crops, Spain built 118 dams and 22 water transfer projects to move water to this arid region from water-rich parts of the country.

The industrialization of agriculture has been made possible by the availability of cheap energy (mostly from oil) used to run farm machinery, process food, irrigate crops, and produce commercial inorganic fertilizers and pesticides. Putting food on the table consumes about 17% of all commercial energy used in the United States each year (Figure 10-4).

The portion of this energy used to produce a unit of food has fallen considerably, so that most crops in the United States provide more food energy than the energy used to grow them. However, when we consider the energy used to grow, store, process, package, transport, refrigerate, and cook all plant and animal food, *about 10 units of nonrenewable fossil fuel energy are needed to put 1 unit of food energy on the table*. In other words, industrialized food production and consumption has a large *net energy loss*. By comparison, every unit of energy from human labor in traditional farming, which we examine next, provides 1 to 10 units of food energy.

THINKING ABOUT
Food and Oil

What might happen to food production and to your lifestyle if oil prices rise sharply in the next two decades, as many analysts predict they will? How would you reduce this risk?

Traditional Agriculture Often Relies on Low-Input Polycultures

Traditional agriculture consists of two main types, which together are practiced by 2.7 billion people (40% of the world's people) in developing countries. They provide

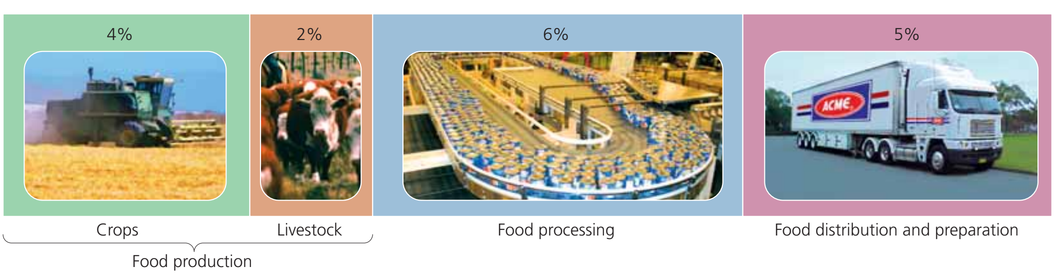


Figure 10-4 Industrialized agriculture uses about 17% of all commercial energy in the United States and food travels an average 2,400 kilometers (1,300 miles) from farm to plate. The resulting pollution degrades the air and water and contributes to global warming. (Data from David Pimentel and Worldwatch Institute)

about one-fifth of the world's food supply on about three-fourths of its cultivated land.

Traditional subsistence agriculture uses mostly human labor and draft animals to produce only enough crops or livestock for a farm family's survival, with little left over to sell or act as a reserve in hard times. In **traditional intensive agriculture,** farmers increase their inputs of human and draft-animal labor, fertilizer, and water to obtain a higher yield per area of cultivated land. If the weather cooperates, they produce enough food to feed their families and to sell some for income.

Some traditional farmers focus on cultivating a single crop (monoculture) such as rice (Figure 10-1). But many grow several crops on the same plot simultaneously, a practice known as **polyculture.** Such crop diversity reduces the chance of losing most or all of the year's food supply to pests, bad weather, and other misfortunes—an example of implementing the **biodiversity principle of sustainability** (see back cover).

SUSTAINABILITY

Slash-and-burn agriculture is a type of subsistence agriculture that involves burning and clearing small plots in tropical forests, growing crops for a few years until the soil is depleted of nutrients, and then shifting to other plots. In South America and Africa, some traditional slash-and-burn farmers grow as many as 20 different crops together on small cleared plots. The crops mature at different times, provide food throughout the year, and keep the soil covered to reduce erosion from wind and water. This lessens the need 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, low-input polyculture produces higher yields per unit of land 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 outproduced plots with 9, 4, or only 1 type of plant species. Therefore, some analysts argue for increasing use of polyculture, along with monocultures for producing food in the future (**Concept 10-2**).

RESEARCH FRONTIER

Investigating the uses and benefits of polyculture

10-3 How Serious Are Soil Erosion and Degradation and How Can They Be Reduced?

CONCEPT 10-3 We can reduce soil erosion and degradation by using proven agricultural techniques and restoring depleted soil nutrients.

Excessive Loss of Topsoil Can Reduce Food Production

Some 15–20 centimeters (6–8 inches) of *topsoil* (Figure 3-A, p. 49) is all that stands between much of the world and mass starvation (**Concept 3-4B**, p. 48). Topsoil is a naturally renewable resource, but its renewal is a slow process. It typically takes decades to centuries to replenish 2.5 centimeters (1 inch) of topsoil, depending mostly on climate and other conditions.

CONCEPT LINK

Soil erosion is the movement of soil components, especially surface litter and topsoil (Figure 3-A, p. 49), from one place to another by the actions of wind and water. When topsoil erodes faster than it forms on a piece of land, it becomes a nonrenewable resource. Entire civilizations have collapsed because they mismanaged the topsoil that supported their populations—an important ecological lesson from the past (see Supplement 6 on p. S31).

Some soil erosion is natural, and some is caused by human activities. Water and wind cause most soil erosion, especially when topsoil is not covered with vegetation. Moving water, the largest cause of erosion, carries away particles of topsoil that have been loosened by rainfall. Wind loosens and blows topsoil particles away, especially in areas with a dry climate and relatively flat and exposed land. This loss of natural capital increases when soil-holding grasses are destroyed through activities such as farming (Figure 10-5), clearcutting (Figure 8-9, p. 157), construction, overgrazing (Figure 8-17, left, p. 164, and photo 10 on p. x), and off-road vehicle use (Figure 8-18, p. 165).

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, which 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 fertilizers and pesticides.

Global Soil Erosion Is a Serious Problem

A joint survey by the U.N. Environment Programme and the World Resources Institute estimated that topsoil is eroding faster than it forms on about 38% of the world's cropland (Figure 10-6). In 2005, the Chinese government estimated that more than one-third of its land was affected by soil erosion, posing a threat to the country's ability to provide enough food and water for its 1.3 billion people. In India, an area larger than the combined areas of Canada and the United States has been degraded by soil erosion. In Africa, three-fourths of the land suitable for growing crops is severely degraded from loss of topsoil, worsening the already serious hunger and malnutrition crisis there. See the Guest Essay on soil erosion by David Pimentel at ThomsonNOW™.

Some analysts contend that erosion estimates are overstated because they underestimate the abilities of some local farmers to restore degraded land. The FAO points out that much of the eroded topsoil does not go far and is deposited on the same slope, valley, or plain from which it came. Thus in some places, the loss in crop yields in one area could be offset by increased yields elsewhere.

In the United States, industrialized farming has been a great success. But a third of the country's original topsoil is gone and much of the rest is degraded. In the U.S. 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 Natural Resources Conservation Service, 90% of American farmland is on average losing topsoil 17 times faster than new topsoil is being formed. In much of the rest of the world, soil erosion is worse than in the United States (Figure 10-6).

Of the world's major food-producing nations, only the United States is sharply reducing some of its soil losses through a combination of planting crops without disturbing the soil and government-sponsored soil conservation programs (**Concept 10-3**). Under the 1985 Food Security Act, farmers receive a subsidy for taking highly erodible land out of production and replanting it with topsoil-saving grass or trees for 10–15 years. Since 1985, these efforts have cut soil erosion on U.S. cropland by 40%. However, effective soil conservation is practiced today on only half of all U.S. agricultural land.


Ron Giling/Peter Arnold, Inc.

Figure 10-5 **Natural capital degradation:** severe gully erosion on cropland in Bolivia.

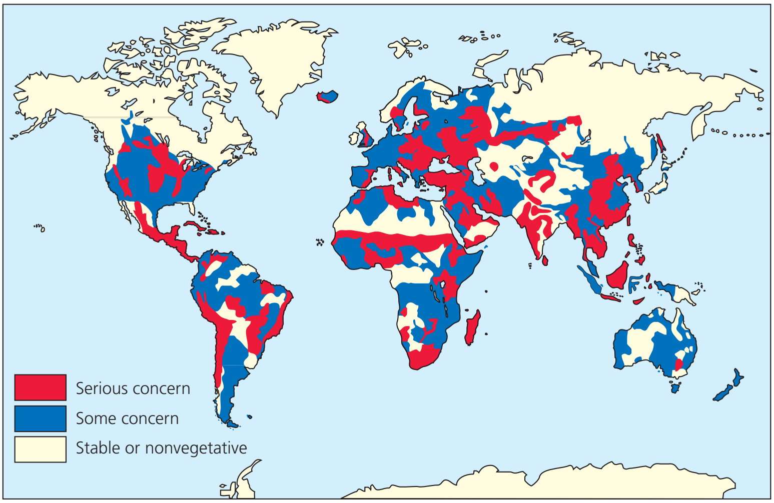
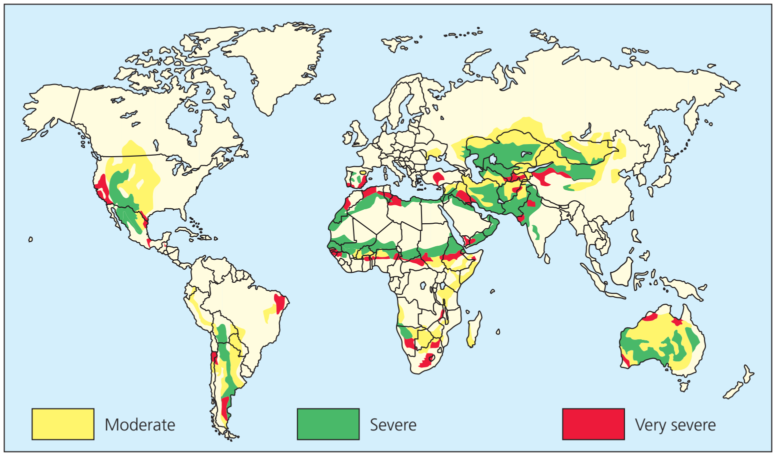


Figure 10-6 **Natural capital degradation:** global soil erosion. **Question:** Can you see any geographical pattern associated with this problem? (Data from U.N. Environment Programme and the World Resources Institute)

Figure 10-7 **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)



Drought and Human Activities Are Degrading Dry Lands

Desertification occurs when the productive potential of dry lands (arid or semiarid land) falls by 10% or more because of a combination of natural climate change that causes 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 than 50%, usually creating huge gullies and sand dunes). Only in extreme cases does desertification lead to what we call desert. Human activities have accelerated desertification in some parts of the world (Figure 10-7).

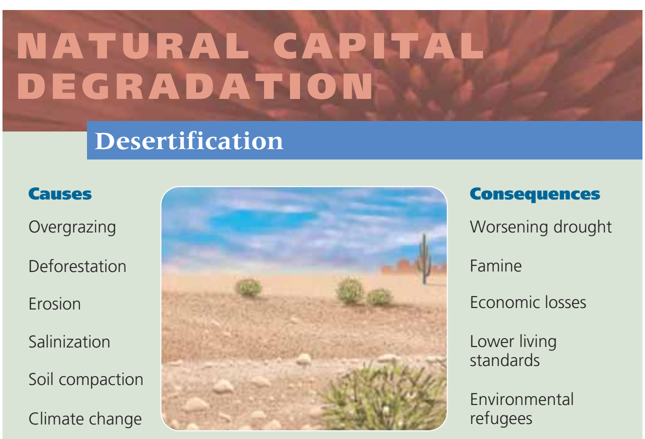


Figure 10-8 Causes and consequences of desertification. **Questions:** How might your life be affected directly or indirectly by these consequences? How might your lifestyle be connected to these causes?

According to a 2003 U.N. conference on desertification, one-third of the world's cropland and rangeland and 70% of all dry lands are suffering from the effects of desertification. U.N. officials estimate that this loss of soil productivity directly affects 250 million people and threatens the livelihoods of up to 1 billion people in 110 countries (70 in Africa). In the 1930s, severe desertification created a dust bowl in the Midwestern United States that displaced several million people (see p. S30 in Supplement 5). Figure 10-8 summarizes the major causes and consequences of desertification.

Two countries suffering heavy losses of land from advancing deserts are China and Nigeria, respectively the most populous countries in Asia and Africa. Over the last 50 years, expanding deserts have displaced tens of millions of people from 24,000 villages in northern and western China and destroyed large areas of cropland and rangeland. Much of the soil in northwest China has dried out, and satellite photos show huge dust storms covering once fertile cropfields, roads, and villages with sand. The Gobi desert (Figure 5-11, bottom, p. 83) has advanced to within 240 kilometers (150 miles) of China's capital city of Beijing, setting off alarm bells for China's leaders. To help protect the city, the government is planting a $1 billion wall of evergreen trees.

The West African nation of Nigeria has 135 million people and 66 million livestock packed into an area slightly larger than the U.S. state of Texas. With a total fertility rate of 5.9 children per woman, its population is projected to reach 299 million by 2050. The country's rapidly-growing human and livestock populations are being squeezed into an ever-smaller area as the plowing of marginal land, overgrazing, and natural factors are slowly turning large areas of the country into desert.

In Mexico, severe desertification hastened by unsustainable farming and livestock grazing forces some

700,000 Mexicans off the land each year. Most migrate to nearby cities or to the United States, searching for jobs.

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 that can leave land vulnerable to soil erosion. We could reduce global warming from greenhouse gases, which is expected to increase droughts in some areas. We can also restore land suffering from desertification by planting trees and grasses that anchor topsoil and hold water, by planting trees to establish windbreaks, and by growing trees and crops together.

Irrigation Can Cause Excessive Salt and Water in Soils

The 20% of the world's cropland that is irrigated produces almost 40% of the world's food. But irrigation has a downside. Because water has a great ability to dissolve many chemicals, most irrigation water is a dilute solution of various salts, picked up as the water flows over or through soil and rocks. Irrigation water not 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** (Figure 10-9). It stunts crop growth, lowers crop yields, and can eventually kill plants and ruin the land.

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 the western states (Figure 10-10).

We know how to prevent and deal with soil salinization, as summarized in Figure 10-11 (p. 208) (**Concept 10-3**). But some of these remedies are expensive, and flushing soil with water to wash away accumulated salts results in more saline water for downstream farmers and towns. One proposed approach is to genetically modify plants to enable them to remove salt from salinized soils or tolerate higher levels of salts.

Another problem with irrigation is **waterlogging** (Figure 10-9). Farmers often apply large amounts of irrigation water to leach salts deeper into the soil. Without adequate drainage, water may accumulate underground and gradually raise the water table. Saline water then envelops the deep roots of plants, lowering their productivity and killing them after prolonged exposure because of a lack of oxygen. At least one-tenth of the world's irrigated land suffers from waterlogging, and the problem is getting worse.

Salinization

1. Irrigation water contains small amounts of dissolved salts.
2. Evaporation and transpiration leave salts behind.
3. Salt builds up in soil.

Waterlogging

1. Precipitation and irrigation water percolate downward.
2. Water table rises.

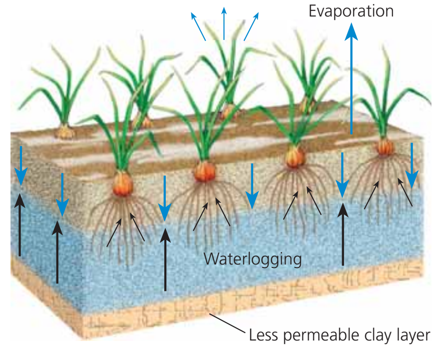


Figure 10-9 *Salinization* and *waterlogging* of soil on irrigated land without adequate drainage can decrease crop yields (**Concept 10-3**).

U.S. Natural Resources Conservation Service

Figure 10-10 **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.

Not Plowing and Tilling Soil Reduces Soil Erosion

Soil conservation involves using a variety of ways to reduce soil erosion and restore soil fertility, mostly by *keeping the soil covered with vegetation* (**Concept 10-3**).

Eliminating the plowing and tilling of soil greatly reduces soil erosion. Many U.S. farmers use **conservation-tillage farming,** which uses special tillers and planting machines that disturb the topsoil as little as possible while planting crops and leaving behind crop residues. Such *no-till* and *minimum-tillage* farming also increases crop yields, reduces the threat of global warming by storing more carbon in the soil, and lowers use of water, pesticides, and tractor fuel.

SOLUTIONS

Soil Salinization

Prevention	Cleanup
Reduce irrigation	Flush soil (expensive and wastes water)
	Stop growing crops for 2–5 years
Switch to salt-tolerant crops (such as barley, cotton, sugarbeet)	Install underground drainage systems (expensive)

Figure 10-11 Methods for preventing and cleaning up soil salinization (**Concept 10-3**). **Question:** Which two of these solutions do you think are the most important? Why?

In 2006, farmers used conservation tillage on about 45% of U.S. cropland. The U.S. Department of Agriculture (USDA) estimates that using conservation tillage on 80% of U.S. cropland would reduce soil erosion by at least half.

No-till cultivation is now spreading rapidly into countries such as Brazil, Argentina, Canada, and Australia. It also has great potential to reduce soil erosion and raise crop yields in dry regions in Africa and the Middle East. Conservation tillage, however, is not a cure-all. It requires costly machinery, works better in some areas than in others, and is more useful for some crops than for others.

Farmers Know How to Reduce Soil Erosion

Figure 10-12 shows some of the methods farmers have used to reduce soil erosion (**Concept 10-3**). **Terracing** is a way to grow food on steep slopes or mountainsides 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 10-12a and Figure 10-1). This retains water for crops at each level and reduces soil erosion by controlling runoff.

When the ground has a significant slope, a technique known a **contour farming** (Figure 10-12b) can be used to reduce soil erosion. It involves plowing and planting crops in rows across the slope of the land. Each row acts as a small dam to help hold topsoil and to slow water runoff.

Strip cropping (Figure 10-12b) involves planting alternating strips of a row crop (such as corn or cotton) and another crop that completely covers the soil (such as a grass or grass–legume mixture). The cover crop traps topsoil that erodes from the row crop and catches and reduces water runoff.

Another way to reduce erosion is to keep the soil covered by leaving crop residues on the land after the crops are harvested. Farmers can also plant *cover crops* such as alfalfa, clover, or rye immediately after harvest to help protect and hold the topsoil.

Alley cropping or *agroforestry* (Figure 10-12c) 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.

Some farmers establish **windbreaks,** or **shelterbelts,** of trees around crop fields to reduce wind erosion (Figure 10-12d). They also help retain soil moisture, supply wood for fuel, increase crop productivity by 5–10%, and provide habitats for birds, pest-eating and pollinating insects, and other animals.

One problem is that many farmers do not practice these known ways to reduce soil erosion. This happens because they are in a desperate struggle to survive or are more interested in increasing short-term income even if it leads to long-term environmental degradation.

We Can Restore Soil Fertility

The best way to maintain soil fertility is through soil conservation. The next best option is to restore some of the plant nutrients that have been washed, blown, or leached out of soil or removed by repeated crop harvesting. 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 feces and urine of cattle, horses, poultry, and in some cases wastes from animal feedlots. It improves soil structure, adds organic nitrogen, and stimulates 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, food wastes, paper, and wood in the presence of oxygen. (See the website for this chapter for more details on composting.)

Crops such as corn, tobacco, and cotton remove large amounts of nutrients (especially nitrogen) from topsoil, especially if such crops are planted on the same land several years in a row. *Crop rotation* provides one way to reduce these losses. Farmers plant areas or

(a) Terracing

(b) Contour planting and strip cropping

(c) Alley cropping

(d) Windbreaks

Figure 10-12 **Solutions:** in addition to conservation tillage, soil conservation methods include **(a)** terracing, **(b)** contour planting and strip cropping, **(c)** alley cropping, and **(d)** windbreaks (**Concept 10-3**).

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. In addition to helping restore soil nutrients, this method reduces erosion by keeping the topsoil covered with vegetation.

Many farmers (especially in developed countries) rely on *commercial inorganic fertilizers.* The active ingredients in these synthetic (human-made) products typically 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 ninefold since 1950 and now accounts for about one-fourth of the world's crop yield. But without careful control, these fertilizers can run off the land and pollute nearby bodies of water.

Inorganic fertilizers can replace depleted inorganic nutrients, but they do not replace organic matter. Thus, for healthy soil, both inorganic and organic fertilizers should be used.

10-4 What Have the Green and Gene Revolutions Done for Food Security?

CONCEPT 10-4 Industrialized agriculture has increased global food production dramatically, but its harmful environmental impacts may limit future food production.

Green Revolutions Have Increased Food Production

Farmers can produce more food by farming more land or by getting higher yields per unit of area from existing cropland. Since 1950, about 88% of the increase in global food production has come from using high-input agriculture to increase yields per unit of cropland in a process called the **green revolution** (**Concept 10-4**).

The green revolution involves three steps. *First,* develop and plant monocultures of selectively bred high-yield varieties of key crops such as rice, wheat, and corn. *Second,* produce high yields by using large inputs of fertilizer, pesticides, and water. *Third,* increase the number of crops grown per year on a plot of land through *multiple cropping.* This high-input approach dramatically increased crop yields in most developed countries between 1950 and 1970 in what is 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 Central and South America. Producing more food on less land has the benefit of protecting biodiversity by saving large areas of forests, grasslands, wetlands, and easily eroded steep mountain terrain from being used to grow food unless rapid population growth requires expanding cropland.

Between 1950 and 1996, mostly because of the two green revolutions, world grain production tripled (Figure 10-13, left). Per capita grain production increased by 31% between 1961 and 1985, but since then has generally declined partly because large amounts of grain are fed to livestock instead of being used to feed people (Figure 10-13, right). Since 1970, the sharpest drop in per capita food production has occurred in Africa, the continent that for decades has had the world's highest rate of population growth. Such growth, plus poor soils, lack of water, soil erosion, limited economic development, and social chaos and warfare in many parts of Africa, have prevented the spread of the green revolutions there.

As incomes grow, more people begin eating more meat, much of which is produced by feeding grain to livestock. This increases the demand for grain and can lead to increased reliance on grain imports. As population and meat consumption grow, at some point the world's major food producing countries may not be able to meet the demand for grain imports. In addition, there is a growing competition for grain between producers of food and producers of biofuels, such as ethanol made from corn, for cars.

There May Be Limits to Expanding Green Revolutions

Analysts point to several factors that have limited the success of the green revolutions to date and that may limit them in the future (**Concept 10-4**). Without huge inputs of fertilizer, pesticides, and water, most green revolution crop varieties produce yields that are no higher (and are sometimes lower) than those from traditional strains. These high-inputs also cost too much for most subsistence farmers in developing countries. Scientists also point out that continuing to increase these inputs eventually produces no additional increase in crop yields. For example, grain yields rose about 2.1% per year between 1950 and 1990, but then dropped to 0.5% by 2005.

No one knows whether this graying of green revolution yields will continue. But the multicropping that is essential to high yields may be limited in some areas by two factors: the available supply of irrigation water and the lack of enough labor to harvest one crop and then plant another as low-cost farm laborers migrate to cities for better jobs. This has forced countries such as Japan, South Korea, and Taiwan to import most of their grain, and it may also cause China to rely more on grain imports.

Can we increase crop yields by irrigating more cropland? Between 1950 and 2006, the world's area of irrigated cropland tripled, with most of the growth occurring from 1950 to 1978. 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 2.2 billion more people.

However, since 1978 the amount of irrigated land per person has been declining and is projected to fall much more between 2006 and 2050. Two reasons are that since 1978, the world's population has grown faster than has use of irrigation, and most of the world's farmers do not have enough money to irrigate their crops. The key is to find ways to grow more food with less water as discussed in Chapter 11.

Is cultivating more land the answer? Theoretically, 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. Cultivation of such land is expensive, is unlikely to be sustainable, and would decrease biodiversity by clearing forest and natural grasslands.

Furthermore, these potential increases in cropland would not offset the projected loss of almost one-third of today's cultivated cropland due to erosion, overgrazing, waterlogging, salinization, desertification, and urbanization. Such cropland expansion would also seriously reduce wildlife habitats and biodiversity.

In addition, during this century fertile cropland in coastal areas is likely to decrease from rising sea levels due to global warming. This could affect food production by flooding low-lying coastal land, including many of the major rice-growing floodplains and river deltas in Asia. In addition, food production could drop sharply in some countries because of increased drought and heat waves from global warming.

Bottom line: *more land can be planted with crops but significant expansion of cropland is unlikely over the next few decades for economic and ecological reasons* (**Concept 10-4**).

We Can Grow More Food in Urban Areas and Reduce Food Waste

According to the United Nations Development Programme, urban gardens provide about 15% of the world's food supply. For example, farmers in or near 18 of China's largest cities provide urban dwellers with

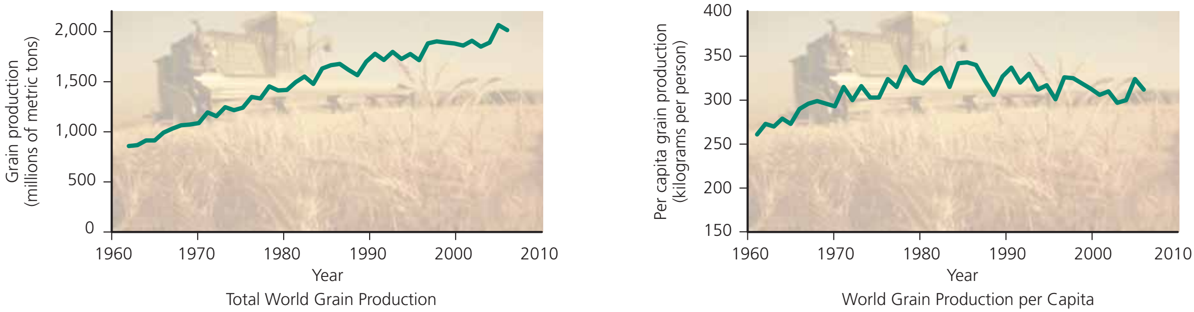


Figure 10-13 *Global outlook:* total worldwide grain production of wheat, corn, and rice (left), and per capita grain production (right), 1961–2005. In order, the world's three largest grain-producing countries are China, the United States, and India. **Question:** Why do you think grain production per 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)

85% of their vegetables and more than half of their meat and poultry. Food experts believe that people in urban areas save money and reduce their environmental impact by growing more of their food in empty lots, in backyards, on rooftops and balconies, and by raising fish in tanks and sewage lagoons.

We can also waste less food. According to the FAO, as much as 70% of the food produced worldwide is lost through spoilage, inefficient processing and preparation, and plate waste. Nationwide, U.S. households throw away food worth as much as $43 billion a year—almost twice the $24 billion a year needed to eliminate global hunger and malnutrition.

We can also collect and use crop residues as feed for livestock or to produce biofuels (such as ethanol) or to make paper. India has used crop residues to increase its milk production fourfold.

Producing Food Has Major Environmental Impacts

Modern agriculture has significant harmful effects on air, soil, water, and biodiversity, as Figure 10-14 (p. 212) shows. According to many analysts, agriculture has a greater harmful environmental impact than any human activity.

There is concern that crop yields in some areas may decline because of environmental degradation factors such as soil erosion; loss of soil fertility; waterlogging and salinization of irrigated soil; depletion and pollution of underground and surface water supplies (from pesticides and nitrates from fertilizers); and rapidly growing populations of pests that have developed genetic immunity to widely used pesticides (**Concept 10-4**). Because of the large number of variables involved, we do not know how close we are to such environmental limits but alarm bells are going off.

Another environmental problem is the increasing loss of *agrobiodiversity*—the world's genetic variety of animals and plants used to provide food. Hundreds of millions of years of natural selection have produced a great diversity of plant life, which has evolved ways to reduce the harmful effects of plant pests, diseases, and climate change.

But we are replacing nature's resilient genetic diversity with human-engineered monocultures. 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 10 varieties and soon almost all of its production may come from just one variety. Rice varieties around the world may drop even more if there is a shift toward genetically engineered golden rice (**Core Case Study**) and other genetically engineered crops.

In other words, we are rapidly shrinking the world's genetic "library," which is critical for increasing food yields. We now need this diversity more than ever to develop new plant and livestock varieties by conventional crossbreeding and genetic engineering in response to changes in growing conditions due to global warming. This failure to preserve agrobiodiversity is a violation of one of the four **scientific principles of sustainability** (see back cover and **Concept 1-6**, p. 19).

Wild varieties of the world's most important plants can be collected and stored in gene or seed banks, agricultural research centers, and botanical gardens. But space and money severely limit the number of species that can be preserved. The seeds of many plants (such as potatoes) cannot be stored successfully in gene banks. And power failures, fires, or unintentional disposal of seeds can cause irreversible losses.

Thus, scientists warn that the only effective way to preserve the genetic diversity of most plant and animal species is to protect representative ecosystems throughout the world from agriculture and other forms of development.

NATURAL CAPITAL DEGRADATION

Food Production

Biodiversity Loss

- Loss and degradation of grasslands, forests, and wetlands
- Fish kills from pesticide runoff
- Killing wild predators to protect livestock
- Loss of genetic diversity of wild crop strains replaced by monoculture strains

Soil

- Erosion
- Loss of fertility
- Salinization
- Waterlogging
- Desertification

Water

- Water waste
- Aquifer depletion
- Increased runoff, sediment pollution, and flooding from cleared land
- Pollution from pesticides and fertilizers
- Algal blooms and fish kills in lakes and rivers caused by runoff of fertilizers and agricultural wastes

Air Pollution

- Greenhouse gas emissions (CO_2) from fossil fuel use
- Greenhouse gas emissions (N_2O) from use of inorganic fertilizers
- Release of methane by cattle (belching and flatulence)
- Other air pollutants from fossil fuel use and pesticide sprays

Human Health

- Nitrates in drinking water (blue baby)
- Pesticide residues in drinking water, food, and air
- Contamination of drinking and swimming water from livestock wastes
- Bacterial contamination of meat

Figure 10-14 Major harmful environmental effects of food production (**Concept 10-4**). According to a 2002 study by the United Nations, nearly 30% of the world's cropland has been degraded to some degree by soil erosion, salt buildup, and chemical pollution, and 17% has been seriously degraded. **Question:** Which item in each of these categories do you believe is the most harmful? Why?

Crossbreeding and Genetic Engineering Can Produce New Crop Varieties

For centuries, farmers and scientists have used *cross-breeding* through *artificial selection* to develop genetically improved varieties of crop and livestock animals. Such selective breeding in this first *gene revolution* has yielded amazing results. Ancient ears of corn were about the size of your little finger and wild tomatoes were once the size of grapes.

Traditional crossbreeding is a slow process, typically taking 15 years or more to produce a commercially valuable new crop variety, and it can combine traits only from species that are genetically similar. Resulting varieties remain useful for only 5–10 years before pests and diseases reduce their effectiveness.

However, important advances are still being made. In 2006, a team led by University of California at Davis researcher Jorge Dubcovsky identified a gene in a type of wild wheat that has higher than normal levels of protein, zinc, and iron. They used conventional cross-breeding to add the gene to cultivated varieties of wheat. This new strain could help as many as 2 million people who get too little zinc and iron and the more than 160 million children under age 5 who get too little protein from their wheat-based diets.

Today, scientists are creating a second *gene revolution*—by using *genetic engineering* to develop genetically improved strains of crops and livestock animals. It involves splicing a gene from one species and transplanting it into the DNA of another species (Figure 4-8, p. 72). Compared to traditional crossbreeding, gene splicing takes about half as long to develop a new crop variety and allows the insertion of genes from almost any other organism into crop cells. For example, genetic engineers used genes from ordinary daffodils and a soil bacterium (Figure 10-1, right) to produce golden rice (**Core Case Study**). CORE CASE STUDY

Ready or not, much of the world is entering the *age of genetic engineering*. In 2006, the United States, Argentina, and Brazil led the world in growing genetically engineered crops, most of them soybeans. Almost one-third of U.S. cropland grows genetically engineered crops. More than two-thirds of the food products on U.S. supermarket shelves now contain some form of genetically engineered crops, 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, salty or acidic soil, and drought. They also hope to develop crop plants that can grow faster and survive with little or no irrigation and with less fertilizer and pesticides. In 2006, Texas A&M University scientists genetically altered normally inedible cotton plants (grown in more than 80 countries worldwide) so that their cottonseeds could be ground into a flour and made into bread and other foods that could potentially meet the protein requirements of half a billion people a year.

RESEARCH FRONTIER

Genetic engineering

There Is Controversy over Genetically Engineered Foods

Despite its promise, considerable controversy has arisen over the use of *genetically modified food* (GMF) and other forms of genetic engineering. Its producers and investors see this kind of food as a potentially sustainable way to solve world hunger problems and improve human health. Some critics consider it potentially dangerous "Frankenfood." Figure 10-15 summarizes the projected advantages and disadvantages of this new technology.

THINKING ABOUT
Golden Rice

CORE CASE STUDY

Do you think that the advantages of genetically engineered golden rice (**Core Case Study**) outweigh its disadvantages? Explain.

Critics recognize the potential benefits of genetically modified 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. Also, if they cause some unintended harmful genetic and ecological effects, as some scientists expect, genetically modified organisms cannot be recalled or cleaned up like a chemical spill can. For example, there is concern that genetically modified food strains can be transferred by wind or released accidentally into areas beyond where they are planted. The new strains can then form hybrids with wild crop varieties and reduce the natural genetic biodiversity of wild strains. This could reduce the gene pool needed to crossbreed new crop varieties and to develop genetically engineered varieties.

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 10-15 Projected advantages and disadvantages of genetically modified crops and foods. **Question:** Which two advantages and which two disadvantages do you think are the most important? Why?

Most scientists and economists who have evaluated the genetic engineering of crops believe that its potential benefits outweigh its risks. But critics call for more controlled field experiments, more research, long-term safety testing to better understand the risks, and stricter regulation of this rapidly growing technology. A 2004 study by the Ecological Society of America recommended more caution in releasing genetically engineered organisms into the environment without stricter government regulation of such releases.

Another issue related to GMF arises from court decisions granting seed companies patents (and thus exclusive ownership) of genetically modified crop varieties. Companies with such patents have successfully sued some farmers for saving and using their seeds the next year rather than buying a new batch of seeds.

Critics of patenting genetically engineered crop and animal varieties argue that it represents a private takeover of a common heritage—the work of all the farmers over the last 10,000 years. Many farmers in developing countries, who are too poor to buy patented seeds each year, have refused to respect the patent claims on such seeds. Seed companies say they have spent large amounts of money developing these new varieties and that patents allow them to recoup their expenses and make profits.

THINKING ABOUT
Gene Patenting

CORE CASE STUDY

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?

Many analysts and consumer advocates believe governments should require mandatory labeling of GMFs to help consumers make informed choices about the foods they buy. Such labeling is required in Japan, Europe, South Korea, Canada, Australia, and New Zealand. Polls show that at least 75% of Americans support mandatory labeling of GMFs.

In the United States, industry representatives and the USDA oppose such labeling, claiming that GMFs are not substantially different from foods developed by conventional crossbreeding methods, and that labeling would be expensive. Also, they fear—probably correctly—that labeling such foods would hurt sales by arousing suspicion. In 1996, the U.S. Court of Appeals upheld the USDA position that labeling of GMFs should not be required simply because consumers want such information.

HOW WOULD YOU VOTE?

Should all genetically engineered foods be so labeled? Cast your vote online at **www.thomsonedu.com/biology/miller**.

10-5 Are There Limits to Providing More Meat and Seafood?

CONCEPT 10-5A Rangeland overgrazing and the harmful environmental impacts of industrial livestock production may limit meat production.

CONCEPT 10-5B We can harvest fish more sustainably to prevent overfishing and use improved types of aquaculture.

Meat Production Has Increased Dramatically but There Are Environmental Consequences

Meat and meat products are good sources of high-quality protein. Between 1950 and 2005, world meat production increased more than fivefold, and is likely to more than double again by 2050 as affluence rises and middle-income people begin consuming more meat in developing countries such as China and India. In fact, China now leads the world in both meat production and consumption.

About half of the world's meat comes from grazing livestock; the other half is produced under factory-like conditions with high environmental impacts. In the first approach, livestock graze on grass in unfenced rangelands and enclosed pastures. The second method is an industrialized system in which pigs, chickens, and cattle are raised in densely packed *feedlots* or cages where they are fed grain or meal produced from fish.

Experts expect industrialized meat production to expand rapidly. This will increase pressure on the world's grain supply. Producing more meat will also increase pressure on the world's fish supply because about 35% of the marine fish catch is used to feed livestock and carnivorous fish raised by aquaculture.

Industrialized meat production has a number of harmful environmental impacts (**Concept 10-5A**). Industrial livestock production is one of the world's biggest consumers of water. Producing just 0.2 kilograms (8 ounces) of grain-fed beef requires 25,000 liters (6,600 gallons) of water. This does not include the large amount of water used in slaughtering cattle and processing their meat.

Energy is also an essential ingredient in industrialized meat production. Producing one calorie of grain-fed beef takes 33% more fossil fuel energy (mostly oil) than producing a calorie of potatoes. Using this energy pollutes the air and water and contributes to global warming. Through belching and flatulence, cattle and dairy cows release methane, the second most powerful greenhouse gas after carbon dioxide, into the atmosphere and account for 16% of the global annual emissions of methane. Thus, raising more cattle and dairy cows means more methane and more global warming.

Livestock in the United States produce 20 times more 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. Much of the other half of this waste ends up polluting the air, water, and soil—a violation of one of the four **scientific principles of sustainability** (see back cover and **Concept 1-6**, p. 19).

SUSTAINABILITY

CONCEPT LINK

We Can Produce Meat More Efficiently and Sustainably

Raising cattle on rangelands and pastures is less environmentally destructive than raising them in feedlots as long as the grasslands are not overgrazed (Figure 8-17, left, p. 164, and photo 10, p. x). Grass-fed cattle require little or no grain, thus eliminating the harmful environmental effects of growing soybeans and corn and shipping these grains to feedlots.

A more sustainable form of meat production and consumption would involve shifting from forms of animal protein, such as beef and pork, to forms of meat, such as poultry and herbivorous farmed fish, which require much less grain or fish meal for each unit of added body weight (Figure 10-16).

> **THINKING ABOUT**
> **Meat Consumption**
> CONCEPT LINK
> Would you be willing to live lower on the food chain (**Concept 3-5**, p. 50) by eating less meat or no meat? Explain.

We Are Vacuuming Fish and Shellfish from the Seas

The world's third major food-producing system consists of **fisheries:** concentrations of particular aquatic species suitable for commercial harvesting in a given ocean area or inland body of water. Humans eat about 1,000 of the world's roughly 30,000 known fish species. About two-thirds of the world's fish and shellfish harvest comes from the oceans and inland freshwater lakes, rivers, reservoirs, and ponds. The other third is produced through *aquaculture*—raising marine and freshwater fish in ponds and underwater cages.

The global fishing industry provides livelihoods for about 200 million people and supplies more than 1 billion people, mostly in Asia, with 30% of their protein. In order, just six fishing nations—China, Peru, India, the United States, Japan, and Chile—account for nearly two-thirds of the global fish catch. Even so, the United States imports 80% of its seafood.

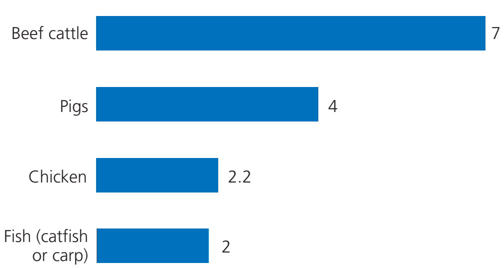


Figure 10-16 Efficiency of converting grain into animal protein. Data in kilograms of grain per kilogram of body weight added to the animal. **Question:** If you eat meat, what are two changes you could make in your meat-eating habits to reduce your environmental impact? (Data from U.S. Department of Agriculture)

The world's commercial marine fishing industry is dominated by industrial fishing fleets that use global satellite positioning systems, sonar, depth sensors, detailed maps of the ocean floor, huge nets and long fishing lines, spotter planes, and large factory ships that can stay at sea for months and process and freeze their catches. Figure 10-17 (p. 216) shows the major ways fish are harvested from the oceans or raised in aquaculture cages. Many commercially valuable species are being overfished by these increasingly efficient methods that "vacuum" many areas of the world's seas of fish and shellfish.

Massive supertrawlers pull huge nylon nets—one with a mouth the size of 50 football fields—through the water, capturing everything in their path. These boats can fish as deep as 1.6 kilometers (1 mile) and catch and deplete bottom-dwelling species. Giant trawling nets dragged across the ocean bottom scoop up massive amounts of fish and shellfish and degrade and destroy bottom habitats. This is similar to clear-cutting a forest (Figure 8-25, right, p. 172). Roughly a third of what is caught by global fishing fleets is not profitable enough to keep. This *bycatch* is chopped up and pumped back into the ocean. This degrades aquatic biodiversity and wastes potentially valuable food resources.

A typical pattern is to fish a species until its larger individuals are gone. Then fishers turn to smaller fish that have not yet spawned. As a species is depleted to the point where it no longer pays to catch it (economic extinction), the fleets begin catching other species lower on the food chain. As these species decline, it makes it even harder for overfished species that feed on them to recover quickly.

Figure 10-18 (p. 217) shows the effects of the global efforts to boost the seafood harvest. Since 1950, the world fish catch (marine plus freshwater harvest, excluding aquaculture) has increased almost sevenfold (Figure 10-18, left) and the global fish catch per person has almost tripled (Figure 10-18, right). The global marine catch from open sea (excluding inland fisheries and aquaculture) fell 13% between 1994 and 2003, despite increased fishing efforts.

Catching wild fish is heavily dependent on fossil fuels, which makes the industry especially vulnerable to increases in oil prices. According to a 2005 study by Peter H. Tyedmers and his colleagues, the world's fishing fleets use about 12.5 times more energy to catch and deliver a given weight of fish than the food energy the fish provide. Even so, fishing takes less energy than raising beef in feedlots or farming salmon in pens.

Today, about two-thirds of the world's major fisheries have been fished at or beyond their sustainable

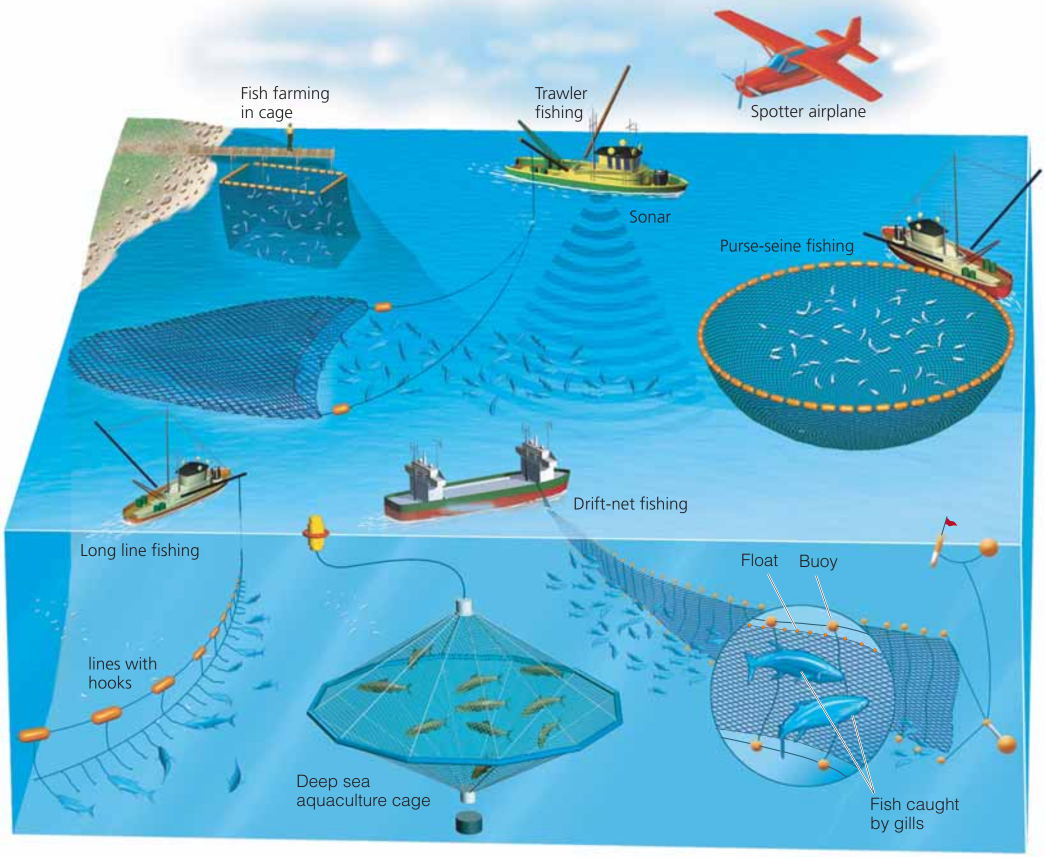


Figure 10-17 Major commercial fishing methods used to harvest or raise various marine species. These methods have become so effective that many fish species have become commercially extinct from overfishing. (**Concept 10-5B**).

capacity, and 29% (up from 14% in 1984) have collapsed as a result of a 90% decline in their catch. In the next few decades, more fisheries may collapse from a combination of overfishing, pollution, loss of highly productive coral reefs and mangroves, and global warming.

According to the Ocean Conservancy, "We are spending the principal of our marine fish resources rather than living off the interest they provide." (**Concept 1-1B**, p. 6). CONCEPT LINK

The oceans can recover and be fished in a well-managed, profitable, and sustainable manner. In 1995, fisheries biologists studying population data for 128 depleted fish stocks concluded that 125 of those depleted stocks could recover with careful management (Figure 8-26, p. 173). This would require establishing fishing quotas, regulating fishing gear and methods, limiting the number of fishing boats, eliminating bottom trawling, reducing pollution, setting aside networks of no-take reserves for 20–30% of the world's oceans (compared to the current figure of less than 0.01%), restoring wetlands, reducing river pollution, and protecting much more of the earth's coral reefs, mangrove forests, wetlands, and river deltas from unsustainable fishing and development (**Concept 10-5B**). We also know how to design trawling equipment that avoids scraping the ocean bottom by gliding slightly above it and fishing equipment that allows small fish to escape and avoids killing so many turtles and dolphins.

In other words, science reveals how we can sustain fisheries and aquatic biodiversity, but so far, few countries are doing these things. To make such a change, Carl Safina of the Blue Ocean Institute calls for us to develop a *sea ethic.* This involves understanding that the interconnected oceans (Figure 5-19, p. 92) are one of the earth's most important global ecosystems (Figure 5-21, p. 94). It means viewing species of fish and shellfish as essential forms of biodiversity that should be protected

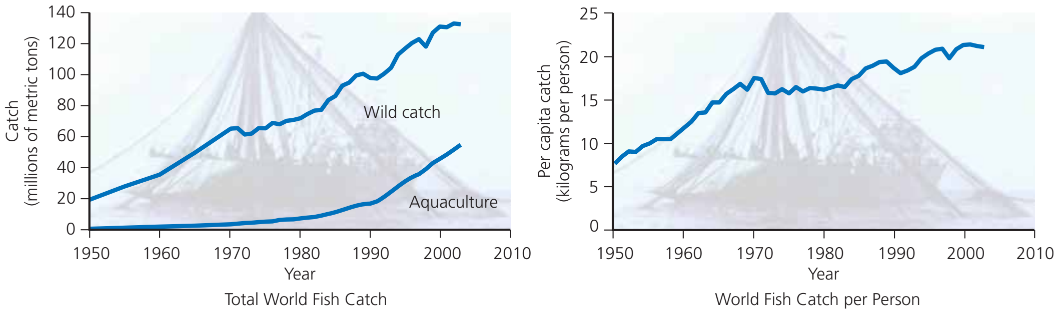


Figure 10-18 Total world fish catch (left) and world fish catch per person (right), 1950–2003. Estimates for both since 1990 may be about 10% lower than shown here, because it was discovered that China had been inflating its fish catches since 1990. **Question:** Why do you think the per capita fish catch has leveled off? (Data from U.N. Food and Agriculture Organization, U.S. Census Bureau, and Worldwatch Institute)

rather than overharvested for short-term economic gain. This requires consumers to choose fish species that are harvested sustainably.* It also means realizing that most of the chemicals we flush down our drains eventually have an impact on the oceans.

Should Governments Continue Subsidizing Fishing Fleets?

Overfishing is a big and growing problem because there are too many commercial fishing boats and fleets trying to hunt and gather a dwindling supply of the most desirable fish.

Each year, the global fishing industry spends about $15–$20 billion more than its catch is worth. Governments use taxpayers' money to make up for this deficit by providing subsidies such as fuel tax exemptions, price controls, low-interest loans, grants for fishing gear, and help for building more supertrawlers. Without such taxpayer subsidies, which average $1.7–2.3 million per hour, up to half of the world's fishing boats would have to go out of business and the number of fish caught would approach their sustainable yield.

Continuing to subsidize excess fishing will allow some fishers to keep their jobs and boats a little longer while making less and less money until the fisheries collapse. Then most jobs will be gone and fishing communities will suffer even more. Critics call for shifting some of the money from such environmentally harmful subsidies to programs to buy out some fishing boats and retrain their crews for other occupations. A 2004 study by Andrew Balmford and several other scientists estimated that protecting 20–30% of the oceans from fishing would create about 1 million jobs and would cost much less than the world's current government subsidies that encourage overfishing.

* You can find guides for choosing sustainable seafood from the Blue Ocean Institute (**blueocean.org/seafood/**) and the Monterey Bay Aquarium (**eaquarium.org/cr/seafoodwatch.asp**).

HOW WOULD YOU VOTE? ✓

Should governments eliminate most fishing subsidies? Cast your vote online at **www.thomsonedu.com/biology/miller**.

We Can Use Fish Farming to Raise Fish and Shellfish

Aquaculture involves raising fish and shellfish for food instead of hunting and gathering them. The world's fastest-growing type of food production, it accounts for about one-third of the global production of fish and shellfish (Figure 10-18, left). Some call aquaculture the *blue revolution.*

Aquaculture involves cultivating fish in a freshwater pond, lake, reservoir, or rice paddy, in fenced-in areas, or in underwater cages in coastal saltwater lagoons, estuaries, or the deep ocean (Figure 10-17). The fish are harvested when they reach the desired size. China raises 70% of the world's farmed fish, mostly in inland ponds and rice fields.

Figure 10-19 (p. 218) lists the major advantages and disadvantages of aquaculture. Some analysts project that freshwater and saltwater aquaculture production could provide at least half of the world's seafood by 2025. Other analysts warn that the harmful environmental effects of aquaculture could limit future production (Figure 10-19, right).

For example, genetically modified aquaculture species can escape and breed with wild fish and thus reduce the gene pools and populations of wild fish species such as salmon. In some Norwegian fjords, 90% of the specially bred salmon in fish farms have escaped.

Shrimp farmers often clear mangrove swamps (Figure 5-20, p. 93), which reduces the populations of wild fish that live in the mangroves. The Worldwatch Institute estimates that each metric ton of shrimp raised in such farms causes an annual loss of about 7 metric tons of harvestable wild shrimp.

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 to feed some species
High profits	Dense populations vulnerable to disease

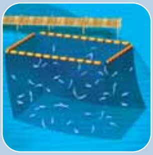


Figure 10-19 Advantages and disadvantages of *aquaculture.* **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

Another problem is that fish raised on fishmeal or fish oil can be contaminated with toxins such as PCBs found on ocean bottoms. In 2003, samples from various U.S. grocery stores revealed that farmed salmon that had been fed contaminated fish meal or fish oil had 7 times more PCBs than wild salmon and 4 times more than feedlot beef.

On the other hand, raising plant-eating fish such as carp and tilapia in freshwater ponds, as is done extensively in China, does not harm the oceans. Instead of using fish meal made from wild fish, such aquaculture can take place on existing farms and make use of agricultural plant wastes.

HOW WOULD YOU VOTE?

Do the advantages of aquaculture outweigh its disadvantages? Cast your vote online at **www.thomsonedu.com/biology/miller**.

Figure 10-20 lists some ways to make aquaculture more sustainable and to reduce its harmful environmental effects (**Concept 10-5B**).

However, even under the most optimistic projections, increasing both the wild catch and aquaculture will not increase world food supplies significantly, because fish and shellfish supply only about 1% of the calories and 6% of the protein in the human diet.

SOLUTIONS

More Sustainable Aquaculture

- Restrict location of fish farms to reduce loss 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 10-20 Ways to make aquaculture more sustainable and reduce its harmful effects (**Concept 10-5B**). **Question:** Which two of these solutions do you think are the most important? Why?

10-6 How Can We Protect Crops from Pests?

CONCEPT 10-6 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 becoming 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 of the potential pest species in keeping with one of the earth's four **scientific principles of sustainability** (see back cover and **Concept 1-6**, p. 19). For example, the world's 30,000 known species of spiders, including the wolf spider (Figure 10-21), kill far more insects every year than insecticides do.

Peter J. Bryant/Biological Photo Service

Figure 10-21 Spiders consume large numbers of insects. Most spiders, including this ferocious-looking wolf spider, do not harm humans.

When we clear forests and grasslands, plant monoculture crops, and douse fields with pesticides, we upset many of these natural population checks and balances. Then we must devise ways to protect our monoculture crops, tree plantations, lawns, and golf courses from insects and other pests that nature once controlled at no charge.

We Use Pesticides to Help Control Pest Populations

To help control pest organisms, we have developed a variety of **pesticides**—chemicals to kill or control populations of organisms, such as insects, weeds, nematodes, rats, and mice, that we consider undesirable.

We did not invent the use of chemicals to repel or kill other species. Plants have been producing chemicals to ward off, deceive, or poison herbivores that feed on them for nearly 225 million years. This battle produces a never-ending, ever-changing coevolutionary process: herbivores overcome various plant defenses through natural selection (**Concept 4-1B**, p. 64); then new plant defenses are favored by natural selection 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.

About one-fourth of pesticide use in the United States is devoted to trying to rid houses, gardens, lawns, parks, playing fields, swimming pools, and golf courses of pests. According to the U.S. Environmental Protection Agency (EPA), the average lawn in the United States is doused with 10 times more synthetic pesticides per unit of land area than the average crop field receives.

Some pesticides, called *broad-spectrum agents,* are toxic to many pest and 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. An example is organophosphates.

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 9-14, p. 188). Others, such as organophosphates, are active for days or weeks and are not biologically magnified. 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 on p. S26 in Supplement 5).

Modern Synthetic Pesticides Have Several Advantages

Proponents of conventional chemical pesticides contend that their benefits (Figure 10-22, left) outweigh their harmful effects (Figure 10-22, right).

Let's look more closely at the major benefits of conventional pesticides.

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).

Figure 10-22 Advantages and disadvantages of conventional chemical pesticides. **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

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, although some studies dispute this.

They increase profits for farmers. Officials of pesticide companies estimate that every $1 spent on pesticides leads to an increase in U.S. crop yields worth approximately $4. (Studies have shown this benefit drops to about $2 if the harmful effects of pesticides are included.)

They work fast. Pesticides control most pests quickly, have a long shelf life, and are easily shipped and applied. When genetic resistance occurs, farmers can switch to other pesticides.

When used properly, their health risks are very low relative to their benefits, according to pesticide industry officials.

Newer pesticides are safer and more effective than many older ones. Greater use is being made of botanicals and microbotanicals. Derived originally from plants, they are safer for users and less damaging to the environment than many older pesticides are. Genetic engineering is also being used to develop pest-resistant crop strains and genetically altered crops that produce pesticides.

Modern Synthetic Pesticides Have Several Disadvantages

Opponents of widespread pesticide use believe that the harmful effects of these chemicals (Figure 10-22, right) outweigh their benefits (Figure 10-22, left). They cite several serious problems with the use of conventional pesticides.

Pest organisms can become genetically resistant to widely used pesticides. Insects breed rapidly, and within five to ten years (much sooner in tropical areas) they can develop immunity to widely used pesticides through natural selection and 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.

They can put farmers on a financial treadmill. Because of genetic resistance, farmers can pay more and more for a pest control program that often becomes less and less effective.

Some insecticides kill natural predators and parasites that help control the pest populations. Wiping out natural predators, such as spiders, can unleash new pests that the predators had previously held in check and cause other unexpected effects (Science Focus, at right). 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.

Pesticides do not stay put and can pollute the environment. According to the USDA, 98–99.9% of the pesticides and more than 95% of the herbicides we apply end up in the air, surface water, groundwater, bottom sediments, food, and nontarget organisms, including humans and wildlife (Figure 9-14, p. 188).

Some pesticides harm wildlife. According to the USDA and the U.S. Fish and Wildlife Service, each year, pesticides applied to cropland in the United States wipe out about 20% of U.S. honeybee colonies and damage another 15%. U.S. farmers lose at least $200 million per year because fewer bees are pollinating vital crops. Pesticides also kill more than 67 million birds and 6–14 million fish each year in the United States. 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. In sharp contrast to the position of the pesticide industry, the WHO and the U.N. Environment Programme estimate 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 (about 25 deaths in the United States) per year. Health officials believe the actual number of pesticide-related illnesses and deaths among the world's farm workers and employees of pesticide companies probably is greatly underestimated because of poor record-keeping, too few doctors, inadequate reporting of illnesses, and faulty diagnoses.

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 for 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. Roughly half of these individuals will die prematurely. 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.

Children are much more susceptible 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, carpets, and soil where pesticides can accumulate. The pesticide industry disputes these claims, arguing that the exposures are not high enough to cause serious harm.

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 in insect ecology, evaluated data from more than 300 agricultural scientists and economists, he found that although the use of synthetic pesticides has increased 33-fold since 1942, 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

SCIENCE FOCUS

Ecological Surprises

Malaria once infected nine of every ten people in the North Borneo, now known as the eastern Malaysian state of Sabah. In 1955, the WHO began spraying the island with dieldrin (a DDT relative) to kill malaria-carrying mosquitoes. The program was so successful that the dreaded disease was nearly eliminated.

Then unexpected things began to happen. The dieldrin also killed other insects, including flies and cockroaches living in houses. The islanders applauded. Next, small insect-eating lizards that also lived in the houses died after gorging themselves on dieldrin-contaminated insects.

Cats began dying after feeding on the lizards. In the absence of cats, rats flourished and overran the villages. When the people became threatened by sylvatic plague carried by rat fleas, the WHO parachuted healthy cats onto the island to help control the rats. Operation Cat Drop worked.

But then the villagers' roofs began to fall in. The dieldrin had killed wasps and other insects that fed on a type of caterpillar that 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 happily: 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 need to ask, "Now what will happen?"

Critical Thinking

Do you think the beneficial effects of spraying pesticides on Sabah outweighed the resulting unexpected and harmful effects? Explain.

13%, despite a ten-fold increase in the use of synthetic insecticides.

Pimentel estimated that environmental, health, and social costs of pesticide use in the United States total about $12 billion per year—an average of $23,000 per minute. The International Food Policy Research Institute puts this figure much higher, at $100–200 billion per year, or $5–10 in damages for every dollar spent on pesticides. Pimentel also concluded that numerous studies and experience show that alternative pest management practices could halve the use of chemical pesticides on 40 major U.S. crops without reducing crop yields (**Concept 10-6**). The pesticide industry disputes these findings.

Sweden has cut pesticide use in half with almost no decrease in crop yields. After a two-thirds cut in pesticide use on rice in Indonesia, yields increased by 15%.

HOW WOULD YOU VOTE?

Do the advantages of using synthetic chemical pesticides outweigh their disadvantages? Cast your vote online at **www.thomsonedu.com/biology/miller**.

Laws and Treaties Can Help Protect Us from the Harmful Effects of Pesticides

In the United States, three 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.

There is controversy over how well the public in the United States is protected from the harmful effects of pesticides. Between 1972 and 2005, the EPA used FIFRA to ban or severely restrict the use of 57 active pesticide ingredients, including DDT and most other chlorinated hydrocarbon insecticides. The 1996 Food Quality Protection Act (FQPA) also increased public protection from pesticides, especially for children.

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.

Figure 10-23 (p. 222) lists some ways you can reduce your exposure to pesticides.

Pesticides Are Not the Only Way to Control Pests and Diseases

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 10-6**). Here are some of these alternatives.

Fool the pest. A variety of *cultivation practices* can be used to fake out pest species. Examples include rotating the types of crops planted in a field each year; adjusting planting times so that food favored by major insect pests is not available, or so that the pests 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 reduce weed

WHAT CAN YOU DO?

Reducing Exposure of 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 or no meat.
- Trim the fat from meat.

Figure 10-23 **Individuals matter:** ways to reduce your exposure to pesticides. **Question:** Which two of these actions are you most likely to take?

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Scott Bauer/USDA Agricultural Research Service

Figure 10-25 *Biological pest control:* wasp depositing an egg that will hatch inside of and feed on a gypsy moth caterpillar.

invasions by cutting grass no lower than 8 centimeters (3 inches) high.

Implant genetic resistance. Use genetic engineering to speed up the development of pest- and disease-resistant crop strains (Figure 10-24). But controversy persists over whether the projected advantages of using genetically modified plants and foods outweigh their projected disadvantages (Figure 10-15 and **Core Case Study**).

CORE CASE STUDY

Bring in natural enemies. Use *biological control* by importing natural predators (Figures 10-21 and 10-25), parasites, and disease-causing bacteria and viruses to help regulate pest populations. This approach is nontoxic to other species, minimizes genetic resistance, and can save large amounts of money—about $25 for every $1 invested in controlling 70 pests in the United States. However, biological control agents cannot always be mass-produced, are often slower acting and more difficult to apply than conventional pesticides, 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 (usually the more effective approach). These chemicals attract only one species, 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, can sometimes affect the target's predators and other beneficial species, and are difficult and costly to produce.

Scald them. Some farmers have controlled certain insect pests by *spraying them with hot water.* This approach has worked well on cotton, alfalfa, and potato fields and in citrus groves in the U.S. state of Florida, and its cost is roughly equal to that of using chemical pesticides.

Integrated Pest Management Is a Component of 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 approach, each crop and its pests are evaluated as parts of an ecological system. Then farmers develop a control program that uses a combination of cultivation, biological, and chemical approaches at specific times (**Concept 10-6**).

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, including using large machines to vacuum up harmful bugs. Small amounts of insecticides—mostly based on natural insecticides produced by plants—are applied only as a last resort and in the smallest amount possible. Broad-spectrum, long-lived pesticides are not used, and chemicals are rotated 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. 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. Thus, IPM is an important way to reduce risks to wildlife and human health, and it applies the **population control principle of sustainability** (see back cover).

Despite its promise, IPM—like any other form of pest control—has some disadvantages. It requires expert knowledge about each pest situation, acts more slowly than conventional pesticides, and takes more effort than dousing crops with large amounts of 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 by government subsidies for conventional chemical pesticides, by opposition from pesticide manufacturers, and by a lack of IPM experts.

A 1996 study by the National Academy of Sciences recommended that the United States shift from chemical-based approaches to ecological-based pest management approaches. Within 5–10 years, such a shift could cut U.S. pesticide use in half, as it has in several other countries. So far, this recommendation has been ignored, mostly because of political opposition from producers of conventional pesticides whose sales would drop sharply.

HOW WOULD YOU VOTE?

Should governments heavily subsidize a switch to integrated pest management? Cast your vote online at **www.thomsonedu.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 use of IPM by disseminating information and establishing networks among researchers, farmers, and agricultural extension agents involved in IPM. **GREEN CAREER:** Integrated pest management

10-7 How Can We Produce Food More Sustainably?

CONCEPT 10-7 Sustainable agriculture involves reducing topsoil erosion, eliminating overgrazing and overfishing, irrigating more efficiently, using integrated pest management, providing government subsidies for sustainable farming and fishing, and promoting agrobiodiversity.

Government Policies Influence Food Production

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, interest rates, and global markets.

Governments use three main approaches to influence food production:

- *Control prices.* Use price controls to keep food prices artificially low. Consumers are happy, but farmers may not be able to make a living.
- *Provide subsidies.* Give farmers subsidies and tax breaks to keep them in business and encourage

them to increase food production. Globally, government price supports, tax breaks, and other subsidies for agriculture in affluent countries totaled more than $279 billion in 2004 (latest data available; about $133 billion in the European Union and $46 billion in the United States)—an average of more than $531,000 per minute! If government subsidies are too generous and the weather is good, farmers and livestock producers may produce more food than can be sold. The resulting surplus depresses food prices, which reduces the financial incentive for farmers in developing countries to increase domestic food production. Some analysts call for phasing out environmentally harmful farm and fishing subsidies over the next decade and replacing them with environmentally beneficial subsidies.

- *Let the marketplace decide.* Another approach is to eliminate most or all price controls and subsidies and let farmers and fishers respond to market demand without government interference. Some analysts urge that any phase-out of farm and fishery subsidies should be coupled with increased aid for the poor and the lower middle class, who would suffer the most from any increase in food prices. Some environmental scientists say that instead of eliminating all subsidies, we should use them to reward farmers and ranchers who practice more sustainable agriculture and fishing and to provide job training programs for out-of-work farmers and fishers.

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.thomsonedu.com/biology/miller**.

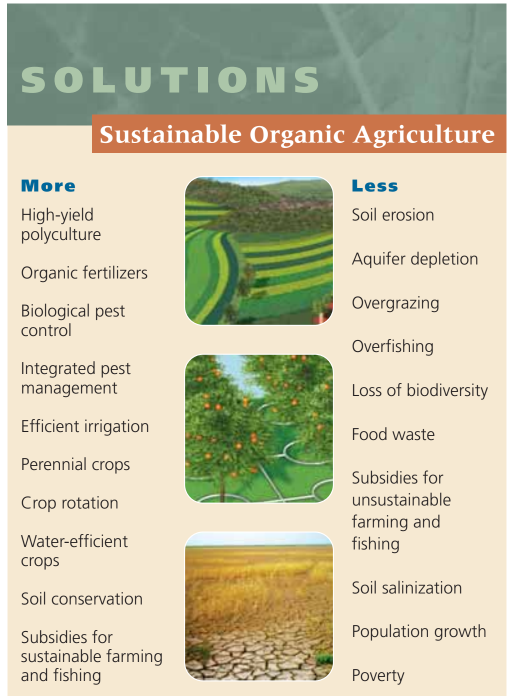


Figure 10-26 Components of more sustainable, low-throughput agriculture based mostly on mimicking and working with nature (**Concept 10-7**). **Question:** Which two solutions do you think are the most important? Why?

We Can Rely More on Low-Input Sustainable Agriculture

There are three main ways to reduce hunger and malnutrition and the harmful environmental effects of agriculture:

- *Slow population growth.*
- *Sharply reduce poverty* so that people can grow or buy enough food for their survival and good health.
- *Develop and phase in systems of more sustainable, low-input agriculture over the next few decades.* One component of this is increased use of **organic agriculture** in which crops are grown without, or with limited use of, synthetic pesticides and synthetic fertilizers, and livestock are raised without synthetic growth regulators and feed additives.

Figure 10-26 lists the major components of more sustainable agriculture (**Concept 10-7**). Low-input organic agriculture produces comparable yields with lower carbon dioxide emissions, uses less energy per unit of yield, improves soil fertility, reduces soil erosion, and can often be more profitable for farmers than high-input farming is. **GREEN CAREER:** Sustainable agriculture scientist or farmer

More sustainable agriculture can help reduce excessive dependence on oil by increasing the use of renewable fuels. Some farmers have shown that they can use energy from the sun, wind, and flowing water, and natural gas produced from farm wastes for most or all of the energy they need for food production. They can also make money by selling their excess electricity to power companies. Sustainably produced crops can also provide transportation fuels such as ethanol and biodiesel, and plastic packaging can be made from cornstarch instead of oil-based chemicals.

Most proponents of more sustainable agriculture are not opposed to high-yield agriculture. Instead, they see it as vital for protecting the earth's biodiversity by reducing the need to cultivate new and often marginal land. They call for using environmentally sustainable forms of both high-yield polyculture and high-yield monoculture, with increasing emphasis on using organic methods for growing crops (Figure 10-26, left).

We Can Shift to More Sustainable Agriculture

Analysts suggest four major strategies to help farmers make the transition to more sustainable organic agriculture (**Concept 10-7**). *First,* greatly increase research on sustainable agriculture and human nutrition. *Second,* set up demonstration projects so farmers can see how more sustainable organic agricultural systems work. *Third,* provide subsidies and increased foreign aid to encourage its use. *Fourth,* establish training programs in sustainable organic agriculture for farmers and government agricultural officials, and encourage the creation of college curricula in sustainable organic agriculture and human nutrition.

Figure 10-27 lists some ways in which you can promote more sustainable agriculture. Buying food from local producers in farmers' markets or other outlets helps support local economies and reduces the environmental impact of food production, including the costs of transporting food over long distances. For example, a typical meal traveling an average of 2,400 kilometers (1,500 miles) from producer to plate accounts for up to four times more greenhouse gas emissions than does the same meal using locally produced food.

WHAT CAN YOU DO?

Sustainable Organic Agriculture

- Waste less food.
- Eat less or no meat.
- Use organic farming to grow some of your food.
- Buy organic food.
- Eat locally grown food.
- Compost food wastes.

Figure 10-27 Individuals matter: ways to promote more sustainable agriculture. **Question:** Which three of these actions do you think are the most important? Why?

REVISITING Golden Rice and Sustainability

CORE CASE STUDY

SUSTAINABILITY

This chapter began with a look at how we might use genetically engineered golden rice (**Core Case Study**) to help prevent blindness in children and increase their resistance to infectious diseases. Proponents of this and other forms of genetically engineered crops see the widespread use of this technology as a way to supplement food produced by conventionally crossbred crops and thus increase crop yields and reduce malnutrition. However, genetically modified crops and foods have a mix of advantages and disadvantages (Figure 10-15).

In addition, a number of scientists warn that yields from both conventionally crossbred and genetically engineered crops may be limited by numerous harmful environmental effects of modern industrial agriculture (Figure 10-14). They call for a shift to more sustainable agriculture (Figure 10-26) over the next few decades.

Making this transition involves applying the four **scientific principles of sustainability** (see back cover). All of these principles are violated by modern industrial 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 habitats and disrupt natural species interactions that help control pest population sizes.

Making the transition to more sustainable agriculture means relying less on oil and more on renewable energy resources based on solar energy, sustaining nutrient cycling by soil conservation, returning crop residues and animal wastes to the soil, and reducing food waste. It also means helping to sustain natural and agricultural biodiversity by relying on a greater variety of crop and animal strains, controlling pest populations by broader use of polyculture and integrated pest management, and controlling human population growth.

The goal is to feed the world's people while sustaining and restoring the earth's natural capital and living off the natural income it provides. This will not be easy, but it can be done.

The sector of the economy that seems likely to unravel first is food. Eroding soils, deteriorating rangelands, collapsing fisheries, falling water tables, and rising temperatures are converging to make it difficult to expand food production fast enough to keep up with the demand.

LESTER R. BROWN

REVIEW QUESTIONS

1. What are the advantages and disadvantages of golden rice?
2. Describe measures that can be taken to improve the food security of a developing country.
3. Summarize the main features of industrialized agriculture and traditional agriculture. Comment on the environmental sustainability of each method of food production.
4. Discuss the major harmful effects of soil erosion. How serious is the problem of soil erosion from a global perspective?
5. Explain the causes and consequences of desertification. Explain how the irrigation of cropland can lead to reduced crop yields.
6. Describe what measures farmers can take to reduce soil erosion and restore soil fertility.
7. How have the Green Revolutions increased food production? Discuss the harmful environmental effects of food production. What are the pros and cons of genetically modified crops and food?
8. Describe the trend in world meat production from 1950 to 2005 and comment on the resulting consequences to the environment. How has the world fish catch changed since 1950, and how has this affected the sustainability of the fishing industry? What are the advantages and disadvantages of aquaculture? How can aquaculture become more sustainable?
9. Discuss the advantages and disadvantages to the use of conventional chemical pesticides. What events led up to cats being parachuted into Sabah? Describe the features of Integrated Pest Management.
10. Describe the components of sustainable organic agriculture and discuss ways to promote its use.

CRITICAL THINKING

1. List three ways in which you could apply **Concept 10-7** to make your lifestyle and that of any children and grandchildren you might have more environmentally sustainable.
2. What are two safeguards that you would want in place before large areas of the world were planted with golden rice (**Core Case Study**)? CORE CASE STUDY
3. What are the three most important actions you would take to reduce hunger **(a)** in the country where you live and **(b)** in the world?
4. List three changes in your lifestyle that could reduce your impact on soil erosion. Which, if any, of these changes are you willing to make?
5. According to physicist 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." Are you willing to eat less meat or no meat? Explain.
6. 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?
7. Explain how widespread use of a pesticide can **(a)** increase the damage done by a particular pest and **(b)** create new pest organisms.
8. If increased mosquito populations threatened you with malaria or West Nile virus, would you want to spray the mostly banned insecticide DDT in your yard and inside your home to reduce the risk? Explain. What are the alternatives?
9. Congratulations! You are in charge of the world. List the three most important features of your **(a)** agricultural policy, **(b)** policy to reduce soil erosion, **(c)** policy 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.

LEARNING ONLINE

Log on to the Student Companion Site for this book at **www.thomsonedu.com/biology/miller** and choose Chapter 10 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Web links, information on Green Careers, and InfoTrac® College Edition articles.

For access to animations and additional quizzing, register and log on to Thomson NOW! at **www.thomsonedu.com/thomsonnow** using the access code card in the front of your book. You can also explore the **Active Graphing** exercises that your instructor may assign.

Water and Water Pollution

11

Water Conflicts in the Middle East: A Preview of the Future?

CORE CASE STUDY

Many countries in the Middle East face water shortages and rising tensions over water sources they must share. Most water in this dry region comes from three river basins: the Nile, the Jordan, and the Tigris–Euphrates (Figure 11-1).

Three countries—Ethiopia, Sudan, and Egypt—use most of the water that flows in Africa's Nile River. Egypt, where it rarely rains, gets more than 97% of its freshwater from the Nile and is last in line to tap this precious source. To meet the water and food needs of their rapidly growing populations, Ethiopia and Sudan plan to divert more water from the Nile. Such upstream diversions would reduce the amount of water available to Egypt, which cannot exist without irrigation water from the Nile.

Egypt could go to war with Sudan and Ethiopia for more water, cut its rapid population growth, or waste less irrigation water. Other options are to import more grain to reduce the need for irrigation water, work out water-sharing agreements with other countries, or suffer the harsh human and economic consequences of *hydrological poverty.*

The Jordan basin is by far the most water-short region, with fierce competition for its water among Jordan, Syria, Palestine (Gaza and the West Bank), and Israel. Syria, which is projected to nearly double its population between 2007 and 2050, plans to build dams and withdraw more water from the Jordan River, decreasing the downstream water supply for Jordan and Israel. If Syria goes through with its plans, Israel warns that it may destroy the largest dam. In contrast, Israel has cooperated with Jordan and Palestine over their shared water resources.

Turkey, located at the headwaters of the Tigris and Euphrates Rivers (Figure 11-1), controls water flowing downstream through Syria and Iraq and into the Persian Gulf. Turkey is building 24 dams along the upper Tigris and Euphrates to generate electricity and irrigate a large area of land.

If completed, these dams will reduce the flow of water downstream to Syria and Iraq by as much as 35% in normal years and by much more in dry years. Syria also plans to build a large dam along the Euphrates to divert water arriving from Turkey. This will leave little water for Iraq and could lead to a water war between Iraq and Syria.

Resolving these water distribution problems will require developing agreements to share water supplies, slowing population growth, wasting less water, raising water prices to help improve irrigation efficiency, and increasing grain imports to reduce water needs.

Two or more countries share some 263 of the world's water basins but countries in only 158 of the basins have water-sharing agreements. This explains why conflicts among nations over shared water resources, especially in Asia, are likely to increase as populations grow and the demand for water increases.

As discussed in this chapter, the world faces three major water resource problems: too little water in some areas, too much water in other areas, and water pollution. To many analysts, emerging water shortages in many parts of the world—along with the related problems of biodiversity loss and climate change—are the three most serious environmental problems the world faces during this century.

Figure 11-1 Many countries in the Middle East, which has one of the world's highest population growth rates, face water shortages and conflicts over access to water because they share water from three major river basins.

Key Questions and Concepts

11-1 Will we have enough 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 do 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 transport systems to transfer water to arid regions has increased water supplies in those 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 improve flood control by protecting more wetlands and natural vegetation in watersheds and by not building in areas subject to frequent flooding.

11-5 How can we best deal with water pollution?

CONCEPT 11-5A Streams can cleanse themselves of many pollutants if we do not overload them.

CONCEPT 11-5B Preventing water pollution usually works better and costs less than trying to clean it up.

CONCEPT 11-5C 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 4, 10, and 11 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 Water?

CONCEPT 11-1A We are using available freshwater unsustainably by wasting it, polluting it, and charging too little for this irreplaceable natural resources.

CONCEPT 11-1B One of every six people do 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 the water planet, with a precious layer of water—most of it saltwater—covering about 71% of the earth's surface (Figure 5-19, p. 92). Look in the mirror. What you see is about 60% water, most of it inside your cells.

Water is an amazing molecule with unique properties that affect life on earth (Science Focus, p. 55). 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 shelter, and meet your other daily needs and wants. Water also plays a key role in sculpting the earth's surface, moderating climate, and removing and diluting 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**).

Only a tiny fraction of the planet's abundant water supply—*about 0.024%*—is readily available to us as liq-

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.

uid freshwater in accessible groundwater deposits and in lakes, rivers, and streams. The rest is in the salty oceans, frozen in polar ice caps and glaciers, or is deep underground and inaccessible.

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 sea, in the air, and on land, which is driven by solar energy and gravity (Figure 3-18, p. 54). This irreplaceable water recycling and purification system works well, unless we overload it with slowly degradable and nondegradable wastes, withdraw water from underground supplies faster than it is replenished, or destroy wetlands and cut down forests that store and slowly release water. In parts of the world, we are doing all of these things (**Concept 5-5**, p. 94, and **Concept 5-6**, p. 100), mostly because we have placed little or no value on the earth's natural ecological services (Figure 1-3, p. 8, and Science Focus, p. 153).

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 (Figure 11-2). The water in these spaces is called **groundwater**—one of our most important sources of freshwater.

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 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 streams. Most aquifers recharge extremely slowly.

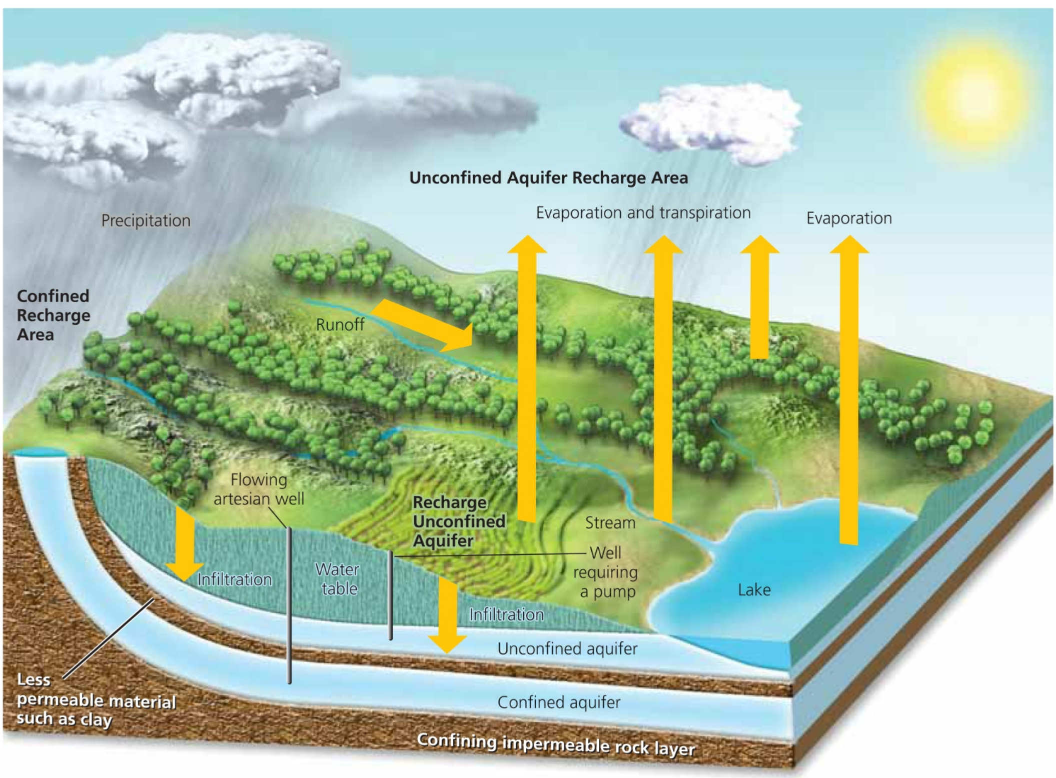


Figure 11-2 Natural capital: groundwater system. An *unconfined aquifer* is an aquifer with a permeable water table. A *confined aquifer* is bounded above and below by less permeable beds of rock where the water is confined under pressure. Some aquifers are replenished by precipitation; others are not.

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. If kept up, such withdrawals will deplete these ancient deposits of liquid natural capital (**Concept 1-1A**, p. 6). CONCEPT LINK

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 rivers, streams, lakes, wetlands, estuaries, and ultimately to the ocean. Precipitation that does not infiltrate the ground or return to the atmosphere by evaporation is called **surface runoff.** Surface water replenished by the *runoff* from precipitation and melting snow and ice is classified as a renewable but finite resource. 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.**

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 runoff:** the amount of surface runoff that we can generally count on as a stable source of freshwater from year to year.

During the last century, the human population tripled, global water withdrawal increased sevenfold, and per capita withdrawal quadrupled. As a result, we now withdraw about 34% of the world's reliable runoff. We use another 20% of this runoff in streams to transport goods by boat, to dilute pollution, and to sustain fisheries and wildlife. In total, *we directly or indirectly use about 54% of the world's reliable runoff of surface water.*

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 exceed 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. In other words, many areas are using their surface water resources unsustainably as our ecological footprints spread across the earth (Figure 1-8, p. 13, and **Concept 1-3**, p. 11). CONCEPT LINK

Most of the Freshwater We Withdraw Is Used to Irrigate Crops

Worldwide, we use 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. For example, it takes 400,000 liters (106,000 gallons) of water to produce an automobile, up to 125,000 liters (33,100 gallons) to produce 1 kilogram (2.2 pounds) of grain-fed beef, and 9,000 liters (2,800 gallons) to produce 1 kilogram (2.2 pounds) of aluminum. You could save more water by reducing your annual consumption of grain-fed beef by 1 kilogram (2.2 pounds) than you would by denying yourself a daily shower for almost 2 years.

■ CASE STUDY

Freshwater Resources in the United States

The United States has more than enough renewable freshwater. But much of it is unevenly distributed or is contaminated by agricultural and industrial practices. The eastern states usually have ample precipitation, whereas many western and southwestern states have too little (Figure 11-3, top).

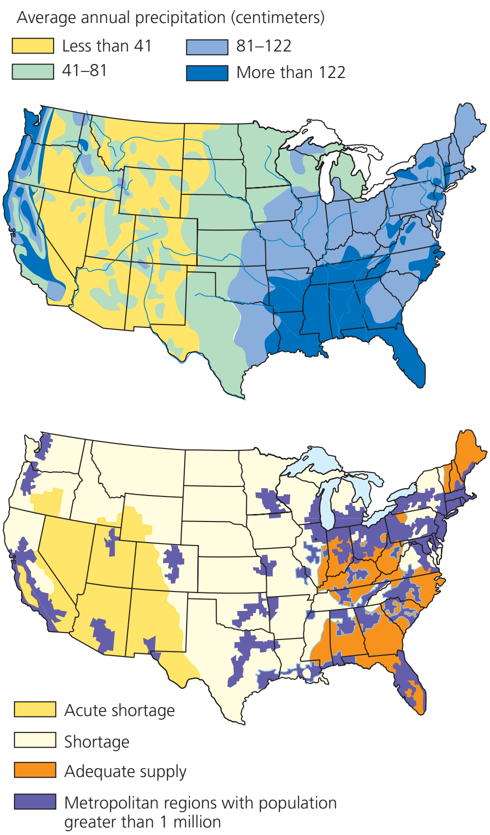


Figure 11-3 Average annual precipitation and major rivers (top) and water-deficit regions in the continental United States and their proximity to metropolitan areas having populations greater than 1 million (bottom). **Question:** If you live in the United States, do you live in a water-short area? (Data from U.S. Water Resources Council and U.S. Geological Survey)

Figure 11-4 Water *hot spots* in 17 U.S. 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 over the next 25 years. **Question:** Do you live, or would you live, in one of these hotspot areas? (Data from U.S. Department of the Interior)

In the East, most water is used for energy production, cooling, and manufacturing. In many parts of the eastern United States, the most serious water problems are flooding, occasional urban shortages, and pollution.

In the arid and semiarid areas of the western half of the United States (Figure 11-3, bottom), irrigation accounts for 85% of water use. The major water problem is a shortage of runoff caused by low precipitation (Figure 11-3, top), high evaporation, and recurring prolonged drought.

Almost half the water used in the United States comes from groundwater sources with the rest coming 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 11-3, bottom) deplete many aquifers faster than they can be recharged.

In 2003, the U.S. Department of the Interior mapped out *water hot spots* in 17 western states (Figure 11-4). 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 during the next 20 years.

Water Shortages Will Grow

Figure 11-5 shows the current degree of stress faced by the world's major river systems, based on a comparison of the amount of surface freshwater available with the amount used by humans. More than 30 countries—most of them in the Middle East (**Core Case Study**) and Africa—now face water scarcity. By 2050, some 60 countries, many of them in Asia, are likely to be suffering from water stress. Per capita water

CORE CASE STUDY

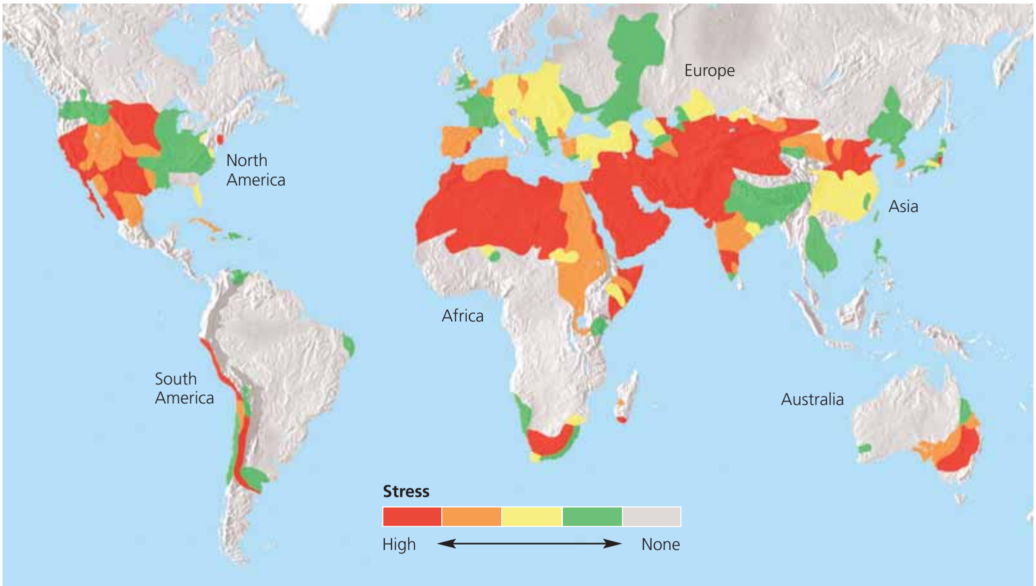


Figure 11-5 **Natural capital degradation:** stress on the world's major river basins, based on a comparison of the amount of water available with the amount used by humans. **Question:** Do you live in a water-stressed area? (Data from World Commission on Water Use in the 21st century)

resources in China, the world's most populous country, are less than a third of the global average, and falling.

THINKING ABOUT
Water and the Middle East

CORE CASE STUDY

How might scarcity of water in the Middle East (**Core Case Study**) affect nations that are dependent on oil from the Middle East, and how could this impact your lifestyle?

Poor people bear the brunt of water shortages. In 2005, the United Nations reported that 1.1 billion people—one of every six—lack regular access to enough clean water for drinking, cooking, and washing, and 2.6 billion people do not have access to basic sanitation.

This already serious situation will almost certainly get worse as resource consumption and population continue to increase. According to the United Nations, between *2 billion* and *7 billion* people will face water shortages by 2050 (**Concept 11-1B**). The likely result: a flood of refugees from arid and semiarid regions searching for water, land, and food.

Water shortages and shifts in water distribution from global warming will also affect many people in developed nations. Because 70% of the world's water is used to produce food, water shortages can translate into food shortages that lead to economic and social stresses.

In addition to global warming, several trends can worsen stresses on the world's interconnected water and food supply systems. They include migration to cities (Figures 7-13, p. 138, and 7-14, p. 139) whose populations divert river water from croplands; more rapid depletion of aquifers through the use of powerful diesel and electric pumps; and degradation and destruction of cropland from urban sprawl (Figure 7-15, p. 139), soil erosion (Figure 10-6, p. 205), desertification (Figure 10-7, p. 206), and salinization (Figures 10-10, p. 207, and 10-11, p. 208).

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 transport systems to transfer water to arid regions has increased water supplies in those 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

The most common ways to increase the supply of freshwater in a particular area are withdrawing groundwater, building dams and reservoirs to store runoff in rivers for release as needed, transporting surface water from one area to another, and converting saltwater to freshwater (desalination) (**Concepts 11-2A**, **11-2B**, and **11-2C**). Other important strategies discussed later in this chapter involve water conservation and better use of the natural hydrologic cycle.

We Are Withdrawing Groundwater Faster Than It Is Replenished in Some Areas

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 irrigation water. Relying more on groundwater has advantages and disadvantages (Figure 11-6).

Water tables are falling in many areas of the world because the rate of pumping water (mostly to irrigate crops) from aquifers 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 (Figure 11-7), Mexico, and Pakistan are overpumping many of their aquifers. Currently, more than half a billion people are being fed by grain produced through the unsustainable use of groundwater, and this number is expected to grow. Worldwide, the unsustainable depletion of aquifers amounts to water that every day would fill a convoy of large tanker trucks stretching 480,000 kilometers (300,000 miles)—more than the distance to the moon.

TRADE-OFFS

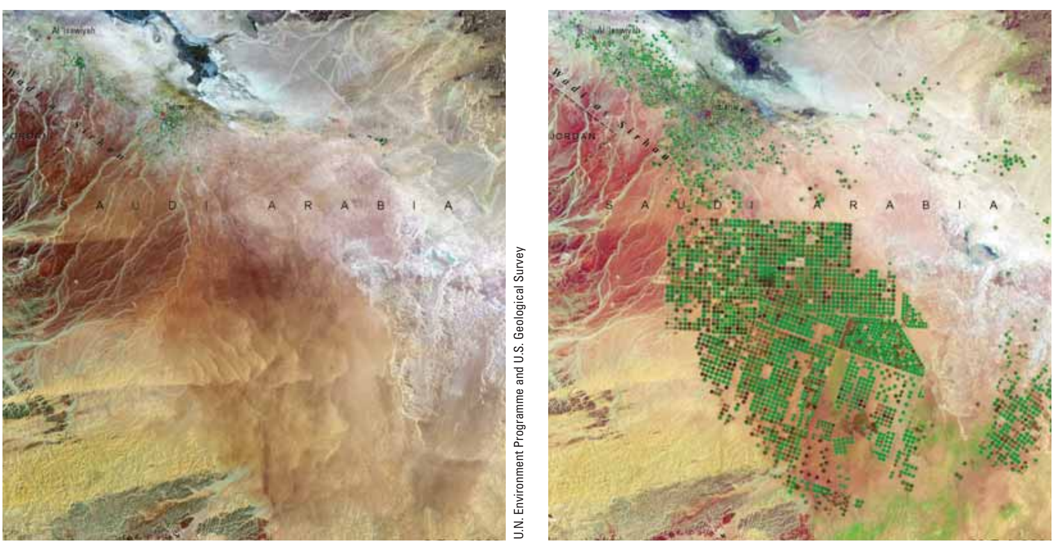
Withdrawing Groundwater

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 11-6 Advantages and disadvantages of withdrawing groundwater. **Question:** Which two advantages and which two disadvantages do you think are the most important?

In the United States, groundwater is being withdrawn on average four times faster than it is replenished (**Concept 11-2A**). Figure 11-8 (p. 234) 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). Although it is gigantic, the Ogallala is essentially a one-time deposit of liquid natural capital with a very slow rate of recharge. In some areas, farmers are withdrawing water from this aquifer as much as 40 times faster than nature replaces it.

Such overdrafting has lowered the water table more than 30 meters (100 feet) in some places. Unless water-saving irrigation systems are used, most hydrologists predict that groundwater levels in much of this aquifer will drop to the point where using deep wells to pump the water out will cost more than the water is worth for growing crops



U.N. Environment Programme and U.S. Geological Survey

U.N. Environment Programme and U.S. Geological Survey

1986 **2004**

Figure 11-7 **Natural capital degradation:** development of irrigation by pumping groundwater from an ancient and nonrenewable aquifer in a vast desert region of Saudi Arabia between 1986 (left) and 2004 (right). Irrigated areas appear as green dots, and brown dots show areas where wells have gone dry and the land has returned to desert. Hydrologists estimate that because of aquifer depletion, most irrigated agriculture in Saudi Arabia may disappear within 10–20 years.

ThomsonNOW™ 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* ThomsonNOW. **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)

and raising cattle. Serious groundwater depletion is also taking place in California's Central Valley, which supplies half of the country's fruit and vegetables (long red area in the California portion of Figure 11-8).

Groundwater overdrafts near coastal areas can contaminate groundwater supplies by causing intrusion of saltwater into freshwater aquifers, which makes such water undrinkable and unusable for irrigation (Figure 11-9). This problem is especially serious in the U.S. coastal areas 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. Rising sea levels from global warming will increase saltwater intrusion and can decrease the amount of groundwater available in heavily populated coastal areas (Figure 7-13, p. 138, and Figure 7-14, p. 139).

If we don't sharply slow the depletion of groundwater, an increasing number of the world's people will have to live on rainwater and suffer from decreased food production. Figure 11-10 lists ways to prevent or slow groundwater depletion by using this potentially renewable resource more sustainably.

With global water shortages looming, scientists are evaluating deep aquifers—found at depths of 0.8 kilometer (0.5 mile) or more—as future water sources. Preliminary results suggest that some of these aquifers hold enough water to support billions of people for centuries. The quality of water in these aquifers may also be much higher than the quality of the water in most rivers and lakes.

Assuming that the costs are not too high, there are two major concerns about tapping these nonrenewable deposits of water. *First,* little is known about the geological and ecological impacts of pumping water from deep aquifers. *Second,* 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 ensue over who has the right to tap into these valuable resources. **GREEN CAREER:** Hydrogeology

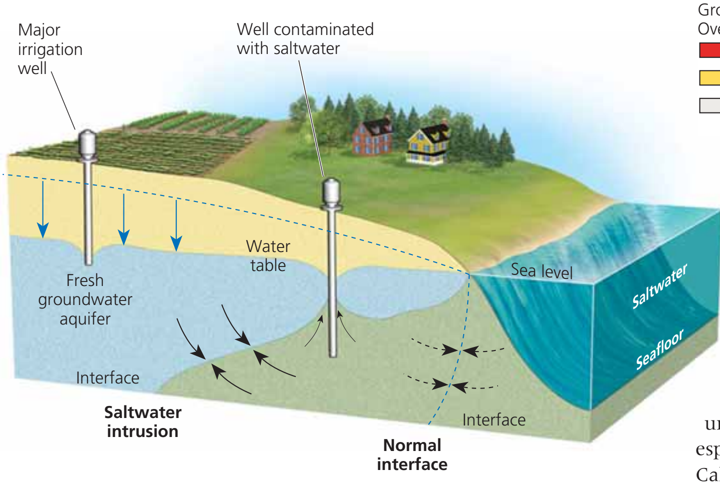


Figure 11-9 *Saltwater intrusion* along a coastal region. When the water table is lowered, the normal interface (dashed line) between fresh and saline groundwater moves inland and contaminates groundwater used for drinking. **Question:** What are two things you would do to reduce the threat of saltwater intrusion?

SOLUTIONS

Groundwater Depletion

Prevention

Waste less water

Subsidize water conservation

Limit number of wells

Do not grow water-intensive crops in dry areas

Control

Raise price of water to discourage waste

Tax water pumped from wells near surface waters

Set and enforce minimum stream flow levels

Divert suface water in wet years to recharge aquifers

Figure 11-10 Ways to prevent or slow groundwater depletion by using water more sustainably. **Question:** Which two of these solutions do you think are the most important? Why?

Large Dams and Reservoirs Have Advantages and Disadvantages

Large dams and reservoirs have both benefits and drawbacks (Figure 11-11). Their main purposes are to capture and store runoff and release it as needed to control floods, generate electricity, and supply water for irrigation and for towns and cities. Reservoirs also provide recreational activities such as swimming, fishing, and boating. Over the past 50 years, an average of two large dams at least 15 meters (49 feet) high have been constructed somewhere on the earth every day. As a result, reservoirs now hold 3 to 6 times more water than flows in the world's natural rivers, many of which no longer reach the sea.

More than 45,000 large dams in the world (22,000 of them in China) have increased the annual reliable runoff available for human use by nearly one-third. But a series of dams on a river and withdrawals of river water for agricultural and urban uses, especially in arid

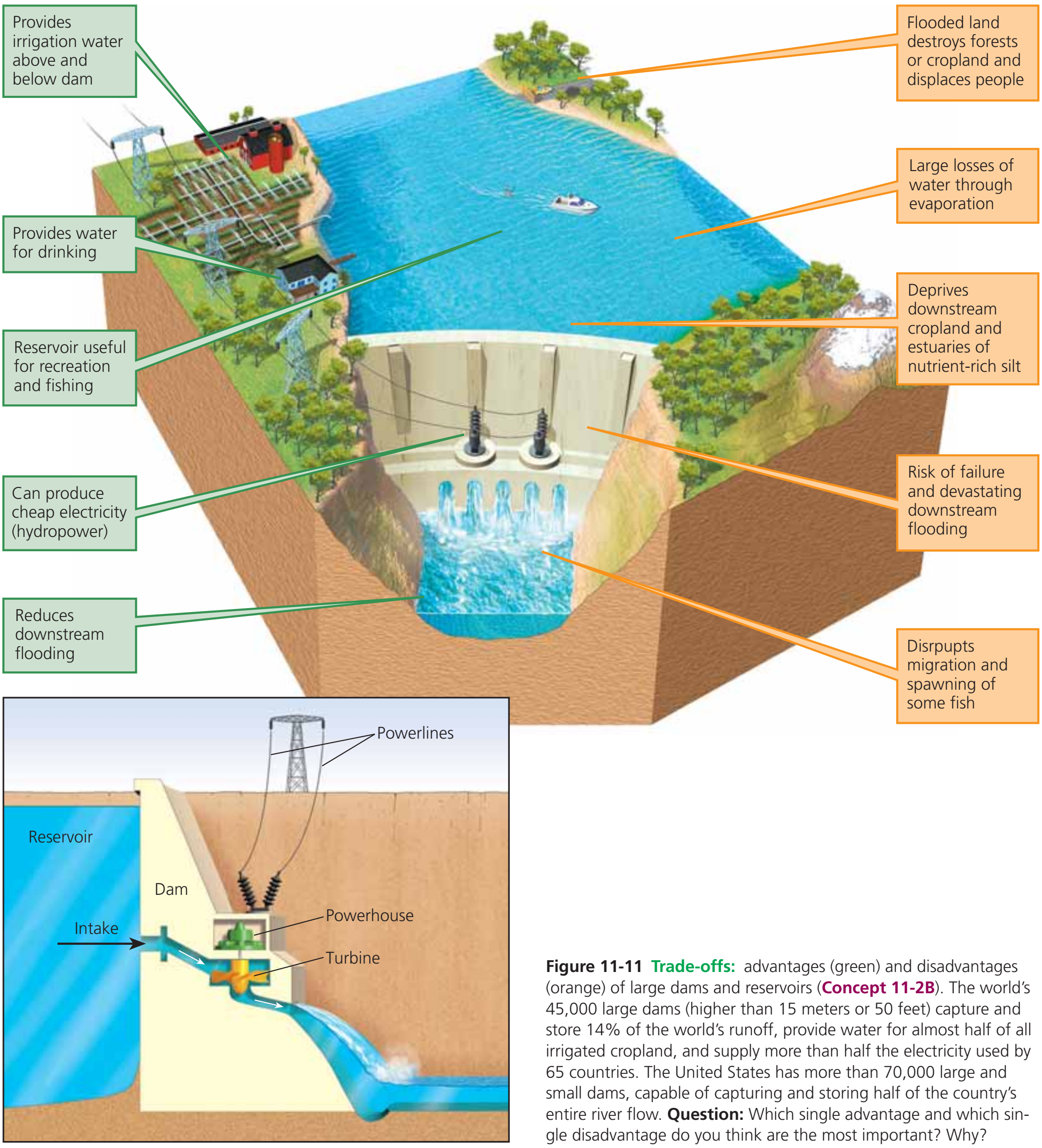


Figure 11-11 **Trade-offs:** advantages (green) and disadvantages (orange) of large dams and reservoirs (**Concept 11-2B**). The world's 45,000 large dams (higher than 15 meters or 50 feet) capture and store 14% of the world's runoff, provide water for almost half of all irrigated cropland, and supply 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. **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

areas, can reduce downstream flow to a trickle and prevent it from reaching the sea as a part of the hydrologic cycle. According to the World Commission on Water in the 21st century, more than half of the world's major rivers go dry part of the year because of such flow reduction especially during drought years.

THINKING ABOUT
Dams and Egypt

CORE CASE STUDY

Upstream dams and diversions of water from the Nile River by Ethiopia and Sudan will reduce the water available to Egypt, which cannot exist without such water. Which one or more of the options discussed in the **Core Case Study** do you think Egypt should pursue? Explain.

Worldwide, this engineering approach to river management has displaced 40–80 million people from their homes, flooded an area of mostly productive land roughly equal to the area of the U.S. state of California, and often impairs some of the important ecological services rivers provide (Figure 11-12) (**Concept 11-2B**). According to water-resource expert Peter H. Gleck, at least a fourth of the world's freshwater fish species are threatened or endangered, primarily because dams and water withdrawals have destroyed many free-flowing rivers.

Since 1960, the Colorado River, the largest river in the U.S. southwest, has rarely made it to the Gulf of California because of a combination of multiple dams, large-scale water withdrawal, and prolonged drought. Such withdrawals threaten the survival of species that spawn in the river, destroy estuaries that serve as breeding grounds for numerous aquatic species, and increase saltwater contamination of aquifers near the coast.

NATURAL CAPITAL

Ecological Services of Rivers

- Deliver nutrients to sea to help sustain coastal fisheries
- Deposit silt that maintains deltas
- Purify water
- Renew and renourish wetlands
- Provide habitats for wildlife

Figure 11-12 Important ecological services provided by rivers. Currently, the services are given little or no monetary value when the costs and benefits of dam and reservoir projects are assessed. **Questions:** Which two of these services do you believe are the most important? Why? Which two of these services do you think we are most likely to decline? Why?

HOW WOULD YOU VOTE?

Do the advantages of large dams outweigh their disadvantages? Cast your vote online at **www.thomsonedu.com/biology/miller**.

Climate change will heighten shortages of water in many parts of the world. Hundreds of millions of people in China, India, and other parts of Asia depend on river flows fed by melting glaciers in the Himalayas. Many of these glaciers in Asia and in parts of South America are receding and are projected to disappear during this century as the earth's atmosphere continues to warm.

Global warming also changes the timing of water flows into rivers from melting snow in mountainous areas. As temperatures rise, the melting snow will fill rivers earlier in spring and sharply reduce the supply needed to grow crops during the summer. Alterations in the patterns of precipitation and evaporation caused by climate change from global warming are still poorly understood, but there is general agreement that some areas will get drier and some will get wetter and that this will change where we can grow food.

California Transfers Massive Amounts of Water from Water-Rich Areas to Water-Poor Areas

Tunnels, aqueducts, and underground pipes can transfer stream runoff collected by dams and reservoirs from water-rich areas to water-poor areas, but they also create environmental problems (**Concept 11-2B**).

One of the world's largest water transfer projects is the *California Water Project* (Figure 11-13). 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, arid agricultural regions and cities. This project supplies massive amounts of water to areas that, without such water transfers, would be mostly desert.

For decades, northern and southern Californians have feuded over how the state's water should be allocated under this project. Southern Californians want more water from the north to grow more crops and to support Los Angeles, San Diego, and other growing urban areas. Agriculture consumes three-fourths of the water withdrawn in California, much of it used inefficiently for water-thirsty crops such as rice and alfalfa growing in desert-like conditions.

Northern Californians counter that sending more water south degrades the Sacramento River, threatens fisheries, and reduces the flushing action that helps clean San Francisco Bay of pollutants. They also argue that much of the water sent south is wasted. They point to studies showing that making irrigation just 10% more efficient would provide enough water for domestic and industrial uses in southern California.

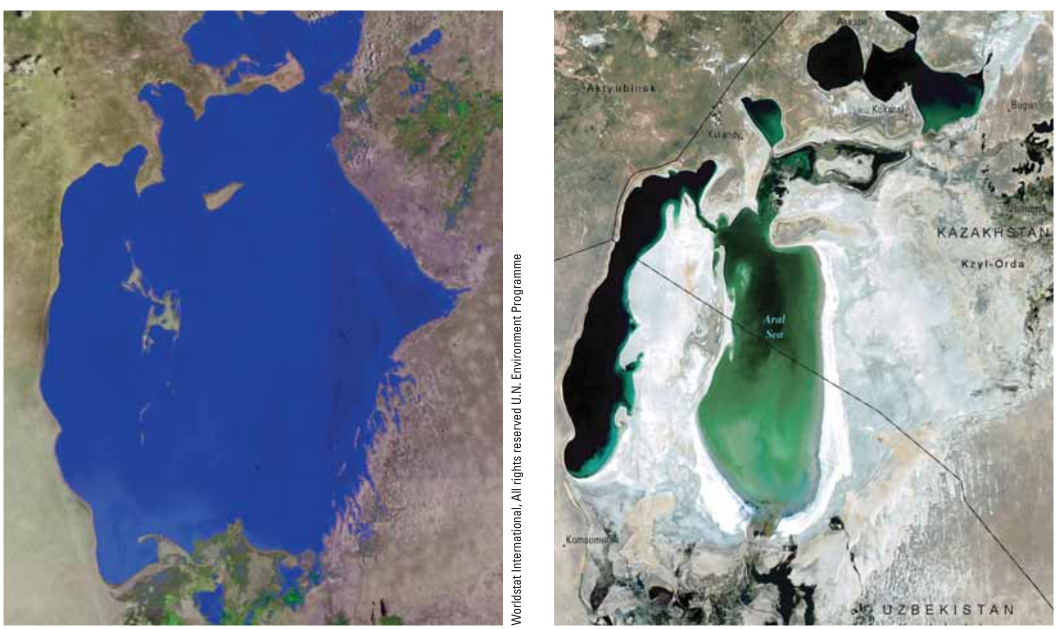
Figure 11-13 California Water Project and the Central Arizona Project. These projects involve large-scale water transfers from one watershed to another. Arrows show the general direction of water flow. **Question:** What are two things you would do to improve this water transfer project?

According to a 2002 study by a group of scientists and engineers, projected global warming will sharply reduce water availability in California (especially southern California) and other water-short states in the western United States even in the best-case scenario. Some analysts project that sometime during this century, many people living in arid southern California cities such as Los Angeles and San Diego, as well as farmers in this area, may have to move elsewhere for water.

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). It would be quicker and cheaper to improve irrigation efficiency, stop growing water-thirsty crops in arid areas, and increase the historically low price of water to reduce water waste.

■ CASE STUDY
The Aral Sea Disaster

The shrinking of the Aral Sea (Figure 11-14) is the result of a large-scale water transfer project in an area of the former Soviet Union with the driest climate in central



1976 **2004**

Figure 11-14 The *Aral Sea* was once the world's fourth largest freshwater lake. 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 2004. It has split into two parts, little Aral on the left and big Aral on the right. As the lake shrunk, it left behind a salty desert, economic ruin, increasing health problems, and severe ecological disruption. **Question:** What are three things that you think should be done to help prevent further shrinkage of the Aral Sea?

Asia. Since 1960, enormous amounts of irrigation water have been diverted from the inland Aral Sea and its two feeder rivers to create one of the world's largest irrigated areas, mostly for raising cotton and rice. The irrigation canal, the world's longest, stretches more than 1,300 kilometers (800 miles).

This large-scale water diversion project, coupled with droughts and high evaporation rates due to the area's hot and dry climate, has caused a regional ecological and economic disaster. Since 1961, the sea's salinity has tripled and the average level of its water has dropped by 22 meters (72 feet). It has lost 90% of its volume of water and has split into two parts (Figure 11-14, right). Water withdrawal for agriculture has reduced the two rivers feeding the sea to mere trickles.

About 85% of the area's wetlands have been eliminated and roughly half the local bird and mammal species have disappeared. In addition, a huge area of former lake bottom has been converted to a human-made desert covered with glistening white salt. The sea's increased salt concentration—three times saltier than ocean water—caused the presumed extinction of 20 of the area's 24 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 the middle of a salt desert (see photo 11, p. xi).

Winds pick up the sand and salty dust and blow it onto fields as far as 300 kilometers (190 miles) away. As the salt spreads, it pollutes water and kills wildlife, crops, and other vegetation. Aral Sea dust settling on glaciers in the Himalayas is causing them to melt at a faster than normal rate—a prime example of unexpected connections and unintended consequences.

Shrinkage of the Aral Sea has also altered the area's climate. The once-huge sea acted as a thermal buffer that moderated the heat of summer and the extreme cold of winter. Now there is less rain, summers are hotter and drier, winters are colder, and the growing season is shorter. The combination of such climate change and severe salinization has reduced crop yields by 20–50% on almost one-third of the area's cropland.

To raise yields, farmers have used more herbicides, insecticides, and fertilizers, which have percolated downward and accumulated to dangerous levels in the groundwater—the source of most of the region's drinking water.

Many of the 45 million people living in the Aral Sea's watershed have experienced increasing health problems—including anemia, respiratory illnesses, kidney disease, 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. This has improved irrigation efficiency and flushed some salts from croplands. A new dike should raise the average level of the small Aral by 3 meters (10 feet). Some artificial wetlands and lakes have been constructed to help restore aquatic vegetation, wildlife, and fisheries.

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.

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**).

One method for desalinating water is *distillation*—heating saltwater until it evaporates, leaving behind salts in solid form, and condenses as freshwater. Another method is *reverse osmosis* (or *microfiltration*), which uses high pressure to force saltwater through a membrane filter with pores small enough to remove the salt. In effect, high pressure is used to push freshwater out of saltwater.

Today about 15,000 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 for freshwater.

There are three major problems with the widespread use of desalination. One is the high cost, because it takes a lot of energy to desalinate water. A second problem is that pumping large volumes of seawater through pipes and using chemicals to sterilize the water and control algae growth kills many marine organisms. A third problem is that desalination produces large quantities of briny wastewater that contain lots of salt and other minerals. Dumping concentrated brine into a nearby ocean increases the salinity of the ocean water, threatening food resources and aquatic life in the vicinity. Dumping it on land could contaminate groundwater and surface water. Some research is being carried out on the economic and ecological feasibility of building desalination plants offshore and pumping the freshwater to the shore. This could help dilute the resulting briny seawater.

Bottom line: Currently, significant desalination is practical only for water-short, wealthy countries and cities that can afford its high cost (**Concept 11-2C**).

RESEARCH FRONTIER

Developing better and more affordable desalination technologies

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

Mohamed El-Ashry of the World Resources Institute estimates that *65–70% of the water people use throughout the world is lost through evaporation, leaks, and other losses,* and global warming is expected to increase evaporation in many parts of the world. The United States does slightly better but still loses about half of the water it withdraws. El-Ashry believes 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.

This win–win solution would decrease the burden on wastewater plants and reduce the need for expensive dams and water transfer projects that destroy wildlife habitats and displace people. It would also slow depletion of groundwater aquifers and save both energy and money.

According to water resource experts, the main cause of water waste is that *we charge too little for water.* Such *underpricing* is mostly the result of government subsidies that provide irrigation water, electricity, and diesel fuel for farmers to pump water from rivers and aquifers at below-market prices.

Because these subsidies keep water prices 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.

Most water resource experts believe that when water scarcity afflicts many areas in this century, governments will have to make the unpopular decision to raise water prices. China did so in 2002 because it faced water shortages in most of its major cities with rivers running dry and water tables falling in key agricultural areas.

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 established *lifeline* rates that give each household a set amount of free or low-priced water to meet basic needs. When users exceed this amount, the price rises as water use increases—*a user-pays approach.*

The second major cause of water waste is *too few government subsidies for improving the efficiency of water use.* A basic rule of economics is that you get more of what you reward. Withdrawing subsidies that encourage water waste and providing subsidies for efficient water use would sharply reduce water waste. There should be two goals: greatly improve the efficiency of irrigation that accounts for 70% of the world's water use and use inexpensive means to collect rainwater and pipe it to where it is needed.

HOW WOULD YOU VOTE?

Should water prices be raised sharply to help reduce water waste? Cast your vote online at **www.thomsonedu.com/biology/miller**.

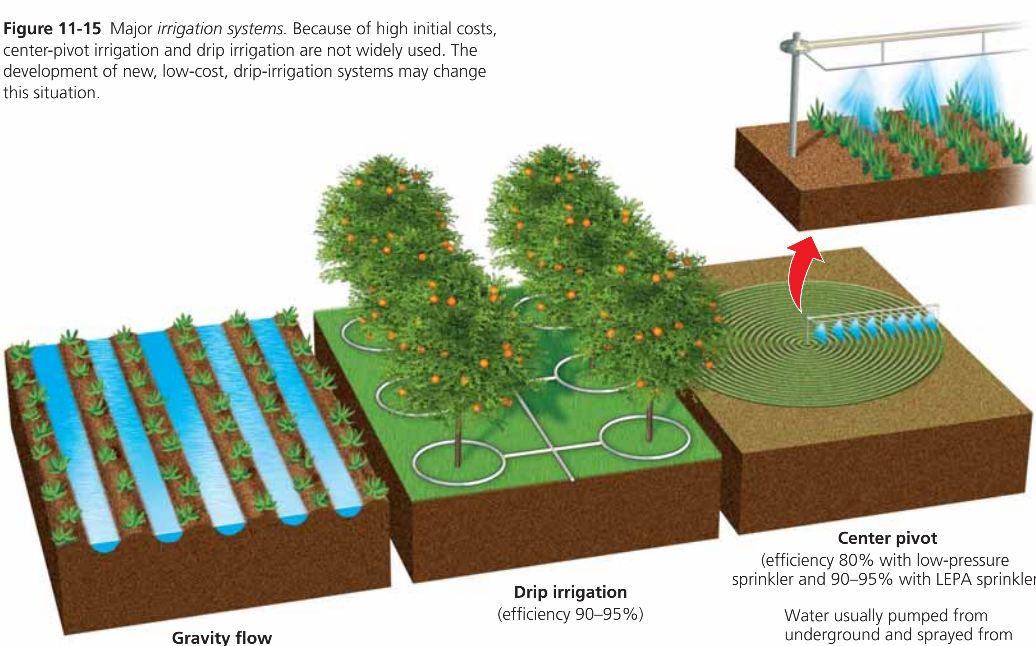
We Can Greatly Cut Water Waste in Irrigation

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 11-15, left, p. 240). 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 11-15, right) uses pumps to spray water on a crop. Typically, it allows 80% of that water to reach crops. *Low-energy, precision application (LEPA) 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 11-15, center), is the most efficient way to

Figure 11-15 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.



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.

Current drip irrigation systems are costly but they drastically reduce water waste, with 90–95% of the water input reaching the crops, and they increase crop yields by 20–90% over conventional gravity flow systems. By using less water, they also reduce the amount of salt that irrigation water leaves in the soil. Increased use of an inexpensive drip irrigation system developed by the nonprofit International Development Enterprises (IDE) will raise crop yields in water-short areas and help lift poor families out of poverty.

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 California. If water were priced closer to the value of the ecological services it provides and if government subsidies that encourage water waste were reduced or eliminated, water experts say that drip irrigation would quickly be used to irrigate most of the world's crops.

RESEARCH FRONTIER

Developing more efficient and affordable irrigation systems

Figure 11-16 lists other ways to reduce water waste in irrigating crops. Since 1950, Israel has used many of these techniques to slash irrigation water waste by 84% while irrigating 44% more land. Israel now treats and reuses 30% of its municipal sewage water for crop production and plans to increase this to 80% by 2025. The government also gradually eliminated most water subsidies to raise Israel's price of irrigation water to one of the highest in the world. Israelis also import most of their wheat and meat and concentrate on growing fruits, vegetables, and flowers that need less water.

Irrigation systems do not have to be complex and expensive. Many of the world's poor farmers use small-scale and low-cost traditional technologies such as human-powered treadle pumps to pump groundwater close to the earth's surface through irrigation ditches.

Rainwater harvesting is another simple and inexpensive way to provide water for drinking and growing crops throughout most of the world. It involves using pipes from rooftops and mini-reservoirs to catch rainwater. In southern Australia, more than 40% of households use rainwater stored in tanks as their main source of drinking water. In Germany, half a million households and buildings harvest rainwater.

Poor farmers can also capture rainfall that would otherwise run off the land and store it in shallow aquifers, ponds, and water tanks for use during dry spells. According to a 2006 report by the U.N. Environment Programme (UNEP), harvesting rainfall in Africa and other parts of the world is an underused and cheap way to provide water compared to the costs of building dams or systems for piping drinking water to homes. Saving rainwater can also save poor women and children from having to spend hours a day fetching water.

Africa is generally viewed as a dry continent but overall it has more water resources per capita than Europe. The UNEP estimates that Kenya has enough rainfall each year to supply 6 or 7 times its current population of 34 million. Increased rainwater harvesting in Ethiopia, where half of its 77 million people suffer from hunger and malnutrition, could supply 520 million people a year with water.

We Can Cut Water Waste in Industry and Homes

The chemical, paper and pulp, oil, coal, primary metals, and food processing industries use 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. However, most industrial processes could be redesigned to use much less water. Figure 11-17 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. Since 1992, U.S. government standards require new toilets to use no more than 6.1 liters (1.6 gallons) of water per flush. Models that use 4.8 liters (1.28 gallons) are available. 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 cut shower water flow in half, save about 19,000 liters (5,000 gallons) per person each year, and reduce water bills.

According to U.N. studies, 40–60% of the water supplied in nearly all of the world's megacities in developing countries (Figure 7-13, p. 138) is lost mostly through leakage of water mains, pipes, pumps, and valves. Even in advanced industrialized countries such as the United States these losses average 10–30%. Water experts say that fixing these leaks should be a high government priority that would cost less than building dams or importing water.

Many homeowners and businesses in water-short areas are using drip irrigation and are copying nature by replacing green lawns with native vegetation. This win–win approach, called *Xeriscaping* (pronounced "ZEER-i-scaping"), reduces water use by 30–85% and sharply reduces needs for labor, fertilizer, and fuel. It also reduces water and air pollution and yard wastes.

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. In Singapore, all sewage water is treated at reclamation plants for reuse by industry. This mimics the way nature

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 waste water
- Import water-intensive crops and meat

Figure 11-16 Methods for reducing water waste in irrigation. **Question:** Which two of these solutions do you think are the most important? Why?

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 11-17 Methods for reducing water waste in industries, homes, and businesses. **Question:** Which three of these solutions do you think are the most important? Why?

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 11-18 Methods for achieving more sustainable use of the earth's water resources (**Concept 11-3**). **Question:** Which two of these solutions do you think are the most important? Why?

purifies water by recycling, and thus follows one of the four **scientific principles of sustainability** (see back cover).

A major cause of excessive water use and waste in homes and industries is underpricing (**Concept 11-3**). 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

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.

One way to do this would be to return the nutrient-rich sludge produced by conventional waste treatment plants to the soil as a fertilizer, instead of using freshwater to transport it. Banning the discharge of industrial toxic wastes into municipal sewer systems would make this feasible. Another way is to rely more on waterless composting toilets that 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. I used one for 15 years without any problems in my environmental experimental office and house in the woods of North Carolina.

We Need to Use Water More Sustainably

Sustainable water use is based on the commonsense principle stated in an old Inca proverb: "The frog does not drink up the pond in which it lives." Figure 11-18 lists ways to implement this principle by using water more sustainably (**Concept 11-3**).

Each of us can help bring about such a blue revolution by using and wasting less water (Figure 11-19). 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 in the early morning or evening.
- Use drip irrigation and mulch for gardens and flowerbeds.

Figure 11-19 **Individuals matter:** ways in which you can reduce your use and waste of water. Visit **www.h2ouse.org** for an array of water-saving tips from the EPA and the California Urban Water Conservation Council that can be used anywhere. **Question:** Which four of these actions do you think are the most important? Why?

11-4 How Can We Reduce the Threat of Flooding?

CONCEPT 11-4 We can improve flood control 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

Whereas some areas have too little water, 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 because of their many advantages, including fertile soil, ample water for irrigation, and availability of nearby rivers for transportation and recreation. Floodplains provide flat land suitable for crops, buildings, highways, and railroads.

To reduce the threat of flooding and thus to allow people to live in 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 (Figure 11-11). But in the long run, such measures can greatly increase flood damage because they can be overwhelmed by prolonged rains, as happened along the Mississippi River in the midwestern United States during the summer of 1993 (Figure 11-20).

Floods 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 refill wetlands.

But floods kill thousands of people each year and cause tens of billions of dollars in property damage. Indeed, floods annually affect more people than the combined numbers affected by drought, tropical cyclones, famine, earthquakes, tsunamis, and volcanic eruptions.

Floods usually are considered natural disasters. Since the 1960s, however, human activities have contributed to the sharp rise in flood deaths and damages. One such activity is removal of water-absorbing vegetation, especially on hillsides (Figure 11-21, p. 244), and replacing that vegetation with farm fields, pastures, pavement, or buildings that cannot absorb rainwater.

Another is draining wetlands that normally absorb floodwaters and building on the land. For example, Hurricane Katrina struck the Gulf Coast of the United States in August 2005 and flooded the city of New

Earth Satellite Corporation

1988

Earth Satellite Corporation

1993

Figure 11-20 The satellite image on the left shows the area around St. Louis, Missouri, on July 4, 1988, under normal conditions. The image on the right shows the same area on July 4, 1993, after severe flooding from prolonged rains. Note the large increase in the flooded (blue) area. **Questions:** Are there any rivers with dams or levees near where you live? How would their flooding affect you?

Orleans and surrounding areas. The damage was intensified because of the degradation and removal of coastal wetlands that had historically buffered the land from storm surges.

Living on floodplains increases the threat of damage from flooding. Many poor people have little choice but to live in such risky areas, as discussed in the following Case Study.

■ CASE STUDY

Living Dangerously on Floodplains in Bangladesh

Bangladesh is one of the world's most densely populated countries, with 147 million people packed into an area roughly the size of the U.S. state of Wisconsin. It is very flat, only slightly above sea level, and it is one of the world's poorest countries.

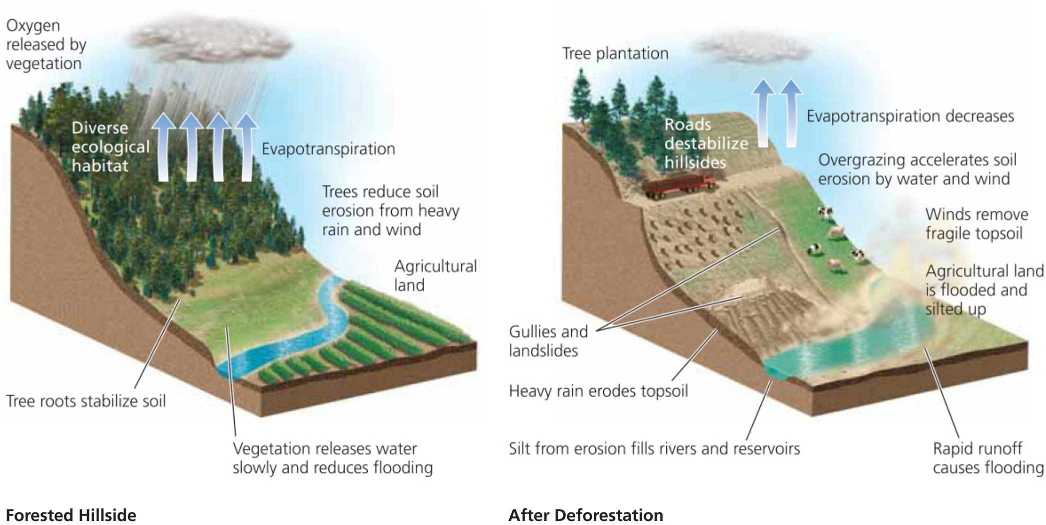
The people of Bangladesh depend on moderate annual flooding during the summer monsoon season to grow rice and help maintain soil fertility in the delta basin. The annual floods deposit eroded Himalayan soil on the country's crop fields.

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 11-21).

This increased runoff of soil, combined with heavier-than-normal monsoon rains, has increased the severity of 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, such as the one in 2004 caused by earthquakes under the Indian Ocean (See Figure 4 on p. S55 in Supplement 12). In 1970, as many as 1 million people drowned as a result of one tropical cyclone. Another cyclone in 2003 killed more than a million people and left tens of millions homeless.

In their struggle to survive, the poor in Bangladesh have cleared many of the country's coastal mangrove forests (Figure 5-20, p. 93) 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.



ThomsonNOW™ **Active Figure 11-21 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* ThomsonNOW. **Question:** How might a drought in this area make these effects even worse?

THINKING ABOUT
Bangladesh

What are three things that could be done to help reduce the threat of flooding in Bangladesh?

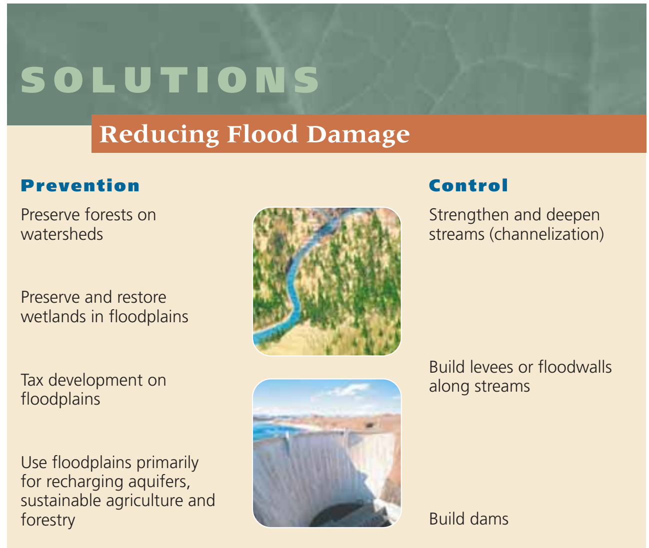


Figure 11-22 Methods for reducing the harmful effects of flooding (**Concept 11-4**). **Question:** Which two of these solutions do you think are the most important? Why?

We Can Reduce Flood Risks

Figure 11-22 lists some ways to reduce flood 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.

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. In addition, 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. They also do not protect against unusually high and powerful floodwaters, such as those occurring in 1993 (Figure 11-20) 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 11-11). Another 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.

On a personal level, we can use the precautionary approach to *think carefully about where we 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 caused by climate factors, increased population, and economic development.

THINKING ABOUT
Where to Live

Do you now live in a flood-prone area? Have you thought about moving to or away from such an area? Do the attractions of living there outweigh the risks for you?

11-5 How Can We Best Deal with Water Pollution

CONCEPT 11-5A Streams can cleanse themselves of many pollutants if we do not overload them.

CONCEPT 11-5B Preventing water pollution usually works better and costs less than trying to clean it up.

CONCEPT 11-5C 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 chemical, biological, or physical change in water quality that harms living organisms or makes water unsuitable for desired uses.

Water pollution can come from single, or **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 water. Examples include factories, sewage treatment plants (which remove some but not all pollutants), underground mines, and oil tankers.

Because point sources are located at specific places, they are fairly easy to identify, monitor, and regulate. Most developed countries have laws that help control point-source discharges of harmful chemicals into aquatic systems. In most developing countries, there is little control of such discharges.

Nonpoint sources are scattered and diffuse and cannot be traced to any single site of discharge. Examples include runoff of chemicals and sediments into surface water from cropland, livestock feedlots, logged forests, urban streets, lawns, and golf courses. We have made little progress in controlling water pollution from nonpoint sources because of the difficulty and expense of identifying and controlling discharges from so many diffuse sources.

Agricultural activities are by far the leading cause of water pollution. Sediment eroded from agricultural lands 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* are another source of water pollution; they emit a variety of harmful inorganic and organic chemicals. *Mining* is the third biggest source. Surface mining creates major erosion of sediments and runoff of toxic chemicals.

Climate change from global warming can also affect water pollution. In a warmer world, some areas will get more precipitation and other areas will get less. 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 classes of water pollutants along with their major human sources and their harmful effects.

The WHO estimates that 3.2 million people—most of them children younger than age 5—die prematurely every year by contracting infectious diseases spread by contaminated water or by having too little water for adequate hygiene. Each year, diarrhea alone kills about 1.9 million people—about 90% of them children under age 5—in developing countries. This means that diarrhea caused mostly by exposure to polluted water kills a young child every 17 seconds.

Streams Can Cleanse Themselves If We Do Not Overload Them

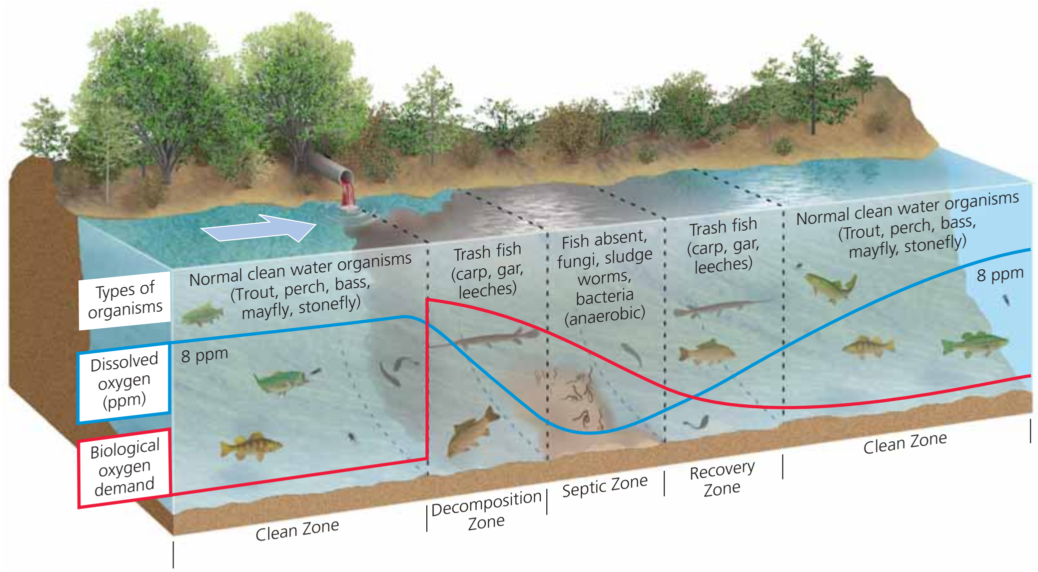
Rivers and streams can recover rapidly from pollution caused by moderate levels of degradable, oxygen-demanding wastes and excess heat. They do so through a combination of dilution, biodegradation, and the presence of bacteria that break down the waste. But this natural recovery process does not work when streams become overloaded with pollutants or when drought, damming, or water diversion reduce their flows (**Concept 11-5A**). Likewise, these processes do not eliminate slowly degradable or nondegradable pollutants.

In a flowing stream, the breakdown of degradable wastes by bacteria depletes dissolved oxygen and creates an *oxygen sag curve* (Figure 11-23). This reduces or eliminates populations of organisms with high oxygen

Table 11-1

Major Water Pollutants and Their Sources

Type/Effects	Examples	Major Sources
Infectious agents cause diseases	Bacteria, viruses, 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, salts, metal compounds	Industry, households, surface runoff
Sediments disrupt photosynthesis, food webs, other processes	Soil, silt	Land erosion
Thermal pollution makes some species vulnerable to disease	Heat	Electric power and industrial plants



ThomsonNOW™ Active Figure 11-23 Dilution and decay of degradable, oxygen-demanding wastes and heat in a stream, showing the oxygen sag curve (blue) and the curve of oxygen demand (red). Depending on flow rates and the amount of pollutants, streams recover from pollution by oxygen-demanding wastes and heat if they are given enough time and are not overloaded (**Concept 11-5A**). *See an animation based on this figure at* ThomsonNOW. **Question:** What would be the effect of putting another waste discharge pipe to the right of the one in this picture?

requirements until the stream is cleansed of wastes. Similar oxygen sag curves can be plotted when heated water from industrial and power plants is discharged into streams.

ThomsonNOW™ Learn more about how pollution affects the water in a stream and the creatures living there at ThomsonNOW.

Water pollution control laws enacted in the 1970s have greatly increased the number and quality of wastewater treatment plants in the United States and most other developed countries. Such laws also require industries to reduce or eliminate their point-source discharges of harmful chemicals into surface waters. This has enabled the United States to hold the line against increased pollution by disease-causing agents and oxygen-demanding wastes in most of its streams. It is an impressive accomplishment given the country's increased economic activity, resource consumption, and population growth since passage of these laws.

But large fish kills and drinking water contamination still occasionally occur in parts of the United States and other developed countries. One cause of such problems is accidental or deliberate releases of toxic inorganic and organic chemicals by industries or mines. Another is malfunctioning sewage treatment plants. A third cause is nonpoint runoff of pesticides and excess plant nutrients from cropland and animal feedlots.

In most developing countries, stream pollution from discharges of untreated sewage and industrial wastes is a serious and growing problem. According to a 2003 report by the World Commission on Water in the 21st Century, half of the world's 500 rivers are heavily polluted, most of them running 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 11-24, p. 248). Only about 10% of the sewage produced in Chinese cities is treated and 300 million Chinese—an amount 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.

Low Water Flow and Too Little Mixing Makes Lakes Vulnerable to Water Pollution

In lakes and reservoirs, dilution of pollutants often is less effective than in streams for two reasons. *First,* lakes and reservoirs often contain stratified layers (Figure 5-29, p. 101) that undergo little vertical mixing.

Figure 11-24 **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.

Second, they have little 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 sediment, plant nutrients, oil, pesticides, and toxic substances such as lead, mercury, and selenium. These contaminants can kill bottom life and fish and birds that feed on contaminated aquatic organisms. 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, mostly from 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 5-30, left, p. 101). Over time, some lakes become more eutrophic (Figure 5-30, right, p. 101) 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.** It is mostly nitrate- and phosphate-containing effluents from various sources that cause this change. These sources include runoff from farmland, animal feedlots, urban areas, chemically fertilized suburban yards, and mining sites, and from the discharge of treated and untreated municipal sewage. 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 5-30, right, p. 101) and thick growths of water hyacinth, duckweed, and other aquatic plants. These dense colonies of plant life can reduce lake productivity and fish growth by decreasing the input of solar energy needed for photosynthesis by the phytoplankton that support fish.

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 can kill 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. EPA, about one-third of the 100,000 medium to large lakes and 85% of the large lakes near major population centers in the United States have some degree of cultural eutrophication. According to the International Water Association, 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 employing soil conservation and land-use control to reduce nutrient runoff.

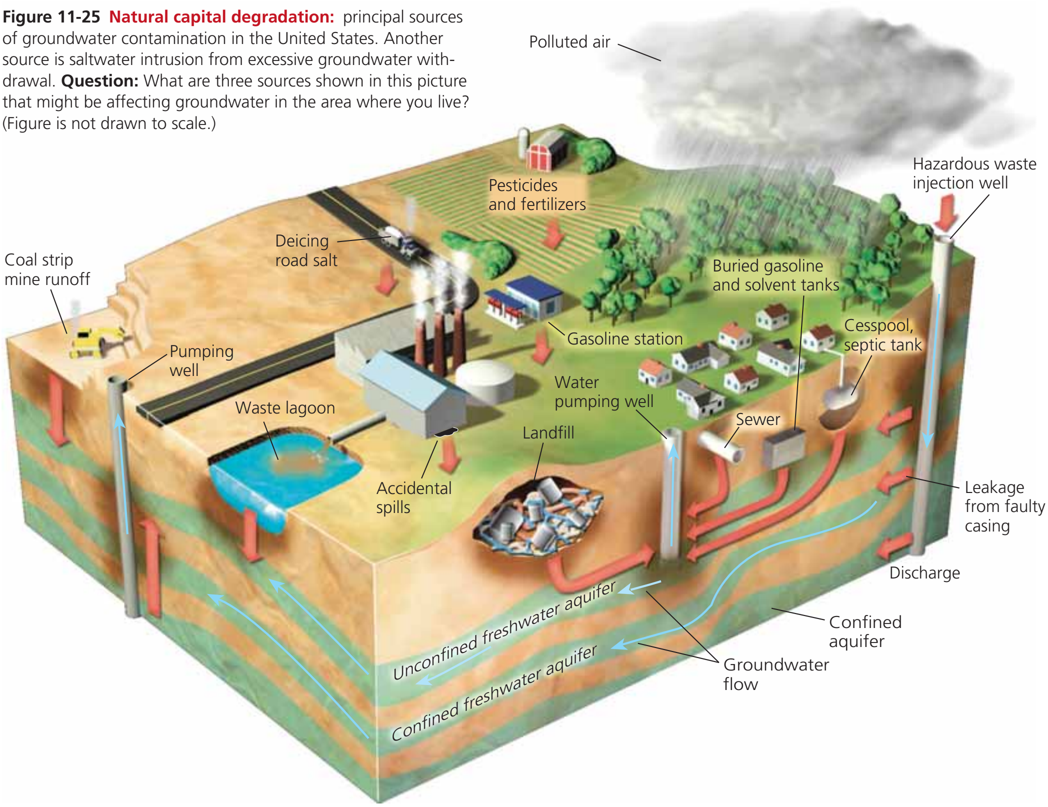
There are also several ways to *clean up* lakes suffering from cultural eutrophication. We can mechanically remove excess weeds, control undesirable plant growth with herbicides and algicides, and pump air through lakes and reservoirs to prevent oxygen depletion, all of which are expensive and energy-intensive methods.

As usual, pollution prevention is more effective and usually cheaper in the long run than cleanup (**Concept 11-5B**). The good news is that if excessive inputs of plant nutrients stop, a lake usually can recover from cultural eutrophication.

Groundwater Cannot Cleanse Itself Very Well

According to many scientists, groundwater pollution is a serious threat to human health. Common pollutants such as fertilizers, pesticides, gasoline, and organic solvents can seep into groundwater from numerous sources (Figure 11-25). People who dump or spill gasoline, oil, and paint thinners and other organic solvents onto the ground also are likely contributing to groundwater contamination.

Figure 11-25 **Natural capital degradation:** principal sources of groundwater contamination in the United States. Another source is saltwater intrusion from excessive groundwater withdrawal. **Question:** What are three sources shown in this picture that might be affecting groundwater in the area where you live? (Figure is not drawn to scale.)



When groundwater becomes contaminated, it cannot cleanse itself of *degradable wastes* as flowing surface water does (Figure 11-23). Groundwater flows so slowly—usually less than 0.3 meter (1 foot) per day—that contaminants are not diluted and dispersed effectively. In addition, groundwater usually has much lower concentrations of dissolved oxygen (which helps decompose many contaminants) and smaller populations of decomposing bacteria. Also, the usually cold temperatures of groundwater slow down chemical reactions that decompose wastes.

Thus, it can take hundreds to thousands of years for contaminated groundwater to cleanse itself of *degradable* and *slowly degradable wastes* (such as DDT). On a human time scale, *nondegradable wastes* (such as toxic lead, arsenic, and fluoride) are permanent pollutants.

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.

China has limited water resources for its huge population. Groundwater is crucial because it provides about 70% of the country's drinking water. In 2006, the Chinese government reported that aquifers in about nine of every ten Chinese cities were polluted or overexploited and could take hundreds of years to recover. An EPA survey of 26,000 industrial waste ponds and lagoons in the United States found that one-third of them had no liners to prevent toxic liquid wastes from seeping into aquifers. One-third of these sites are within 1.6 kilometers (1 mile) of a drinking water well. In addition, almost two-thirds of America's liquid hazardous wastes are injected into the ground in disposal wells (Figure 11-25), some of which leak water into aquifers used as sources of drinking water.

The EPA has completed the cleanup of about 300,000 of 436,000 underground tanks that were found to be leaking gasoline, diesel fuel, home heating oil, or toxic solvents into groundwater in the United States. During this century, scientists expect many of the millions of such tanks installed around the world to corrode, leak, contaminate groundwater, and cause 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. *Bottom line:* Wastes that we think we have thrown away or stored safely can escape and come back to haunt us.

In the United States, groundwater pollution by MTBE (methyl tertiary butyl ether)—a gasoline additive used since 1979—is a serious problem. MTBE is a suspected carcinogen. By the time this was discovered in the 1990s, about 250,000 leaking gasoline tanks had contaminated aquifers in many parts of the country. Use of MTBE is being phased out but plumes of groundwater contaminated with MTBE will move through aquifers for decades.

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 mining or other activities release it into drinking water supplies. According to the WHO, more than 112 million people are drinking water with arsenic levels 5–100 times the 10 ppb standard, mostly in Bangladesh, China, and India's state of West Bengal.

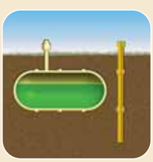
There is also concern over arsenic levels in drinking water in parts of the United States, where several thousand communities, mostly in the western half of the country, have arsenic levels of 3–10 ppb in their drinking water. According to the WHO and other scientists, even the 10 ppb standard is not safe. Many scientists call for lowering the standard to 3–5 ppb, but it would be costly to comply with such a low standard.

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 11-26 Methods for preventing and cleaning up contamination of groundwater. **Question:** Which two of these preventive solutions do you think are the most important? Why?

In 2006, researchers from Rice University in Houston, Texas (USA), reported that fashioning a common mineral similar to rust into a powder of tiny nanocrystals (see p. S38 in Supplement 7) could greatly reduce the threat of arsenic in drinking water at a cost of a few cents a day for families. Stay tuned as this new process is evaluated.

Pollution Prevention Is the Only Effective Way to Protect Groundwater

Figure 11-26 lists ways to prevent and clean up groundwater contamination. Pumping polluted groundwater to the surface, cleaning it up, and returning it to the aquifer is very expensive.

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 11-26, left, and **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 11-27). This is not surprising because about 40% of the world's population (53% in the United States) lives on or near the coast. Of the world's 15 largest metropolitan areas (each with 10 million people or more), 14 are near coastal waters (Figure 7-13, p. 138). Coastal populations are expected to double by 2050.

According to a 2006 report, *State of the Marine Environment* by the U.N. Environment Programme (UNEP), an estimated 80% of marine pollution originates on land and could rise significantly by 2050 if coastal populations double as projected. According to the report, 80–90% of the municipal sewage from most coastal developing countries and in some coastal developed countries is dumped into oceans without treatment. This is overwhelming the ability of these bodies of water to biodegrade these wastes. According to the UNEP, fixing the global sewage problem alone will cost at least $56 billion a year—an average of $107,000 a minute.

In deeper waters, the oceans can dilute, disperse, and degrade large amounts of raw sewage and other types of degradable pollutants. Some scientists suggest that it is safer to dump sewage sludge and most other harmful wastes into the deep ocean than to bury them on land or burn them in incinerators. Other scientists disagree, pointing out that we know less about the deep ocean than we do about the moon. They add that dumping harmful wastes into the ocean would delay urgently needed pollution prevention efforts and promote further degradation of this vital part of the earth's life-support system.

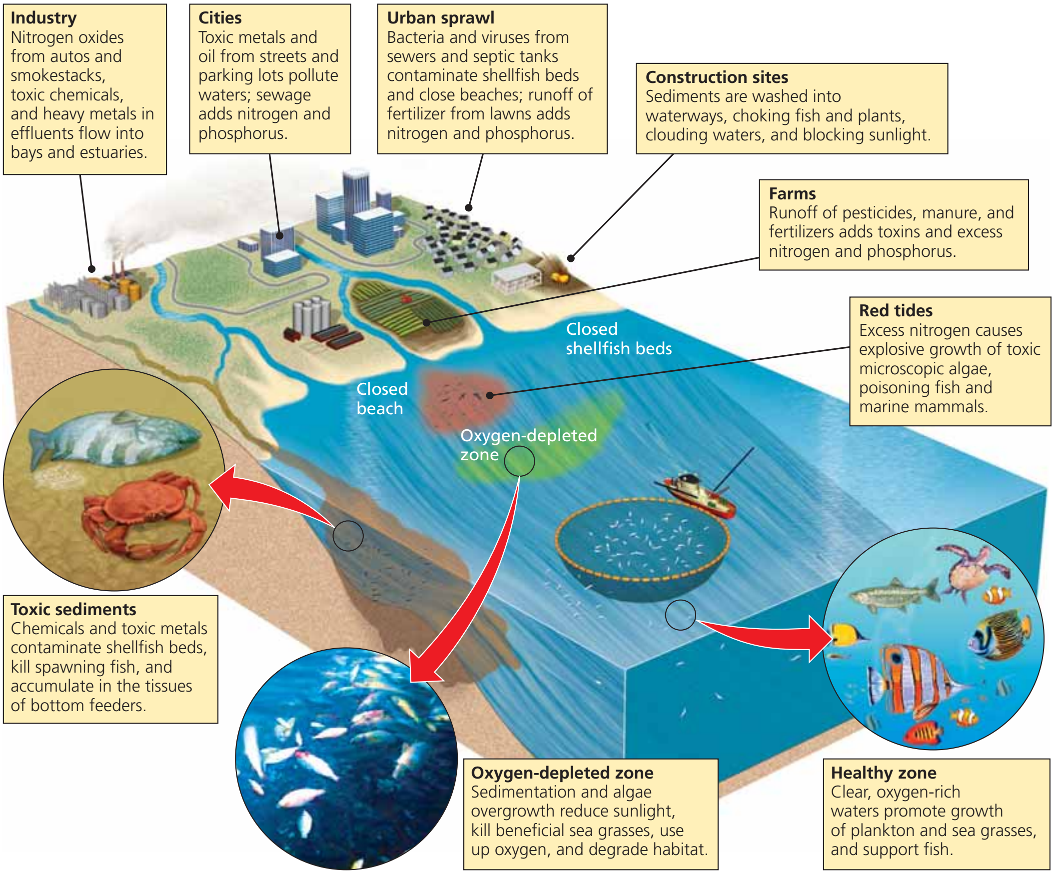


Figure 11-27 **Natural capital degradation:** residential areas, factories, and farms all contribute to the pollution of coastal waters and bays. According to the U.N. Environment Programme, coastal water pollution costs the world $16 billion annually—$731,000 a minute—due to ill health and premature death. **Question:** What are three changes you could make in your lifestyle that might help prevent this pollution?

THINKING ABOUT
Ocean Pollution

Should we dump sewage sludge and other harmful pollutants into the deep ocean? Explain.

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.

Runoffs of sewage and agricultural wastes into coastal waters introduce large quantities of nitrate and phosphate plant nutrients, which can cause explosive growths of harmful algae. These *harmful algal blooms* (HABs) are called red, 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.

According to a 2006 report by the U.N. Environment Programme, each year at least 200 *oxygen-depleted zones* form, mostly in temperate coastal waters and in landlocked seas such as the Baltic and Black Seas. They are incorrectly called *dead zones.* Because of low oxygen levels (hypoxia), the zones contain few oxygen-consuming fish and bottom-dwelling organisms, but they abound with decomposing bacteria. The low oxygen levels are caused by the rapid growth of algae in nutrient-rich waters, which are decomposed by large colonies of oxygen-consuming bacteria.

Evidence indicates that oxygen-depleted zones result from excessive inputs of nitrates and phosphates from runoff fertilizers and animal wastes and

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 at the mouth of the Mississippi River (Figure 11-A).

The Mississippi River basin drains all or part of 31 U.S. states and two Canadian provinces. Its watershed contains more than half of all U.S. croplands and is one of the world's most productive agricultural regions.

According to a 2005 study of sediment cores by geologist Lisa Osterman, seasonal oxygen-depleted zones in the northern Gulf of Mexico existed as long ago as the 1800s. But since 1950, when fertilizer use began increasing sharply, the sizes of the zones and levels of oxygen-depletion have been increasing and in recent years have covered an area larger than the U.S. state of Connecticut.

Because of the size and agricultural importance of the Mississippi River Basin, there are no easy solutions to the severe cultural eutrophication in this and other overfertilized coastal zones around the world. Preventive measures include applying less fertilizer, reducing nitrogen inputs from various sources, planting strips of forests and grasslands along waterways to soak up excess nitrogen, and restoring and creating wetlands between crop fields and streams emptying into the Mississippi River.

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 phasing in forms of renewable energy to replace the burning of fossil fuels.

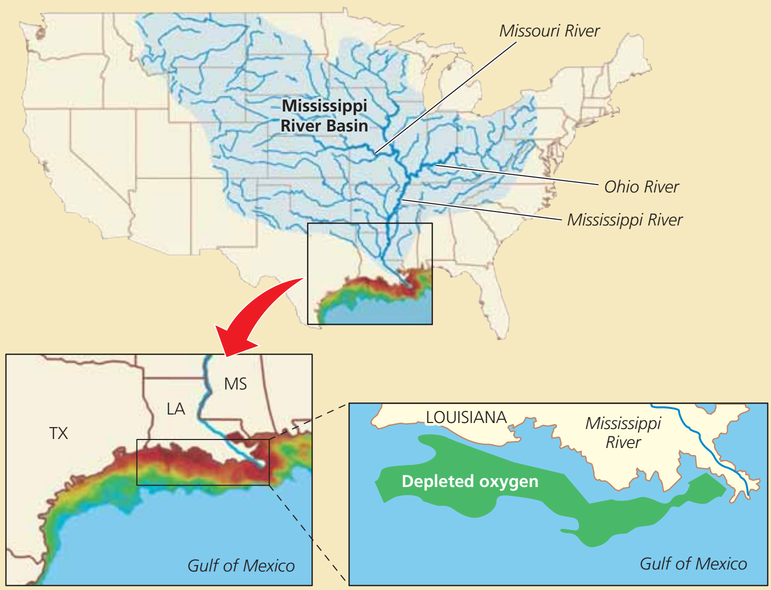


Figure 11-A A *large zone of oxygen-depleted water* (less than 2 ppm dissolved oxygen) forms for half of the year in the Gulf of Mexico as a result of oxygen-depleting algal blooms. Evidence indicates that it is created mostly by huge inputs of nitrate (NO_3^-) plant nutrients from farms, cities, factories, and sewage treatment plants in the vast Mississippi River basin. The satellite image (bottom left) shows the inputs of such nutrients into the Gulf of Mexico during the summer of 2004. In the photo, reds and greens represent high concentrations of phytoplankton and river sediment. This problem is worsened by loss of wetlands, which help filter plant nutrients. **Question:** What are three things that could be done to prevent or sharply reduce this sort of pollution? (Data from NASA)

Critical Thinking

What are three common activities in an average person's daily life that contribute to the formation of oxygen-depletion zones such as that found in the northern Gulf of Mexico?

deposition of nitrogen compounds from the atmosphere. About 43 of these zones occur in U.S. waters (Science Focus, above).

■ CASE STUDY

The Chesapeake Bay Is an Estuary in Trouble

Since 1960, the Chesapeake Bay—the largest estuary in the United States—has been in serious trouble from water pollution, mostly because of human activities. One contributing factor is population growth: between 1940 and 2006, the number of people living in the Chesapeake Bay area grew from 3.7 million to 16 million. With more than 300 new people moving into the watershed each day, it may soon reach 17 million.

The estuary receives wastes from point and nonpoint sources scattered throughout a huge drainage basin that includes 9 large rivers and 141 smaller streams and creeks in parts of six U.S. states. The shallow bay has become a huge pollution sink, because only 1% of the waste entering it is flushed into the Atlantic Ocean.

Phosphate and nitrate levels have risen sharply in many parts of the bay, causing algal blooms and oxygen depletion. Commercial harvests of its once-abundant oysters, crabs, and several important fish have fallen sharply since 1960 because of a combination of pollution, overfishing, and disease.

Point sources—primarily sewage treatment plants and industrial plants (often in violation of their discharge permits)—account for 60% by weight of the phosphates. Nonpoint sources—mostly runoff of fertilizer and animal wastes from urban, suburban, and agricultural land and deposition from the atmosphere—account for 60% by weight of the nitrates. According to 2004 study by the Chesapeake Bay Foundation, animal manure is the largest source of nitrates and phosphates from agricultural pollution.

In 1983, the United States implemented the Chesapeake Bay Program. In this ambitious attempt at *integrated coastal management,* citizens' groups, communities, state legislatures, and the federal government are working together to reduce pollution inputs into the bay.

Strategies include establishing land-use regulations in the bay's six watershed states to reduce agricultural and urban runoff. Other strategies are to ban phosphate detergents, upgrade sewage treatment plants, and improve monitoring of industrial discharges. In addition, wetlands are being restored and large areas of the bay are being replanted with sea grasses to help filter out nutrients and other pollutants.

The efforts to improve the water quality of the Chesapeake Bay have paid off. Between 1985 and 2000, phosphorus levels declined 27%, nitrogen levels dropped 16%, and grasses growing on parts of the bay's floor have made a comeback. This is a significant achievement given the increasing population in the watershed and the fact that nearly 40% of the nitrogen inputs come from the atmosphere.

There is still a long way to go, and sharp cuts in state and federal funding have slowed progress. According to a 2006 report by the Chesapeake Bay Foundation, "the bay's health remains dangerously out of balance." The report gave the Chesapeake a score of 29 out of 100 for 2006, up from 6 in 1983. But despite some setbacks, the Chesapeake Bay Program shows what can be done when diverse groups work together to achieve goals that benefit both wildlife and people.

THINKING ABOUT
The Chesapeake Bay

Think of a nonpoint source of pollution in the Chesapeake Bay. How would you go about reducing or preventing pollution from that source?

Oil Can Pollute the Ocean

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. But *studies show that the largest source of ocean oil pollution is urban and industrial runoff from land.*

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. Some good news: according to a 2006 UNEP study, since the mid-1980s the amount of oil entering the marine environment from oil tanker accidents has decreased 75% and oil discharges from industry and cities have dropped by nearly 90%.

Volatile organic hydrocarbons in oil immediately kill a number of 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. This oil coating destroys their natural insulation and buoyancy, causing many of them to drown or die of exposure from loss of body heat.

Heavy oil components that sink to the ocean floor or wash into estuaries can smother bottom-dwelling organisms such as crabs, oysters, mussels, and clams, or make them unfit for human consumption. Some oil spills have killed coral reefs.

Research shows that populations of many forms of marine life recover from exposure to large amounts of *crude oil* within about 3 years. But recovery from exposure to *refined oil,* especially in estuaries and salt marshes, can take 10–20 years. Oil slicks that wash onto beaches can have a serious economic impact on coastal residents, who lose income normally gained from fishing and tourist activities. In 2006, some 17 years after the *Exxon Valdez* spill, researchers found patches of oil remaining on some parts of the shoreline of Alaska's Prince William Sound.

Scientists estimate that current cleanup methods can recover no more than 15% of the oil from a major spill. Thus, *preventing* oil pollution is the most effective and, in the long run, the least costly approach (**Concept 11-5B**).

One of the best ways to prevent tanker spills is to use only oil tankers with double hulls. After the 1989 *Exxon Valdez* accident, oil companies promised that they would do that. But eighteen years later, in 2007, about half of the world's 10,000 oil tankers still had the older and more vulnerable single hulls.

We Need to Protect Coastal Waters

Figure 11-28 (p. 254) lists ways to prevent and reduce pollution of coastal waters.

The key to protecting the oceans is to reduce the flow of pollution from land and air and from streams emptying into these waters (Figure 11-27). Thus, ocean pollution control must be linked with land-use and air pollution control policies.

Figure 11-28 Methods for preventing and cleaning up excessive pollution of coastal waters. **Question:** Which two of these solutions do you think are the most important? Why?

We Need to Reduce 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.

Applying pesticides only when needed and relying more on integrated pest management (pp. 222–223) 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.thomsonedu.com/biology/miller**.

Laws Can Help Reduce Water Pollution from Point Sources

The Federal Water Pollution Control Act of 1972 (renamed the Clean Water Act when it was amended in 1977) and the 1987 Water Quality Act form the basis of U.S. efforts to control pollution of the country's surface waters. The Clean Water Act sets standards for allowed levels of 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* that uses market forces to reduce water pollution in the United States. Under this program, a permit holder can pollute at higher levels than allowed in its permit if it buys credits from permit holders who are polluting below their allowed levels.

Environmental scientists warn that such a system is no better than the cap set for total pollution levels in any given area. 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 gradual lowering of the caps to encourage prevention of water pollution and development of better pollution control technology. Scientists point out that neither adequate scrutiny of the cap levels nor gradual lowering of caps is a part of the current EPA discharge trading system.

Sewage Treatment Reduces Water Pollution

In rural and suburban areas with suitable soils, sewage from each house usually is discharged into a **septic tank.** 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 in a large drainage (absorption) field through small holes in perforated pipes embedded in porous gravel or crushed stone just below the soil's surface. As these wastes drain from the pipes and percolate downward, the soil filters out some potential pollutants and soil bacteria decompose biodegradable materials. About one-fourth of all homes in the United States are served by septic tanks.

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

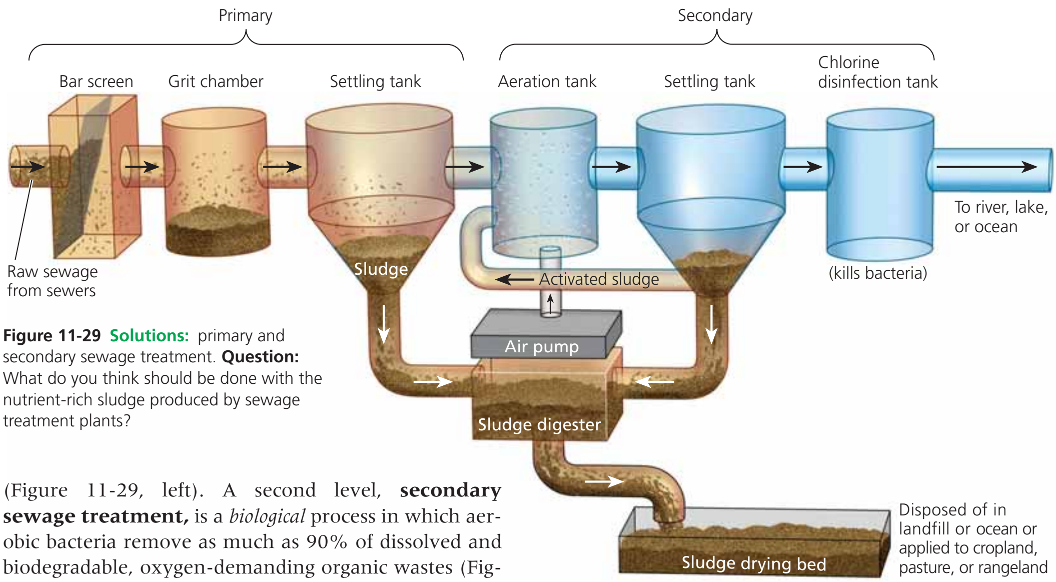


Figure 11-29 **Solutions:** primary and secondary sewage treatment. **Question:** What do you think should be done with the nutrient-rich sludge produced by sewage treatment plants?

(Figure 11-29, left). A second level, **secondary sewage treatment,** is a *biological* process in which aerobic bacteria remove as much as 90% of dissolved and biodegradable, oxygen-demanding organic wastes (Figure 11-29, 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 chlorination.

We Can Improve Conventional Sewage Treatment

Environmental scientist Peter Montague calls for redesigning the conventional sewage treatment system shown in Figure 11-29. 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 11-5B** and **Concept 1-4**, p. 14). CONCEPT LINK

Montague suggests several ways to do this. One is to require industries and businesses to remove toxic and hazardous wastes from water sent to municipal sewage treatment plants. Another is to encourage industries to reduce or eliminate use and waste of toxic chemicals.

Another suggestion is to have more households, apartment buildings, and offices eliminate sewage outputs by switching to waterless *composting toilet systems* that are installed, maintained, and managed by professionals. Such systems would be cheaper to install and maintain than current sewage systems because they do not require vast systems of underground pipes connected to centralized sewage treatment plants. They also save large amounts of water. Many communities are using unconventional, but highly effective, sewage treatment systems that work with nature (Science Focus, p. 256).

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.thomsonedu.com/biology/miller**.

The United States Has Reduced Water Pollution from Point Sources

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):

- 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.

SCIENCE FOCUS

Treating Sewage by Working with Nature

Some communities and individuals are seeking better ways to purify sewage by working with nature (**Concept 11-5C**). 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 (sequester) toxic metals such as lead and mercury and secrete natural antibiotic compounds that kill pathogens.

Next, the water flows into aquarium tanks. 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 for a conventional sewage treatment plant.

More than 800 cities and towns around the world and 150 in the United States (such as West Palm Beach, Florida, and Phoenix, Arizona) use natural or artificially created wetlands to treat sewage as a lower-cost alternative to expensive waste treatment plants. For example, Arcata, California—a coastal town of 16,000 people—created some 65 hectares (160 acres) of wetlands between the town and the adjacent Humboldt Bay. The marshes and ponds, developed on land that was once a dump, act as a natural waste treatment plant. The cost was less than half the estimated price of a conventional treatment plant. The marshes and ponds also serve as an Audubon Society bird sanctuary and provide 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 three of the four **scientific principles of sustainability** (see back cover): using solar energy, using natural processes to remove and recycle nutrients and other chemicals, and relying on a diversity of organisms and natural processes.

Critical Thinking

Can you think of any disadvantages of using such a nature-oriented system instead of a conventional sewage treatment plant? Do you think any such disadvantages outweigh the advantages? Why or why not?

- The amount of topsoil lost through agricultural runoff was cut by about 1.1 billion metric tons (1 billion tons) annually.
- 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. Unfortunately, there is also bad news. 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 runoff of animal wastes from hog, poultry, and cattle feedlots and meat processing facilities had polluted 7 of every 10 U.S. rivers. Livestock wastes are stored in lagoons that sometimes leak and can overflow or rupture as a result of excessive rainfall. They can spill their contents into nearby streams and rivers and sometimes into residential areas.

Also, 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 2003 study by the EPA also found that at least half of the country's 6,600 largest industrial facilities and municipal wastewater treatment plants have illegally discharged toxic or biological wastes into waterways for years without government enforcement actions or fines.

Should the U.S. Clean Water Act Be Strengthened or Weakened?

Some environmental scientists, echoing a 2001 report by the EPA's inspector general, call for strengthening the Clean Water Act. Suggested improvements include shifting the emphasis to preventing water pollution instead of focusing mostly on end-of-pipe removal of specific pollutants. The report also calls for increased funding and authority to control nonpoint sources of pollution, greatly increased monitoring for compliance with the law, much larger mandatory fines for violators, and stronger programs to prevent and control toxic water pollution.

Other suggestions include providing more funding and authority for integrated watershed and airshed planning to protect groundwater and surface water from contamination, and expanding the rights of citizens to bring lawsuits to ensure that water pollution laws are enforced. Studies have shown that many violators of federal water pollution standards receive no fines or only small ones. The National Academy of Sciences also calls for halting the loss of wetlands, instituting higher standards for wetland restoration, and creating new wetlands before filling any natural wetlands.

Many people oppose these proposals, contending that the Clean Water Act's regulations and government wetlands regulations are already too restrictive and costly. Farmers and developers see the law as limiting their rights as property owners to fill in wetlands. They also believe they should be compensated for any property value losses resulting from federal wetland protection.

State and local officials want more discretion in testing for and meeting water quality standards. They argue that in many communities, it is unnecessary and too expensive to test for all the water pollutants required by federal law.

Many officials are also fed up with so called "unfunded mandates" from Congress. Federal laws require states and localities to spend a great deal of money to meet federal water pollution standards without reimbursing them for most of the costs from federal tax revenues. Many small cities cannot afford such costs.

HOW WOULD YOU VOTE?

Should the U.S. Clean Water Act be strengthened? Cast your vote online at **www.thomsonedu.com/biology/miller**.

Developed Countries Purify Urban Drinking Water

Most developed countries have laws establishing drinking water standards, but most developing countries do not have such laws or do not 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.

Next, the water is 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 except for disinfection is necessary. Some cities (including Boston, New York, Seattle, and Portland in the United States and Bogotá, Colombia) have found that protecting watersheds that supply their drinking water is a lot cheaper than building water purification plants.

Simple 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. Heat and the sun's 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 that applies one of the four **principles of sustainability** (see back cover). Where this measure has been used, incidence of dangerous childhood diarrhea has decreased by 30–40%.

In 2007, Mikkel Frandsen, CEO of a Danish company, developed a $3 Lifestraw that allows individuals to suck contaminated water through a purifying device. The straw filters up to 700 liters (185 gallons) of water before it needs to be replaced.

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 the water regularly for a number of pollutants and to make such information available to citizens. Yet about half of all Americans worry about getting sick from tap water contaminants, and many drink bottled water or install expensive water purification systems. Other countries must rely on bottled water wherever their tap water is too polluted to drink.

Studies reveal that in the United States bottled water costs 120 to 7,500 times more than tap water. Yet studies indicate that about one-fourth of it is ordinary tap water in a bottle, and bacteria or fungi contaminate about 40% of bottled water.

Before drinking expensive bottled water and buying costly home water purifiers, health officials suggest that consumers have their water tested by local health authorities or private labs (but not by companies trying to sell water purification equipment). The goals are to identify what contaminants (if any) must be removed and to determine the type of purification needed to remove such contaminants. 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.

Buyers should check out companies selling water purification equipment and be wary of claims that the EPA has approved a treatment device. Although it does *register* such devices, the EPA neither tests nor approves them.

HOW WOULD YOU VOTE?

Should quality standards be established for bottled water? Cast your vote online at **www.thomsonedu.com/biology/miller**.

There Are More 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.

Conversely, little has been done to reduce water pollution in most developing countries. However, by

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 four R's of resource use (refuse, reduce, recycle, reuse)
- Reduce air pollution
- Reduce poverty
- Slow population growth

Figure 11-30 Methods for preventing and reducing water pollution (**Concept 11-5B**). **Question:** Which two of these solutions do you think are the most important? Why?

WHAT CAN YOU DO?

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.
- Grow or buy organic foods.
- Compost your food wastes.
- 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 11-31 **Individuals matter:** ways to help reduce water pollution. **Question:** Which three of these actions do you think are the most important? Why?

2010 China plans to provide small sewage treatment plants for all of its cities that will purify their water to a quality such that it can be recycled back into the urban water supply system. If successful, China could become a world leader in modern sewage treatment plants that tackle both pollution and water scarcity by reprocessing water and thus following the **recycling principle of sustainability** (see back cover).

To environmental and health scientists, the next step is to increase efforts to reduce and prevent water pollution in developed and developing countries by asking the question: *How can we avoid producing water pollutants in the first place?* (**Concept 11-5B**). Figure 11-30 lists ways to achieve this goal over the next several decades.

This shift to pollution prevention will not take place without citizens putting bottom-up political pressure on elected officials. Developing countries will also need financial and technical aid from developed countries. Figure 11-31 lists some actions you can take to help reduce water pollution.

REVISITING Water Conflicts in the Middle East and Sustainability

CORE CASE STUDY

The **Core Case Study** that opens this chapter discussed the problems and tensions of Middle Eastern countries trying to share limited water resources. Israel has become the world's most water-efficient nation and has led the world in developing technologies and a water pricing system that help the country to use its limited water supplies more sustainably. Other water-short nations would benefit from following its example in saving water.

Most of the water resource strategies of the 20th century have worked against natural ecological cycles and processes. Large dams, river diversions, levees, and other big engineering schemes have helped 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 problems of water pollution in developed and developing countries. Pollution control for the world's water supplies is within our reach. But even more hopeful is the possibility of shifting our emphasis from cleaning up water pollution to reducing and preventing it.

The four **scientific principles of sustainability** (see back cover) can guide us in reducing and preventing pollution and in using water more sustainably during this century. We can promote research that will allow us to use solar energy to desalinate water for increasing supplies and to purify the water we use. Recycling more water will help us to reduce water waste and increase supplies. Preserving biodiversity by avoiding disruption of aquatic systems and their bordering terrestrial systems is a key factor in maintaining water supplies and water quality. And controlling human population growth is fundamental to using water resources more sustainably while maintaining water quality.

This *blue revolution* will provide innumerable economic and ecological benefits. There is no time to lose in implementing it.

It is a hard truth to swallow, but nature does not care if we live or die.
We cannot survive without the oceans, for example,
but they can do just fine without us.

ROGER ROSENBLATT

REVIEW QUESTIONS

1. Discuss how conflicts among nations over water resources are likely to increase as populations grow and the demand for water increases.
2. Discuss the distribution of water resources on the earth. How much is freshwater and where is it located? Why is water such an important molecule for us? Explain how we obtain freshwater from the groundwater system. How is the freshwater used?
3. What are the advantages and disadvantages of withdrawing groundwater? How can groundwater be used more sustainably?
4. Discuss the pros and cons of large dams and reservoirs. Describe the ecological services provided by rivers.
5. Describe the California Water Project. Discuss the problems that are affecting the Aral Sea. Comment on the feasibility of desalination as a method of obtaining more freshwater.
6. Describe the major irrigation systems and suggest methods for reducing water waste in irrigation. What methods are available for reducing water waste in industries, homes, and businesses that would lead to more sustainable use of our water resources?
7. Explain how human activities have resulted in more flood deaths and damages over the past 50 years. How can the harmful effects of flooding be reduced?
8. Describe the main classes of water pollution, their major human sources, and their harmful effects. What are the principle sources of groundwater pollution in the United States and how can the contamination of groundwater be prevented and cleaned up?
9. Explain what would occur if an oxygen-demanding waste, such as sewage, entered a stream. Describe the options available for treating wastewater and sewage.
10. Discuss the causes of pollution in coastal waters and bays. How can we prevent and reduce water pollution in coastal waters, rivers, and lakes?

CRITICAL THINKING

1. List three ways in which you could apply **Concept 11-3** (p. 239) and **Concept 11-5C** (p. 245) to make your lifestyle and that of any children and grandchildren you might have more environmentally sustainable.
2. What do you believe are the three most important priorities for dealing with water shortages in parts of the Middle East as discussed in the **Core Case Study** that opens this chapter?
3. List three ways in which human activities are affecting the water cycle (Figure 3-18, p. 54). How might your lifestyle be contributing to these effects?
4. What role does population growth play in **(a)** water supply problems and **(b)** water pollution problems?
5. Explain why you are for or against **(a)** raising the price of water while allowing affordable rates for the poor and lower middle class, and **(b)** providing government subsidies to farmers for improving irrigation efficiency.
6. If you were a regulator charged with drawing up plans for controlling pollution, briefly describe one idea for controlling 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 11-29 (p. 255). What happens to the sludge produced by this plant? What improvements, if any, would you suggest for this plant?
8. In your community,
   a. What are the principal nonpoint sources of contamination of surface water and groundwater?

b. What is the source of drinking water?
c. How is drinking water treated?
d. How many times during each of the past 5 years have levels of tested contaminants violated federal standards? Were violations reported to the public?
e. What problems related to drinking water, if any, have arisen in your community? What actions, if any, has your local government taken to solve such problems?

9. Congratulations! You are in charge of the world. What are three actions you would take to **(a)** sharply reduce point-source water pollution in developed countries, **(b)** sharply reduce nonpoint-source water pollution throughout the world, **(c)** sharply reduce groundwater pollution throughout the world, and **(d)** provide safe drinking water for the poor and for other people in developing countries?

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

LEARNING ONLINE

Log on to the Student Companion Site for this book at **www.thomsonedu.com/biology/miller** and choose Chapter 11 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Web links, information on Green Careers, and InfoTrac® College Edition articles.

For access to animations and additional quizzing, register and log on to ThomsonNOW! at **www.thomsonedu.com/thomsonnow** using the access code card in the front of your book. You can also explore the **Active Graphing** exercises that your instructor may assign.

12

Geology and Nonrenewable Mineral Resources

The Nanotechnology Revolution

CORE CASE STUDY

Nanotechnology, or *tiny tech,* uses science and engineering to create materials out of atoms and molecules at the scale of less than 100 nanometers. A nanometer equals one billionth of a meter. The page you are reading is about 100,000 nanometers thick.

This approach to manufacturing envisions arranging atoms of abundant elements such as carbon, oxygen, and silicon to create everything from medicines and solar cells (Figure 12-1) to automobile bodies. At the nanoscale level, conventional materials have unexpected properties, as discussed in more detail on page S38 in Supplement 7.

Nanomaterials are currently used in more than 350 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, cosmetics, sunscreens with nanomolecules that block ultraviolet light, and food containers that release nanosilver ions to kill bacteria and molds. The U.S. National Science Foundation projects that nanotechnology will also create more than 2 million jobs by 2014. **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.

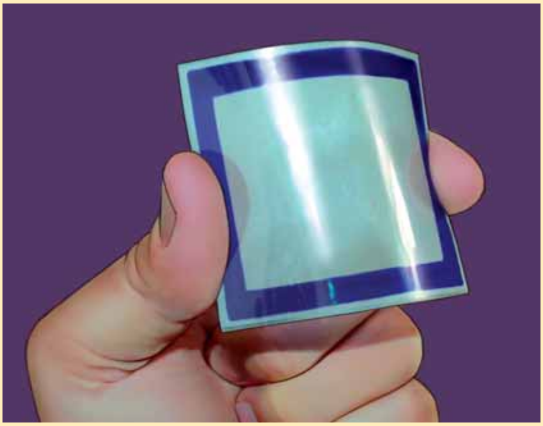
Nanoparticles could also be used to remove industrial pollutants in contaminated air, soil, and groundwater, and nanofilters might be used to purify water and to desalinate water at an affordable cost. The technology could also be used to turn garbage into breakfast by mimicking how nature turns wastes into plant nutrients, thus following one of the four **scientific principles of sustainability** (see back cover). The list could go on.

So what is the catch? Ideally, this bottom-up manufacturing process would occur with little environmental harm, without depleting nonrenewable resources, and with many potential environmental benefits. But there are concerns over some potential unintended harmful consequences.

So far we know little about possible harmful effects of some (but not all) nanoparticles for workers and consumers, but a few studies have raised red flags (Supplement 7, p. S38). As particles get smaller, they become more reactive and potentially more toxic to humans and other animals. Animal studies show that some nanoparticles can move across the placenta from mother to fetus and from the nasal passage to the brain. They could 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.

Nanotechnology could revolutionize the way we make all materials, or it could end up causing major problems, or it could do both. So far, governments have done little to evaluate and regulate the potentially harmful effects of this rapidly emerging technology.



Nanosys

Figure 12-1 **Solutions:** nanotechnology researchers are racing to develop cheap, flexible, and efficient, nanosolar cells that can be mass-produced. They can be used to produce electricity that could desalinate water, heat and cool buildings, and decompose water to make hydrogen fuel for cars. Thin, flexible sheets of these cells could be applied or sprayed onto surfaces such as roofs and the sides of buildings, bridges, and even T-shirts.

Key Questions and Concepts

12-1 **What are the earth's major geological processes?**

CONCEPT 12-1 Gigantic plates in the earth's crust move very slowly atop the planet's mantle, and wind and water move matter from place to place across the earth's surface.

12-2 **What are minerals and rocks and how are rocks recycled?**

CONCEPT 12-2A Some naturally occurring substances in the earth's crust can be extracted and processed into useful materials.

CONCEPT 12-2B Igneous, sedimentary, and metamorphic rocks in the earth's crust are recycled very slowly by geologic processes.

12-3 **What are the harmful environmental effects of using mineral resources?**

CONCEPT 12-3 Extracting and using mineral 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 mineral resources last?**

CONCEPT 12-4 An increase in the price of a scarce mineral resource can lead to increased supplies and more efficient use of the mineral, but there are 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, recycle and reuse minerals, reduce resource waste, and convert the wastes from some businesses into raw materials for other businesses.

Note: Supplements 5, 7, 12, and 14 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?

CONCEPT 12-1 Gigantic plates in the earth's crust move very slowly atop the planet's mantle, and wind and water move matter from place to place across the earth's surface.

The Earth Is a Dynamic Planet

Geology, the subject 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 3-5, p. 42).

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 pliable 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 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, p. 264).

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.

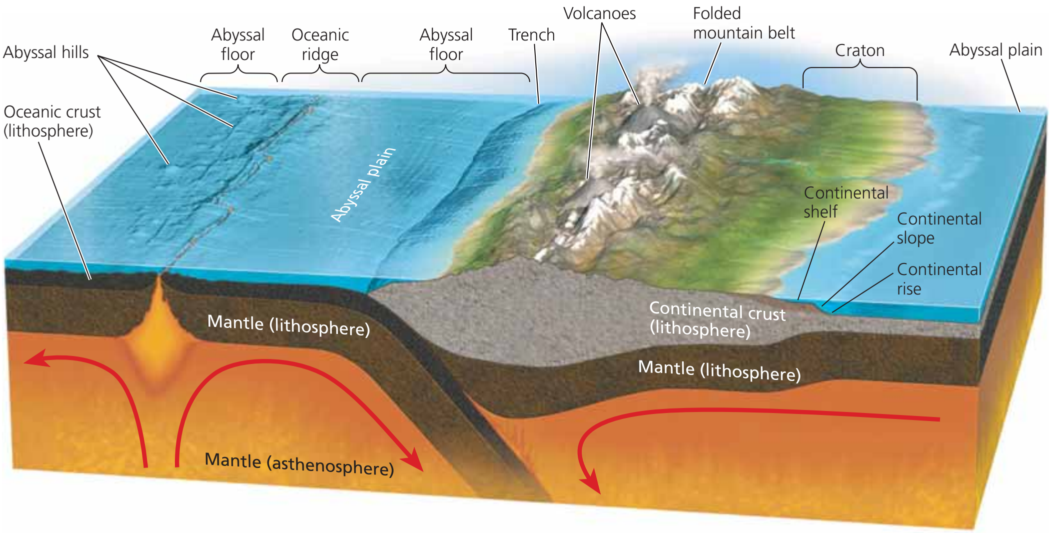


Figure 12-2 Major features of the earth's crust and upper mantle. The *lithosphere,* composed of the crust and outermost mantle, is rigid and brittle. The *asthenosphere,* a zone in the mantle, can be deformed by heat and pressure.

The flows of energy and heated material in the mantle's convection cells cause rigid plates, called **tectonic plates,** to move extremely slowly atop the earth's mantle (Figures 12-3, p. 264, and 12-4, p. 265) (**Concept 12-1**). These seven very large and many smaller plates, each about 80 kilometers (50 miles) thick, are composed of the continental and oceanic crust and the rigid, outermost part of the mantle (above the asthenosphere), a combination called the **lithosphere.**

These gigantic plates are somewhat like the world's largest and slowest-moving surfboards. Their typical speed is about the rate at which fingernails grow. You ride or surf on one of these plates throughout your entire life, but the motion is too slow for you to notice. Throughout the earth's history, continents have split apart and joined as tectonic plates drifted thousands of kilometers (Figure 4-3, p. 67).

When oceanic plates move apart from one another at a *divergent plate boundary,* molten rock (magma) flows up through the resulting cracks. This creates *oceanic ridges* (Figure 12-2) that have peaks higher than the tallest mountains and canyons deeper than the deepest valleys found on earth's continents. A *convergent plate boundary* occurs when internal forces push two plates together.

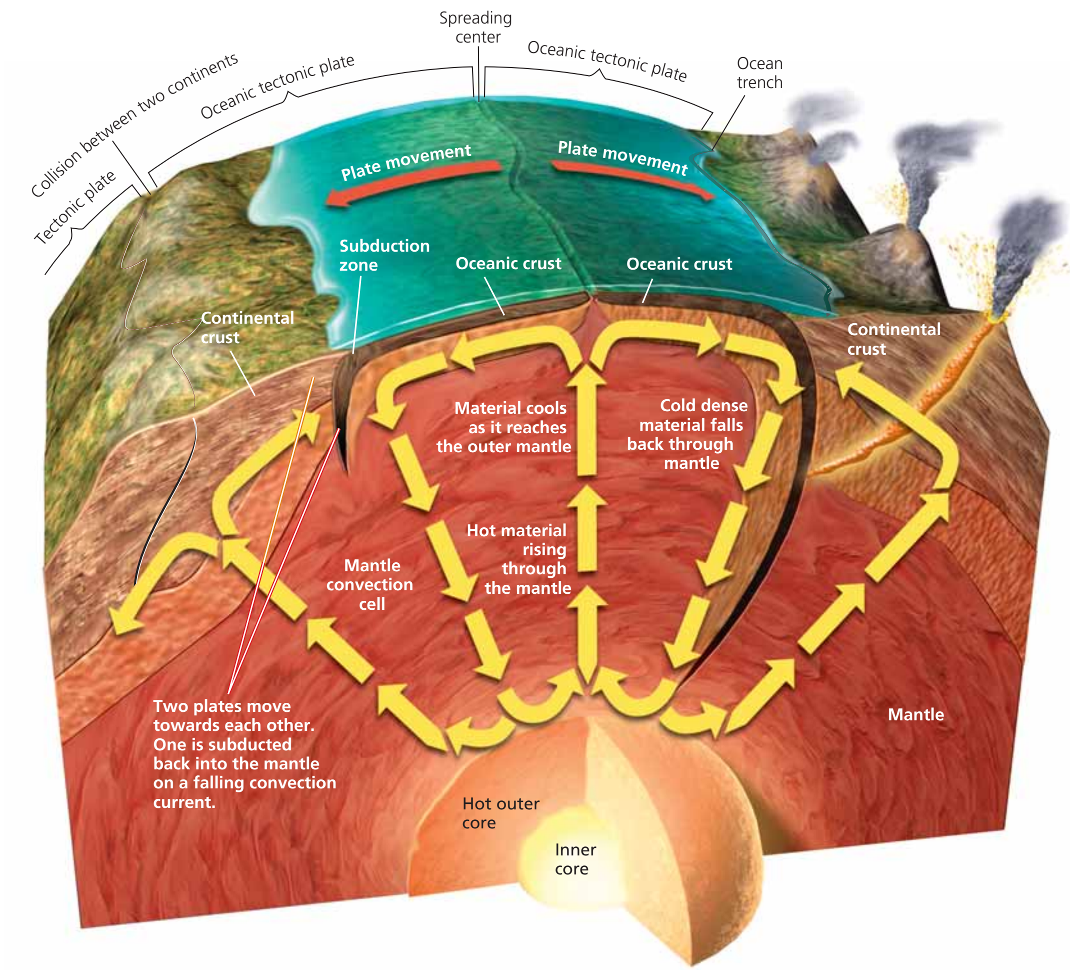
When an oceanic plate collides with a continental plate, the continental plate usually rides up over the denser oceanic plate and pushes it down into the mantle (Figures 12-2 and 12-3) in a process called *subduction.* The area where this collision and subduction takes place is called a *subduction zone.* Over time, the subducted plate melts and then rises again to the earth's surface as molten rock or magma. When two oceanic plates collide, a *trench* (Figure 12-2) ordinarily forms at the boundary between the two converging plates. When two continental plates collide, they push up mountain ranges along the collision boundary.

The third type of boundary is a *transform fault,* where plates slide and grind past one another along a fracture (fault) in the lithosphere. 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, p. 265).

Natural hazards such as *earthquakes* (Figure 1 on p. S54 in Supplement 12) and *volcanoes* (Figure 6 on p. S57 in Supplement 12) are likely to be found at plate boundaries. Taken together, the various tectonic plate interactions, driven mostly by heat energy in the mantle, are part of the earth's *internal processes.* In one such process, colliding plates create tremendous pressures in the earth's crust that are released by earthquakes. In another internal process, as one plate plunges under another, part of the descending plate melts and rises to form volcanoes on the land (Figure 12-2).

On December 26, 2004, a large earthquake in the Indian Ocean sent giant sea swells, or *tsunamis,* racing across the Indian Ocean. They devastated parts of Asia, especially Indonesia (see Figure 4 on p. S55 and Figure 5 on p. S56 in Supplement 12), and killed more than 221,000 people.

Movement of the earth's tectonic plates is part of the recycling of the planet's crust over geological time, which has helped form deposits of mineral



ThomsonNOW™ **Active Figure 12-3** The *earth's crust* is made up of a mosaic of huge rigid plates, called *tectonic plates,* which move around in response to forces in the mantle. *See an animation based on this figure at* ThomsonNOW.

resources. It has also promoted biodiversity; as continents joined or split apart, so did populations of species (**Concept 4-2**, p. 66). Speciation (Figure 4-6, p. 70) occurred partly because of tectonic plate movements.

CONCEPT LINK

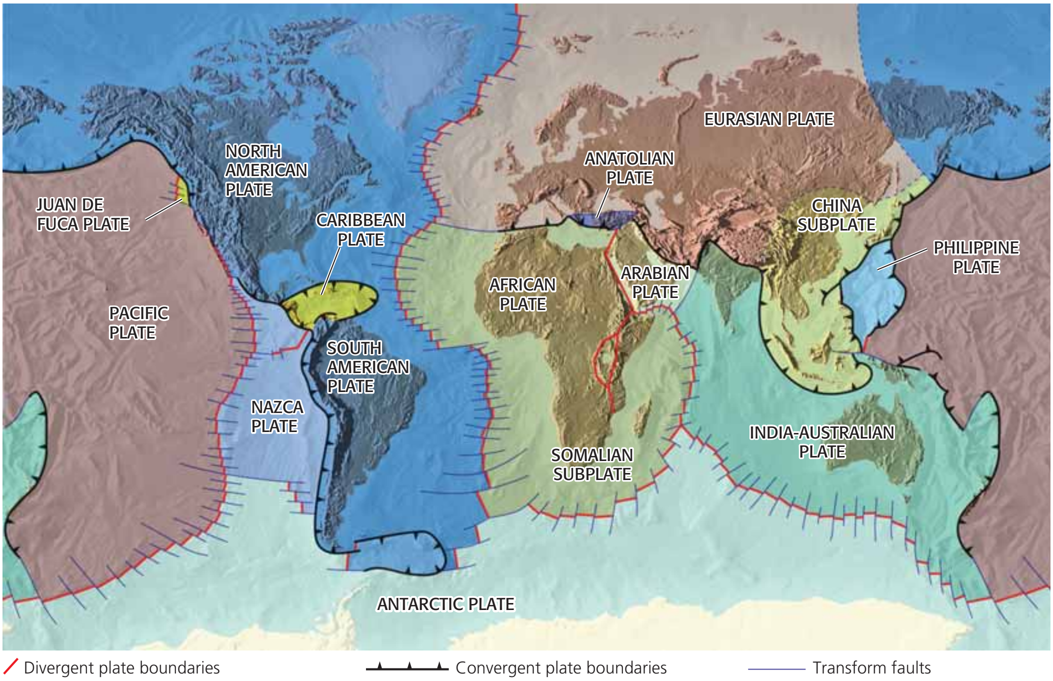
Some Parts of the Earth's Surface Are Wearing Down and Some Are Building Up

Geologic changes based directly or indirectly on energy from the sun—mostly in the form of flowing water and wind—and on gravity are called *external processes.* Whereas internal processes, generated by heat from the earth's interior, typically build up the earth's surface, external processes tend to wear down the earth's surface and move matter from one place to another (**Concept 12-1**).

One major external process is **weathering,** the physical, chemical, and biological processes that break down rocks into smaller particles that help build soil. These weathering processes play a key role in soil formation (Figure 3-A, p. 49), a vital part of the earth's natural capital (**Concept 1-1A**, p. 6).

CONCEPT LINK

Another major external process is *erosion,* discussed in Chapter 10 (pp. 204–209). In this process, material is dissolved, loosened, or worn away from one part of the earth's surface and deposited elsewhere. Flowing streams and rain cause most erosion. Wind also blows particles of soil from one area to another (Figure 5-1,



ThomsonNOW™ Active Figure 12-4 The earth's major tectonic plates. The extremely slow movements of these plates cause them to grind into one another at *convergent plate boundaries,* move apart from one another at *divergent plate boundaries,* and slide past one another at *transform plate boundaries. See an animation based on this figure at* ThomsonNOW. **Question:** What plate are you riding on?

p. 75). Human activities—particularly those that destroy vegetation that holds soil in place—accelerate the process (see p. S30 in Supplement 5).

While erosion depletes topsoil in one place, it can help build soil in other locations. The resulting buildup of eroded topsoil, sand, and sediment produces a variety of landforms and environments.

Slowly flowing bodies of ice called *glaciers* also cause erosion. Under the influence of gravity, glaciers move slowly down a mountainside or over a wide area. During this movement, rock frozen to the glacial ice is pulled or plucked out of the land surface. During the last ice age, which ended about 10,000 years ago, ice sheets called *continental glaciers* covered vast areas of North America (Figure 4-4, p. 67), Europe, and Asia. The Great Lakes, the world's largest volume of freshwater, formed during this period as retreating glaciers gouged out huge basins. As the climate warmed and the glaciers melted, water filled these basins.

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 along 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?

12-2 What Are Minerals and Rocks and How Are Rocks Recycled?

CONCEPT 12-2A Some naturally occurring substances in the earth's crust can be extracted and processed into useful materials.

CONCEPT 12-2B Igneous, sedimentary, and metamorphic rocks in the earth's crust are recycled very slowly by geologic processes.

We Use a Variety of Nonrenewable Mineral Resources

Minerals and rocks comprise the earth's crust, which continues to form in various places. A **mineral** is an element or inorganic compound that occurs naturally in the earth's crust and is 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. S33 in Supplement 7) and quartz (silicon dioxide or SiO_2).

A **mineral resource** is a concentration of naturally occurring material in or on the earth's crust that can be extracted and processed into useful materials at an affordable cost (**Concept 12-2A**). 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, iron, and copper), and *nonmetallic minerals* (such as sand, gravel, and limestone). Because they take so long to produce, these components of the earth's natural capital are classified as *nonrenewable mineral resources.*

Nonrenewable metal and nonmetal mineral resources are important parts of our lives that we often take 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. *Manganese* (Mn), *cobalt* (Co), and *chromium* (Cr) are widely used in important steel alloys. *Copper* (Cu), a good conductor of electricity, is used for electrical and communications wiring. *Platinum* (Pt) is used in electrical equipment and in automobile pollution control devices. In the not too distant future, stronger and lighter materials made from nanoparticles of carbon and other atoms may replace some conventional metal materials (**Core Case Study** and p. S38 in Supplement 7). 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. *Limestone* (mostly calcium carbonate, or $CaCO_3$) is crushed to make road rock, concrete, and cement. *Phosphate salts* are mined and used in inorganic fertilizers and in some detergents.

> **THINKING ABOUT**
> **Materials and Nanotechnology** CORE CASE STUDY
> Suppose we could use nanotechnology (**Core Case Study**) to design any type of new material? What single type of material would you want to **(a)** improve your own lifestyle, **(b)** help the world's poor, **(c)** preserve biodiversity, and **(d)** reduce pollution and waste?

Nonrenewable mineral resources can be categorized as **identified resources,** which consist of deposits with a known location, quantity, and quality, or deposits whose existence is based on direct geologic evidence and measurements. 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 can increase when new profitable deposits are found or when higher prices or improved mining technology make it profitable to extract deposits that previously were considered too expensive to extract.

If nanotechnology (**Core Case Study**) lives up to its potential, the mining and processing of most of these resources may become obsolete businesses. This would eliminate the harmful environmental effects of mining and processing such resources into materials, and it would increase profits for nanomaterial companies. However, it would also eliminate businesses and export income related to conventional supplies of mineral resources—many of them in developing countries—and could cause severe economic and social stress as jobs and entire industries disappear. CORE CASE STUDY

The Earth's Rocks Are Recycled Very Slowly

Rock is a solid combination of one or more minerals that is part of the earth's crust. Some kinds of rock, such as limestone (calcium carbonate, or $CaCO_3$) and quartzite (silicon dioxide, or SiO_2), contain only one mineral. Most rocks consist of two or more minerals. For example, granite is a mixture of mica, feldspar, and quartz crystals.

An **ore** is a rock that contains a large enough concentration of a particular mineral—often a metal—to make it suitable for mining and processing. A **high-grade ore** contains a fairly large amount of the desired mineral, whereas a **low-grade ore** contains a smaller amount.

Based on the way it forms, rock is placed in one of three broad classes: igneous, sedimentary, or metamorphic. **Igneous rock** forms below or on the earth's surface when molten rock (magma) wells up from the earth's upper mantle or deep crust, cools, and hardens. Examples include *granite* (formed underground) and *lava rock* (formed aboveground). Although often covered by sedimentary rocks or soil, igneous rocks form the bulk of the earth's crust. They also are the main source of many metal and nonmetal mineral resources.

Sedimentary rock is made of *sediments*—dead plant and animal remains and existing rocks that are weathered and eroded into small pieces. 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 and increase the weight and pressure on underlying layers. Examples include *sandstone* and *shale* (formed from pressure created by deposited layers of mostly 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).

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 *anthracite* (a form of coal), *slate* (formed when shale and mudstone are heated), and *marble* (produced when limestone is exposed to heat and pressure).

The interaction of physical and chemical processes that change rocks from one type to another is called the **rock cycle** (Figure 12-6). 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 12-2B**). It also concentrates the planet's nonrenewable mineral resources on which we depend. Without the incredibly slow rock cycle, you would not exist.

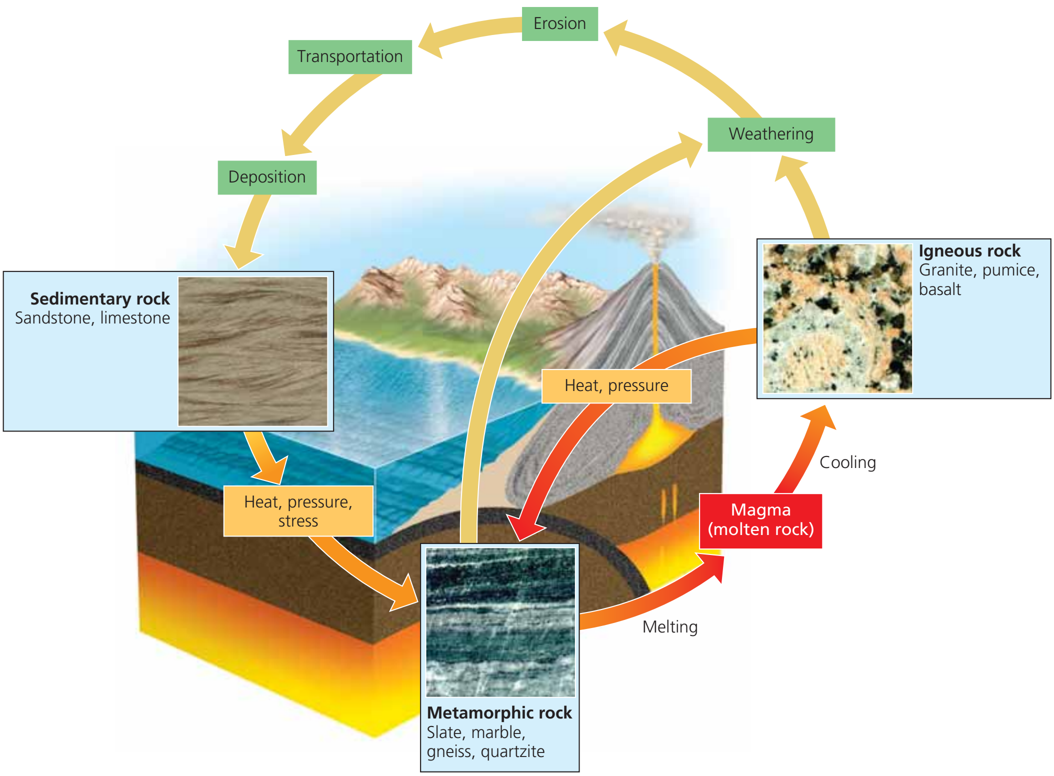


Figure 12-6 **Natural capital:** the *rock cycle* is the slowest of the earth's cyclic processes. Rocks are recycled over millions of years by three processes: *melting, erosion,* and *metamorphism,* which produce *igneous, sedimentary,* and *metamorphic* rocks. Rock from any of these classes can be converted to rock of either of the other two classes, or can be recycled within its own class (**Concept 12-2B**). **Question:** What are three ways in which the rock cycle benefits your lifestyle?

12-3 What Are the Harmful Environmental Effects of Using Mineral Resources?

CONCEPT 12-3 Extracting and using mineral resources can disturb the land, erode soils, produce large amounts of solid waste, and pollute the air, water, and soil.

Mineral Use Has a Large Environmental Impact

Figure 12-7 depicts the typical life cycle of a metal resource. The mining, processing, and use of mineral resources take enormous amounts of energy and can disturb the land, erode soil, produce solid waste, and pollute the air, water, and soil (Figure 12-8) (**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

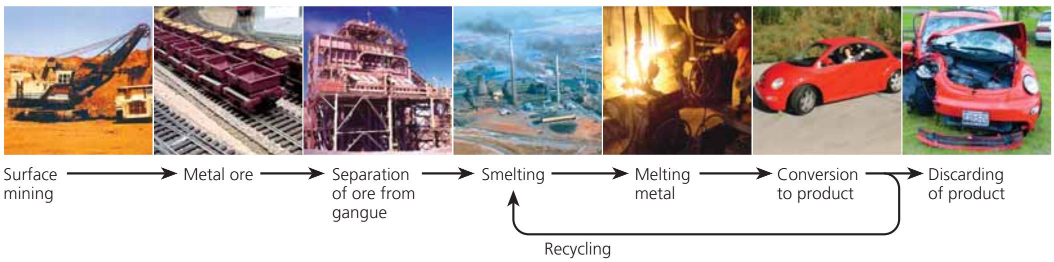


Figure 12-7 *Life cycle of a metal resource.* Each step in this process uses large amounts of energy and produces some pollution and waste.

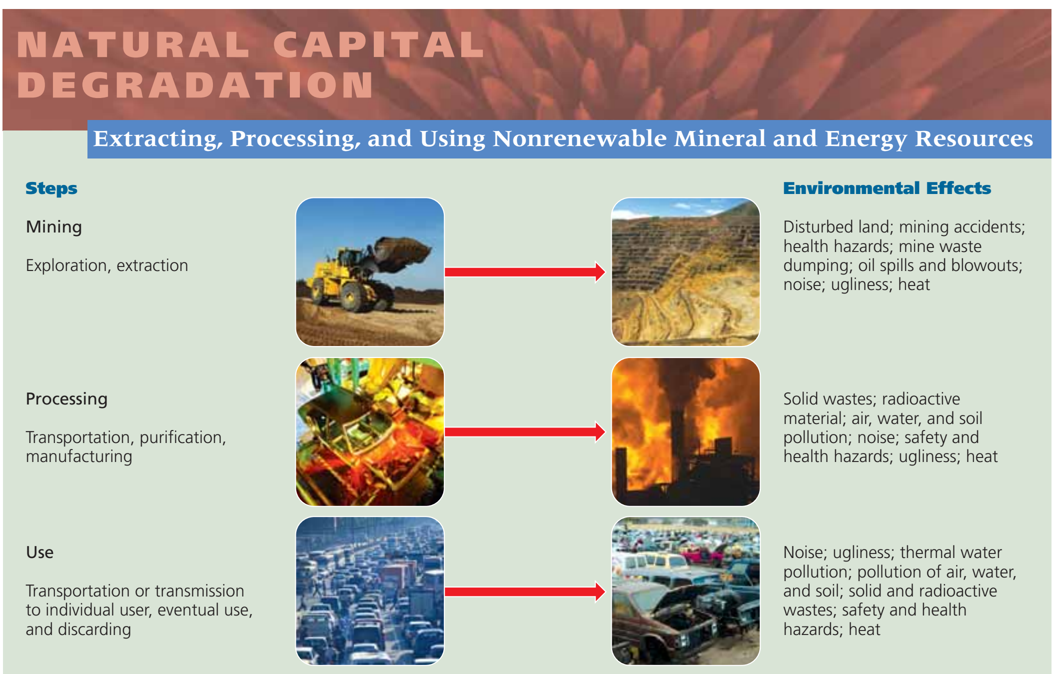


Figure 12-8 Some harmful environmental effects of extracting, processing, and using nonrenewable mineral and energy resources (**Concept 12-3**). The energy required to carry out each step causes additional pollution and environmental degradation. **Question:** What are three resources that you used today that caused some of these harmful environmental effects?

by our extracting, processing, and converting them to products.

THINKING ABOUT
Nanotechnology and the Environmental Effects of Mineral Production

CORE CASE STUDY

How might a nanotech revolution in the next few decades (**Core Case Study**) affect the environmental consequences of the use of nonrenewable mineral and energy resources shown in Figure 12-8? List three ways in which this might affect your lifestyle.

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 2-4B**, p. 33) 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 suitable mineral deposits are located, several different mining techniques are used to remove them, depending on their location and type. Shallow deposits are removed by **surface mining,** and deep deposits are removed by **subsurface mining.**

In surface mining, gigantic mechanized equipment strips away the **overburden,** the soil and rock overlying a useful mineral deposit, and usually discards it as waste material called **spoils.** Surface mining extracts about 90% of the nonfuel mineral and rock resources and 60% of the coal (by weight) used in the United States. If forests are present, they are also removed, and the resulting spoils can bury or contaminate nearby streams and groundwater.

The type of surface mining used depends on two factors: the resource being sought and the local topography. In **open-pit mining** (Figure 12-9), machines dig holes and remove ores (such as iron and copper), sand, gravel, and stone (such as limestone and marble).

Strip mining is useful and economical for extracting mineral deposits that lie close to the earth's surface in large horizontal beds. **Area strip mining** may be used where the terrain is fairly flat. A gigantic earthmover strips away the overburden, and a power shovel—some as tall as a 20-story building—removes the mineral deposit. The trench is filled with overburden, and a new cut is made parallel to the previous one. This process is repeated over the entire site. Often this leaves a wavy series of hills of rubble called *spoil banks* (Figure 12-10), which 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 have to follow the long path of primary ecological succession (Figure 6-8, p. 115, and **Concept 6-4A**, p. 115).

CONCEPT LINK

Don Green/Kennecott Copper Corporation, now owned by British Petroleum

Figure 12-9 Natural capital degradation: This *open-pit* copper mine in Bingham, Utah (USA), near Salt Lake City, is the world's largest human-made hole—0.8 kilometers (0.5 miles) deep and 4 kilometers (2.5 miles) wide at its top. A thick toxic soup of groundwater accumulates in the pit and can pollute nearby watersheds and endanger wildlife.

National Archives/EPA Documerica

Figure 12-10 Natural capital degradation: banks of waste or spoils created by unrestored *area strip mining* of coal on a mostly flat area 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 arid areas.

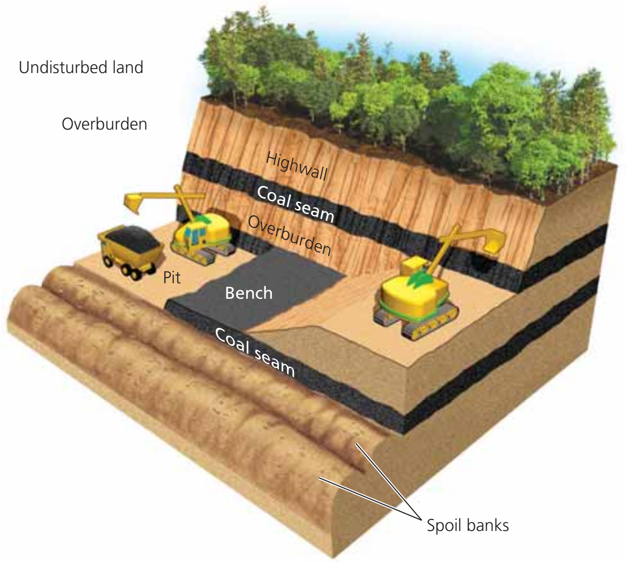


Figure 12-11 Natural capital degradation: *contour strip mining* of coal used in hilly or mountainous terrain.

Contour strip mining (Figure 12-11) 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. An earthmover removes 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** (Figure 12-12). Explosives, 20-story-tall shovels, and huge machinery called draglines remove the top of a mountain and expose seams of coal underneath. The resulting waste rock and dirt are dumped into the streams and valleys below, burying the streams and increasing flood hazards. Toxic wastewater, produced when the coal is processed, is often stored in the valley behind coal waste sludge dams, which can overflow or collapse and release toxic substances such as selenium, arsenic, and mercury.

Subsurface mining removes coal and metal ores that are too deep to be extracted by surface mining. Miners dig a deep vertical shaft, blast subsurface tunnels and chambers to reach the deposit, and use machinery to remove the ore or coal and transport it to the surface.

Subsurface mining disturbs less than one-tenth as much land as surface mining and usually produces less waste material. However, it leaves much of the resource in the ground and is more dangerous and expensive than surface mining. Hazards include cave-ins, explosions, fires, and diseases such as black lung, caused by prolonged inhalation of mining dust.

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 12-9 through 12-12).

Jim Wark/Peter Arnold, Inc.

Figure 12-12 Natural capital degradation: mountaintop coal mining operation in the U.S. state of West Virginia. The large amount of resulting debris is deposited in the valleys and streams below. **Question:** Are you for or against mountaintop coal mining? Explain.

The U.S. Department of the Interior estimates that at least 500,000 surface-mined sites dot the U.S. landscape, mostly in the West. Cleaning up these sites would cost taxpayers as much as an estimated $70 billion. Worldwide, cleaning up abandoned mining sites would cost trillions of dollars. Most of these sites will never be cleaned up.

Another problem is collapse of land above underground mines. Such *subsidence* can tilt houses, crack sewer lines, break gas mains, and disrupt groundwater systems.

Mining operations are also major polluters of the air and water, and mining produces three-fourths of all U.S. solid waste. For example, most newlyweds would be surprised to know that, typically about 5.5 metric tons (6 tons) of solid waste from mining is created to make a pair of gold wedding rings.

Toxin-laced mining wastes are often deposited away from mining sites by wind or water erosion. *Acid mine drainage* occurs when rainwater seeping through a mine or mine wastes carries sulfuric acid (H_2SO_4, produced when aerobic bacteria act on iron sulfide minerals in spoils) to nearby streams and groundwater. In addition, much of the huge amounts of water used to process ore contain pollutants such as sulfuric acid, mercury, and arsenic. This contaminates water supplies and can destroy some forms of aquatic life. According to the EPA, mining has polluted about 40% of western watersheds in the United States.

Mining can 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 piles of waste 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.** Without effective pollution control equipment, smelters emit enormous quantities of air pollutants such as sulfur dioxide and suspended particles, which damage vegetation and acidify soils in the surrounding area. They also cause water pollution and produce liquid and solid hazardous wastes that require safe disposal.

Chemicals are also used to remove metals from their ores. To extract the gold from the ore, miners spray a dilute solution of highly toxic cyanide salts on huge open-air heaps of crushed ore. As the solution percolates through the heap, the cyanide reacts with and removes the gold from its ore. The solution is stored in leach beds and overflow ponds for recirculation. Cyanide is extremely toxic to birds and mammals drawn to these ponds for their water. The ponds can leak or overflow, posing threats to groundwater and wildlife (especially fish) in lakes and streams.

12-4 How Long Will Mineral Resources Last?

CONCEPT 12-4 An increase in the price of a scarce mineral resource can lead to increased supplies and more efficient use of the mineral, but there are 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 fairly scarce.

The earth's geological processes have not distributed deposits of nonrenewable mineral resources evenly. Some countries have rich mineral deposits and others have few or none.

Massive exports can deplete the supply of a country's nonrenewable mineral resources. During the 1950s, for example, South Korea exported large amounts of its iron and copper. Since the 1960s, the country has not had enough domestic iron and copper to support its rapid economic growth and now must import these metals to meet its domestic needs.

Five nations—the United States, Canada, Russia, South Africa, and Australia—supply most of the nonrenewable mineral resources used by modern societies. Three countries—the United States, Germany, and Russia—with only 8% of the world's population consume about 75% of the most widely used metals, but China is rapidly increasing its use of key metals.

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 metal mineral resources such as lead, aluminum, and iron. Currently, it depends on imports for 50% or more of 24 of its most important nonrenewable mineral resources. Some of these minerals are imported because they are used faster than they can be produced from domestic supplies; others are imported because foreign mineral deposits are of a higher grade and cheaper to extract than remaining U.S. reserves.

Most U.S. imports of nonrenewable metal resources come from reliable and politically stable countries. But experts are concerned about the availability of four *strategic metal resources*—manganese, cobalt, chromium, and platinum—that are essential for the country's economy and military strength. The United States has little or no reserves of these metals and gets some of them from potentially unstable countries in the former Soviet Union and in Africa. Some analysts believe that nanomaterials (**Core Case Study**) may eventually replace dependence on some of these metals. CORE CASE STUDY

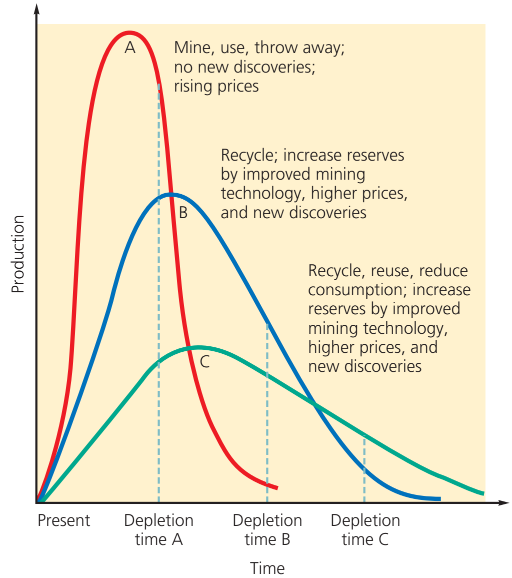


Figure 12-13 *Depletion curves* for a nonrenewable resource (such as aluminum or copper) using three sets of assumptions. Dashed vertical lines represent times when 80% depletion occurs.

Supplies of Nonrenewable Mineral Resources Can Be Economically Depleted

The future supply of nonrenewable mineral resources depends on two factors: the actual or potential supply of the mineral and the rate at which we use it. We 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 deposit. At that point, there are five choices: *recycle or reuse existing supplies, waste less, use less, find a substitute,* or *do without.*

Depletion time is how long it takes to use up a certain proportion—usually 80%—of the reserves of a mineral at a given rate of use. When experts disagree about depletion times, it is often because they are using different assumptions about supply and rate of use (Figure 12-13).

The shortest depletion time assumes no recycling or reuse and no increase in reserves (curve A, Figure 12-13). A longer depletion time assumes that recycling will stretch existing reserves and that better mining technology, higher prices, and new discoveries will increase reserves (curve B, Figure 12-13). An even longer depletion time assumes that new discoveries will further expand reserves and that recycling, reuse, and reduced consumption will extend supplies (curve C, Figure 12-13). Finding a substitute for a resource leads to a new set of depletion curves for the new resource.

According to a 2006 study by Thomas Graedel of Yale University, if all nations 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.

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 free market, a plentiful mineral resource is cheap when its supply exceeds demand. When a resource becomes scarce, its price rises. This can encourage exploration for new deposits, stimulate development of better mining technology, and make it profitable to mine lower-grade ores. It can also encourage a search for substitutes and promote resource conservation.

According to some economists, this price effect may no longer apply well in most developed countries. Industry and government in such countries often use subsidies, taxes, regulations, and import tariffs to control the supplies, demands, and prices of minerals to such an extent 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 (depending on the mineral). They can also reduce their taxes by deducting much of their costs for finding and developing mineral deposits. In addition, hardrock mining companies operating in the United States pay very low royalties to the government on minerals they extract from public lands, as discussed in Supplement 14 on p. S60.

Most consumers are unaware that the costs of consumer products made from mineral resources are higher than their market prices 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 (Figure 12-8). If these hidden extra costs were included in the market prices of such goods, minerals would not be wasted, recycling and reuse would increase dramatically, and many of these minerals would be replaced with less environmentally harmful substitutes.

Between 1982 and 2006, U.S. mining companies received more than $6 billion in government subsidies. Critics argue that eliminating or sharply reducing such environmentally harmful subsidies would promote more efficient resource use, waste reduction, pollution prevention, and recycling and reuse of 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 the subsidies encourage the companies not to move their mining operations to other countries with no such taxes and less stringent mining and pollution control regulations.

THINKING ABOUT
Minerals and Nanotechnology

CORE CASE STUDY

How might these arguments for and against subsidies and low taxes for mineral resource extraction be affected by the development of nanotechnology (**Core Case Study**) over the next 20 years?

Economic problems can also hinder the development of new supplies of mineral resources because finding them takes increasingly scarce investment capital and is financially risky. Typically, if geologists identify 10,000 possible deposits of a given resource, only 1,000 sites are worth exploring; only 100 justify drilling, trenching, or tunneling; and only 1 becomes a producing mine or well.

Is Mining Lower-Grade Ores the Answer?

Some analysts contend that all we need to do to increase supplies of a mineral is to extract 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.

In 1900, the average copper ore mined in the United States was about 5% copper by weight. Today that ratio is 0.5%, and copper costs less (adjusted for inflation). New methods of mineral extraction may allow for even lower-grade ores of some metals to be used.

Several factors can limit the mining of lower-grade ores. One is the increased cost of mining and processing larger volumes of ore. Another is the availability of freshwater 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 12-8).

One way to improve mining technology is to inject microorganisms for in-place (*in situ,* pronounced "in SY-too") mining. If naturally occurring bacteria cannot be found to extract a particular metal, genetic engineering techniques could be used to produce such bacteria. This biological approach, called *biomining,* removes desired metals from ores while leaving the surrounding environment undisturbed. It also reduces the air pollution associated with the smelting of metal ores and the water pollution associated with using hazardous chemicals such as cyanides and mercury to extract gold.

RESEARCH FRONTIER

Biomining and other new methods for extracting more resources from ores

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. So far, biological mining methods are economically feasible only with low-grade ores for which conventional techniques are too expensive.

Is Getting More Minerals from the Ocean the Answer?

Some ocean mineral resources are dissolved in seawater. However, most of the chemical elements found in seawater occur in such low concentrations that recovering them takes more energy and money than they are worth. At current prices and with existing technology, only magnesium, bromine, and sodium chloride are abundant enough to be extracted profitably. On the other hand, deposits of minerals (mostly sediments) along the shallow continental shelf and near shorelines are significant sources of sand, gravel, phosphates, sulfur, tin, copper, iron, tungsten, silver, titanium, platinum, and diamonds.

THINKING ABOUT

Extracting Minerals from Seawater

CONCEPT LINK

Use the second law of thermodynamics (**Concept 2-4B**, p. 33) 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, black 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. There are also disputes over ownership of such resources located in international waters.

Another potential source of metals from the ocean floor is potato-size *manganese nodules* that cover about 25–50% of the Pacific Ocean floor. They might be sucked up from the ocean floor by giant vacuum pipes or scooped up by buckets on a continuous cable operated by a mining ship. However, marine scientists are concerned about the effects of such mining on aquatic life.

So far these nodules and resource-rich mineral beds in international waters have not been developed. As with hydrothermal ore deposits, this is because of high costs and squabbles over who owns the resources and how any profits from extracting them should be distributed among the world's nations.

Some environmental scientists believe seabed mining probably would cause less environmental harm than mining on land. However, they are concerned that removing seabed mineral deposits and dumping back unwanted material will stir up ocean sediments, destroy sea floor organisms, and have potentially harmful effects on poorly understood ocean food webs and marine biodiversity. They call for more research to help evaluate such possible effects.

12-5 How Can We Use Mineral Resources More Sustainably?

CONCEPT 12-5 We can try to find substitutes for scarce resources, recycle and reuse minerals, reduce resource waste, and convert the wastes from some businesses into raw materials for other businesses.

We Can Find Substitutes for Some Scarce Mineral Resources

Some analysts believe that even if supplies of key minerals become too expensive or scarce due to unsustainable use, human ingenuity will find substitutes. They point to the current *materials revolution* in which silicon and new materials, particularly ceramics and plastics, are being used as replacements for metals. And nanotechnology (**Core Case Study**) may also lead to the development of materials that can serve as substitutes for various minerals (**Concept 12-5**).

CORE CASE STUDY

In 2005, for example, builders began constructing houses made of Styrofoam sprayed with a ceramic spray called Grancrete. This ceramic is affordable, is twice as strong as structural concrete, and will not leak or crack. It reduces the cost of house frame construction to about one-fifteenth of current cost. It also reduces the need for timber (thereby sparing many trees) and nonrenewable mineral resources used to construct houses. Lightweight Styrofoam blocks are also being used to pave bridges.

Plastic has replaced copper, steel, and lead in much piping. Fiber-optic glass cables that transmit pulses of light are replacing copper and aluminum wires in telephone 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 because they take less energy, do not need painting, and can be molded into any shape. New plastics and gels are also being developed to provide superinsulation without taking up much space.

RESEARCH FRONTIER

Materials science and engineering

Use of plastics has drawbacks, chief of which is that making them by current methods requires the use of oil and other fossil fuels. These energy resources are nonrenewable and they have their own environmental impacts, discussed in the next chapter. However, chemists are learning how to make some plastics from plant materials.

Substitution is not a cure-all. For example, currently, platinum is unrivaled as an industrial catalyst, and chromium is an essential ingredient of stainless steel. We can try to find substitutes for scare resources but this may not always be possible.

We Can Recycle and Reuse Valuable Metals

Once smelting or chemical extraction produces a pure metal, it is usually melted and converted to desired products, which are then used and discarded or recycled (Figure 12-7). Another way to use nonrenewable mineral resources (especially valuable or scarce metals such as gold, silver, iron, copper, steel, aluminum, and platinum) more sustainably is to recycle or reuse them (**Concept 12-5**).

Recycling also has a much lower environmental impact than 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.

> **THINKING ABOUT**
> **Metal Recycling and Nanotechnology**
> How might the development of nanotechnology (**Core Case Study**) over the next 20 years affect the recycling of metal mineral resources?
>
> CORE CASE STUDY

We Can Use Nonrenewable 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 (Figure 2-9, p. 36, and **Concept 2-5B**, p. 35). Answering that second question could provide important ways to use mineral resources more sustainably (**Concept 12-5**). Figure 12-14 and the Case Study at right describe some of these strategies.

CONCEPT LINK

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, its air pollutant emissions per unit of production were 70% lower, and the company had saved more than $750 million in waste disposal and material costs. This is an excellent example of how pollution prevention pays (**Concept 1-4**, p. 14).

CONCEPT LINK

Since 1990, a growing number of companies have adopted similar pollution and waste prevention programs that lead to *cleaner production.* See the Guest Essay by Peter Montague on cleaner production at ThomsonNOW™.

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 12-14 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 is to make industrial manufacturing processes cleaner and more sustainable by redesigning them to mimic how nature deals with wastes. According to one **scientific 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.

SUSTAINABILITY

One way industries can 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

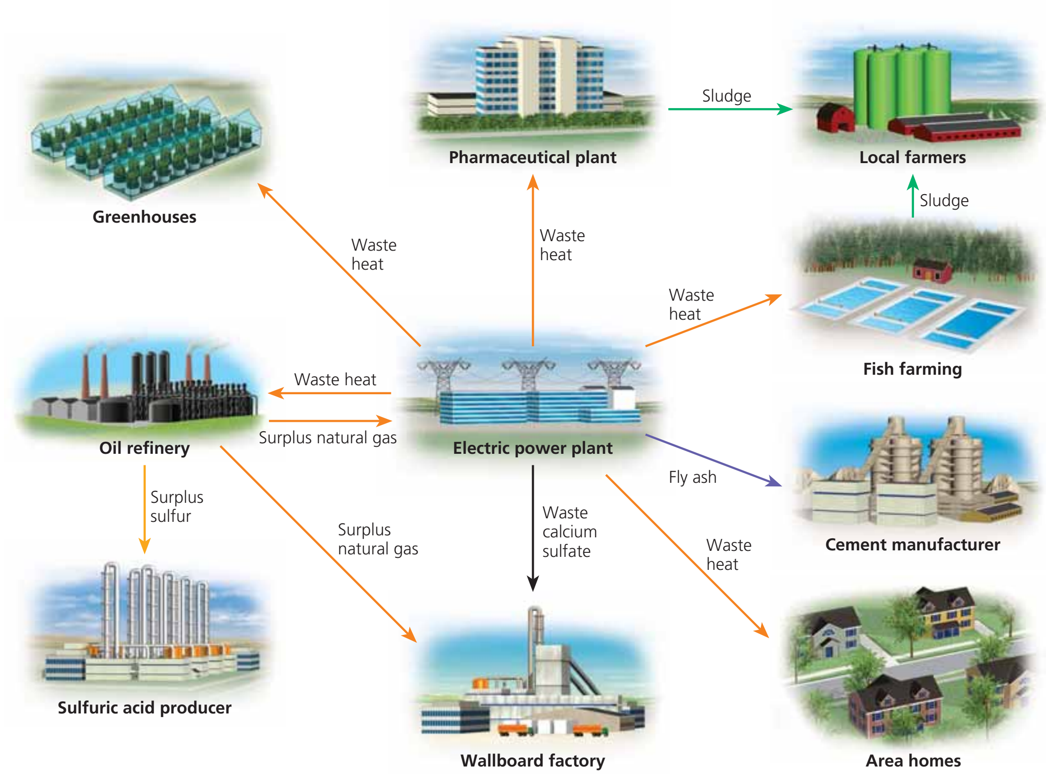


Figure 12-15 **Solutions:** an *industrial ecosystem* in Kalundborg, Denmark, reduces waste production by mimicking a food web in natural ecosystems. The wastes of one business become the raw materials for another. **Question:** Is there an industrial ecosystem near where you live or go to school? If not, why not?

materials for another—similar to food webs in natural ecosystems (Figure 3-15, p. 51) (**Concept 12-5**).

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 12-15. 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 parts of the world, including the U.S. city of Chattanooga, Tennessee (Case Study, p. 18). And more are being built or planned—some of them on abandoned industrial sites, called *brownfields.* Within the rapidly growing field of *industrial ecology,* there are widespread efforts to develop a global network of industrial ecosystems over the next few decades. This could lead to an *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 chemical outputs. In addition, companies improve the health and safety of workers by reducing their 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. Another benefit: such companies have a better image among consumers, based on results rather than public relations campaigns.

THINKING ABOUT
Nanotechnology and the Ecoindustrial Revolution

CORE CASE STUDY

What role might the nanotech revolution (**Core Case Study**) play in bringing about an ecoindustrial revolution?

RESEARCH FRONTIER

Developing biomimicry and other ecoindustrial tools

REVISITING Nanotechnology and Sustainability

In this chapter we have seen a number of exciting possibilities for extracting and using nonrenewable mineral resources in more sustainable ways. One example is *nanotechnology* (**Core Case Study**). It can create products from atoms and molecules and eliminate many of the harmful environmental effects of extracting, processing, and using nonrenewable mineral resources.

Nanotechnology could be used to make inexpensive solar cells (Figure 12-1). This could enable the use of solar energy—applying the first **scientific principle of sustainability**—to produce electricity, generate hydrogen fuel, purify drinking water, and desalinate seawater. Nanotechnology could also be used to apply another **scientific principle of sustainability**, mimicking how nature recycles nutrients by turning garbage into food. Doing all this, plus using microbes to extract mineral resources, also reduces the destruction and degradation of biodiversity and the disruption of species interactions that help regulate population sizes, thereby applying the two remaining **scientific principles of sustainability**.

To enjoy the benefits of a nanotechnology revolution, we must also quickly learn about its potentially harmful effects on health, societies, economies, and the environment. Then we must regulate and reduce these effects. There is no free lunch.

We can also use mineral resources more sustainably by recycling and reusing them. Industries can mimic nature by converting wastes to resources, exchanging them on a web (Figure 12-15). If they are monitored and regulated properly and provided with environmentally friendly government subsidies, the nanotech and ecoindustrial revolutions could allow us to make more sustainable use of nonrenewable mineral resources.

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 QUESTIONS

1. Discuss the potential opportunities and pitfalls of nanotechnology.
2. Describe the major features of the earth's crust and upper mantle.
3. Identify the three types of boundaries between tectonic plates and describe the plate movements for each type of boundary.
4. Define the following terms: mineral; mineral resources; identified resources; reserves; ore. Give examples, and describe the uses, of four nonrenewable metal mineral resources and four nonmetal mineral resources that are important in our daily lives.
5. Describe the three main types of rock and explain how rock changes from one form to another through the rock cycle.
6. Explain how mineral deposits are removed from the earth by surface and subsurface mining.
7. Summarize the harmful environmental effects of extracting, processing, and using nonrenewable mineral and energy resources.
8. Discuss how the location of a nonrenewable mineral resource affects the use of the mineral. Explain how a mineral can become economically depleted and what the options are for such depleted minerals.
9. Describe ways to achieve more sustainable use of nonrenewable mineral resources.
10. With reference to Kalundborg, Denmark, explain the operation of an industrial ecosystem.

CRITICAL THINKING

1. List three ways in which you could apply **Concept 12-5** (p. 274) to making your lifestyle more environmentally sustainable.
2. List three ways in which a nanotechnology revolution (**Core Case Study**) could benefit you and three ways in which it could harm you.
3. List three types of jobs that would be created by a nanotechnology revolution (**Core Case Study**) and three types of jobs that would be eliminated by such a revolution.
4. What do you think would happen if **(a)** plate tectonics stopped and **(b)** erosion and weathering stopped? Explain.

5. You are an igneous rock. Write a report on what you experience as you move through the rock cycle (Figure 12-6, p. 267). Repeat this exercise, assuming you are a sedimentary rock and then a metamorphic rock.

6. Use the second law of thermodynamics (**Concept 2-4B**, p. 33) to analyze the scientific and economic feasibility of each of the following processes:

CONCEPT LINK

   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

7. What are three things that could be done to promote the spread of the ecoindustrial revolution? List three ways in which this could benefit your lifestyle.

8. Which one of the four **scientific principles of sustainability** (see back cover) applies most readily to the use of nonrenewable mineral resources? Explain.

SUSTAINABILITY

9. Congratulations! You are in charge of the world. What are the three most important features of your policy for developing and sustaining the world's nonrenewable mineral resources?

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

LEARNING ONLINE

Log on to the Student Companion Site for this book at **www.thomsonedu.com/biology/miller** and choose Chapter 12 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Web links, information on Green Careers, and InfoTrac® College Edition articles.

For access to animations and additional quizzing, register and log on to ThomsonNOW! at **www.thomsonedu.com/thomsonnow** using the access code card in the front of your book. You can also explore the **Active Graphing** exercises that your instructor may assign.

Energy

13

How Long Will Supplies of Conventional Oil Last?

CORE CASE STUDY

Oil, which supplies about one-third of the world's energy, is the lifeblood of most of the world's economies and modern lifestyles. We use oil to grow most of our food, transport people and goods, and make most of the things we use every day—from plastics to asphalt on roads.

Stretched end to end, the number of barrels of oil the world used in 2007 would circle the equator 650 times! And projected oil use in 2020 would raise that number to 870. To meet this rapidly growing demand, oil companies have drilled wells on the land and at sea (Figure 13-1).

Geologists report that known and projected global reserves of conventional oil are expected to be 80% depleted sometime between 2050 and 2100, depending on consumption rates. If that is correct, conventional oil should be reaching its sunset years sometime during this century. (See Supplement 15 on p. S61 for a brief history of the Age of Oil.)

We have three options: look for more oil, use or waste less oil, or use something else. Many analysts think we should vigorously pursue all three options. Some contend that higher prices will stimulate the search for new oil to meet global oil needs. Some doubt that we can increase oil reserves enough to meet the rapidly growing future demand for oil. For example, between 2000 and 2007, the world consumed nine times more oil than the oil industry discovered. Yet, because oil companies and many governments are secretive about oil reserves, no one really knows how much oil might be available.

Others argue that even if we find much more conventional oil or if rising prices make it profitable to develop unconventional sources of oil, we are ignoring the consequences of the high exponential growth in global oil consumption. Suppose we continue to use oil reserves at the current exponential rate of about 2.8% per year with the unlikely assumption that the rate won't increase. Here are some projections based on this scenario:

- Saudi Arabia, with the world's largest known crude oil reserves, could supply the world's entire oil needs for about 10 years.
- The 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 for 3 years.
- The estimated reserves in Alaska's Arctic National Wildlife Refuge (ANWR) would meet current world oil demand for only 1–5 months and U.S. demand for 7–24 months.

To keep using conventional oil at the projected rate of increase, we must discover global oil reserves equivalent to two new Saudi Arabian supplies every 10 years. Most oil geologists say this is highly unlikely.

The exciting and urgent challenge for this century is to sharply reduce our waste of oil and other energy resources and to find an array of substitutes for oil and other fossil fuels. This would help to slow emissions of carbon dioxide that contribute to global warming and climate change. There are no easy solutions because all energy options have advantages and disadvantages, as discussed in this chapter.

British Petroleum

Figure 13-1 Thunder Horse offshore floating oil production platform, located in the Gulf of Mexico.

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 usable energy available from a resource after the amount of energy needed to make it available is subtracted.

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 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 low accident risk, but high costs, radioactive wastes, vulnerability to sabotage, and the potential for spreading nuclear weapons technology have limited its use.

13-4 **Why is energy efficiency an important energy source?**

CONCEPT 13-4 We could save more than 40% of all the energy we use by improving energy efficiency.

13-5 **What are the advantages and disadvantages of renewable energy resources?**

CONCEPT 13-5 Using a mix of renewable energy sources—especially wind, solar energy, hydropower, biofuels, geothermal energy, and hydrogen—can drastically reduce pollution, greenhouse gas emissions, and biodiversity losses.

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 of a mix of renewable energy resources, and including environmental costs in the market prices of all energy resources.

Note: Supplements 7, 8, 15, and 16 can be used with this chapter.

Typical citizens of advanced industrialized nations each consume as much energy in six months as typical citizens in developing countries consume during their entire life.

MAURICE STRONG

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 usable energy available from a resource after the amount of energy needed to make it available is subtracted.

Most of Our Energy Comes from the Sun and Fossil Fuels

Almost all of the energy that heats the earth and our buildings comes from the sun at no cost to us—one of the four **scientific principles of sustainability** (see back cover). Without this essentially inexhaustible solar energy (solar capital, **Concept 1-1A**, p. 6), the earth's average temperature would be −240°C (−400°F), and life as we know it would not exist. This direct input of solar energy produces several indirect forms of renewable solar energy: *wind, hydropower* (falling and flowing water), and *biomass* (solar energy converted to chemical energy and stored in trees and other plants).

SUSTAINABILITY

CONCEPT LINK

The *commercial energy,* sold in the marketplace, makes up the 1% of the energy we use that is not supplied directly by the sun. Currently, most commercial energy comes from extracting and burning *nonrenewable energy resources* obtained from the earth's crust, primarily carbon-containing fossil fuels—oil, natural gas, and coal (Figure 13-2—formed from the decay of plants and animals over millions of years.

About 82% of the commercial energy consumed in the world comes from *nonrenewable* energy resources—76% from fossil fuels (oil, natural gas, and coal) and 6% from nuclear power (Figure 13-3, left). The remaining 18% of the commercial energy we use comes from *renewable* energy resources—biomass, hydropower, geothermal, wind, and solar energy (**Concept 13-1A**).

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.

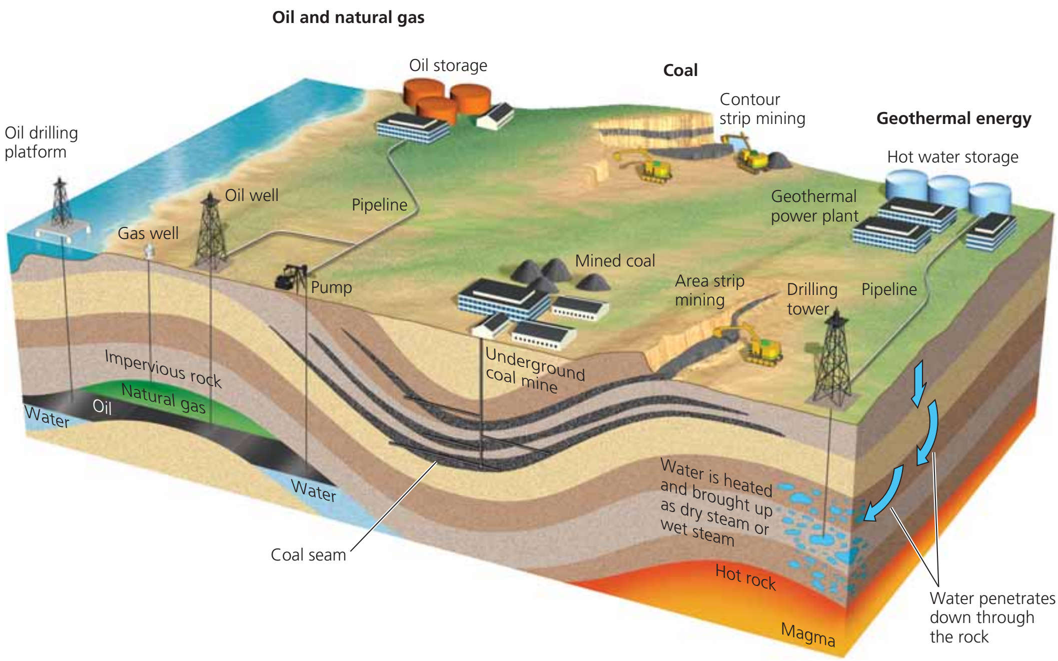


Figure 13-2 **Natural capital:** important nonrenewable energy resources that can be removed from the earth's crust are coal, oil, natural gas, and some forms of geothermal energy. Nonrenewable uranium ore is also extracted from the earth's crust and processed to increase its concentration of uranium-235, which can serve as a fuel in nuclear reactors to produce electricity. **Question:** Can you think of a time during a typical day when you are not directly or indirectly using one of these resources?

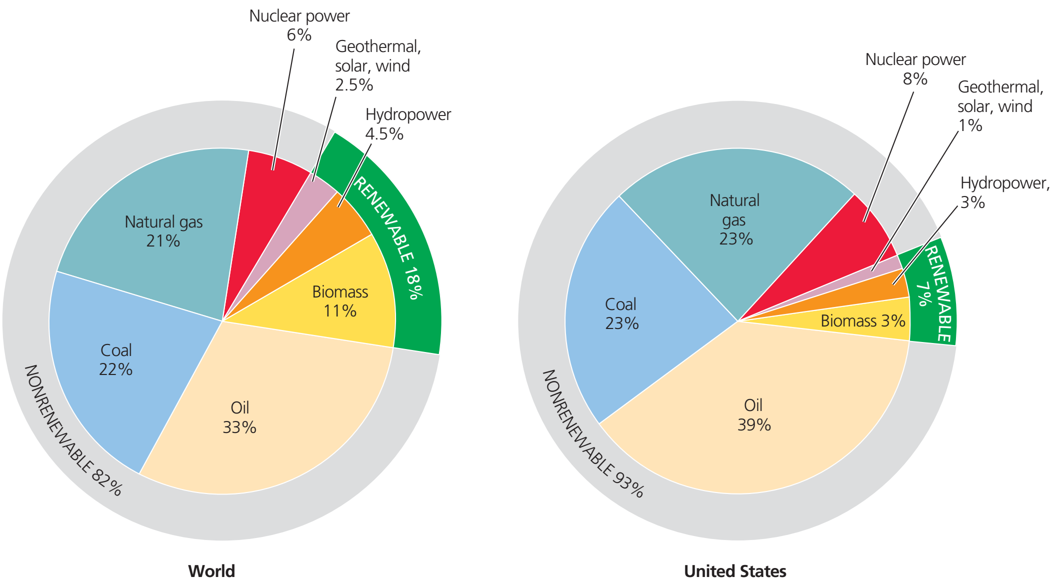


Figure 13-3 Commercial energy use by source for the world (left) and the United States (right) in 2004. Commercial energy amounts to only 1% of the energy used in the world; the other 99% is direct solar energy received from the sun and, of course, not sold in the marketplace. **Question:** Why do you think the world as a whole relies more on renewable energy than the United States does? (Data from U.S. Department of Energy, British Petroleum, Worldwatch Institute, and International Energy Agency)

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 and converted to useful fuels, transported to users, and burned in furnaces and cars. 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 2-4B**, p. 33). 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 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 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, concentrating, and transporting the useful energy to users.

Net energy is like the net profit in a business after expenses. For example, the net profit in a business with $1 million in sales and $800,000 in expenses is $200,000, and that is the only number that really matters.

For example, suppose that it takes 8 units of energy to produce 10 units of energy from a particular energy resource. Then the net energy yield is only 2 units 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 10/8, or approximately 1.25. 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, oil has a high net energy ratio because much of it comes from large, accessible, and cheap-to-extract deposits such as those in the Middle East. As these sources are depleted, the net energy ratio of oil will decline and its price is expected to rise sharply.

Electricity produced by nuclear power has a low net energy ratio because large amounts of energy are needed to extract and process uranium ore, convert it into nuclear fuel, build and operate nuclear power plants, dismantle the highly radioactive plants after their 15–60 years of useful life, and store the resulting highly radioactive wastes safely for 10,000–240,000 years. Each of these steps in the *nuclear fuel cycle* uses energy and costs money. Some analysts estimate that ultimately the conventional nuclear fuel cycle will lead to a net energy loss because we will have to put more energy into it than we will ever get out of it.

Critical Thinking

Should governments require that all energy resources be evaluated in terms of their net energy? Why do you think this is not being done?

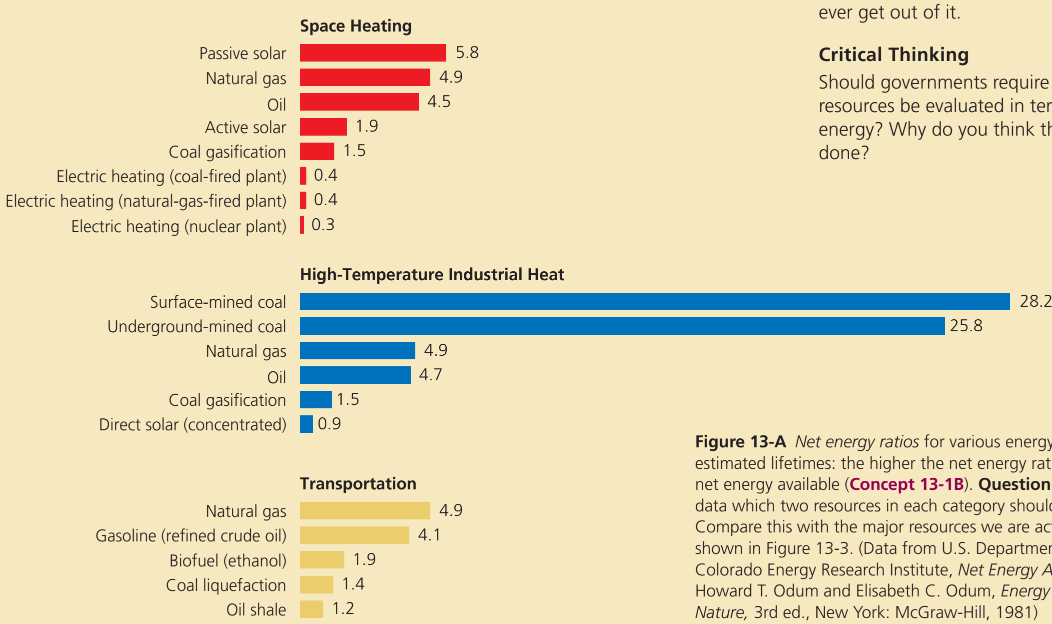


Figure 13-A *Net energy ratios* for various energy systems over their estimated lifetimes: the higher the net energy ratio, the greater the net energy available (**Concept 13-1B**). **Question:** Based on these data which two resources in each category should we be using? Compare this with the major resources we are actually using as shown in Figure 13-3. (Data from U.S. Department of Energy and 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)

Nonrenewable fossil fuels are widely used because they are abundant, easily transportable, and inexpensive compared to most other alternatives. In order, the three largest users of fossil fuels are the United States, China, and the European Union, together accounting for more than half of all fossil fuel consumption. Energy use per person varies throughout the world (see Figure 1 on p. S62 in Supplement 16).

Roughly half the world's people in developing countries burn potentially renewable wood and charcoal 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 biomass energy used in the world is higher than the 11% figure shown in Figure 13-3 (left). Many of these individuals face a *fuelwood shortage* that is expected to worsen because fuelwood is being harvested faster than nature replaces it.

All energy resources should be evaluated on the basis of their supplies, environmental impact, and how much useful energy they actually provide (Science Focus, at left).

ThomsonNOW™ Examine and compare energy sources used in developing and developed countries at ThomsonNOW.

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 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 thick and gooey liquid consisting of hundreds of combustible hydrocarbons along with small amounts of sulfur, oxygen, and nitrogen impurities. It is also known as *conventional* or *light oil.* Crude oil and natural gas are called fossil fuels because they were formed from the decaying remains (fossils) of organisms living 100–500 million years ago.

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 (Figure 13-2). The crude oil is dispersed in pores and cracks in underground rock formations, somewhat like water saturating a sponge. To extract the oil, a well is drilled into the deposit. High-tech equipment can drill oil and natural gas wells on land and at sea (Figure 13-1) to a depth of 8 kilometers (5 miles). Then oil, drawn by gravity out of the rock pores and into the bottom of the well, is pumped to the surface.

At first oil almost squirts from the well. But after years of pumping, pressure disappears and production starts declining at a point referred to as the *peak production* of a well, usually after a decade or so. For global oil production to expand, the oil output from newly found reserves must stay ahead of the declining output from wells that have passed their peak.

After it is extracted, crude oil is transported to a *refinery* by pipeline, truck, or ship (oil tanker). There it is heated and distilled to separate it into components with different boiling points (Figure 13-4)—a technological marvel based on complex chemistry and engineering. Some of the products of oil distillation, called **petrochemicals,** are used as raw materials in industrial organic chemicals, pesticides, plastics, synthetic fibers, paints, medicines, and many other products. Producing a desktop computer, for example, consumes 10 times its weight in fossil fuels, mostly oil.

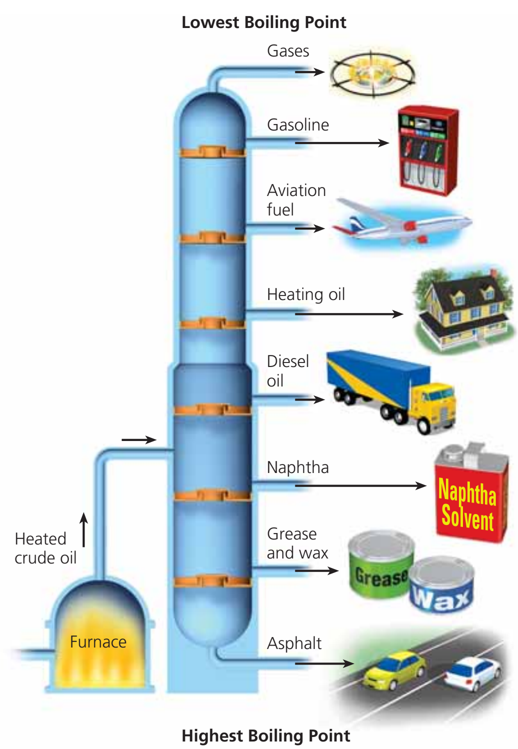


Figure 13-4 Refining crude oil. Based on their boiling points, components are removed at various levels in a giant distillation column. The most volatile components with the lowest boiling points are removed at the top of the column.

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 ways in which your lifestyle will be affected if oil becomes unaffordable (**Core Case Study**)?

OPEC Controls Most of the World's Oil Supplies

The oil industry is the world's largest business. This explains why control of oil reserves is currently the single greatest source of global economic and political power.

Oil *reserves* are identified deposits from which conventional oil can be extracted profitably at current prices with current technology. The 11 countries that make up the Organization of Petroleum Exporting Countries (OPEC) have 78% of the world's crude oil reserves. Thus, OPEC is expected to have long-term control over the supplies and prices of the world's conventional oil. Today OPEC's members are Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela. OPEC oil revenue tripled from $199 billion in 2002 to about $600 billion in 2006—an average of $1.1 million per minute.

Saudi Arabia has the largest proportion of the world's crude oil reserves (25%). It is followed by Canada (15%), whose huge supply of oil sand was recently classified as a conventional source of oil. In order, other countries with large proven reserves are Iran, Iraq, Kuwait, the United Arab Emirates, and Venezuela. At least 65% of the world's oil reserves are in the hands of government-owned companies.

Based on different assumptions, some geologists expect the world's production of conventional oil to peak within the next 10 to 33 years (**Core Case Study**) and then begin a long decline. Oil production has already peaked or declined in 15 of the 23 largest oil-producing countries, including the United States, the United Kingdom, and six OPEC countries. There is disagreement over whether we can continue to find enough new oil to meet our exponentially growing needs (**Core Case Study**).

The United States Uses Much More Oil Than It Produces

About 29% of U.S. domestic oil production and 21% of domestic natural gas comes from offshore drilling, mostly off the coasts of Texas and Louisiana in the Gulf of Mexico (see Figure 2 on p. S63 in Supplement 16)—an area subject to hurricanes, which on average are increasing in intensity. Another 17% of domestic oil comes from Alaska's North Slope via oil tankers and the Trans-Alaska Pipeline.

The United States produces about 9% of the world's oil but uses 25% of global oil production, yet it has only 2.9% of the world's oil reserves. Oil use in the United States has exceeded new domestic discoveries for more than two decades.

The United States produces most of its dwindling domestic supply of oil at a high cost, about $7.50–$10 per barrel compared to $1–$2 per barrel in Saudi Arabia. This helps explain why in 2007 the United States imported about 60% of its oil at a cost of about $1.25 billion a day—an average of $868,000 per minute.

According to a 2005 report by the Institute for the Analysis of Global Security, almost one-fourth of the world's conventional oil is controlled by states that sponsor or condone terrorism. This means that, in buying oil from those countries, the United States and other countries fighting and funding a war on terrorism are simultaneously funding the enemy. According to a 2006 poll of 100 foreign policy experts in *Foreign Policy* magazine, *the highest priority in fighting terrorism must be to sharply reduce America's dependence on foreign oil.*

According to DOE estimates, if current trends continue, America will depend on imports for 70% of its oil by 2025. At the same time, it will be facing stiff competition for oil imports from rapidly industrializing countries such as China, which by 2025 expects to be importing twice as much oil as the United States imports.

According to the U.S. Geological Survey, potentially vast domestic oil and natural gas reserves remain to be discovered in the United States, much of it beneath federal lands and coastal waters. Other geologists disagree. They say that if we think of U.S. conventional oil reserves as a six-pack of oil, four of the cans are empty. They estimate that if the country opens up virtually all of its public lands and coastal regions to oil exploration, it may find at best about half a can of new oil at a high cost (compared to much cheaper OPEC oil) and with serious harmful environmental effects. In other words, according to these energy analysts, *the United States cannot feed its oil addiction by trying to increase domestic oil supplies.*

Oil Has Advantages and Disadvantages

Figure 13-5 lists the advantages and disadvantages of using conventional crude oil as an energy resource. The extraction, processing, and use of nonrenewable oil and other fossil fuels have a severe environmental impact (Figure 12-8, p. 268).

A serious problem is that burning oil or any carbon-containing fossil fuel releases CO_2 into the atmosphere and thus can help to promote global warming (**Concept 13-2**). Currently, burning oil mostly as gasoline and diesel fuel for transportation accounts for 43% of global CO_2 emissions. Figure 13-6 compares the rel-

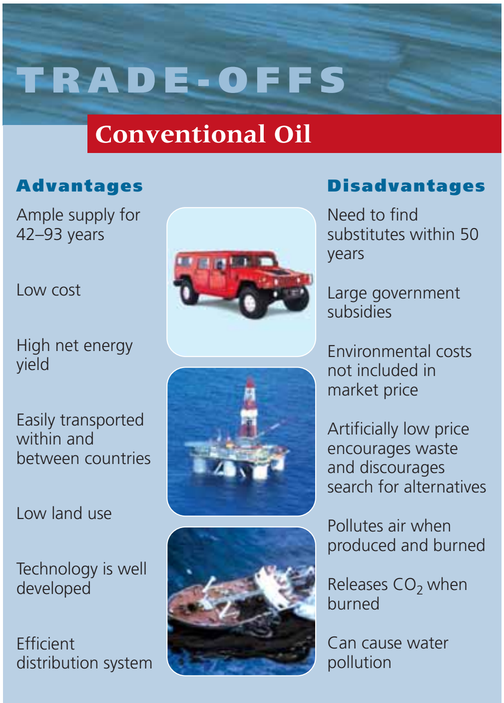


Figure 13-5 Advantages and disadvantages of using conventional crude oil as an energy resource (**Concept 13-2**). **Question**: Which single advantage and which single disadvantage do you think are the most important? Why?

ative amounts of CO_2 emitted per unit of energy in using fossil fuels, nuclear power, and geothermal energy.

HOW WOULD YOU VOTE?

Do the advantages of relying on conventional oil as the world's major energy resource outweigh its disadvantages? Cast your vote online at **www.thomsonedu.com/biology/miller**.

Will Oil Sand and Oil Shale Save Us?

Oil sand, or **tar sand,** is a mixture of clay, sand, water, and a combustible organic material called *bitumen*—a thick and sticky heavy oil with a high sulfur content. Oil sands nearest the earth's surface are dug up by gigantic electric shovels and loaded into house-sized trucks that carry them to upgrading plants. There they are mixed with hot water and steam to extract the bitumen, which is converted into a low-sulfur, synthetic crude oil suitable for refining.

Northeastern Alberta in Canada has three-fourths of the world's oil sand resources. Other deposits are in Venezuela, Colombia, Russia, and the U.S. state of Utah. Together the sticky oil sands of Canada and Venezuela contain more oil than is found in Saudi Arabia and nearly as much as the total conventional oil reserves in the Middle East.

In 2003, the oil industry began counting Canada's oil sands as reserves of conventional oil. As a consequence, Canada has 15% of the world's oil reserves, second only to Saudi Arabia. By building a pipeline to transfer some of this synthetic crude oil from western Canada to the northwestern United States, Canada could greatly reduce future U.S. dependence on Middle East oil imports and add to Canadian income.

However, extracting and processing oil sands has a severe impact on the land and produces huge amounts of toxic sludge, as well as more water pollution, air pollution, and CO_2 per unit of energy than does extracting and processing conventional crude oil. Producing oil from oil sands also requires large inputs of natural gas, which greatly reduces its net energy yield (**Concept 13-1B**). According to energy economist Peter Tertzakian, it takes the energy equivalent of 0.7 barrels of oil to produce 1 barrel of oil from oil sands.

Oily rocks are another potential supply of heavy oil. Such rocks, called *oil shales* (Figure 13-7, left, p. 286), contain a solid combustible mixture of hydrocarbons called *kerogen*. It can be extracted from crushed oil shales by heating them in a large container, a process that yields a distillate called **shale oil** (Figure 13-7, 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 half of the world's estimated oil shale reserves are buried deep in rock formations in the western

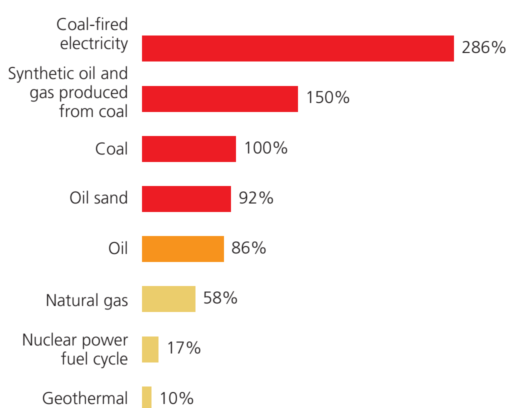


Figure 13-6 *Altering the carbon cycle:* CO_2 emissions per unit of energy produced by using various energy resources to generate electricity, expressed as percentages of emissions released by burning coal directly. These emissions can enhance the earth's natural greenhouse effect (Figure 3-7, p. 44) and lead to warming of the atmosphere (**Concept 13-2**). **Question:** Which produces more CO_2 emissions: burning coal to heat a house, or heating with electricity generated by coal? (Data from U.S. Department of Energy)

U.S. Department of Energy

Figure 13-7 Oil shale rock (left) and the *shale oil* (right) extracted from it.

United States. According to the Bureau of Land Management, these deposits contain potentially recoverable heavy oil equal to three times the size of Saudi Arabia's oil reserves and enough to meet the current U.S. oil demand for 110 years.

Other large reserves are in Brazil, Jordan, Australia, China, and Estonia. Estimated potential global supplies of shale oil are about 240 times larger than estimated global supplies of conventional oil. China, which has been using oil shale since 1929, is the world's largest producer of oil from oil shale and plans to double its production soon. In 1991, Brazil built the world's largest oil shale facility.

But 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 crude oil. In other words, its net energy is low. Producing and using shale oil also has a much higher environmental impact than exploiting conventional oil.

Figure 13-8 lists the advantages and disadvantages of using heavy oil from oil sand and oil shale as energy resources.

THINKING ABOUT
Heavy Oils

Do the advantages of relying on heavy oils from oil 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 ethane (C_2H_6), propane (C_3H_8), and butane (C_4H_{10}), and small amounts of highly toxic hydrogen sulfide (H_2S). It is a versatile fuel that can be used for cooking and heating, powering vehicles, and producing electricity (accounting for 20% of the world's electricity in 2006, up from 12% in 1973, and 21% of the electricity in the United States).

Conventional natural gas lies above most reservoirs of crude oil (Figure 13-2). However, unless a natural gas pipeline has been built, these deposits cannot be used. Indeed, the natural gas found above oil reservoirs in deep-sea and remote land areas is often viewed as an unwanted by-product and is burned off. This wastes a valuable energy resource and releases carbon dioxide into the atmosphere.

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 dried to remove water vapor, cleansed of poisonous hydrogen sulfide and other impurities, and pumped into pressurized pipelines for distribution.

Unconventional natural gas is also found in underground sources. One is *coal bed methane gas* found in coal beds across parts of the United States and Canada (most yellow areas in Figure 2 on p. S63 in Supplement 16). But the environmental impacts of producing it—scar-

TRADE-OFFS

Heavy Oils from Oil Shale and Oil Sand

Advantages	Disadvantages
Moderate cost (oil sand)	High cost (oil shale)
Large potential supplies, especially oil 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 is well developed	Severe land disruption
	Severe water pollution
	Air pollution when burned
	CO_2 emissions when produced and burned

Figure 13-8 Advantages and disadvantages of using heavy oils from oil sand and oil shale as energy resources (**Concept 13-2**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

ring of the land and air and water pollution—are causing a public backlash in parts of the western United States against using this energy source.

Another unconventional source of natural gas is *methane hydrate*—methane trapped in icy, cage-like structures of water molecules. They are buried under arctic permafrost and deep beneath the ocean bottom (see Figure 3 on p. S64 in Supplement 16). So far, it costs too much to get natural gas from methane hydrates, and the release of methane to the atmosphere during its removal and processing will amplify global warming.

RESEARCH FRONTIER

Finding affordable and environmentally acceptable ways to tap methane hydrates

At a very low temperature, natural gas can also be converted to **liquefied natural gas (LNG).** This highly flammable liquid can then be shipped to other countries in refrigerated tanker ships. Japan and several countries import LNG now, 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 politically unstable or unfriendly countries such as Russia and Iran for supplies of LNG. In addition, LNG has a low net energy yield, with more than a third of its energy content used to compress, decompress, refrigerate, and transport it long distances.

Russia—the Saudi Arabia of natural gas—has about 27% of the world's proven natural gas reserves, followed by Iran (15%) and Qatar (14%). The United States has only 3% of the world's proven natural gas reserves (see Figure 2 on p. S63 in Supplement 16) but uses about 27% of the world's annual production. Japan and Europe import most of their natural gas from Russia.

The long-term global outlook for conventional natural gas supplies is better than that for conventional oil. At the current consumption rate, known reserves and undiscovered, potential reserves of conventional natural gas should last the world for 62–125 years and the United States for 55–80 years, depending on how rapidly they are used.

Geologists project that *conventional* and *unconventional* supplies of natural gas (the latter available at higher prices) should last at least 200 years at the current consumption rate and 80 years if usage rates rise 2% per year.

Natural Gas Has More Important Advantages Than Disadvantages

Figure 13-9 lists the advantages and disadvantages of using conventional natural gas as an energy resource. Because of its advantages over oil, coal, and nuclear energy, some analysts see natural gas as the best fuel to help make the transition to improved energy efficiency and greater use of renewable energy over the next 50 years. For example, motor vehicles can be converted to run on natural gas at an affordable cost.

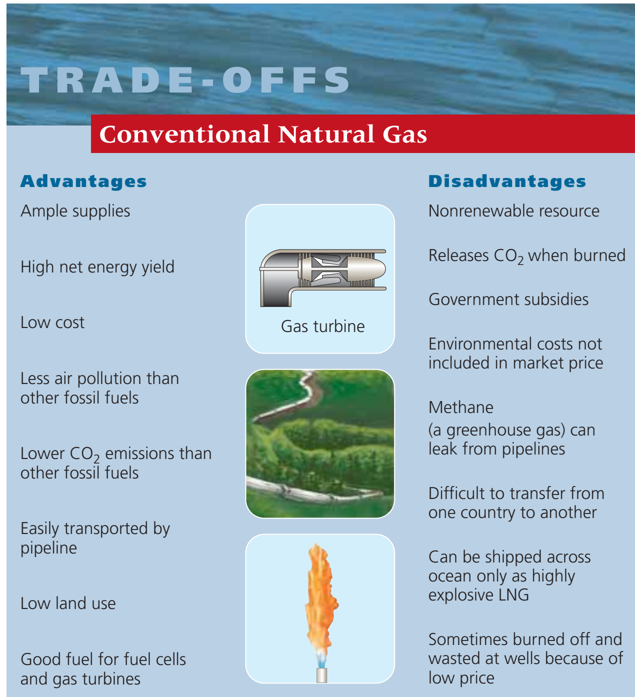


Figure 13-9 Advantages and disadvantages of using conventional natural gas as an energy resource (**Concept 13-2**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

Coal Is a Plentiful But Dirty Fuel

Coal is a solid fossil fuel that was formed in several stages as the buried remains of land plants that lived 300–400 million years ago were subjected to intense heat and pressure over many millions of years (Figure 13-10, p. 288). Coal is mostly carbon (C) but contains small amounts of sulfur (S), which are released into the air as sulfur dioxide (SO_2) when the coal burns (see Figure 1 on p. S39 in Supplement 8). Burning coal also releases large amounts of the greenhouse gas carbon dioxide (Figure 13-6) and trace amounts of toxic mercury and radioactive materials.

Coal is burned in power plants (Figure 13-11, p. 288) to generate about 40% of the world's electricity. China is by far the world's largest producer and consumer of coal. It uses coal for cooking and to provide

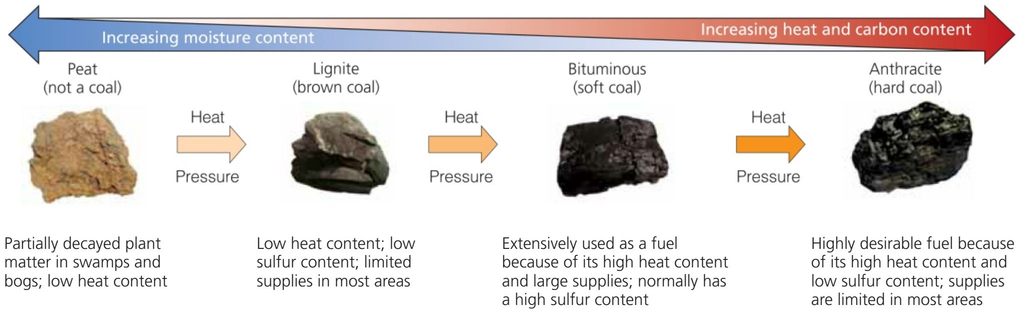


Figure 13-10 **Natural capital:** stages in the formation of coal over millions of years. Peat is a soil material made of moist, partially decomposed organic matter.

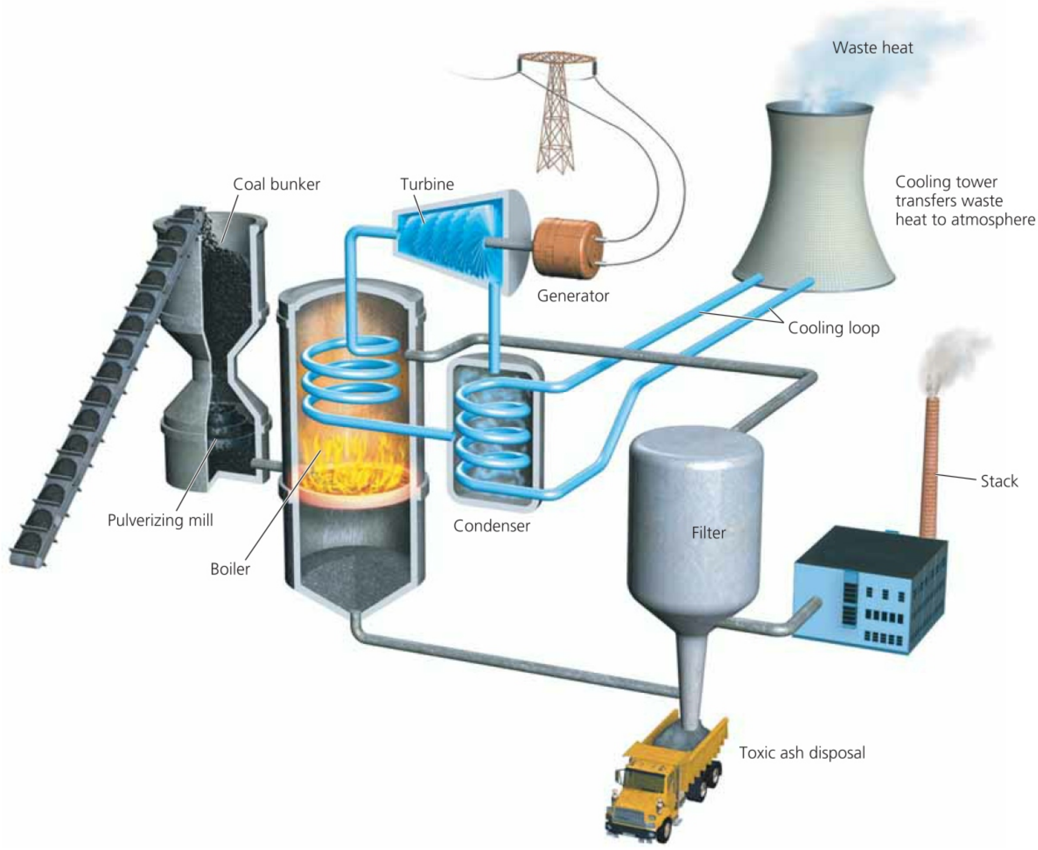


Figure 13-11 *Coal-burning power plant.* Heat produced by burning pulverized coal in a furnace boils water to produce steam that spins a turbine to produce electricity. The steam is cooled, condensed, and returned to the boiler for reuse. A large cooling tower transfers waste heat to the atmosphere. The largest coal-burning power plant in the United States in Indiana burns 23 metric tons (25 tons) of coal per minute, or three 100-car trainloads of coal per day. **Question:** Does the electricity that you use come from a coal-burning power plant?

69% of its total energy and 75% of its electricity. Currently, a new, large coal-burning plant opens every 10 days in China. India burns more coal than any developing country and uses it to produce about 60% of its total energy. In 2006, coal produced 49% of electricity used in the United States, followed by natural gas (21%), nuclear power (19%), renewable energy (9%), and oil (2%).

Coal is the world's most abundant fossil fuel. According to the U.S. Geological Survey, identified and unidentified 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, on p. S63, in Supplement 16). Russia has 17%, followed by China with 12%, India with 10%, and Australia with 9%.

According to the U.S. Geological Survey, identified U.S. coal reserves should last about 300 years at the current consumption rate, and unidentified U.S. coal resources could extend those supplies for perhaps another 100 years, although at a higher cost. If U.S. coal use should increase by 4% per year—as the coal industry projects—the country's proven coal reserves would last only 64 years.

Environmental scientists call for redesigning coal plants so they have the latest pollution control devices and methods for removing CO_2 emissions and storing them underground or in deep-sea beds. So far little progress has been made in building such cleaner coal plants, mostly because they cost 10–20% more per unit of electricity than conventional plants, and the price of electricity produced by conventional plants does not include its harmful environmental costs.

Environmental economists call for including these environmental costs in the price of electricity by taxing each unit of carbon dioxide produced by burning coal and other fossil fuels as Norway and Sweden have done since 1991. This would promote cleaner coal burning and increased use of renewable energy sources such as wind, solar, hydroelectricity, and geothermal energy.

Instead of building new cleaner coal-burning power plants, in 2007 some U.S. utility companies were racing to build more new conventional coal-fired power plants before the U.S. Congress could impose carbon taxes or stricter regulation of CO_2 emissions. This would lock the United States into decades of unnecessarily high CO_2 emissions.

Coal Has Advantages and Disadvantages

Figure 13-12 lists the advantages and disadvantages of using coal as an energy resource. *Bottom line:* Coal is cheap, plentiful, and is distributed over much of the planet. But mining and burning coal has a severe impact on the earth's air, water, land, and climate, as well as on human health. Coal is the single biggest air polluter in coal-burning nations. It accounts for more than one-third of the world's annual CO_2 emissions (Figure 13-6)—the main culprit in enhanced global warming from human activities—and 36% of those for the United States. To a growing number of scientists and economists, the burning of coal is one of the most serious environmental problems of the 21st century.

TRADE-OFFS

Coal

Advantages

- Ample supplies (225–900 years)
- High net energy yield
- Low cost
- Well-developed technology
- Air pollution can be reduced with improved technology

Disadvantages

- Severe land disturbance, air pollution, and water pollution
- Severe threat to human health when burned
- Environmental costs not included in market price
- Large government subsidies
- 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 (**Concept 13-2**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

HOW WOULD YOU VOTE?

Should coal use be phased out over the next 20–30 years? Cast your vote online at **www.thomsonedu.com/biology/miller**.

We Can Convert Coal into Gaseous and Liquid Fuels

Solid coal can be converted into **synthetic natural gas (SNG),** by **coal gasification,** and into a liquid fuel such as methanol or synthetic gasoline by **coal liquefaction.** Without huge government subsidies, most analysts expect these *synfuels* to play a minor role as energy resources in the next 20–50 years. Compared to burning conventional coals, they require mining 50% more coal, and producing and burning them could add 50% more carbon dioxide to the atmosphere (Figure 13-6). Also, they cost more to produce than coal. Figure 13-13 (p. 290) lists the advantages and disadvantages of using synfuels.

By 2007, China was far ahead of the United States in building coal gasification plants. General Electric researchers have developed a prototype fuel cell that runs on hydrogen gas produced by gasifying coal. If

TRADE-OFFS

Synthetic fuels

Advantages	Disadvantages
Large potential supply	Low to moderate net energy yield
Vehicle fuel	Higher cost than coal
Moderate cost	Requires mining 50% more coal
Lower air pollution than coal when burned	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 (syngas) and liquid synfuels produced from coal (**Concept 13-2**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

successful and affordable, such fuel-cell power plants would have an energy efficiency greater than 50%, compared to the 35% efficiency of conventional coal and nuclear power plants.

The U.S. state of Montana has one-third of U.S. coal reserves and 8% of the world's coal reserves. In 2007, the state's governor, Brian Schweitzer, proposed extracting and burning this coal more cleanly by

- Setting a permanent floor price for crude oil in the United States at $40 a barrel so that investors in newer, cleaner coal technologies (and in various types of renewable energies) cannot be undercut by any lowering of oil prices by OPEC. Under this system, any alternative that can provide energy at or below this price could compete with oil in the marketplace.
- Setting up a cap-and-trade CO_2 emissions system that rewards companies that use cleaner-coal technologies and punishes those that don't. In such a system, widely used in Europe, a cap on total CO_2 emissions is established, and the allowed emissions are allocated among producers. Those who produce less than their allowed limit can sell the amount they saved to other producers who exceeded their limits.
- Greatly increasing federal and state government funding of research and development of pilot coal gasification and liquefaction technologies and of technologies that remove CO_2 from plant emissions and store it underground or beneath the sea bottom.
- Establishing federal regulations for removing CO_2 from plant emissions and storing it underground or beneath the sea bottom.

RESEARCH FRONTIER

Improving coal gasification and coal liquefaction

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 low accident risk, but high costs, radioactive wastes, vulnerability to sabotage, and the potential for spreading nuclear weapons technology have limited its use.

How Does a Nuclear Fission Reactor Work?

To evaluate the advantages and disadvantages of nuclear power, we must know how a conventional 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: using heat produced by a controlled nuclear chain reaction (Figure 2-5, center, p. 32) to boil water to produce steam that spins a turbine and generates electricity.

Light-water reactors (LWRs) like the one diagrammed in Figure 13-14 produce 85% of the world's nuclear-generated electricity (100% in the United States). *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 wa-

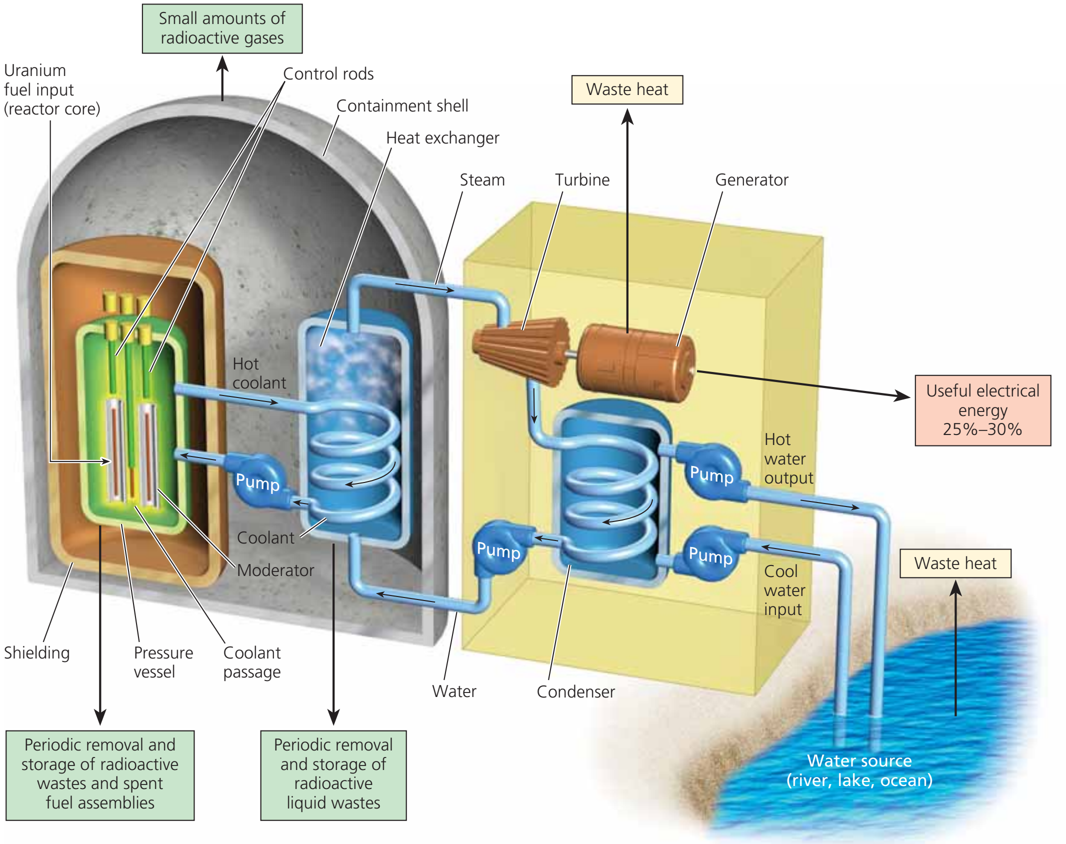


Figure 13-14 **Science:** light-water–moderated and –cooled nuclear power plant with a pressurized water reactor. Some nuclear plants withdraw water for cooling from a nearby source of water and return the heated water to such a source, as shown here. Other nuclear plants that do not have access to a source of cooling water transfer the waste heat to the atmosphere by using one or two cooling towers, as shown in Figure 13-11, for a coal-burning power plant. **Question:** How does this plant differ from the coal-burning plant in Figure 13-11?

ter, circulates through the reactor's core to remove heat to keep fuel rods and other materials from melting and releasing massive amounts of radioactivity into the atmosphere and water. An LWR includes an emergency core cooling system as a backup to help prevent such meltdowns.

A *containment vessel* with thick, steel-reinforced, concrete walls surrounds the reactor core. It is designed to keep radioactive materials from escaping into the environment in case of an internal explosion or core meltdown within the reactor, and to protect the core from external threats such as a tornado or plane crash.

When reactors are refueled about once a year, intensely hot and highly radioactive fuel rod assemblies are removed and stored outside of the nuclear reactor building in *water-filled pools* (Figure 13-15, left, p. 292) or *dry casks* (Figure 13-15, right). Spent-fuel pools or casks are not nearly as well protected as the reactor core and are much more vulnerable to acts of terrorism. The long-term goal is to transport spent fuel rods and other long-lived radioactive wastes to an underground facility for long-term storage. But after almost 60 years of nuclear power, no country has developed such a facility.

The overlapping and multiple safety features of a modern nuclear reactor greatly reduce the chance of a serious nuclear accident. But these safety features make nuclear power plants very expensive to build and maintain.

Nuclear power plants, each with one or more reactors, are only one part of the *nuclear fuel cycle* (Figure 13-16, p. 292). This cycle includes the mining of uranium, processing and enriching the uranium to make a satisfactory fuel, using it in a reactor, and safely storing the resulting highly radioactive wastes for 10,000–240,000 years until their radioactivity falls to

U.S. Department of Energy/Nuclear Regulatory Commission

U.S. Department of Energy/Nuclear Regulatory Commission

Figure 13-15 *Nuclear waste storage.* After three or four 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, the fuel rods are sometimes moved to dry-storage containers made of steel or concrete (right). **Question:** Do you think these are safe storage methods? Why or why not?

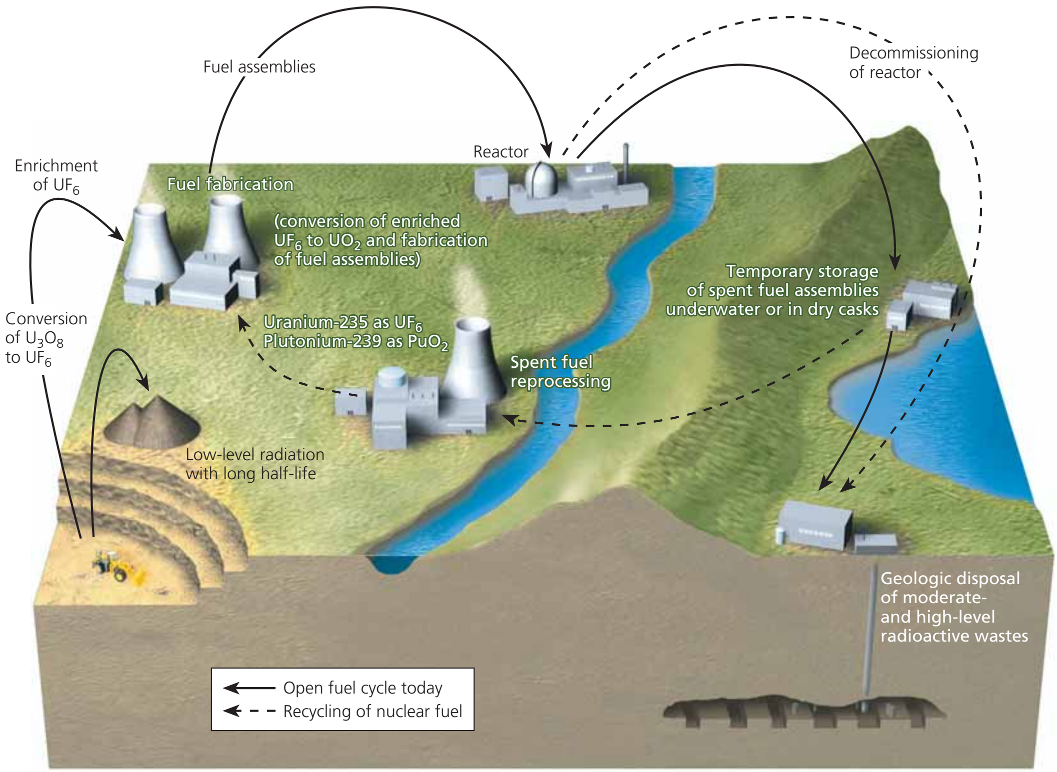


Figure 13-16 *The nuclear power fuel cycle* (**Concept 13-3**) has a fairly low environmental impact and a very low risk of an accident, but costs are high, radioactive wastes must be stored safely for thousands of years, facilities are vulnerable to terrorist attack, and the technology can be used to produce material for use in nuclear weapons. **Question:** Do you think the price of nuclear-generated electricity should include all the costs of the fuel cycle? Why or why not?

safe levels. The final step in the cycle occurs when, after 15–60 years, a reactor comes to the end of its useful life and must be retired or decommissioned. It cannot simply be shut down and abandoned because it contains large quantities of intensely radioactive materials that must be kept out of the environment for many 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**).

In evaluating the safety, economic feasibility, and overall environmental impact of nuclear power, energy experts and economists caution us to look at the entire fuel cycle, not just the nuclear plant.

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 more than 50 years of development, enormous government subsidies, and an investment of $2 trillion, these goals have not been met. Instead, in 2007, 443 commercial nuclear reactors in 30 countries produced only 6% of the world's commercial energy and 16% of its electricity. Nuclear power is now the world's slowest-growing energy source. The International Atomic Energy Agency and the U.S. Department of Energy predict that the percentage of the world's electricity produced by nuclear power will peak around 2015 and then decline gradually to about 10–14% by 2030 because the retirement of aging plants is expected to exceed the construction of new ones.

No new nuclear power plants have been ordered in the United States since 1978, and all 120 plants ordered since 1973 have been canceled. In 2007, there were 104 licensed commercial nuclear power reactors in 31 states—most of them located in the eastern half of the country. These reactors generate about 19% of the country's electricity. This percentage is expected to decline over the next two to three decades as existing reactors wear out and are retired, even if a few new reactors are built.

According to energy analysts and economists, several reasons explain the failure of nuclear power to grow as projected. They include multibillion-dollar construction cost overruns, higher operating costs, more malfunctions than expected, and poor management. Two other obstacles have been public concerns about safety and stricter government safety regulations, especially after the accidents in 1979 at the Three Mile Island nuclear plant in the U.S. state of Pennsylvania and in 1986 at the Chernobyl nuclear plant in Ukraine (see Case Study, at right)

Another problem is investor concerns about the economic feasibility of nuclear power, taking into account the entire nuclear fuel cycle (Figure 13-16). Even with massive government subsidies, the nuclear fuel cycle (not just the plant itself) costs more than using coal, natural gas, or wind power to produce electricity.

There is serious concern about possible terrorist attacks on nuclear power facilities. Experts are especially concerned about the vulnerability of poorly protected and intensely radioactive spent fuel rods stored in water pools or casks (Figure 13-15) outside of reactor buildings. Another serious problem is that the spread of nuclear power provides countries with the ability to produce enriched uranium that can be used in nuclear weapons.

■ **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, a series of 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, releasing over 100 times more radiation into the atmosphere than did the atomic bombs dropped by the United States on the Japanese cities of Hiroshima and Nagasaki at the end of World War II. The initial explosion and the prolonged fires released a huge radioactive cloud that spread over much of Belarus, Russia, Ukraine, and Europe and eventually encircled the planet.

According to U.N. studies, the disaster, which was caused by poor reactor design and human error, had serious consequences. By 2005, 56 people had died from radiation released by the accident and at least 4,000 more people will eventually die from cancers caused by radiation exposure from the accident. Government agencies in Belarus, Russia, and Ukraine, and other researchers put the eventual death toll at 25,000 to 60,000. Because of secrecy and sparse reliable data, we will never know the real death toll.

Some 350,000 people had to abandon their homes because of contamination by radioactive fallout. In addition to fear about long-term health effects such as cancers, many of these victims continue to suffer from stress and depression. In many parts of Ukraine, people still cannot drink the water or eat locally produced fruits, vegetables, fish, meat, or milk.

Chernobyl taught us a hard lesson: a major nuclear accident anywhere has effects that reverberate throughout much of the world. One more bad nuclear power accident anywhere in the world could have a major impact on the future of nuclear power.

ThomsonNOW™ Watch how winds carried radioactive fallout around the world after the Chernobyl meltdown at ThomsonNOW.

Conventional Nuclear Power Has Advantages and Disadvantages

Figure 13-17 lists the major advantages and disadvantages of the conventional nuclear fuel cycle. Using nuclear power to produce electricity has some important advantages over coal-burning power plants (Figure 13-18).

Let's examine some of these advantages and disadvantages more closely.

Nuclear Power Is Vulnerable to Terrorist Acts

Because of the 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, a partial or complete meltdown or explosion is possible, as the accidents at Chernobyl and Three Mile Island taught us.

In addition to worries about accidents, the 2001 terrorist attacks in the United States raised fears of the vulnerability of U.S. nuclear power plants to terrorist attack. One concern is insufficient security at the plants against ground-level attacks. During a series of security exercises performed by the NRC between 1991 and 2001, mock attackers were able to simulate the destruction of enough equipment to cause a meltdown at nearly half of all U.S. nuclear plants. The NRC contends that the security weaknesses revealed by mock tests have been corrected. But it stopped such testing in 2001, so there is no way for scientists and the public to evaluate this claim.

A 2005 study by the U.S. National Academy of Sciences warned that pools and casks used to store spent fuel rods at 68 nuclear power plants in 31 U.S. states are especially vulnerable to sabotage or terrorist attack. A spent-fuel pool (Figure 13-15, left) typically holds 5–10 times more long-lived radioactivity than does the radioactive core inside a plant's reactor. A 2002 study by the Institute for Resource and Security Studies and the Federation of American Scientists found that about 161 million people—54% of the U.S. population—live

TRADE-OFFS

Conventional Nuclear Fuel Cycle

Advantages

- Large fuel supply
- Low environmental impact (without accidents)
- Emits 1/6 as much CO_2 as coal
- Moderate land disruption and water pollution (without accidents)
- Moderate land use
- Low risk of accidents because of multiple safety systems (except for Chernobyl-type reactors)

Disadvantages

- Cannot compete economically without huge government subsidies
- Low net energy yield
- High environmental impact (with major accidents)
- Environmental costs not included in market price
- Risk of catastrophic accidents
- 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 conventional nuclear fuel cycle (Figure 13-16) to produce electricity (**Concept 13-3**). **Question:** 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	Low 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 the nuclear power fuel cycle and 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.

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 has not been done.

THINKING ABOUT

Nuclear Power Plant Security

Do you favor strengthening security at nuclear power plants and providing better protection for pools and dry casks used to store spent nuclear fuel rods, even if this raises the cost of electricity? Why do you think this hasn't been done?

Currently, 60 countries—1 of every 3 in the world—have nuclear weapons or the knowledge and ability to build them. The United States and 14 other countries have been giving away and selling nuclear reactors and uranium enrichment technology in the international marketplace for decades. Much of this information and equipment can be used to produce weapons-grade material. Some see this as the single most important reason for not expanding the use of nuclear power, especially when there are cheaper, quicker, and safer ways to produce electricity.

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*, consisting mainly of spent fuel rods from commercial nuclear power plants and assorted wastes from the production of nuclear weapons, must be stored safely for 10,000–240,000 years. According to a Nevada state agency report, 10 years after being removed from a reactor, an unshielded spent-fuel assembly would still emit enough radiation to kill a person standing 1 meter (39 inches) away in less than 3 minutes.

Most scientists and engineers agree in principle that deep burial is the safest and cheapest way to store high-level radioactive waste. However, after more than 50 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 10,000–240,000 years (Case Study, at right).

For decades, researchers have been looking for ways—without success—to change harmful radioactive isotopes into less harmful isotopes. Even if a method were developed, costs would probably be extremely high, and the resulting toxic materials and low-level (but very long-lived) radioactive wastes would still require a safe disposal method.

RESEARCH FRONTIER

Safe, affordable nuclear waste storage

■ **CASE STUDY**

Experts Disagree over What to Do with Radioactive Wastes in the United States

In 1985, the DOE announced plans to build a repository for underground storage of high-level radioactive wastes from commercial nuclear reactors. The proposed site is on federal land in the Yucca Mountain desert region, 160 kilometers (100 miles) northwest of Las Vegas, Nevada.

The projected cost of this facility (financed jointly by nuclear power companies and taxpayers) is at least $58 billion and may reach $100 billion. The projected opening date is 2017, but there is no official opening date because of a number of legal battles and scientific problems with the site.

Critics charge that the selection of the Yucca Mountain site has been based more on political suitability than on scientific suitability. Some scientists argue that the site should never be allowed to open, mostly because rock fractures and tiny cracks may allow water to leak into the site and eventually corrode radioactive waste storage casks. In addition, the site is located in the third most seismically active region in the United States.

According to a 2004 review panel, rain that percolates into the mountain each year 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."

In 2002, the U.S. National Academy of Sciences, in collaboration with Harvard University and University of Tokyo scientists, urged the U.S. government to slow down and rethink its nuclear waste storage process. These scientists contend that storing spent fuel rods in dry-storage casks in well-protected buildings at nuclear plant sites, or at several other larger interim storage sites, is an adequate solution for at least 100 years, in terms of safety and national security. This would buy time to carry out more research on this complex problem and to evaluate other sites and storage methods.

Opponents also contend that the Yucca Mountain waste site should not be opened because it can 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 across much of the country for the estimated 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 the same as that stored before the Yucca Mountain repository opened. Critics contend that it will be much more difficult to protect such a large number of shipments from terrorist attacks than to provide more secure ways to store such wastes at nuclear power plant sites or other centralized sites.

Despite serious objections from scientists and citizens, in 2002 Congress approved Yucca Mountain as the official site for storing the country's commercial nuclear wastes.

HOW WOULD YOU VOTE?

Should highly radioactive spent fuel be stored in casks at high-security sites at or near nuclear power plants instead of being shipped to a single site for underground burial? Cast your vote online at **www.thomsonedu.com/biology/miller**.

What Do We Do with Worn-Out Nuclear Power Plants?

A nuclear power plant eventually comes to the end of its useful life, mostly because of corrosion and radiation damage to its metal parts. Because it contains intensely radioactive materials, it cannot simply be abandoned. Instead, it must be *decommissioned,* or retired—the last step in the nuclear power fuel cycle (Figure 13-16). Scientists have proposed three ways to do this.

One strategy is to dismantle the plant after it closes and store its large volume of highly radioactive materials in a high-level, nuclear waste storage facility, 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 before the plant is dismantled after its radioactive materials have reached safer levels.

A third option is to enclose the entire plant in a tomb that must last and be monitored for several thousand years. Regardless of the method chosen, decommissioning adds to the total costs of nuclear power and reduces its already low net energy. 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 443 large commercial reactors worldwide (20 in the United States) are scheduled for retirement by 2012. However, by 2006 the NRC had approved extending the operating licenses for 42 of the 104 U.S. nuclear reactors from 40 years to 60 years. Opponents contend this could increase the risk of nuclear accidents in aging reactors. At the same time, the NRC is cutting back on the frequency of safety tests from four times a year to once a year.

Can Nuclear Power Lessen Dependence on Imported Oil and Help Reduce Global Warming?

Some proponents of nuclear power in the United States claim it will help reduce the country's dependence on imported oil. Other analysts argue that it will not because less than 2% of the electricity 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 would reduce the threat of global warming by greatly reducing or eliminating emissions of CO_2. 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 13-16)—a fact rarely reported in media stories about nuclear power.

Such emissions are much less than those produced by burning coal or natural gas to generate the same amount of electricity (Figure 13-6). However, according to a 2004 study by German scientists, considering the entire nuclear fuel cycle, CO_2 emissions per kilowatt-hour of electricity are much higher than the numbers in Figure 13-6 indicate. Analysts contend that wasting less energy and increasing the use of wind turbines, solar cells, geothermal energy, and eventually hydrogen to produce electricity are much better ways to reduce CO_2 emissions.

Are New and Safer Nuclear Reactors the Answer?

Partly to address economic and safety concerns, the U.S. nuclear industry hopes to persuade the Congress to provide government subsidies to help them build hundreds of smaller, second-generation plants using standardized designs. The industry claims these plants are 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 or the release of radioactive emissions almost impossible. Most are *high-temperature, gas-cooled reactors* (HTGC) that avoid some of the problems associated with water-cooled reactors. Proponents also contend that gas-cooled reactors could be used to decompose water to produce hydrogen fuel that could be used to power motor vehicles and planes.

However, according to *Nucleonics Week,* an important nuclear industry publication, "Experts are flatly unconvinced that safety has been achieved—or even substantially increased—by the new designs." In addition, these new designs do not eliminate the expense and hazards of long-term radioactive waste storage, power plant decommissioning, and the spread of knowledge and materials for the production of nuclear weapons.

In 2006, researchers at the Massachusetts Institute of Technology developed a new design for uranium fuel containers in conventional nuclear power plants that within about 10 years might make the plants 50% more powerful and much safer by lowering operating temperatures. Much testing needs to be done and such plants would still produce radioactive wastes and have the potential to spread the development of nuclear weapons.

Some nuclear power proponents urge the development and widespread use of *breeder nuclear fission reactors,* which generate more nuclear fuel than they consume by converting nonfissionable uranium-238 into fissionable plutonium-239. However, if the safety system of a breeder reactor fails, it could create a runaway fission chain reaction and perhaps a nuclear explosion powerful enough to blast open the containment building and release a cloud of highly radioactive gases and particles into the atmosphere.

In December 1986, France opened a commercial-size breeder reactor. It was so expensive to build and operate that after spending $13 billion the government spent another $2.75 billion to shut it down permanently in 1998. Because of this experience, most countries have abandoned their plans to build full-size commercial breeder reactors. However, India, China, Japan, South Korea, and Russia have built or are planning to build small-scale breeder reactors to continue evaluating this technology.

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. Scientists hope that controlled nuclear fusion will provide an almost limitless source of high-temperature heat and electricity. Research has focused on the D–T nuclear fusion reaction, in which two isotopes of hydrogen—deuterium (D) and tritium (T)—fuse at about 100 million degrees (Figure 2-5, bottom, p. 32).

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 the hydrogen gas needed to run a hydrogen economy by the end of this century.

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 (taxpayer) 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 on a joint process to build a large-scale experimental nuclear fusion reactor by 2040 and to see if it can produce a net energy yield. If everything goes well, after 34 years, the plant is supposed to produce enough electricity to run the air conditioners in a small city for a few minutes. This helps explain why many energy experts do not expect nuclear fusion to be a significant energy source until 2100, if then.

Experts Disagree over the Future of Nuclear Power

Proponents of nuclear power argue that governments should continue funding research and development and pilot-plant testing of potentially safer and cheaper conventional fission reactor designs along with breeder fission and nuclear fusion. They say we need to keep these nuclear options available for use in the future, in case energy efficiency and renewable energy options fail to keep up with electricity demands while reducing CO_2 emissions to acceptable levels.

Others would support expansion of nuclear power only after we have solved the serious problems of storing nuclear wastes, improving security at nuclear power plants and waste storage facilities, and decreasing the threat from nuclear weapons proliferation.

Other analysts call for phasing out all or most government subsidies and tax breaks for nuclear power. They argue that conventional nuclear power is a complex, expensive, and inflexible way to produce electricity. They contend it is too vulnerable to terrorist attack and that it threatens global security by spreading knowledge and materials that can be used to build nuclear weapons.

According to many investors and World Bank economic analysts, conventional nuclear power cannot compete in today's increasingly open, decentralized, and unregulated energy market unless it is shielded from competition by government subsidies (as is the case in every country that has nuclear power plants).

Opponents of nuclear power say it makes better sense to invest limited government research and development funds in spurring the more rapid development of energy efficiency and renewable energy resources that are much safer and can be developed more quickly. We turn now to look at those alternatives.

HOW WOULD YOU VOTE? ✓

Should nuclear power be phased out in the country where you live over the next 20–30 years? Cast your vote online at **www.thomsonedu.com/biology/miller**.

13-4 Why Is Energy Efficiency an Important Energy Resource?

CONCEPT 13-4 We could save more than 40% of all the energy we use by improving energy efficiency.

We Waste Huge Amounts of Energy

Energy conservation involves reducing or eliminating the unnecessary waste of energy. One way to do this is to improve **energy efficiency** by getting more work from each unit of energy we use. You may be surprised to learn that 84% of all commercial energy used in the United States is wasted (Figure 13-19). About 41% of this energy is wasted automatically because of the degradation of energy quality imposed by the second law of thermodynamics (**Concept 2-4B**, p. 33). CONCEPT LINK

The other 43% is wasted unnecessarily, mostly due to the inefficiency of many motor vehicles, furnaces, industrial motors, and other devices. Another reason is that many people live and work in leaky, poorly insulated, badly designed buildings. According to energy expert Amory Lovins, "If the United States wants to save a lot of oil and money and increase national security, there are two simple ways to do it: Stop driving petropigs and stop living in energy sieves." (See Lovins's Guest Essay on this topic at ThomsonNOW™.) He and other energy experts point out that the cleanest and safest power plant is one we don't need to build, if we make improvements in energy efficiency, which are far less costly than building plants.

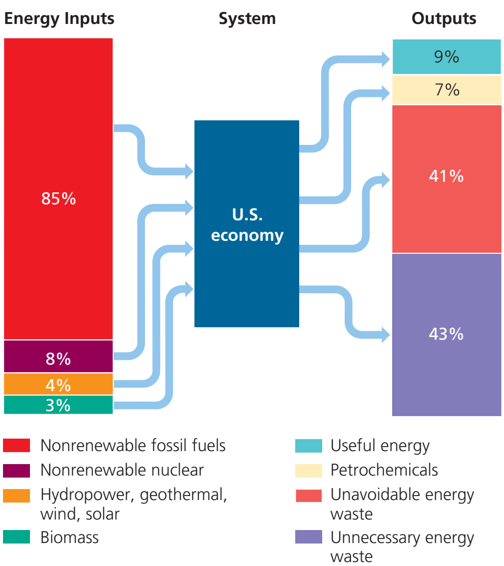


Figure 13-19 Flow of commercial energy through the U.S. economy. Only 16% of all commercial energy used in the United States ends up performing useful tasks or being converted to petrochemicals; the rest is unavoidably wasted because of the second law of thermodynamics (41%) or is wasted unnecessarily (43%). **Question:** What are three ways in which your lifestyle contributes to unnecessary energy waste? (Data from U.S. Department of Energy)

Energy efficiency in the United States has improved since the early 1980s. But unnecessary energy waste still costs the United States about $300 billion per year—an average of $570,000 per minute.

Between 1980 and 2000, when gasoline was still cheap, many Americans switched from cars to SUVs and minivans, moved from the cities to the suburbs and then to the exurbs, and began living in larger, less energy-inefficient houses. Now 3 of every 4 Americans drive to work, mostly in gas-guzzling vehicles, and only 5% rely on mass transit. As a result, two-thirds of the petroleum used in the United States is for transportation and 60% of the country's oil is imported, causing a massive hemorrhage of money that could be used for other purposes. In addition, much of this money goes to countries that support terrorist activities against the oil-addicted United States.

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, slow global warming, and increase economic and national security.*

Four widely used devices waste large amounts of energy:

- An *incandescent light bulb* uses only 5% of the electricity it draws to produce light, while the other 95% is wasted as heat. It is really a *heat bulb.*
- A motor vehicle with an *internal combustion engine* wastes 94% of the energy in its fuel.
- A *nuclear power plant* producing electricity for space heating or water heating wastes about 86% of the energy in its nuclear fuel and probably 92% when we include the energy needed to deal with its radioactive wastes and to retire the plant.
- A *coal-burning power plant* wastes two-thirds of the energy released when the coal is burned.

Energy experts call for us to replace these energy-wasting devices or greatly improve their energy efficiency over the next few decades.

According to a 2004 study by David Pimentel and other scientists, the U.S. government could, within a

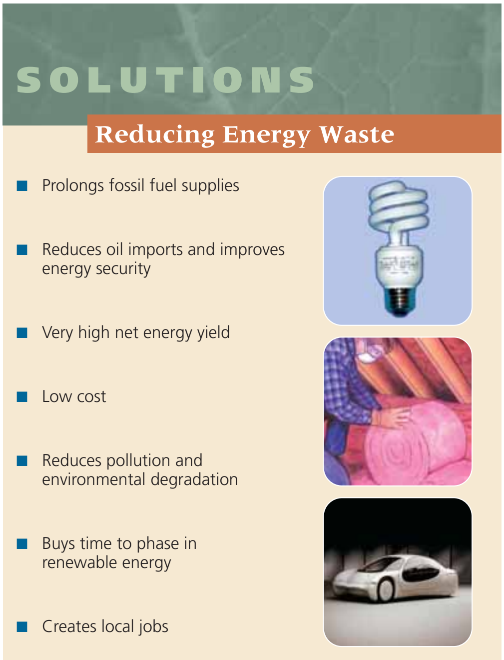


Figure 13-20 Advantages of reducing unnecessary energy waste and improving energy efficiency. Global improvements in energy efficiency could save the world about $1 trillion per year—an average of $114 million per hour! **Question:** Which two of these advantages do you think are the most important? Why?

decade, implement energy conservation and efficiency measures that would reduce current U.S. energy consumption by one-third and save consumers $438 billion per year or $833,000 per minute (**Concept 13-4**).

We Can Save Energy and Money in Industry

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 power plant 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), and they emit two-thirds less CO_2 per unit of energy produced than conventional coal-fired boilers do.

Cogeneration has been widely used in Western Europe for years. Its use in the United States (where it now produces 9% of the country's electricity) and in China is growing.

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. Each year, a heavily used electric motor consumes 10 times its purchase cost in electricity—equivalent to using $200,000 worth of gasoline each year to fuel a $20,000 car! The costs of replacing such motors with more efficient ones would be paid back in about 1 year and would save an amount of energy equal to that generated by 150 large (1,000-megawatt) power plants.

A third 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.*

We Can Save Energy in Transportation

Transportation accounts for two-thirds of U.S. oil consumption and is the predominant source of the country's urban air pollution and inputs of CO_2 into the atmosphere. 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 sold in the United States decreased by 5%, mostly because there has been no increase in the CAFE standards and because mileage standards for popular trucks and SUVs are not as high as those for cars. China now has higher mileage standards for its autos than the United States does.

Fuel-efficient cars are available but account for less than 1% of all car sales in the United States. One reason is that the inflation-adjusted price of gasoline in the United States today is fairly low—costing less per liter than bottled water.

Most U.S. consumers do not realize that gasoline costs them much more than the price they pay at the pump. According to a 1998 study by the International Center for Technology Assessment, if the hidden environmental and health costs of using gasoline were included as taxes in the market price of gasoline, the *true cost* of gasoline for U.S. consumers would be about $2.90 per liter ($11 per gallon). Filling a 20-gallon tank would cost about $220 and consumers would demand much more energy-efficient and less polluting cars.

These hidden costs include government subsidies and tax breaks for oil companies and road builders; costs of pollution control and cleanup; costs of military protection of oil supplies in the Middle East; increased medical bills and insurance premiums; time wasted in traffic jams; and increased deaths from air and water pollution. Politically powerful oil and car companies benefit financially by keeping these costs hidden and passing them on to consumers, future generations, and the environment.

> **THINKING ABOUT**
> **Gasoline Taxes**
>
> Would you support drastically higher gasoline taxes to encourage higher fuel efficiency, to lessen dependence on foreign oil, and to help reduce global warming, if payroll and income taxes were reduced to balance the increase in gasoline taxes? Explain.

A *second* reason for low fuel efficiency is that more than half of all U.S. consumers own SUVs, pickup trucks, minivans, and other large, inefficient vehicles compared to 5% in 1990. And *third,* the government has not given buyers large enough tax breaks to encourage them to buy more fuel-efficient vehicles.

In 1991, energy expert Amory Lovins proposed a *feebate* program in which fuel-inefficient vehicles would be taxed heavily and the resulting revenue would be given to buyers of efficient vehicles as rebates (not tax deductions). For example, the tax on a $50,000 Hummer H2 that averages about 5 kilometers per liter (kpl), or 12 miles per gallon (mpg), might be $10,000. The same amount could go as a rebate to the buyer of a $22,000 hybrid car that averages 21 kpl, or 50 mpg. Within a short time, such a program—endorsed in 2001 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.

> **THINKING ABOUT**
> **Feebates**
>
> Do you support implementation of a feebate program? Explain. Why do you think this hasn't been done?

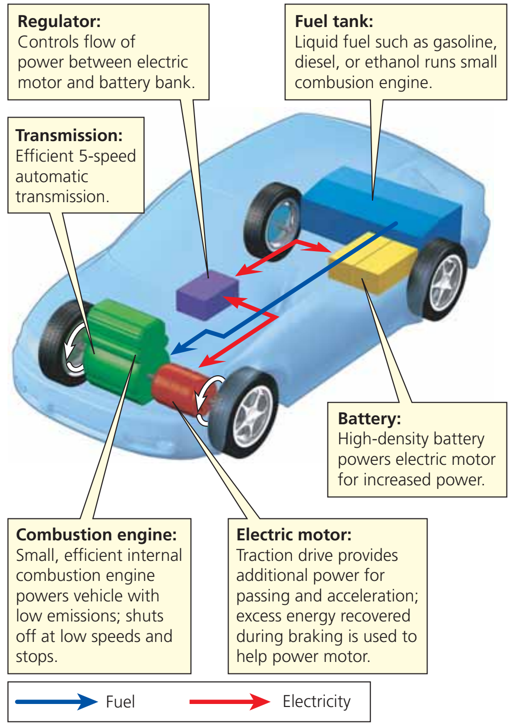


Figure 13-21 **Solutions:** general features of a car powered by a *hybrid gasoline–electric engine.* **Question:** Would you buy such a car? Why or why not? (CONCEPT information from DaimlerChrysler, Ford, Honda, and Toyota)

Hybrid Vehicles Can Reduce Oil Imports and Greenhouse Gas Emissions

There is growing interest in developing *super-efficient and ultralight cars* that could eventually get 34–128 kpl (80–300 mpg), as proposed in 1991 by Amory Lovins. (See his Guest Essay on this topic at ThomsonNOW.)

One of these vehicles is the energy-efficient gasoline–electric *hybrid car* (Figure 13-21). It has a small traditional gasoline-powered motor and an electric motor used to provide the energy needed for acceleration and hill climbing. Current models of these cars get up to 21 kpl (50 mpg).

The next step is a *plug-in hybrid electric vehicle* with a second bigger and more powerful battery that can be plugged into a standard outlet and recharged overnight (at lower off-peak electric rates) or during the day.

By running primarily on electricity, such a vehicle could easily get the equivalent of at least 43 kpl (100 mpg) for highway and city driving, and up to 430 kpl (1,000 mpg) if used only for trips of less than 32 kilometers (40 miles). Such cars are technically feasible today but more research is needed to develop a battery that is strong, safe, and inexpensive enough to use in a mass auto market. Replacing the current U.S. vehicle fleet with plug-in hybrids over the next 20 years would cut U.S. oil consumption by 70–90%, eliminate the need for oil imports, improve national security, and greatly reduce CO_2 emissions.

In the United States, most of the electricity used to recharge the extra battery would be generated by coal and nuclear power plants that have a number of disadvantages (Figure 13-12 and Figure 13-17). However, if renewable wind energy and solar cells (discussed later in this chapter) were used to generate electricity to charge their batteries, these vehicles would come close to being pollution-free, implementing the solar energy **scientific principle of sustainability** (see back cover).

The fuel efficiency for all types of cars could nearly double if car bodies were 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 be lowered by mass production and further research.

We Can Run Vehicles on Hydrogen

Another type of super-efficient car is an electric vehicle that uses a *fuel cell*—a device that combines hydrogen gas (H_2) and oxygen gas (O_2) to produce electricity and water vapor, which is emitted into the atmosphere (Figure 13-22).

Fuel cells are at least twice as efficient as internal combustion engines, have no moving parts, require little maintenance, and emit no air pollutants or CO_2 if the hydrogen is produced from renewable-energy resources. The problem is that they are quite expensive, although scientists and engineers are working hard to bring down the price.

Energy experts see the following progression: today's gasoline hybrids; followed by plug-in gasoline hybrids; ultralight and ultrastrong plug-in hybrids; and ultimately ultralight and ultrastrong fuel-cell vehicles. In 20 years, China plans to become the world's largest producer and seller of such motor vehicles as part of its plan to become the world's leading economy.

RESEARCH FRONTIER

Developing better and more affordable hybrid and fuel-cell vehicles

We Can Design New Buildings That Save Energy and Money: Green Architecture

Many commercial buildings and homes are energy-wasting hogs. According to the U.S. Department of Energy, commercial and residential buildings in the United States consume more energy than the country's cars and trucks consume. These buildings use 65% of the country's electricity and emit about a third of its greenhouse gases. Most consumers don't think about

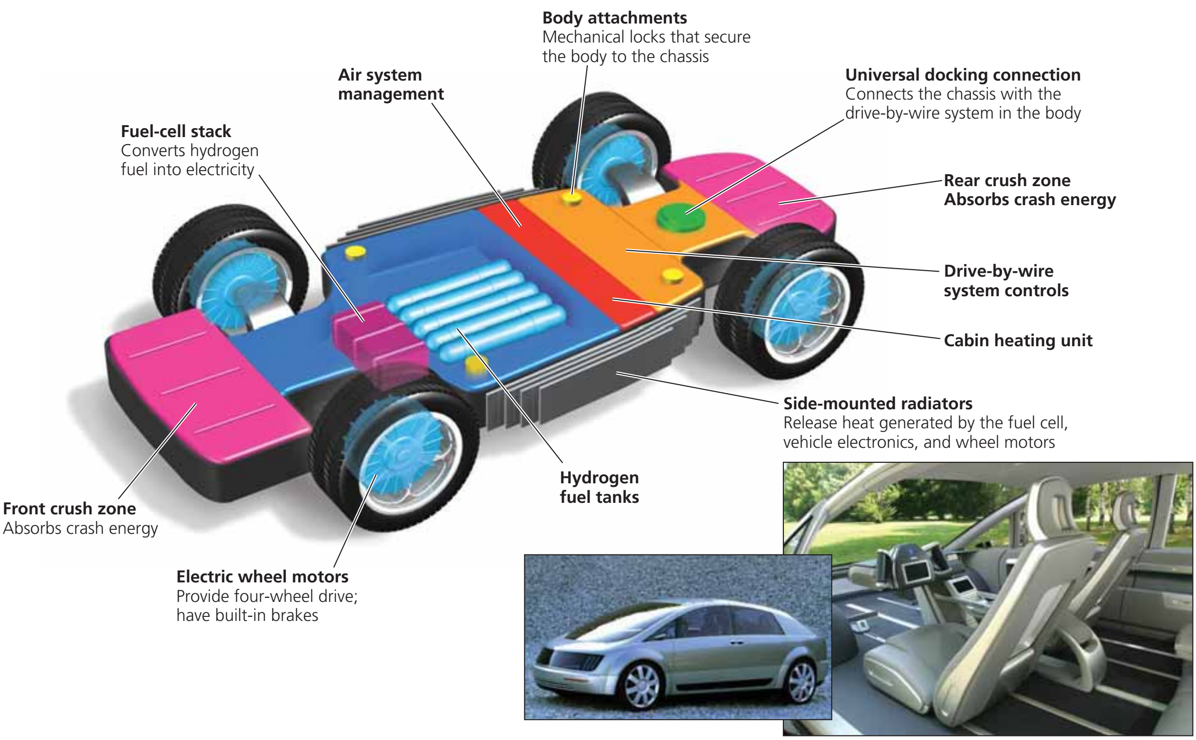


Figure 13-22 **Solutions:** prototype *hydrogen fuel-cell car* developed by General Motors. This ultralight and ultrastrong car consists of a skateboard-like chassis and a variety of snap-on fiberglass bodies. It handles like a high-speed sports car, zips along with no engine noise, and emits only wisps of warm water vapor and heat—no smelly exhaust, no smog, no greenhouse gases. General Motors claims the car could be on the road within a decade, but some analysts believe that it will be 2020 before this and fuel-cell cars from other manufacturers will be mass produced. **Question:** Would you buy such a car if it became available? Explain. (Basic information from General Motors)

such connections when they flip a light switch or turn on their air conditioner. It doesn't have to be this way.

A 2007 study showed that orienting a building correctly 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 makes effective use of renewable energy. 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 solar energy. 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.

Such *green architecture,* based on energy-efficient and money-saving designs, makes use of solar cells, fuel cells, roofs covered with soil and vegetation, and recycled materials. It is beginning to catch on in Europe, the United States, and Japan (which is the world's most energy-efficient nation). In the United States, energy-efficiency building guidelines and standards have been established by the Green Building Council's Leadership in Energy and Environmental Design (LEED) program and the federal government's Energy Star program. There is a long way to go, but by 2007 about 5% of new commercial construction in the U.S. met LEED standards and 10% of new homes met Energy Star guidelines. **GREEN CAREERS:** Green architect or builder

Another energy-efficient design is a *super-insulated house.* Such houses typically cost 5% more to build than conventional houses of the same size. The extra cost is paid back by energy savings within about 5 years and can save a homeowner $50,000–100,000 over a 40-year period. Super-insulated houses in Sweden use 90% less energy for heating and cooling than the typical American home of the same size uses.

Since the mid-1980s, there has been growing interest in *straw bale houses* (Figure 13-23). The walls of these super-insulated 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. The main problem is getting banks and other moneylenders to recognize the potential of this and other unconventional types of housing and to provide homeowners and developers with construction loans. See the Guest Essay about straw bale and solar energy houses by Nancy Wicks at ThomsonNOW.

Living roofs, or *green roofs,* covered with plants have been used for decades in Germany, Iceland, and other parts of Europe, and in U.S. cities such as Chicago, Illinois. These roofs save energy and help to preserve biodiversity.

We Can Save Energy and Money in Existing Buildings

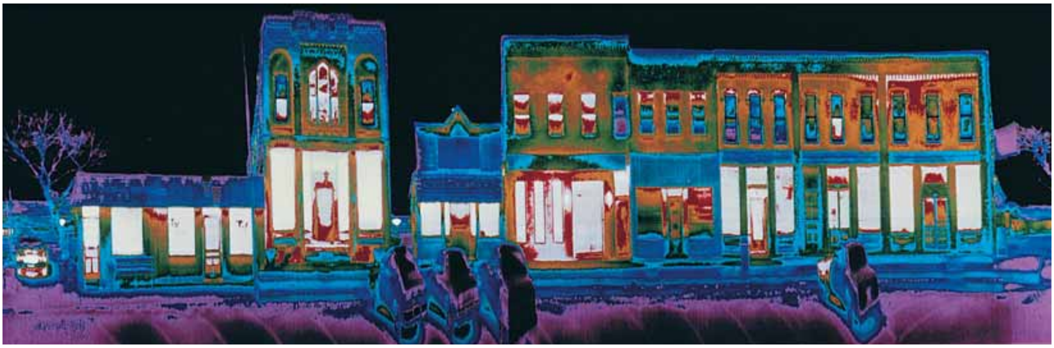
Here are some ways to save energy in existing buildings.

- *Insulate and plug leaks.* About one-third of the heated air in typical U.S. homes and buildings escapes through closed windows, holes, and cracks (Figure 13-24)—roughly equal to the energy in all

Alison Gannett

Alison Gannett

Figure 13-23 **Solutions:** energy-efficient, environmentally healthy, and affordable Victorian-style *straw bale house* designed and built by Alison Gannett in Crested Butte, Colorado (USA). The left photo was taken during construction; the right photo shows the completed house. Depending on the thickness of the bales, plastered straw bale walls have an insulating value of R-35 to R-60, compared to R-12 to R-19 in a conventional house. (The R-value is a measure of resistance to heat flow.) Such walls are also great sound insulators. **Questions:** What are some possible disadvantages of straw bale construction? Do you think they outweigh the advantages? Explain.



VANSCAN® Continuous Mobile Thermogram by Daedalus Enterprises, Inc.

Figure 13-24 A *thermogram* (infrared photo) showing heat loss (red, white, and orange) around the windows, doors, roofs, and foundations of houses and stores in Plymouth, Michigan. 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 having a large window-sized hole in the wall of the house. **Question:** How do you think the place where you live would compare to these houses in terms of heat loss?

the oil flowing through the Alaska pipeline every year. During hot weather, these windows and cracks let heat in, increasing the use of air conditioning. Adding insulation and plugging leaks in a house are two of the quickest, cheapest, and best ways to save energy and money.

- *Use energy-efficient windows.* Replacing inefficient windows with energy-efficient windows can cut expensive heat losses from houses by two-thirds, lessen cooling costs in the summer, and help to reduce CO_2 emissions. Widely available super-insulating windows do the job of 8–12 sheets of glass. Even better windows will reach the market soon.
- *Stop other heating and cooling losses.* Leaky heating and cooling ducts in attics and unheated basements allow 20–30% of a home's heating and cooling energy to escape and draw unwanted moisture and heat into the home. Careful sealing can reduce this loss. Some designs for new homes keep the air ducts inside the home's thermal envelope so that escaping hot or cool air is fed back into the living space. Also, using light-colored roofing shingles instead of dark singles—or using living roofs—can cut electricity use for air conditioning.
- *Heat houses more efficiently.* In order, the most energy-efficient devices we use to heat space are superinsulation; a geothermal heat pump that transfers heat stored in the earth to a home; passive solar heating; a conventional heat pump (in warm climates only); small cogenerating microturbines; and a high-efficiency (85–98%) natural gas furnace. The most wasteful and expensive way to heat a space is to use electric resistance heating with the electricity produced by a coal-fired or nuclear power plant.
- *Heat water more efficiently.* One approach is to use a *tankless instant water heater* (about the size of a suitcase) fired by natural gas or LPG but not by electricity. These devices, widely used in many parts of Europe, heat water instantly as it flows through a small burner chamber, providing hot water only when it is needed, and using less energy than traditional water heaters. They cost 2–4 times more than conventional water heaters, but save money in the long run because they last 3–4 times longer and cost less to operate than conventional water heaters. They work. I (Miller) used them in a passive solar office and living space for 15 years.
- *Use energy-efficient appliances and lighting.* According to the EPA and Amory Lovins, if all U.S. households used the most efficient frost-free refrigerator now available, 18 large (1,000-megawatt) power plants could close. Microwave ovens can cut electricity use for cooking by 25–50% and convection ovens cut energy use by about 20%. Clothes dryers with moisture sensors cut energy use by 15%, and front-loading washers use 55% less energy and 67% less water than do top-loading models. A compact fluorescent bulb produces as much light as a regular incandescent bulb, but lasts up to 10 times longer, produces 206 kilograms (450 pounds) less CO_2, uses 75% less electricity, and saves consumers $30 over the life of each bulb. Replacing 20 incandescent light bulbs in a home or business with energy-efficient compact fluorescent bulbs can save about $600. The Department of Energy estimates that if every U.S. home replaced just one incandescent bulb with a compact fluorescent bulb, the nation would save enough energy to fully light more than 2.5 million homes a year and prevent greenhouse gases equivalent to the emissions of nearly 800,000 cars. Although their initial cost is eight times higher than that of conventional bulbs, this cost is paid back within a few months because of cheaper electricity bills, after which consumers make money on their investment). Earlier fluorescent bulbs gave off a

harsh light and were too large to fit in many lighting fixtures and lamps, but new ones have overcome these problems. In 2007, Wal-Mart began using its marketing clout to convince consumers to switch to power-sipping and money-saving compact fluorescent bulbs. Even more energy-efficient light-emitting diode (LED) bulbs will soon be available. LEDs use about one-seventh of the energy of an incandescent bulb and can last about 100 times as long, up to 100,000 hours.

THINKING ABOUT
Saving Energy and Money

In your home, do you use any of the energy-saving measures listed above? Which, if any, do you plan to use in the future?

Why Are We Still Wasting So Much Energy?

If there is such an impressive array of benefits (Figure 13-20), why is there so little emphasis on improving energy efficiency? One reason is a glut of fairly low-cost fossil fuels. As long as energy remains artificially cheap because market prices do not include its harmful environmental and health costs, people are more likely to waste it and less likely to make investments in improving energy efficiency.

Another reason is that there are few *large* and *long-lasting* tax breaks; rebates; low-interest, long-term loans; and other economic incentives for consumers and businesses to invest in improving energy efficiency.

Would you like to earn about 20% per year on your money, tax free and risk free? Invest it in improving the energy efficiency of your home, lights, and appliances. You will get your investment back in a few years and then make about 20% per year by having lower heating, cooling, and electricity bills. This is a win–win deal for you and the earth.

HOW WOULD YOU VOTE?

Should the United States (or the country where you live) greatly increase its emphasis on improving energy efficiency? Cast your vote online at **www.thomsonedu.com/biology/miller**.

13-5 What Are the Advantages and Disadvantages of Renewable Energy Resources?

CONCEPT 13-5 Using a mix of renewable energy sources—especially wind, solar energy, hydropower, biofuels, geothermal energy, and hydrogen—can drastically reduce pollution, greenhouse gas emissions, and biodiversity losses.

We Can Use Renewable Energy to Provide Heat and Electricity

One of nature's four **scientific principles of sustainability** is to *rely mostly on solar energy* (see back cover). We can get renewable solar energy directly from the sun or indirectly from moving water, wind, and biomass. Another form of renewable energy is geothermal energy from the earth's interior. Recent studies show that with increased and consistent government backing, renewable energy could provide 20% of the world's electricity by 2025 and 50% by 2050 at little or no additional net cost. The European Union has a binding target of getting 20% of its energy from renewable sources by 2020 (compared to 7% in 2006). China has a goal of getting 10% of its energy from renewable sources by 2020. China, Japan, and the European Union countries see green energy as the growth industry of the 21st century and want to be in a position to profit from such growth.

Renewable energy technology has become one of the hottest investment opportunities for venture capitalists around the globe. Such investments are spurring rapid advances in energy technologies, driving down costs, and creating jobs—many of them high-paying. Today, the production, installation, and maintenance of various types of renewable energy systems provide approximately 2 million jobs worldwide.

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 is less vulnerable to supply cutoffs from terrorist attacks and natural disasters such as hurricanes.
- Improve national security by reducing the need to import oil from the Middle East.
- Reduce trade deficits resulting from importing oil.
- Greatly reduce air pollution and emissions of greenhouse gases.

- Create large numbers of high-paying jobs for skilled workers.
- Save consumers money.

If renewable energy is so great, why does it provide only 18% of the world's energy and 6% of the energy used in the United States (Figure 13-3)? One reason is that since 1950 renewable energy resources have received much lower government tax breaks, subsidies, and research and development funding than have fossil fuels (especially oil) and nuclear power, although subsidies for renewables have increased in recent years. The other reason is that the prices we pay for fossil fuels and nuclear power do not include the costs of their harm to the environment and to human health.

If these two economic handicaps—*inequitable 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.

Things are beginning to change. Some of the world's largest companies, including BP, Royal Dutch/Shell, General Electric, Dupont, Toyota, and Honda, are beginning to move into the rapidly growing global market for renewable energy technologies. In addition, a growing coalition of farmers, ranchers, forestry and business interests, insurance and investment interests, organized labor, and environmental and religious groups are pushing for much greater dependence on renewable energy because it makes economic and environmental sense.

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 structure without the need for pumps or fans to distribute the heat (Figure 13-25, left). Energy-efficient windows and attached greenhouses face the sun to collect solar energy directly. Walls and floors of concrete, adobe, brick, stone, or salt-treated timber, and metal or plastic water tanks can store much of the collected solar energy as heat and release it slowly throughout the day and night. A small backup heating system such as a vented natural gas or propane heater may be used, but is not necessary in many climates. (See the Guest Essay by Nancy Wicks at ThomsonNOW.)

On a life cycle cost basis, good passive solar and super-insulated design is the cheapest way to heat a home or small building in sunny areas. The typical payback time for passive solar features is 3–7 years.

An **active solar heating system** absorbs 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. 306) 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 4 on p. S65 in Supplement 16 for a global map of solar energy availability and Figures 5 and 10 in the same supplement for maps of its availability in North America and the United States.) But solar energy cannot be used to heat existing homes and buildings that are not oriented to receive sunlight or that are blocked from sunlight by other buildings or trees.

Active solar collectors provide hot water for more than 40 million households—59% of them in China,

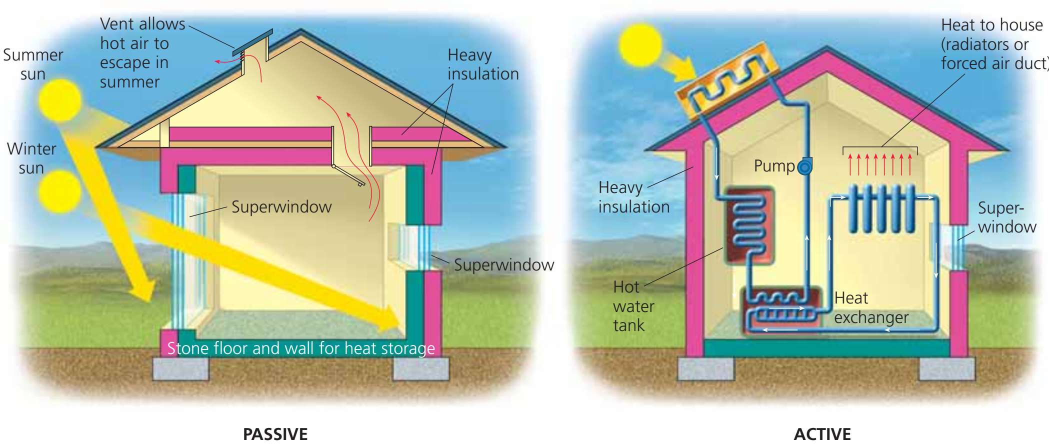


Figure 13-25 **Solutions:** passive and active solar heating for a home (**Concept 13-5**). **Question:** Would you, or do you, rely on active or passive solar heating? Explain why or why not and which type you prefer.

TRADE-OFFS

Passive or Active Solar Heating

Advantages	Disadvantages
Energy is free	Need access to sun 60% of time
Net energy is moderate (active) to high (passive)	Sun can be blocked by trees and other structures
Quick installation	Environmental costs not included in market price
No CO_2 emissions	Need heat storage system
Very low air and water pollution	High cost (active)
Very low land disturbance (built into roof or windows)	Active system needs maintenance and repair
Moderate cost (passive)	Active collectors unattractive

Figure 13-26 Advantages and disadvantages of heating a house with passive or active solar energy (**Concept 13-5**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

which plans to expand their use fourfold by 2015. They are also widely used in countries such as Germany, Japan, Israel, Turkey, and Spain (which in 2007 began requiring them on all new or renovated buildings). They work. I (Miller) used both passive and active solar collectors for 15 years to provide hot water in my office-home structure.

TRADE-OFFS

Solar Energy for High-Temperature Heat and Electricity

Advantages	Disadvantages
Moderate net energy	Low efficiency
Moderate environmental impact	High costs
No CO_2 emissions	Environmental costs not included in market price
Fast construction (1–2 years)	Needs backup or storage system
Costs reduced with natural gas turbine backup	Need access to sun most of the time
	High land use
	May disturb desert areas

Figure 13-27 Advantages and disadvantages of using solar energy to generate high-temperature heat and electricity. **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

We Can Cool Houses Naturally

Conventional air conditioning uses a lot of electricity and relies largely on fossil fuels, violating the **principles of sustainability**. Here are some ways to cool a house by working with nature and following those principles. Use super-insulation and super-insulating windows, open windows to take advantage of breezes, and use fans to keep air moving. Block the high summer sun with window overhangs or awnings. 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). Or use a green roof with soil and vegetation to provide some insulation. Suspend reflective insulating foil in the attic to block heat from radiating down into the house.

Another option is to place plastic *earth tubes* underground where the earth is cool year-round. In this inexpensive geothermal cooling system, a tiny fan can pipe cool and partially dehumidified air into a house. (They worked for me [Miller]. I used them for 15 years in my passively heated and cooled office and home with an electricity cost of about $1 a month.) People allergic to pollen and molds should add an air purification system, but this is also necessary with conventional cooling systems.

Geothermal heat pumps for cooling (and heating in winter) are another alternative. Using conventional central air conditioning units with a *seasonal energy-efficiency rating* (SEER) of 14 or higher is also a reasonably efficient way to cool a house.

We Can Use Sunlight to Produce High-Temperature Heat and Electricity

Solar thermal systems can collect and transform energy from the sun into high-temperature thermal energy (heat), which can then be used directly or converted to electricity. These systems are used mostly in desert areas with ample sunlight. Figure 13-27 lists advantages and disadvantages of concentrating solar energy to produce high-temperature heat or electricity.

One approach is a *solar thermal plant* in which sunlight is collected and focused on oil-filled pipes running through the middle of a large area of curved solar collectors (bottom drawing in Figure 13-27). This concentrated sunlight can generate temperatures high enough to produce steam for running turbines and generating electricity. Since the mid-1980s, nine plants using this technology have been producing electricity in California's Mojave Desert.

Most analysts do not expect widespread use of such technologies over the next few decades because of their

Figure 13-28 **Solutions:** woman in India uses a solar cooker to prepare a meal for her family.

high costs, low net-energy yields, the limited number of suitable sites, and availability of cheaper alternatives.

THINKING ABOUT
Using Solar Energy to Produce High Temperatures

CONCEPT LINK

Use the first and second laws of thermodynamics (**Concepts 2-4A** and **2-4B**, p. 33) and the related concept of net energy (p. 282) to explain why generating high-temperature heat and electricity from solar energy is likely to be quite costly.

On a smaller scale, inexpensive *solar cookers* can focus and concentrate sunlight to cook food, especially in rural villages in sunny areas (Figure 13-28). A solar cooker can be built for $2–10 by fitting an insulated box big enough to hold three or four pots with a transparent, removable top. Solar cookers reduce deforestation and save time and labor needed to collect firewood. They also reduce indoor air pollution from smoky fires.

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.

Solar cells have no moving parts, are safe and quiet, require little maintenance, produce no pollution during operation, and last as long as a conventional fossil fuel or nuclear power plant. The semiconductor material used in solar cells can be made into paper-thin rigid or flexible sheets (Figure 12-1, p. 261) that can be incorporated into traditional-looking roofing materials (Figure 13-29, right) and attached to walls, windows, and clothing. Recently, U.S. companies have produced small, "plug-and-play" solar cell systems that can be used to supply electricity for new or existing homes and other buildings.

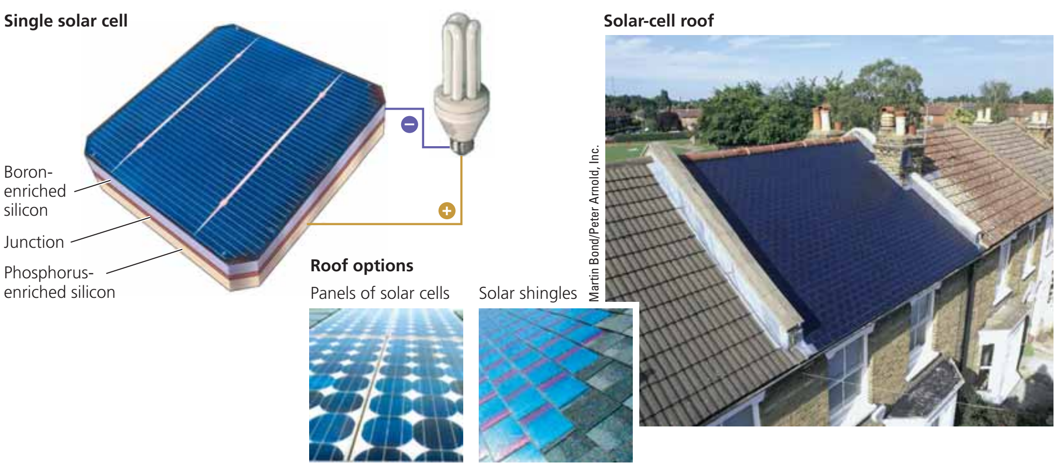


Figure 13-29 **Solutions:** Photovoltaic (PV) or solar cells can provide electricity for a house or building using solar-cell roof shingles, as shown in this house in Richmond Surrey, England. Solar-cell roof systems that look like a metal roof are also available. In addition, new thin-film solar cells can be applied to windows and outside glass 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 aid poor countries to obtain such solar cells? Explain.

TRADE-OFFS

Solar Cells

Advantages

- Fairly high net energy yield
- Work on cloudy days
- Quick installation
- Easily expanded or moved
- No CO_2 emissions
- Low environmental impact
- Last 20–40 years
- Low land use (if on roof or built into walls or windows)
- Reduces dependence on fossil fuels

Disadvantages

- Need access to sun
- Low efficiency
- Need electricity storage system or backup
- Environmental costs not included in market price
- High costs (but should be competitive in 5–15 years)
- High land use (solar-cell power plants) could disrupt desert areas
- DC current must be converted to AC

Figure 13-31 Advantages and disadvantages of using solar cells to produce electricity (**Concept 13-5**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

Easily expandable banks of solar cells can be used in developing countries to provide electricity for many of the 1.7 billion people in rural villages (Figure 13-30). With financing from the World Bank, India is installing solar-cell systems in 38,000 remote villages. Mark Bent has developed a $20 solar flashlight with a long-lasting LED bulb that uses a small strip of solar cells to recharge its batteries. Private charities and U.N. agencies are distributing thousands of them to remote villages in Africa.

China plans to use solar cells and wind turbines to provide electricity for 29,000 villages to ease its dependence on coal. Within 10 to 20 years China plans to become the world's largest producer and seller of solar cells as part of its long-range plan to lead the world in carrying out a new *green industrial revolution.*

Figure 13-31 lists the advantages and disadvantages of solar cells. The key problem is the high cost of using solar cells to produce electricity. Table 13-1 compares the total costs of producing electricity from various renewable and nonrenewable sources. Note that when their generating costs and their estimated harmful environmental costs are combined, wind and hydropower are the two cheapest ways to produce electricity, and the nuclear power fuel cycle and solar cells are the most expensive. But the costs for solar cells are expected to drop in coming years because of improved designs and mass production. **GREEN CAREER:** Solar cell technology

Currently, solar cells supply less than 0.05% of the world's electricity and only 0.01% of electricity used in the United States. Energy analysts say that with greatly increased government and private research and development, plus much greater and more consistent government tax breaks and other subsidies, they could provide 16% of the world's electricity by 2040 (**Concept 13-5**). According to the International Energy Agency (IEA), installing large-scale solar-cell systems on just 4% of the world's deserts could generate enough electricity annually to meet the entire world's electrical power demand. If these projections are correct, the production, sale, and installation of solar cells could become one of the world's largest and fastest-growing businesses and represent a major step on the path to sustainability.

However, using large-scale solar cell systems will require countries including the United States to upgrade and greatly expand their inadequate and outdated national electricity distribution systems. China, with the world's second largest power market, plans to spend $25 billion building an ultra high voltage (UHV) electricity network by 2020.

In 1980, the United States led the world in solar cell research and production but lost the lead to Japan and Germany as a result of sharp cutbacks in government research and development for solar cells. Now Americans buy most of their solar cells from Japanese and German companies. But General Electric has gotten into the solar cell business and may help the United States to again become the world's leader in technology and sales of solar cells.

RESEARCH FRONTIER

Developing more efficient and affordable solar cells

HOW WOULD YOU VOTE?

Should the United States (or the country where you live) greatly increase its dependence on solar cells for producing electricity? Cast your vote online at **www.thomsonedu.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. Since it is based on the water cycle, which is powered by the sun (Figure 3-18, p. 54), renewable hydropower is an indirect form of solar energy.

The most common way to harness 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 11-11, p. 235).

Hydropower is the leading renewable energy source used to produce electricity and is the second cheapest way to produce electricity when operating and environmental costs are included (Table 13-1). In order, the world's top five producers of hydropower are Canada, China, Brazil, the United States, and Russia. In 2005, hydropower supplied about 25% of the world's electricity, including 99% of that used in Norway, 75% in New Zealand, 15% in China, and 7% in the United States (but about 50% on the West Coast).

Because of increasing concern about the harmful environmental and social consequences of large dams (Figure 11-11, p. 235), the World Bank and other development agencies have been pressured to stop funding new large-scale hydropower projects. 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.

Figure 13-32 lists the advantages and disadvantages of using large-scale hydropower plants to produce electricity.

HOW WOULD YOU VOTE?

Should the world greatly increase its dependence on large-scale dams for producing electricity? Cast your vote online at **www.thomsonedu.com/biology/miller**.

The use of *micro-hydro generators* may become an increasingly important way to produce electricity. These floating turbines use the power of a river's flow to turn a rotor with blades that feed generators to produce

Table 13-1

Total Costs of Electricity from Different Sources in 2004 (U.S. cents per kilowatt hour)*

Electricity Source	Generating Costs	Environmental Costs	Total Costs
Wind	3–7	0.1–0.3	3.1–7.3
Hydropower	3–8	0–1.1	3.0–9.1
Geothermal	5–8	1 (approx.)	6.0–9.0
Natural gas	5–7	1.1–4.5	6.1–11.5
Coal	4–6	2.3–17.0	6.3–23.0
Biomass	6–9	1.0–3.4	7.0–12.4
Nuclear fuel cycle	8–12	0.2–0.7	8.2–12.7
Solar cells	12–26	0.7	12.7–26.7

*Data from U.S. Department of Energy and a variety of sources compiled by the Worldwatch Institute; from the latest year for which all such data are available.

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 CO_2 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	

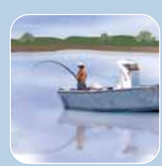


Figure 13-32 Advantages and disadvantages of using large dams and reservoirs to produce electricity (**Concept 13-5**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

electric current. About the size of an overnight suitcase, such a generator 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.

We can also produce electricity from flowing water by tapping into the energy from *ocean tides* and *waves.* A number of devices for this purpose are being tested. Great Britain could generate up to 20% of its electricity from waves and tides. However, most analysts expect these sources to make only a tiny contribution to world electricity supplies, primarily because of a lack of suitable sites, high costs, and vulnerability of equipment to corrosion and storm damage.

Using Wind to Produce Electricity Is an Important Step on the Path to 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.* This indirect form of solar energy can be captured by wind turbines and converted into electrical energy (Figure 13-33). A modern wind turbine can be as tall as 30 stories and have blades as long as a typical jumbo jet plane, which allows it to tap into 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 2006 were Germany, Spain, the United States, and India. A wind farm can be built fairly quickly, can be controlled by a single laptop computer, and at good sites can produce electricity as cheaply as coal, natural gas, and hydropower (Table 13-1). Within a few years, wind is expected to be the cheapest way to produce electricity. If the environmental costs of energy resources are included, wind energy is already the cheapest and least polluting way to produce electricity (Table 13-1 and **Concept 13-5**).

In 2004, Stanford University engineers Cristina L. Archer and Mark Z. Jacobson mapped the global potential for wind energy (see Figure 6 on p. S67 in Supplement 16). Their data indicate that capturing only 20% of the wind energy at the world's best energy sites could generate more than seven times the amount of electricity currently used in the world. This could replace the energy output of 500 large nuclear power plants and thousands of large coal-burning power plants.

Analysts expect increasing use of offshore wind farms (Figure 13-33, right) because wind speeds over water are often stronger and steadier than those over land, any noise produced is muffled by surf sounds, and negotiations with multiple landowners are unnecessary. However, offshore installation costs are higher and some coastal towns and cities oppose such installations because of their visual pollution—just as they oppose offshore oil platforms (Figure 13-1, p. 279).

Figures 7 and 10 in Supplement 16 (pp. S68–S69) show the potential land areas for use of wind power in the United States, which currently gets less than 1% of its electricity from this energy resource, with Texas and California leading the way. However, this percentage is poised to expand dramatically. **GREEN CAREER:** Wind prospector

The DOE calls the Great Plains states of North Dakota, South Dakota, Kansas, and Texas the "Saudi Arabia of wind power." These four states in principle have enough wind resources to more than meet all of the nation's current electricity needs without preventing the land from being used to grow crops or raise cat-

Wind turbine **Wind farm** **Wind farm (offshore)**

Figure 13-33 **Solutions:** Wind turbines can be used individually to produce electricity. But 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 or offshore. **Question:** Would you object to having a wind farm located near where you live? Why or why not?

tle. These wind resources are in some of the country's least densely populated areas and require virtually no water to operate. However, making this electricity available to consumers will require the United States to upgrade and greatly expand its outdated national electricity distribution system.

According to the American Wind Energy Association, with increased and consistent government subsidies and tax breaks, wind power in the United States could produce 20% of the country's electricity by 2030. A problem with wind energy is that its availability varies, although new turbines adjust automatically to keep working at different wind speeds. But wind power sometimes needs a backup (such as efficient turbines that burn natural gas) or a way to store the electricity it produces. With an upgraded national electrical grid, electricity generated by wind could be stored by using it to recharge plug-in hybrid vehicles (p. 300). And wind could be used to produce hydrogen gas, which could in turn run fuel cells to help meet the country's energy needs. The U.S. Department of Energy estimates that offshore wind resources within 46–92 kilometers (5–10 nautical miles) of the U.S. coastline in principle could also produce enough electricity to meet all of the country's current electricity needs.

Some people in populated areas and in coastal areas oppose wind farms as being unsightly and noisy—a "not in my backyard (NIMBY)" attitude. In the Midwest, however, many farmers and ranchers have a "put it in my backyard (PIMBY)" attitude. They become wind developers themselves or receive lease payments of $1,000–$4,000 a year for each turbine they allow a wind developer to place on a small plot of their land, which can still be used to grow crops or to graze cattle.

Europe is leading the world into the *age of wind energy,* producing about three-fourths of the world's wind-generated power. European companies—mostly in Denmark, Germany, and Spain—manufacture 80% of the wind turbines sold in the global marketplace. They are aided by strong and consistent government subsidies, tax breaks, and low-cost loans. The European Wind Energy Association projects that by 2020 half of Europe's population will be getting their residential electricity from wind. In 2002, General Electric entered the wind business and has become one of the world's top producers of wind turbines. **GREEN CAREER:** Wind energy engineering

Studies indicate that wind turbines kill as many as 40,000 birds a year in the United States. However, each year glass windows, buildings, and electrical transmission towers in the United States kill more than 1 billion birds; electric transmission lines kill up to 175 million; housecats, 100 million; hunters kill more than 100 million; and cars and trucks, 50–100 million, according to Defenders of Wildlife.

Most studies show that as long as wind farms are not located along bird migration routes, birds will fly around them. Wind power developers now make sophisticated studies of bird migration paths to help them locate onshore and offshore wind farms. Newer turbines also reduce this problem by using slower blade rotation speeds and by not providing places for birds to perch or nest.

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. Many governments, corporations, and investment firms now recognize that wind is a vast, renewable energy resource that can supply energy at an affordable cost with a low environmental impact. They understand that *there is money in wind* and that our energy future may be *blowing in the wind.*

HOW WOULD YOU VOTE?

Should the country where you live greatly increase its dependence on wind power? Cast your vote online at **www.thomsonedu.com/biology/miller**.

TRADE-OFFS

Wind Power

Advantages

- Moderate to high net energy yield
- High efficiency
- Moderate capital cost
- Low electricity cost (and falling)
- Very low environmental impact
- No CO_2 emissions
- Quick construction
- Easily expanded
- Can be located at sea
- Land below turbines can be used to grow crops or graze livestock

Disadvantages

- Steady winds needed
- Backup systems needed when winds are low
- Plastic components produced from oil
- Environmental costs not included in market price
- High land use for wind farm
- Visual pollution
- Noise when located near populated areas
- Can interfere with flights of migratory birds and kill birds of prey

Figure 13-34 Advantages and disadvantages of using wind to produce electricity (**Concept 13-5**). By 2020, wind power could supply more than 10% of the world's electricity and 10–25% of the electricity used in the United States. **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

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.** Biomass is an indirect form of solar energy because it consists of combustible organic compounds produced by photosynthesis.

Biomass is burned mostly for heating and cooking, but also for industrial processes and for generating electricity. Wood, charcoal made from wood, animal manure, and other forms of biomass used for heating and cooking, supply 10% of the world's energy, 35% of the energy used in developing countries, and 95% of the energy needs in the poorest countries. But wood is a renewable fuel only as long if it is not harvested faster than it is replenished.

Unfortunately, about 2.7 billion people in 77 developing countries face a *fuelwood crisis* and are forced to meet their fuel needs by harvesting wood faster than it can be replenished. Figure 10 on p. S69 in Supplement 16 shows the potential for biomass energy in the continental United States.

One way to produce solid biomass fuel is in plantations of fast-growing trees (such as cottonwoods, poplars, and sycamores), shrubs, perennial grasses (such as switchgrass and miscanthus), and water hyacinths. But repeated cycles of growing and harvesting these plantations can deplete the soil of key nutrients. And clearing forests for such plantations destroys or degrades biodiversity.

In agricultural areas, *crop residues* (such as sugarcane residues, rice husks, cotton stalks, and coconut shells) and *animal manure* (Figure 13-35) can be collected and burned or converted to biofuels.

Pierre A. Pittet/UN Food and Agriculture Organization

Figure 13-35 *Burning cow dung.* Briquettes are made from cow dung in India, partly because of the scarcity of fuelwood. However, this practice deprives the soil of an important source of plant nutrients from dung decomposition. **Question:** Which is more important—burning manure briquettes to save trees, or leaving the dung to replenish the soil? Explain.

TRADE-OFFS

Solid Biomass

Advantages

- Large potential supply in some areas
- Moderate costs
- No net CO_2 increase if harvested and burned sustainably
- Plantation can be located on semiarid land not needed for crops
- Plantation can help restore degraded lands
- Can make use of agricultural, timber, and urban wastes

Disadvantages

- Nonrenewable if harvested unsustainably
- Moderate to high environmental impact
- Environmental costs not included in market price
- CO_2 emissions if harvested and burned unsustainably
- Low photosynthetic efficiency
- Soil erosion, water pollution, and loss of wildlife habitat
- Plantations could compete with cropland
- Often burned in inefficient and polluting open fires and stoves

Figure 13-36 General advantages and disadvantages of burning solid biomass as a fuel (**Concept 13-5**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

Figure 13-36 lists the general advantages and disadvantages of burning solid biomass as a fuel. One problem is that 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 (which takes up CO_2), there is no net increase in CO_2 emissions.

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.thomsonedu.com/biology/miller**.

We Can Convert Plants and Plant Wastes to Liquid Biofuels

Liquid biofuels such as *ethanol* (ethyl alcohol) and *biodiesel* produced from plants and plant wastes can help replace gasoline and diesel fuel and dominate the rapidly growing *bioenergy* industry.

The biggest producers—Brazil, the United States, the European Union, and China—plan to double their production of biofuels by 2020. U.S. government agencies estimate that ethanol and biodiesel could fuel 25–50% of U.S. motor vehicles by 2030.

Biofuels have three major advantages over gasoline and diesel fuel. First, while oil resources are concentrated in a small number of countries, biofuel crops can be grown in almost all countries. Second, if these crops are not used faster than they are replenished by new plant growth (which takes up CO_2), there is no net increase in CO_2 emissions. Third, biofuels are available now and can be used in vehicles at little or no additional cost.

However, there is the question of whether using industrialized agriculture to grow large monoculture crops for biofuels can be done sustainably. The challenge is to grow crops for food and biofuels by using sustainable agriculture (Figure 10-27, p. 224) that will not degrade land, increase air and water pollution, increase emissions of carbon dioxide and other greenhouse gases, and degrade and decrease biodiversity. In addition, any system for producing a biofuel should have a favorable net energy yield. Also, if growing biofuel crops becomes more profitable than producing food on limited cropland, world food supplies could be threatened.

Ethanol can be made through the fermentation and distillation of sugars in plants such as sugarcane, corn, and switchgrass and from agricultural, forestry, and municipal wastes. Gasoline mixed with 10–23% pure ethanol can be burned in conventional gasoline engines. Pure ethanol or E85 (a mixture of 85% ethanol and 15% gasoline) can be burned in *flexible fuel cars* with engines designed to run on a variety of fuels.

Brazil, the Saudi Arabia of sugarcane, is the world's second leader in ethanol production after the United States. When burned as a fuel, ethanol produced from sugarcane yields 8.3 times the amount of energy used to produce it. About 40% of Brazil's motor vehicles run on ethanol or ethanol-gasoline mixtures. Pure gasoline is no longer sold there.

Within a decade, Brazil could expand its sugarcane production, eliminate all oil imports, and greatly increase ethanol exports to other countries. However, the increased demand for ethanol has reduced Brazil's ability to export sugar, contributing to a doubling of the world price for sugar between 2004 and 2006. The U.S. state of Hawaii, a large producer of sugar cane, plans to get most of its fuel by converting sugar cane to ethanol.

In the United States, most ethanol is made from corn. 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 1.5 units of energy per unit of fossil fuel input. This helps explain why Brazil, getting a net energy yield of 8.3, can produce ethanol from sugarcane at about half the cost of producing it from corn in the United States. The U.S. government (taxpayers) hinders the importing of cheaper ethanol from Brazil by subsidizing U.S. corn-based ethanol and imposing a tariff on such imports.

Analysts warn that U.S. citizens should not think of ethanol produced from corn as the best way to reduce the country's oil imports. Processing all corn grown in the United States into ethanol each year would cover only about 55 days of current auto fuel needs. This could leave no corn for cattle feed and food. The United States produces 40% of the world's corn and provides 70% of the world's corn exports. In addition, E85 can be used only on flex-fuel vehicles, is hard to find outside of the Midwest, may corrode gasoline pumps, has a lower fuel efficiency, and costs more than conventional gasoline (even with subsidies). Moreover, producing ethanol from corn requires large amounts of natural gas and increases U.S. dependence on imported natural gas. Such production also produces about the same amount of greenhouse gases as gasoline production and offers little if any reduction in air pollution.

Another approach is to produce *cellulosic ethanol.* This process uses bacteria to convert the cellulose and lignin in certain nonfood plants and in agricultural, forestry, and municipal wastes into starches that can be fermented by other bacteria to produce ethanol. A promising candidate is *switchgrass* (Figure 13-37). Its

National Renewable Energy Laboratory

Figure 13-37 **Natural capital:** the cellulose in this rapidly growing switchgrass in Manhattan, Kansas (USA), can be converted into a biofuel and does not require irrigation or annual plowing of the soil. This plant can also help reduce global warming by removing carbon dioxide from the atmosphere and storing it as organic compounds in the soil. **Question:** Why might use of this form of biomass be a better way to produce ethanol than using corn?

net energy yield is about 4, which is much greater than the 1.5 yield for corn. In a competitive global market, most of the world's ethanol is likely to be produced from sugarcane and fast-growing cellulosic crops such as switchgrass. According to a joint study by the U.S. Departments of Energy and Agriculture, America can use cellulosic resources to produce enough ethanol to meet more than one-third of its current gasoline needs. But the technology is still being developed and may not be cost-competitive without government subsidies (as is the case for U.S. ethanol production).

Figure 13-38 lists the advantages and disadvantages of using ethanol as a vehicle fuel compared to gasoline.

HOW WOULD YOU VOTE? ✓

Do the advantages of using liquid ethanol as a fuel outweigh its disadvantages? Cast your vote online at **www.thomsonedu.com/biology/miller**.

If a truck or bus whizzing by you leaves a scent of fast food, it is probably running on *biodiesel*—a diesel biofuel based on vegetable oil extracted from soybeans, rapeseeds, sunflowers, oil palms, jatropha shrubs, and fats, including used vegetable oils from restaurants.

European Union countries (primarily Germany, France, and Italy) produce about 95% of the world's biodiesel. Biodiesel production is also growing rapidly in the United States since the government provided a subsidy of $1 per gallon in 2005. India, Brazil, Malaysia and Indonesia also produce biofuel. However, clearing more forests in those countries to plant oil palm and soybean plantations threatens biodiversity.

A 2006 study by the U.S. National Academy of Sciences found that soybean-based biodiesel returns much more energy than corn-based ethanol does. The study also estimated that converting all current U.S. corn and soybean production to biofuels would meet only 12% of the country's gasoline demand and 6% of diesel demand and that neither fuel is currently cost-competitive without government subsidies.

Oil from the seeds of jatropha plants, which can grow in hot dry tropical areas, are a promising source of biodiesel. These plants are unlikely to threaten rain forests or compete with food crops. Figure 13-39 lists the advantages and disadvantages of using biodiesel as a vehicle fuel compared to gasoline.

THINKING ABOUT
Biodiesel

Do you think that the advantages of using biodiesel as a fuel outweigh its disadvantages? Explain.

TRADE-OFFS
Ethanol Fuel

Advantages	Disadvantages
High octane	Lower driving range
Some reduction in CO_2 emissions	Low net energy yield (corn)
High net energy yield (bagasse and switchgrass)	Much higher cost
Reduced CO emissions	Environmental costs not included in market price
Can be sold as E85 or pure ethanol	May compete with growing food on cropland
Potentially renewable	Higher NO_x emissions and more smog
	Corrosive
	Can make engines hard to start in cold weather

Figure 13-38 Advantages and disadvantages of using ethanol as a vehicle fuel compared to gasoline (**Concept 13-5**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

TRADE-OFFS
Biodiesel

Advantages	Disadvantages
Reduced CO emissions	Increased NO_x emissions and more smog
Reduced CO_2 emissions (78%)	Higher cost than regular diesel
High net energy yield for oil palm crops	Environmental costs not included in market price
Moderate net energy yield for rapeseed crops	Low net energy yield for soybean crops
Reduced hydrocarbon emissions	May compete with growing food on cropland
Better gas mileage (40%)	Loss and degradation of biodiversity from crop plantations
Potentially renewable	Can make engines hard to start in cold weather

Figure 13-39 Advantages and disadvantages of using biodiesel as a vehicle fuel compared to gasoline (**Concept 13-5**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

Some proponents envision replacing large oil refineries with localized *bio-refineries* that produce a combination of biofuels, plastics, chemicals, and pharmaceuticals and create local jobs and tax revenues.

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 12-3, p. 264). We can tap into this stored energy to heat and cool buildings and to produce electricity. Scientists estimate that using just 1% of 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 oil and natural gas reserves.

A *geothermal heat pump* system can heat and cool a house by exploiting the difference between the earth's surface and temperatures in underground water or earth almost anywhere in the world. These devices, along with a closed loop of buried pipes, extract heat from the earth in winter. In summer, they can remove heat from a house and store it in the earth. They perform very efficiently and cost-effectively without producing air pollutants or CO_2.

We have also learned to tap into deeper, more concentrated underground *hydrothermal reservoirs* of geothermal energy. One type of reservoir contains *dry steam* with water vapor but no water droplets. Another consists of *wet steam,* a mixture of steam and water droplets. A third is *hot water* trapped in fractured or porous rock at various places in the earth's crust.

If such geothermal sites are close to the surface, wells can be drilled to extract the dry steam, wet steam, or hot water (Figure 13-2). It can then be used to heat homes and buildings or to spin turbines and produce electricity.

See Figure 8 on p. S68 in Supplement 16 for a map of the global reserves of usable geothermal energy. Currently, about 40 countries (most of them in the developing world) extract enough energy from geothermal sites to produce about 1% of the world's electricity. Iceland uses geothermal energy to heat 80% of its buildings, to produce electricity, and to grow most of the country's fruits and vegetables in greenhouses.

The United States is the world's biggest producer of geothermal electricity, mostly in California, Nevada, Utah, and Hawaii (see Figure 9 on p. S69 in Supplement 16). Geothermal energy meets the electricity needs of about 6 million Americans, supplies 6% of California's electricity, and is comparable to the electricity currently produced by solar and wind power combined. In 1999, Santa Monica, California, became the first city to get all its electricity from geothermal energy.

Currently, the cost of tapping large-scale reservoirs of geothermal energy is too high for all but the most concentrated and accessible sources, although new technologies may bring these costs down. Also, some dry- or wet-steam geothermal reservoirs can be depleted if heat is removed faster than natural processes renew it. Recirculating the hot water back into the underground reservoirs could slow such depletion.

A 2007 study by an 18-member panel, led by Massachusetts Institute of Technology scientists, estimated that with increased government and private research and development, geothermal power could meet roughly 10% of U.S. electricity needs by 2050. The panel also pointed out that the harmful environmental impacts of geothermal energy are much lower than those from fossil fuels and the nuclear power fuel cycle.

RESEARCH FRONTIER

Finding better and affordable ways to tap different sources of geothermal energy

Figure 13-40 lists the advantages and disadvantages of using geothermal energy.

HOW WOULD YOU VOTE?

Should the United States (or 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.thomsonedu.com/biology/miller**.

TRADE-OFFS

Geothermal Energy

Advantages	Disadvantages
Very high efficiency	Scarcity of suitable sites
Moderate net energy at accessible sites	Depleted if used too rapidly
Lower CO_2 emissions than fossil fuels	Environmental costs not included in market price
Low cost at favorable sites	CO_2 emissions
Low land use and disturbance	Moderate to high local air pollution
Moderate environmental impact	Noise and odor (H_2S)
	Cost too high except at the most concentrated and accessible sources

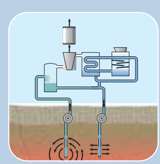


Figure 13-40 Advantages and disadvantages of using geothermal energy for space heating and to produce electricity or high-temperature heat for industrial processes (**Concept 13-5**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

Can Hydrogen Replace Oil?

When oil supplies have peaked (**Core Case Study**), or when the remaining oil costs too much to use, how will we fuel vehicles, industries, and buildings? Many scientists and executives of major oil companies and automobile companies say the fuel of the future is hydrogen gas (H_2)—first envisioned as a fuel in 1874 by science fiction writer Jules Verne in his book *The Mysterious Island.*

When hydrogen gas burns in air or in fuel cells, it combines with oxygen gas in the air to produce nonpolluting water vapor ($2H_2 + O_2 \longrightarrow H_2O$ + energy). Widespread use of hydrogen as a fuel would eliminate most of the air pollution problems we face today. It would also greatly reduce the threats of global warming, because it emits no CO_2—as long as the hydrogen is not produced with the use of fossil fuels or other carbon-containing compounds. Hydrogen also provides more energy per gram than any other fuel.

So what is the catch? Four problems arise in turning the vision of widespread use of hydrogen as a fuel into reality. *First,* hydrogen is chemically locked up in water and in organic compounds such as methane and gasoline. *Second,* it takes energy and money to produce hydrogen from water ($2H_2O$ + energy $\longrightarrow 2H_2 + O_2$) and organic compounds. In other words, hydrogen 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. *Third,* fuel cells are the best way to use hydrogen to produce electricity, but current versions of fuel cells are expensive.

Fourth, whether a hydrogen-based energy system produces less air pollution and CO_2 than a fossil fuel system depends on how the hydrogen is produced. Using electricity from coal-burning and conventional nuclear power plants to decompose water into hydrogen and oxygen gas does not avoid the harmful environmental effects associated with using fossil fuels (Figures 13-12 and 13-17). We can also make hydrogen from coal and strip it from organic compounds found in fuels such as methanol, gasoline, or natural gas. However, according to a 2002 scientific study, producing hydrogen from coal and organic compounds will 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 receive its very low pollution and low CO_2 emission benefits, the energy used to produce H_2 must come from low-polluting, renewable sources that emit little or no CO_2. The most likely sources are electricity generated by wind farms, solar cells, geothermal energy, micro-hydropower plants, and biological processes in bacteria and algae.

Once produced, hydrogen can be stored in a pressurized tank, as liquid hydrogen, and in solid metal hydride compounds, which when heated release hydrogen gas. Scientists are also evaluating ways to store H_2 by absorbing it onto the surfaces of activated charcoal or carbon nanofibers, which release hydrogen gas when heated. Because H_2 can be stored in pressurized tanks and transported in pipelines, using it is a way to reduce the use of oil and natural gas.

Metal hydrides, sodium borohydride, charcoal powders, ammonia borane, carbon nanotubes, and glass microspheres containing hydrogen will not explode or burn when ruptured in an accident—making hydrogen a much safer fuel than gasoline, diesel fuel, methanol, and natural gas. Also, a fuel-cell stack about the size of a refrigerator could provide heat, hot water, and electricity for a home. **GREEN CAREERS:** Hydrogen energy engineering and sales

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. If perfected, this approach means that hydrogen would not have to be transported or stored. Hydrogen would be generated as needed inside tanks about the same size as today's gasoline tanks. Merely replacing the gasoline fuel injector with a hydrogen injector would allow current internal combustion engines to run on hydrogen.

RESEARCH FRONTIER

Developing better and more affordable ways to produce and store hydrogen

These technologies are being tested and implemented now, especially in Iceland, as discussed in the case study below. Figure 13-41 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.thomsonedu.com/biology/miller**.

■ CASE STUDY

Iceland Is a Sustainable Energy Laboratory

By 2050, tiny Iceland (with 300,000 people) has plans to run its entire economy on renewable hydropower, geothermal energy, and wind, and to use these sources to produce hydrogen for running all of its motor vehicles and ships. Since 1999, DaimlerChrysler, Royal Dutch Shell, Norsk Hydro, and Icelandic New Energy have been working to convert this dream into reality.

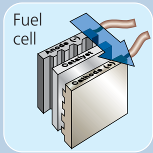
The country would produce hydrogen by using its ample supplies of renewable hydropower and geothermal energy (which together supply 70% of Iceland's energy) to produce hydrogen from water and supplement this with offshore wind farms. The world's first hydrogen fueling station, built in the capital city of Reykjavik, is supplying hydrogen to power three fuel-cell buses.

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 13-41 Advantages and disadvantages of using hydrogen as a fuel for vehicles and for providing heat and electricity (**Concept 13-5**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

The next steps are to test a fleet of hydrogen-powered cars for use by corporate or government employees and then to use hydrogen to power fuel cells in all of the country's cars.

However, a 2006 article in *Worldwatch* by energy consultant Freyr Sverrisson warned that Iceland's plan to convert to a hydrogen economy has stalled, despite government promises and extensive media hype. No research facilities have been built and no major hydrogen industry is being developed.

If it actually takes place, could Iceland's model of a hydrogen economy built on using renewable energy be applied to a country such as the United States? There are two problems. Running motor vehicles on hydrogen would require building at least 12,000 hydrogen-fueling stations throughout the country at a cost of $1 million apiece. Only 16 stations are needed to fuel Iceland's cars. Alternatively, home fueling units may become feasible.

A second problem is the high cost of fuel cells. But car companies say they could easily modify traditional internal combustion engines to run directly on hydrogen and sell such cars now if demand were high enough. And nanotechnology (**Core Case Study**, p. 261) and other developments will likely make fuel cells more efficient and cheaper.

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 of a mix of renewable energy resources, and including environmental costs in the market prices of all energy resources.

What Are the Best Energy Alternatives for the 21st Century?

Scientists and energy experts who have evaluated energy alternatives have come to three general conclusions.

First, *there will be a gradual shift from large, centralized macropower systems to smaller, decentralized micropower systems* (Figure 13-42, p. 318) such as wind turbines, fuel cells for cars, household solar panels, and small natural gas turbines and stationary fuel cells for commercial buildings. Currently, most countries have a centralized and geographically concentrated system of large power plants, refineries, pipelines, and other infrastructure that is vulnerable to disruption from events such as natural disasters and terrorist attacks. For example, in 2005, Hurricane Katrina crippled about 10% of America's oil and gas producing wells

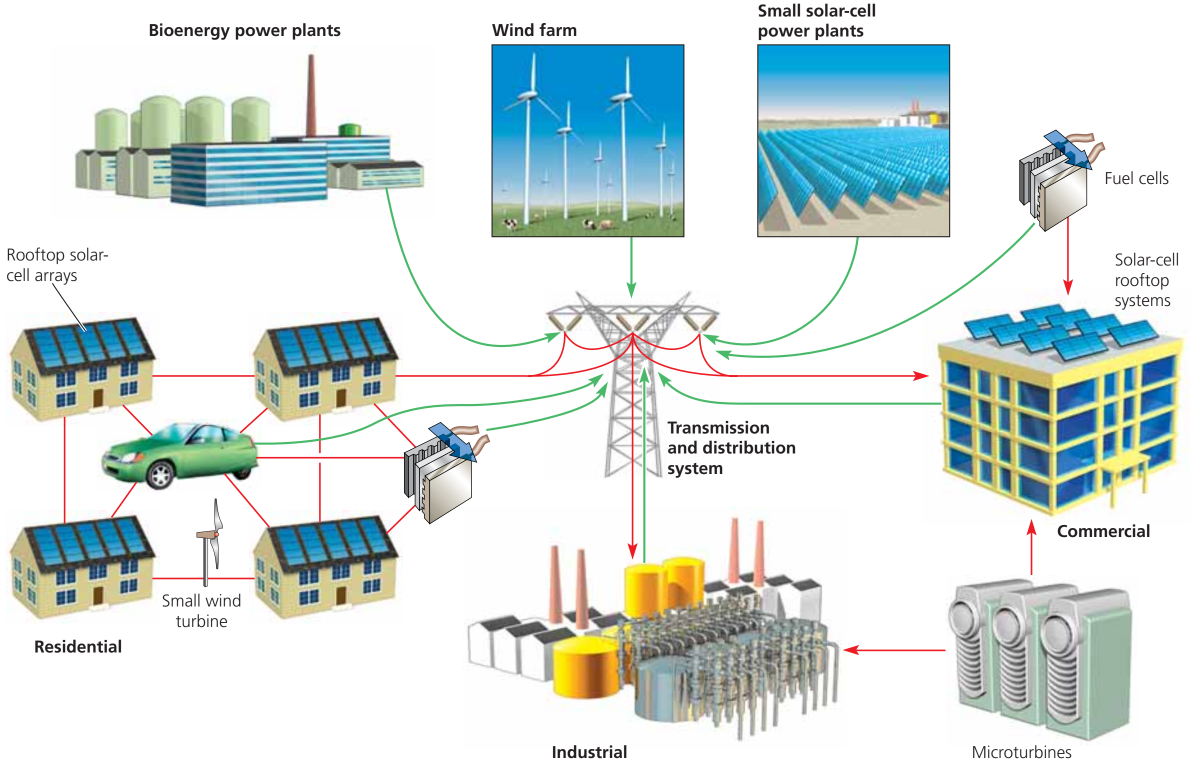


Figure 13-42 **Solutions:** *decentralized power system* in which electricity is produced by a large number of dispersed, small-scale *micropower systems*. Some would produce power on site; others would feed the power they produce into a conventional electrical distribution system. Over the next few decades, many energy and financial analysts expect a shift to this type of power system. **Questions:** Can you think of any disadvantages of such a decentralized power system? Do they outweigh the advantages? Explain.

(See Figure 2, bottom, on p. S63 in Supplement 16) 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 a diversity of small and dispersed domestic renewable energy resources instead of on a small number of large and vulnerable coal and nuclear power plants.

Second, *the best alternatives combine improved energy efficiency and the use of a mixture of sustainably produced biofuels to make the transition to a diverse mix of locally available renewable energy resources* (**Concepts 13-5** and **13-6**) *over the next several decades.* Instead of depending mostly on nonrenewable fossil fuels produced elsewhere, people would make use of abundant, locally available renewable energy resources. For example, Costa Rica gets 92% of its energy from renewable sources; Iceland gets all of its energy from renewable resources and hopes to use this energy to run the country on hydrogen (Case Study, p. 316).

Third, because of their supplies and artificially low prices, fossil fuels will continue to be used in large quantities. The challenge is to find ways to reduce the harmful environmental impacts of widespread fossil fuel use, with special emphasis on reducing air pollution and emissions of greenhouse gases, as less harmful alternatives are phased in.

Figure 13-43 lists strategies for making the transition to a more sustainable energy future over the next 50 years.

Making our cities more sustainable (**Concept 7-7**, p. 146, and **Core Case Study**, p. 123) and using more sustainable agriculture (**Concept 10-7**, p. 223, and Figure 10-26, p. 224) would also reduce energy use and waste and the resulting pollution and environmental degradation.

CONCEPT LINKS

SOLUTIONS

Making the Transition to a More Sustainable Energy Future

Improve Energy Efficiency

Increase fuel-efficiency standards for vehicles, buildings, and appliances

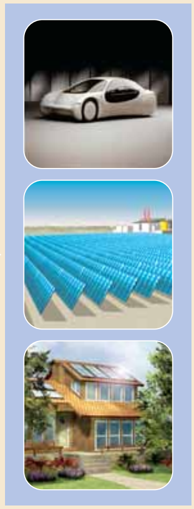
Mandate government purchases of efficient vehicles and other devices

Provide large tax credits 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 devices

Greatly increase renewable energy research and development

Reduce Pollution and Health Risk

Cut coal use 50% by 2020

Phase out coal subsidies

Levy taxes on coal and oil use

Phase out nuclear power subsidies

Figure 13-43 Suggestions of various energy analysts to help make the transition to a more sustainable energy future (**Concept 13-6**). **Question:** Which five of these solutions do you think are the most important? Why?

Economics, Politics, and Education Can Help Us Shift to More Sustainable Energy Resources

To most analysts, making a shift to more sustainable energy resources will require using economic and political strategies. Governments at local, state, and national levels must develop and sustain consistent energy policies to encourage such a shift. Businesses will need consistent, long-term policies in order to make long-range plans.

Governments can use three strategies to help stimulate or dampen the short-term and long-term use of a particular energy resource. First, they can *keep prices artificially low to encourage use of selected energy resources.* They can provide research and development subsidies and tax breaks and enact regulations that help stimulate the development and use of energy resources receiving such support. 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. For example, according to the U.S. Department of Energy and the International Energy Agency, between 1974 and 2005, the U.S. federal government provided (in 2005 dollars) \$47.9 billion in energy research and development for nuclear fission and fusion, \$20 billion for fossil fuels, \$12.4 billion for renewable energy, and \$11.7 billion for improving energy efficiency.

This has created an uneven economic playing field that *encourages* energy waste and rapid depletion of nonrenewable energy resources and *discourages* improvements in energy efficiency and the development of renewable energy. If subsidies were equitable and the environmental costs of energy resources were included in their market prices (Table 13-1), it's possible that wind farms would dot the landscape, people would drive mostly plug-in hybrids, most light bulbs would be compact fluorescents or LEDs, buildings would be energy efficient, and the United States and other countries would not be heavily dependent on imported oil.

All but four U.S. states now have incentives to promote renewable energy. California leads the way by getting 31% of its electricity from renewable resources, including 12% from wind, solar, and geothermal sources. Texas now has more wind turbines than any state. And Iowa leads the way in producing ethanol fuel. A national coalition of more than 200 citizen and business organizations—led by farm and forestry interests—is pushing for a national commitment to get one-fourth of U.S. energy from renewable sources by 2025.

WHAT CAN YOU DO?

Shifting to 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 homes, 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 13-44 **Individuals matter:** ways to reduce your use and waste of energy and your CO_2 emissions. **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?

The second strategy that governments can use is to *keep energy prices artificially high to discourage use of a resource*. They can raise the price of a nonrenewable energy resource by eliminating existing tax breaks and other subsidies, enacting restrictive regulations, or adding taxes on its use. This would increase government revenues, encourage improvements in energy efficiency, reduce dependence on imported energy, and decrease use of an energy resource that has a limited future supply. To make this acceptable to the public, analysts call for the government to offset energy taxes by reducing income and payroll taxes and providing an energy safety net for low-income individuals.

HOW WOULD YOU VOTE?

Should the government of the country where you live increase taxes on fossil fuels and offset this by reducing income and payroll taxes and providing an energy safety net for the poor and lower middle class? Cast your vote online at **www.thomsonedu.com/biology/miller**.

A third strategy is to *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 of such options, advantages and disadvantages, and the comparative hidden environmental costs of various energy resources (Table 13-1). For example, there are more solar water heaters in cloudy Germany than in sunny France and Spain, mostly because the German government has made the public aware of the benefits of this technology.

The good news is that, currently, we have the technology, creativity, and wealth to make the transition to a more sustainable energy future within your lifetime. Making this transition depends on *politics*—on how individuals vote and then influence their elected officials. People can also vote with their pocketbooks by refusing to buy inefficient and environmentally harmful products and by letting company executives know about their choices. Figure 13-44 lists some ways in which you can contribute to making this transition.

REVISITING Oil and Sustainability

CORE CASE STUDY

SUSTAINABILITY

In this chapter, we have seen that oil—the lifeblood of today's economies—may become unaffordable sometime during this century (**Core Case Study** and Supplement 15 on p. S61). If this happens, we will need to find substitutes for oil and begin phasing them in during your lifetime. This urgent and complex challenge is controversial and involves interactions between science, economics, politics, and ethics.

A serious long-term problem is that, in using nonrenewable fossil fuels and nuclear power, we violate the four **scientific principles of sustainability** (see back cover). We depend not on solar energy but on technologies that disrupt the earth's chemical cycles by emitting large quantities of pollutants and greenhouse gases. Using these technologies also destroys and degrades biodiversity and population control interactions in ecosystems by causing land disruption and pollution and by promoting global warming.

We can make the transition to a more sustainable energy future by applying the four **scientific 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.
- Reducing use and waste of energy and other resources by slowing population growth.

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 QUESTIONS

1. Identify the types of renewable and nonrenewable energy that we use and explain how each energy source originates. Compare and contrast the world's commercial energy use with that of the United States. Explain why it is beneficial to look at the various energy sources in terms of the net energy that each source provides.
2. Choose one type of fossil fuel and provide an argument for its continued exploitation and use. Choose one fossil fuel and explain why we should phase out or not exploit its future use.
3. Describe how electricity is generated in a coal-burning power plant.
4. Describe how electricity is generated in a nuclear power plant with a pressurized water reactor.
5. Compare and contrast the use of nuclear power plants and coal-burning power plants to produce electricity.
6. Explain how energy conservation and energy efficiency can lead to a reduction in energy use and energy waste.
7. Choose one type of renewable energy source and provide an argument for its continued exploitation and use. Choose one type of renewable energy source and explain why it may be difficult to exploit its use in the future.
8. Compare and contrast the use of biodiesel, ethanol, and hydrogen as fuel for vehicles.
9. Discuss the advantages of shifting from centralized macropower energy production to dispersed micropower energy production.
10. Summarize the suggestions that various energy analysts have made to help make the transition to a more sustainable energy future.

CRITICAL THINKING

1. List three ways in which you could apply **Concept 13-6** (p. 317) to making your lifestyle more environmentally sustainable.
2. To continue using oil at the current rate (not the projected higher exponential increase in its annual use), we must discover and add to global oil reserves the equivalent of two new Saudi Arabian supplies *every 10 years,* as discussed in the **Core Case Study** that opened this chapter. Do you think this is possible? If not, what effects might the failure to find such supplies have on your life and on the lives of your children or grandchildren? CORE CASE STUDY
3. List three actions you can take to reduce your dependence on oil. Which of these things do you already do or plan to do?
4. 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 oil
   b. Place a heavy federal tax on gasoline and imported oil to help reduce the waste of oil resources
   c. Increase dependence on coal
   d. Increase dependence on nuclear power
   e. Phase out all nuclear power plants by 2025
5. Would you favor having high-level nuclear waste from nuclear power plants transported by truck or train through the area where you live to a centralized underground storage site? Explain. What are the options?
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 2-4B**, p. 33) and net energy (Figure 13-A, p. 282) to evaluate this claim. CONCEPT LINK
7. Should buyers of energy-efficient motor vehicles receive large government subsidies, funded by the taxes 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 fuels (oil, natural gas, and coal), synthetic

natural gas, and nuclear power should be phased out and 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 subsidies.

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.

LEARNING ONLINE

Log on to the Student Companion Site for this book at **www.thomsonedu.com/biology/miller** and choose Chapter 13 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Web links, information on Green Careers, and InfoTrac® College Edition articles.

For access to animations and additional quizzing, register and log on to ThomsonNOW! at **www.thomsonedu.com/thomsonnow** using the access code card in the front of your book. You can also explore the **Active Graphing** exercises that your instructor may assign.

Environmental Hazards and Human Health

14

The Global HIV/AIDS Epidemic

CORE CASE STUDY

The global spread of *acquired immune deficiency syndrome* (AIDS), caused by infection with the *human immunodeficiency virus* (HIV), is a serious and rapidly growing health threat. The virus itself is not deadly, but it cripples the immune system and leaves the body susceptible to infections such as tuberculosis (TB) and rare forms of cancer such as *Kaposi's sarcoma* (Figure 14-1).

The virus is transmitted from one person to another through 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 World Health Organization (WHO), in 2006 about 37 million people worldwide (1.1 million in the United States) were infected with HIV. Almost two-thirds of them were in African countries located south of the Sahara Desert (sub-Saharan Africa). The Caribbean is the second most affected region.

In 2006 alone, about 4.3 million people (42,500 in the United States) became infected with HIV—an average of 11,800 new cases per day—half of them between the ages of 15 and 24. Within 7–10 years, at least half of all HIV-infected people will develop AIDS. This long incubation period means that infected people often spread the virus for several years without knowing they are infected.

There is no vaccine to prevent HIV 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 2006, more than 37 million people (531,000 in the United States) died of AIDS-related diseases. Each year, AIDS claims about 3 million more lives (16,000 in the United States).

AIDS has reduced the life expectancy of the 750 million people living in sub-Saharan Africa from 62 to 47 years—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 such countries leads to diminished education and health care, decreased food production and economic development, and disintegrating families.

This means that countries like Botswana and Zimbabwe will each lose half of their adult population within a decade. Such death rates drastically alter a country's age structure (Figure 14-2). AIDS has also left more than 15 million children orphaned—roughly equal to the number of children under age 5 in the United States. Many of them are forced into child labor or the sex trade. Between 2006 and 2030, the WHO projects 117 million more deaths from AIDS and a death toll reaching as high as 5 million a year—an average of about 13,700 largely preventable deaths per hour.

In this chapter, we will look at connections between environmental hazards and human health and at what we can do to reduce the deadly global pandemic of AIDS and other environmental health threats.

Figure 14-1 Lesions that are a sign of Kaposi's sarcoma, a rare form of cancer common among AIDS patients.

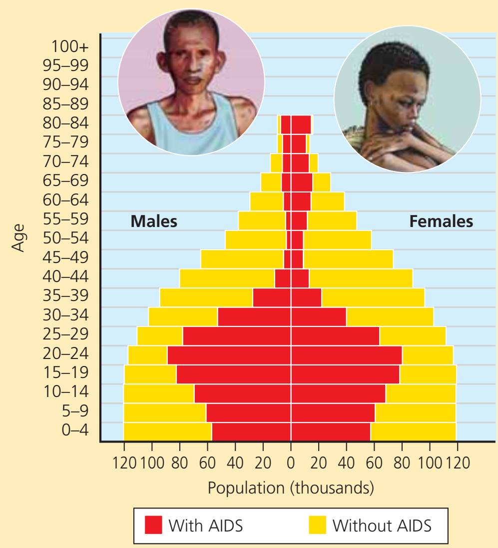


Figure 14-2 *Global outlook:* Worldwide, AIDS is the leading cause of death for people of ages 15–49. This loss of productive working adults can affect the age structure of a population. In Botswana, more than 24% of this age group is infected with HIV. This figure shows the projected age structure of Botswana's population in 2020 with and without AIDS. **Question:** How might this affect Botswana's economic development? (Data from the U.S. Census Bureau)

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 choices they make in their lifestyles.

14-2 **What types of biological hazards do we face?**

CONCEPT 14-2 In terms of death rates, the most serious infectious diseases are flu, AIDS, diarrhea, and malaria, with most of these deaths occurring in developing countries.

14-3 **What types of chemical hazards do we face?**

CONCEPT 14-3 There is growing concern about chemicals that can cause cancer and disrupt the human immune, nervous, and endocrine systems.

14-4 **How can we evaluate chemical hazards?**

CONCEPT 14-4A Any synthetic or natural chemical can be harmful if ingested in a large enough quantity.

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 7, 12, and 17 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 choices they make in their lifestyles.

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 environmental damage. It is usually expressed in terms of *probability*—a mathematical statement about how likely it is 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).

It is important to distinguish between *possibility* and *probability*. When we say that it is *possible* that a smoker can get lung cancer, we are saying that this event could happen. *Probability* gives us an estimate of the likelihood of such an event.

Risk assessment is the scientific process of using statistical methods to estimate how much harm a particular hazard can cause to human health or to the environment. It is a way to estimate the probability of a risk, compare it with the probability of other risks, and establish priorities for avoiding or managing risks. **Risk management** involves deciding whether or how to reduce a particular risk to a certain level and at what cost. Figure 14-3 summarizes how risks are assessed and managed.

A major problem is that most people are not good at understanding and comparing risks. Because of sen-

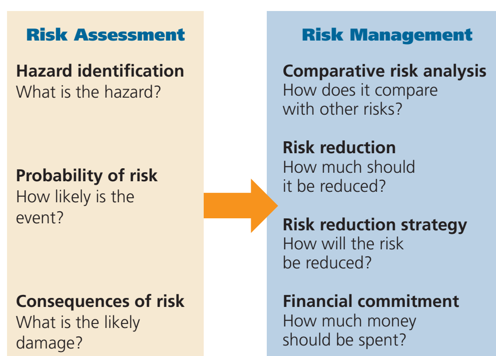


Figure 14-3 *Risk assessment and risk management.* **Question:** When was the last time you applied this process in your own daily living? Explain.

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.

sational news coverage about the latest scare, many people worry about the highly unlikely possibility of minor risks and ignore the significant probability of harm from major risks. In other words, many people suffer from *possibility anxiety* over minor risks and *probability neglect and denial* over serious risks.

For example, some Americans worry about getting avian flu, which by mid-2007 had killed no one in the United States, but they do not get vaccinated for the common flu, which contributes to the deaths of about 36,000 Americans each year. Thus, educating people and members of the news media about the meaning of risk assessments and the ability to make risk comparisons is an important priority.

We Face Many Types of Hazards

All of us take risks every day. Examples include driving or riding in a car, eating foods with a high cholesterol or fat content that contribute to heart attacks, drinking alcohol, smoking or being in an enclosed space with a smoker, lying out in the sun or going to a tanning parlor and increasing the risk of getting skin cancer and wrinkled skin, practicing unsafe sex, and living in a hurricane-prone area. The key questions are, How serious are the risks we face, and do the benefits of certain activities outweigh the risks? We examine many of these risks in this chapter.

We can suffer harm from four major types of hazards (**Concept 14-1**):

- *Biological hazards* from more than 1,400 *pathogens* (bacteria, viruses, parasites, protozoa, and fungi) that can infect humans
- *Chemical hazards* from harmful chemicals in air, water, soil, and food
- *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, poor food choices, taking illicit drugs, drinking too much alcohol, and having unsafe sex

THINKING ABOUT
Hazards

Which three of the hazard types listed here are most likely to harm you?

14-2 What Types of Biological Hazards Do We Face?

CONCEPT 14-2 In terms of death rates, the most serious infectious diseases are flu, AIDS, diarrhea, and malaria, with most of these deaths occurring in developing countries.

Some Diseases Can Spread from One Person to Another

A **nontransmissible disease** is caused by something other than living organisms and does not spread from one person to another. Such diseases tend to develop slowly and have multiple causes. Examples include most cancers, most cardiovascular (heart and blood vessel) disorders, asthma, emphysema, and malnutrition.

Other diseases can spread from one person to another. Such diseases start when a *pathogen* such as a bacterium, virus, or parasite invades the body and multiplies in its cells and tissues. This can lead to an **infectious** or **transmissible disease**—a disease that is caused by a pathogen and can be spread among people. If the body cannot mobilize its defenses fast enough to keep the pathogen from interfering with bodily functions, the disease can have worse effects and be spread more easily.

Figure 14-4 (p. 326) shows major pathways for infectious diseases in humans. Once people are infected, such diseases can be spread through air, water, food, or body fluids such as feces, urine, the blood of infected people, or droplets sprayed by sneezing and coughing—depending on the disease organism.

A large-scale outbreak of an infectious disease in an area or country is called an *epidemic,* and a global epidemic is called a *pandemic.* AIDS (**Core Case Study**) is a pandemic as is tuberculosis (Case Study, p. 326). Figure 14-5 (p. 326) shows the annual death toll from the world's seven deadliest infectious diseases (**Concept 14-2**). The deaths *each year* from these diseases are 58 times the 221,000 people killed by the December 2004 tsunamis (see pp. S55–S56 in Supplement 12).

CORE CASE STUDY

Great news. Since 1900, 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.

Bad news. Many disease-carrying bacteria have developed genetic immunity to widely used antibiotics

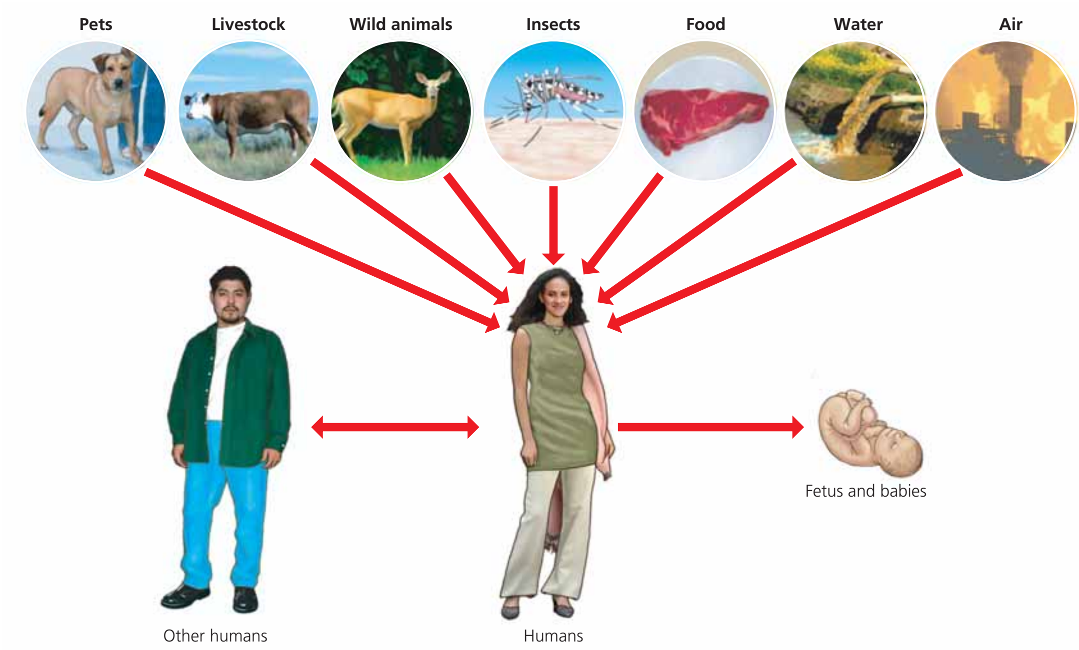


Figure 14-4 **Science:** pathways for infectious disease in humans. **Question:** Can you think of other pathways not shown here?

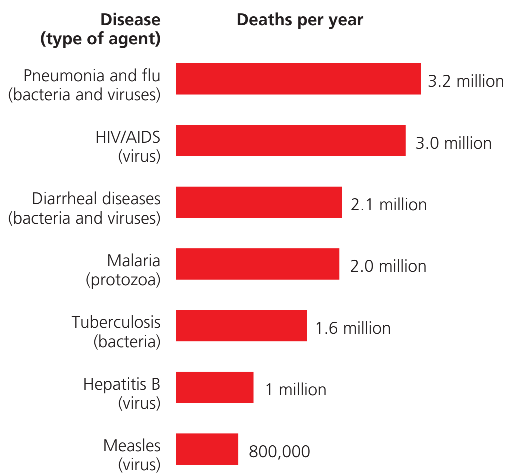


Figure 14-5 *Global outlook:* the WHO estimates that each year the world's seven deadliest infectious diseases kill 13.5 million people—most of them poor people in developing countries (**Concept 14-2**). This amounts to about 37,000 mostly preventable deaths every day. **Question:** How many people die prematurely on average from these diseases each hour, 24 hours a day? (Data from the World Health Organization)

(Science Focus, at right). Also, many disease-transmitting species of insects such as mosquitoes have become immune to widely used pesticides that once helped 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). According to the WHO, this highly infectious bacterial disease strikes 9 million people per year and kills 1.6 million—about 84% of them in developing countries. The WHO projects that between 2006 and 2020, 25 million people will die of this disease unless current funding and efforts to control TB are greatly strengthened and expanded.

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.

Several factors account for the recent increase in TB incidence. One is the lack of TB screening and control programs, especially in developing countries, where 95% of the new cases occur. A second problem is that most strains of the TB bacterium have developed genetic resistance to most of the effective antibiotics.

Population growth, urbanization, and air travel have greatly increased person-to-person contacts, and TB has spread, especially in areas where large numbers of poor people crowd together. In addition, AIDS (**Core Case Study**) greatly weakens its victims' immune systems and allows TB bacteria to multiply in AIDS victims.

Growing Germ Resistance to Antibiotics

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. Their high reproductive rate allows these organisms to become genetically resistant to an increasing number of antibiotics through natural selection (**Concept 4-1B**, p. 64). CONCEPT LINK Some can also transfer such resistance to nonresistant bacteria even more quickly by exchanging genetic material.

Other factors play a key role 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 by doctors. According to a 2000 study by Richard Wenzel and Michael Edward, at least half of all antibiotics used to treat humans are prescribed unnecessarily. In many countries, antibiotics are available without a prescription, which also promotes unnecessary use. Resistance to some antibiotics has also increased because of their widespread use in livestock and dairy animals to control disease and to promote growth.

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 we use to treat bacterial infections such as tuberculosis (Case Study, p. 326). Each year, genetic resistance to antibiotics plays a role in the deaths of least 90,000 of the 2 million people who pick up mostly preventable infections while they are in U.S. hospitals.

Critical Thinking

What are three things you would do to slow the rate at which disease-causing organisms develop resistance to antibiotics?

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 inexpensive drugs can cure 90% of individuals with active TB. To be effective, the drugs must be taken every day for 6–8 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.

Some Viral Diseases Kill Large Numbers of People

What are the world's three most widespread and dangerous viruses? 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. Easily transmitted and especially potent flu viruses could spread around the world in a pandemic that could kill millions of people in only a few months (Science Focus, p. 328). Influenza occurs year round in the tropics. By expanding tropical climates, global warming could lengthen the flu season in other areas.

The second biggest killer is the *human immunodeficiency virus* (HIV) (**Core Case Study** and **Concept 14-2**). CORE CASE STUDY On a global scale, HIV infects about 4.9 million people each year and the resulting complications from AIDS kill about 3 million people annually. AIDS is a serious and growing threat but fortunately it is not as easily spread as the common flu.

ThomsonNOW™ Examine the HIV virus and how it replicates by using a host cell at ThomsonNOW.

Antiviral drugs can slow the progress of AIDS, but they are expensive. With such drugs, an American with AIDS, on average, can expect to live about 24 years at a cost of about $25,200 a year. Such drugs cost too much for widespread use in developing countries.

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 a mass-advertising and education program geared toward adults and schoolchildren to help prevent the disease, emphasizing abstinence, condom use, and circumcision (which can reduce the transmission of HIV by up to 60%). *Fifth,* provide free or low-cost drugs to slow the progress of the disease. *Sixth,* increase funding for research on the development of microbiocides such as a vaginal gel that could help women protect themselves against HIV in countries and situations where men are reluctant to use condoms. If these things are done, the WHO estimates that the projected death toll from AIDS between 2006 and 2030 could be reduced from 117 million to about 89 million.

HOW WOULD YOU VOTE?

Should developed and developing nations mount an urgent global campaign to reduce the spread of HIV (**Core Case Study**) and to help countries afflicted by the disease? CORE CASE STUDY Cast your vote online at **www.thomsonedu.com/biology/miller**.

The third largest viral killer is the *hepatitis B virus* (HBV), which damages the liver and kills about a million

SCIENCE FOCUS

A Nightmare Flu Scenario

Common flu viruses kill up to 2% of the people they infect, most of them very young, old, weak, or sick. Most die from secondary infections of bacterial pneumonia. Flu viruses regularly contribute to the deaths of about 1 million people a year—36,000 of them in the United States.

Every now and then an especially potent flu virus develops that can kill up to 80% of it victims, including healthy young adults. The result: a global flu pandemic that can kill millions of people within a few months and cause economic and social chaos.

This happened in 1918 when a virus called Spanish flu spread rapidly around the globe and within a few months killed 20–50 million people—including 500,000 in the United States. Some people woke up healthy and were dead by nightfall.

Many health scientists believe that sooner or later a mass infection from a new and very potent flu virus will sweep the world again, its spread hastened by infected people crisscrossing the world every day in airliners. Health officials project that within a few months such a pandemic could infect up to one-fourth of the world's population and kill anywhere from 2 million to 360 million people. According to the U.S. Centers for Disease Control and Prevention (CDC), a worst-case pandemic could kill as many as 1.9 million and hospitalize 8.5 million Americans and result in economic losses of $167–683 billion.

Pigs, chickens, ducks, and geese are the major reservoirs of flu viruses. As these viruses move from one animal species to another, they can mutate and exchange genetic materials with other flu viruses to create new flu viruses.

In 1997, a new H5N1 avian strain of flu virus genetically related to the 1918 killer strain emerged in Asia. This strain, commonly known as *bird flu* or *avian flu,* first showed up in chickens that were probably infected by wild bird droppings. The virus then spread to people in Hong Kong, and since then, has spread to chickens and wild birds, including migratory birds that can spread the viruses far and wide. Between 2003 and 2006, it is known to have infected 258 people in around 50 countries and killed 154 (99 of them in Vietnam and Indonesia).

The only remaining hurdle keeping it from becoming a pandemic is that by 2007, the new forms of this virus did not have the ability to spread easily from person to person. Health officials tracking this virus say it is probably only a matter of time before strains with this ability emerge.

Critical Thinking

What would you do to help protect yourself if a global flu pandemic occurred?

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people each year. Like HIV, 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.

In recent years, several other viruses that cause previously unknown diseases have received widespread media coverage. One is the *West Nile virus,* 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, infected about 1.3 million people, killed almost 800, and caused severe illness in more than 8,500 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 easily spread from person to person and quickly turn into life-threatening pneumonia. During six months in 2003, the disease began spreading beyond China, infecting at least 8,500 people and causing 812 deaths. Swift local action by the WHO and other health agencies helped contain the spread of this disease by July 2003. But without careful vigilance, it might 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**). In 2004, for example, flu killed about 36,000 Americans and West Nile virus killed 100.

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.

Parasites, protozoa, and fungi cause other infectious diseases. They can also be quite deadly and costly for societies, especially in developing countries. See the Case Study that follows.

■ **CASE STUDY**

Malaria—Death by Mosquito

According to a 2005 study, about 40% of the world's people—most of them living in poor African countries—are at risk from malaria (Figure 14-6). This disease should also be of concern to anyone traveling to malaria-prone areas because there is no vaccine for it.

Malaria is caused by a parasite that is spread by the bites of certain mosquito species. It infects and destroys red blood cells, causing fever, chills, drenching sweats, anemia, severe abdominal pain, headaches, vomiting, extreme weakness, and greater susceptibility to other diseases. It kills at least 2 million people each year—an average of at least 5,500 deaths per day (**Concept 14-2**). About 90% of those dying are children younger than

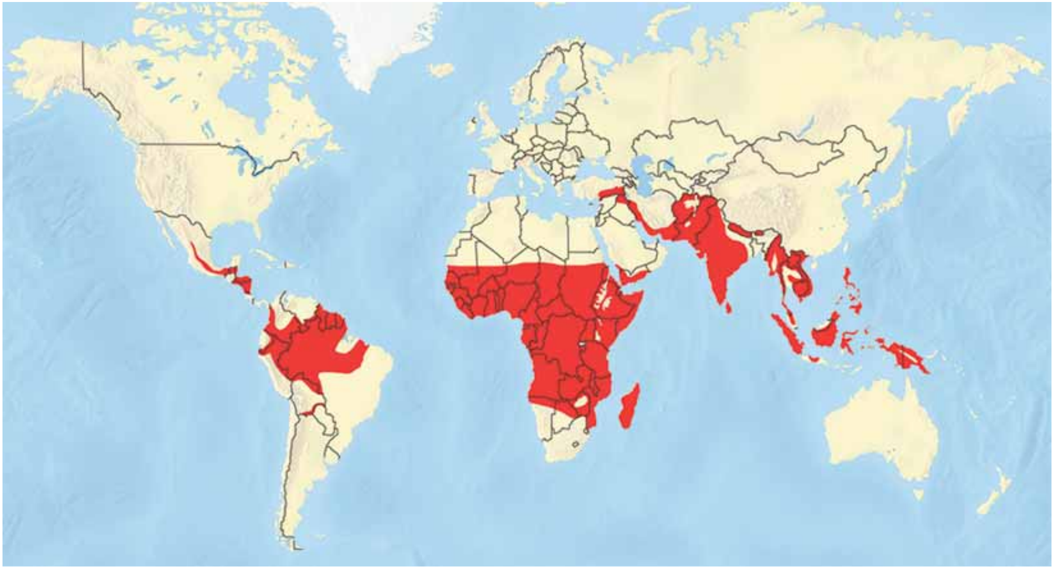


Figure 14-6 *Global outlook:* distribution of malaria. About 40% of the world's population lives in areas in which malaria is prevalent. Malaria kills at least 2 million people a year, more than 80% of them in sub-Saharan Africa, and most of them children under the age of five (**Concept 14-2**). (Data from the World Health Organization, U.S. Centers for Disease Control and Prevention, and Malaria Atlas Project)

age 5. Many of those who survive suffer brain damage or impaired learning ability.

Four species of protozoan parasites in the genus *Plasmodium* cause malaria. Most cases of the disease occur when an uninfected female of any of about 60 *Anopheles* mosquito species bites a person (usually at night) 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, multiply in the liver, and enter blood cells to continue multiplying. Malaria can also be transmitted by blood transfusions or by 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 by draining swamplands and marshes, spraying breeding areas with insecticides, and using drugs to kill the parasites in the bloodstream. 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, building roads into tropical forests, and clearing them (Figure 8-7, p. 156) has increased the risk of malaria for workers and the settlers that follow. Global warming is also likely to increase cases of malaria because of the spread of malaria-carrying mosquitoes to warmer areas.

Malaria and the AIDS virus interact in a vicious cycle because of the weakened condition of people with these diseases, especially in parts of Africa where both diseases are prevalent. People with HIV are more vulnerable to malaria and people with malaria are more vulnerable to HIV.

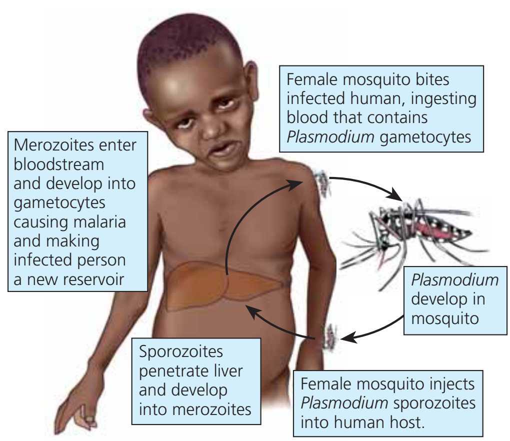


Figure 14-7 *The life cycle of malaria. Plasmodium* parasites circulate from mosquito to human and back to mosquito.

Researchers are working to develop new antimalarial drugs (such as *artemisinins,* a Chinese remedy derived from the sweet wormwood plant and possibly a genetically engineered version), vaccines, and biological controls for *Anopheles* mosquitoes. But these approaches receive too little funding and have proved difficult to implement. In 2005, malaria researchers were evaluating the use of two fungi, which are apparently harmless to humans and the environment, to kill malaria-carrying mosquitoes. If effective, they could be sprayed on walls or soaked into mosquito nets.

RESEARCH FRONTIER

Finding new drugs and other treatments for malaria and other infectious diseases

One approach is to provide poor people in malarial regions with insecticide-treated bed nets (which cost about $5 and last for five years) and window screens for their dwellings. Another is to use zinc and vitamin A supplements to boost resistance to malaria in children. We can also greatly reduce the number of malaria cases by spraying the insides of homes with low concentrations of the pesticide DDT twice a year at a cost of about $10. Under an international treaty enacted in 2002, DDT and five similar pesticides are being phased out in developing countries. However, the treaty allows 25 countries to continue using DDT for malaria control until other alternatives become available.

The cost of lifesaving malaria treatment for one person is 25 cents to $2.40. Columbia University economist Jeffrey Sachs estimates that spending $2–3 billion on malaria might save more than a million lives a year. To him, "This is probably the best bargain on the planet."

ThomsonNOW™ Watch through a microscope what happens when a mosquito infects a human with malaria at ThomsonNOW.

Ecological Medicine Can Help Us Reduce the Spread of Infectious Diseases

Infectious diseases are moving from one animal species to another and from wild and domesticated animal species to humans. Examples of infectious, or so-called *zoonotic,* diseases transmitted from wild and domesticated animals to humans include avian flu (Science Focus, p. 328), HIV (**Core Case Study**), SARS, West Nile virus, and Lyme disease. A 2006 study in the Journal of Internal Medicine estimated that 50 million people worldwide have been infected with zoonotic diseases since 2000 and as many as 78,000 have died. Most people do not realize that pets such as turtles, rabbits, hamsters, and other "pocket pets" can transfer various infectious diseases to humans.

CORE CASE STUDY

The new interdisciplinary field of *ecological* or *conservation medicine* is devoted to tracking down these connections between wildlife and humans. Scientists in this new field are looking for ways to slow or prevent the spread of such diseases, and they have identified several human actions that encourage the spread of diseases from animals to humans.

One is the clearing of forests, which forces wild animals to move to other areas. For example, cutting down tropical rain forests has increased the spread of malaria by increasing the range of *Anopheles* mosquito species that survive in sunlit ponds and carry the parasite that infects humans. There is also concern that global warming will expand northward the tropical areas where malaria-carrying species thrive (Figure 14-6).

Forest clearing and fragmentation to build suburbs in the eastern United States has increased the chances of many suburbanites becoming infected with debilitating Lyme disease. The bacterium that causes this disease lives in the bodies of deer and white mice and is passed between these two animals by certain types of ticks. Expanding suburbs have fragmented woodland areas and greatly reduced populations of foxes and wildcats that kept down populations of white mice that carried the Lyme bacterium. The result: white mice and tick populations have exploded, and more suburbanites and hikers have become infected. Fortunately, the Lyme bacterium does not spread from person to person.

In parts of Africa and Asia, local people who kill monkeys and other animals for bushmeat (Figure 9-16, p. 190) come in regular contact with primate blood and can be exposed to a simian strain of the HIV virus that causes AIDS. Some monkeys also carry dangerous viruses such as herpes B that can be transferred to humans. Other factors are *global trade,* which can transfer infectious organisms in crates, agricultural products, and ship ballast water, and *global travel,* including ecotourism in wilderness areas.

A major factor is the legal and illegal international trade in wild species. In 2005, some 210 million wild animals—such as kangaroos, iguanas, kinkajous, and tropical fish—were legally imported into the United States with no quarantining (except for wild birds, primates, and some cud-chewing wild animals) and minimal screening for disease. Each year countless more animals, bushmeats, and animal parts are smuggled illegally across U.S. borders. A backpack carried off a flight from Nigeria may contain bushmeat that could harbor the lethal Ebola virus. Salted duck eggs from South Korea could carry the deadly bird flu virus. Exotic birds taped to a passenger's legs or monkey paws concealed in a bag could harbor various diseases that could jump to humans.

The U.S. government employs only 120 full-time inspectors to inspect hundreds of millions of wild animals arriving legally or illegally each year at 39 airports and border crossings. This small group of overwhelmed inspectors is responsible for screening some 317 million automobile passengers, 86 million airplane passengers, and 11 million seaborne containers entering the United States annually.

Factory meat production and the global trade of livestock animals can decrease food security by increasing the spread of food-borne infectious diseases to humans. For example, a deadly form of *E. coli* bacteria can spread from livestock animals and animals such as wild boars to humans when people eat food contaminated by animal manure. Salmonella bacteria found on animal hides and on meat contaminated with animal feces left by careless meat processors also can cause food-borne disease.

RESEARCH FRONTIER

Ecological medicine

SOLUTIONS

Infectious Diseases

- Increase research on tropical diseases and vaccines
- Reduce poverty
- Decrease malnutrition
- Improve drinking water quality
- Reduce unnecessary use of antibiotics
- Educate people to take all of an antibiotic prescription
- Reduce antibiotic use to promote livestock growth
- Require careful hand washing by all medical personnel
- Immunize children against major viral diseases
- Provide oral rehydration for diarrhea victims
- Conduct global campaign to reduce HIV/AIDS

Figure 14-8 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? Why?

We Can Reduce the Incidence of Infectious Diseases

Great news. According to the WHO, the global death rate from infectious diseases decreased by about two-thirds between 1970 and 2000 and is projected to continue dropping. Also, between 1971 and 2000, the percentage of children in developing countries immunized with vaccines to prevent tetanus, measles, diphtheria, typhoid fever, and polio increased from 10% to 84%—saving about 10 million lives each year. It costs about $30 to get a basic package of vaccines to a child—an affordable way to save a child's life for roughly the price of a single night out at the movies in a developed country.

Figure 14-8 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 (**Concept 14-2**). 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 2.1 million in 2006. Few investments have saved so many lives at such a low cost. In 2006, the WHO estimated that implementing the solutions in Figure 14-8 could save the lives of as many as 4 million children under age 5 each year—an average of 456 an hour.

Recall that more than a third of the world's people—2.6 billion—do not have decent bathroom facilities, and more than a 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 abut $20 billion a year—about what rich countries with almost universal access to clean water spend each year on bottled water.

The WHO estimates that only 10% of global medical research and development money goes toward preventing infectious diseases in developing countries, even though more people worldwide suffer and die from these diseases than from all other diseases combined.

However, the problem is getting more attention. In recent years, Bill and Melinda Gates and Warren E. Buffet have donated billions of dollars to improve global health, with primary emphasis on infectious diseases in developing countries. **GREEN CAREER:** Disease prevention

14-3 What Types of Chemical Hazards Do We Face?

CONCEPT 14-3 There is growing concern about chemicals that can cause cancer and disrupt the human immune, nervous, and endocrine systems.

Some Chemicals Can Cause Mutations, Birth Defects, and Cancers

A **toxic chemical** is defined as one that can cause temporary or permanent harm or death to humans and animals. A **hazardous chemical** is a chemical that can harm humans and other animals by being flammable or explosive or by irritating or damaging the skin or lungs, interfering with oxygen uptake, or inducing allergic reactions.

There are three major types of potentially toxic agents. **Mutagens** include 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 preservatives in foods, can cause mutations linked to increases in stomach cancer in people who consume large amounts of processed foods and wine that contain nitrate preservatives. Harmful mutations occurring in reproductive cells can be passed on to offspring and to future generations. There is no safe threshold for exposure to mutagens.

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 arsenic, benzene, chlorine, chloroform, chromium, DDT, lead, mercury, PCBs, phthalates, thalidomide, and vinyl chloride.

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 death. Examples of carcinogens are arsenic, benzene, vinyl chloride, chromium, PCBs, and certain chemicals in tobacco smoke.

Many cancerous tumors spread by **metastasis,** in which malignant cells break off from tumors and travel in body fluids to other parts of the body. There they start new tumors, making treatment much more difficult. 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.

Some Chemicals May Affect Our Immune, Nervous, and Endocrine Systems

Since the 1970s, a growing body of research on wildlife and laboratory animals, along with some studies of humans, suggest 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 and dioxins can weaken the human immune system and leave the body vulnerable to attacks by allergens, 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). They inhibit, damage, or destroy nerve cells (neurons) that transmit electrochemical messages throughout the body. Effects can include behavioral changes, learning disabilities, retardation, attention deficit disorder, paralysis, and death. Examples of neurotoxins are PCBs, methyl mercury, 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 have shapes similar to those of natural hormones and can disrupt the endocrine system in people and some other animals. These molecules are called *hormonally active agents* (HAAs). Exposure to low levels of HAAs, also sometimes called *hormone mimics,* could impair reproductive systems and sexual development and cause physical and behavioral disorders. Examples of HAAs include DDT, PCBs, atrazine and several other herbicides, aluminum, mercury, and bisphenol-A (found in certain plastics used in a variety of products including water bottles, baby bottles, food storage containers, liners for food and beverage cans, toys, pacifiers, baby teethers, automobile interiors, and dental fillings).

Natural biological evolution has not equipped us to deal with these new synthetic hormone imposters.

Some hormone mimics are chemically similar to estrogens (female sex hormones). 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. 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).

There is also growing concern about still another group of HAAs—pollutants that can act as *thyroid disrupters* and cause growth, weight, brain, and behavioral disorders. A number of scientists fear that very low levels of HAAs in the environment from the widespread use of pesticides and other chemicals such as bisphenol-A can disrupt the human endocrine and nervous systems and cause or promote certain types of cancers.

RESEARCH FRONTIER

Evaluating the health effects of HAAs

There is also concern about the harmful effects of certain *phthalates* (pronounced thall-eights) used as softeners in products made with polyvinyl chloride (PVC) plastic and as solvents in many consumer products. Phthalates are found in perfumes, cosmetics, hair sprays, deodorants, nail polish, and PVC products such as soft vinyl toys, and blood storage bags and tubes used in hospitals.

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. But there is not enough evidence to conclusively link these chemicals to human health and reproductive problems.

Much more research is needed to evaluate the effects of low levels of HAAs on humans. Some scientists say we need to wait for the results of such research before banning or severely restricting HAAs, which would cause huge economic losses for companies making them. Such research will take decades. Meanwhile, some scientists believe that as a precaution, we should sharply reduce our use of potential hormone disrupters. This important issue involves the interaction of science, economics, politics, and ethics.

THINKING ABOUT
Hormone Disrupters

Should we ban or severely restrict the use of potential hormone disrupters? What beneficial or harmful effects might this have on your life?

14-4 How Can We Evaluate Chemical Hazards?

CONCEPT 14-4A Any synthetic or natural chemical can be harmful if ingested in a large enough quantity.

CONCEPT 14-4B Many health scientists call for much greater emphasis on pollution prevention to reduce our exposure to potentially harmful chemicals.

Determining the Safety of a Chemical Is Not Easy

Toxicology is the science that studies the harmful effects of chemicals on humans, wildlife, and ecosystems, studies the mechanisms that cause toxicity, and evaluates ways to prevent or minimize the harmful effects. **Toxicity**—a measure of how harmful a substance is in causing injury, illness, or death to a living organism—depends on several factors. One is the **dose,** the amount of a substance a person has ingested, inhaled, or absorbed through the skin. A basic concept of toxicology is that *any synthetic or natural chemical can be harmful if ingested in a large enough quantity* (**Concept 14-4A**).

Other factors are how often the exposure occurred, who is exposed (adult or child, for example), and how well the body's detoxification systems (such as the liver, lungs, and kidneys) work. 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).

Five other factors can help determine the harm caused by a substance. 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.

A second factor is a substance's *persistence,* or resistance to breakdown. Many chemicals, such as DDT, have been used precisely because of their persistence. But the problem is that they can have long-lasting harmful effects on the health of wildlife and people.

A third factor for some substances is *bioaccumulation,* in which some molecules are absorbed and stored in specific organs or tissues at higher than normal levels. As a consequence, a chemical found at a fairly low concentration in the environment can build up to a harmful level in certain organs and tissues.

A related factor is *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. Organisms at low trophic levels might ingest only small amounts of a toxin, but each animal on the next trophic level up that eats many of those organisms will take in increasingly larger amounts of that toxin (Figure 9-14, p. 188).

A fifth factor is *chemical interactions* that can decrease or multiply the harmful effects of a toxin. An *antagonistic interaction* can reduce harmful effects. For example, there is preliminary evidence that vitamins E and A can interact to reduce the body's response to some cancer-causing chemicals. On the other hand, a *synergistic interaction* multiplies harmful effects. For instance, workers exposed to tiny fibers of asbestos increase their chances of getting lung cancer 20-fold. But asbestos workers who also smoke have a 400-fold increase in lung cancer rates.

The type and severity of health damage resulting from exposure to a chemical or other agent are called the **response.** An *acute effect* is an immediate or rapid harmful reaction to an exposure—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.

Again, any substance can be harmful if ingested in a large enough quantity (**Concept 14-4A**). For example, drinking 100 cups of strong coffee one after another would expose most people to a lethal dosage of caffeine. Similarly, downing 100 tablets of aspirin or 1 liter (1.1 quarts) of pure alcohol would kill most people.

The critical question is this: *How much exposure to a particular toxic chemical causes a harmful response?* This is the meaning of the chapter-opening quote by the German scientist Paracelsus about the dose making the poison.

Your body has three major mechanisms for reducing the harmful effects of some chemicals. *First,* it can use liver enzymes to break down, dilute, or excrete (by breathing, sweating, and urinating) small amounts of most toxins to keep them from reaching harmful levels. However, accumulations of high levels of toxins can overload these body systems. *Second,* your cells have enzymes that can sometimes repair damage to DNA and protein molecules. *Third,* cells in some parts of your body (such as your skin and the linings of your gastrointestinal tract, lungs, and blood vessels) can reproduce quickly enough to replace damaged cells.

The effects of a particular chemical can depend upon the age of the person exposed to it. For example, infants and young children are more susceptible to the effects of toxic substances than are adults for three major reasons. *First,* children 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 and soil when they put their fingers, toys, or other objects in their mouths, as they frequently do. *Third,* children usually have less well-developed immune systems and body detoxification processes than adults have.

In 2003, the U.S. Environmental Protection Agency (EPA) proposed that in determining the risk of exposure to cancer-causing chemicals, regulators should assume that children face a risk 10 times higher than that faced by adults. Some health scientists contend that these guidelines are too weak. They suggest that, to be on the safe side, we should assume that this risk for children is 100 times that of adults.

Examples of toxicants include certain pesticides, radioactive isotopes, heavy metals such as mercury and lead, industrial chemicals such as PCBs (polychlorinated biphenyls), and flame retardants such as PBDEs (polybrominate diphenyl ethers). Estimating the levels and effects of human exposure to chemicals is very difficult because of the numerous and often poorly understood factors involved (Figure 14-9). Supplement 17 on pp. S71–S72 discusses methods that scientists use to estimate the toxicity of chemicals.

Are Trace Levels of Toxic Chemicals Harmful?

Almost everyone is now exposed to potentially harmful chemicals (Figure 14-10, p. 336) that have built up to trace levels in their blood and other parts of their bodies. Traces of many of these chemicals are also found in the blood and fatty tissues of polar bears in the Arctic—likely carried from the continental United States to this isolated area by winds and ocean currents.

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 of a lack of data and the difficulty of determining the effects of exposures to low levels of chemicals, as discussed in Supplement 17 on pp. S71–S72.

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. Others view the risks from such trace levels as minor. They point out that average life expectancy has been increasing in most countries, especially developed ones, for decades.

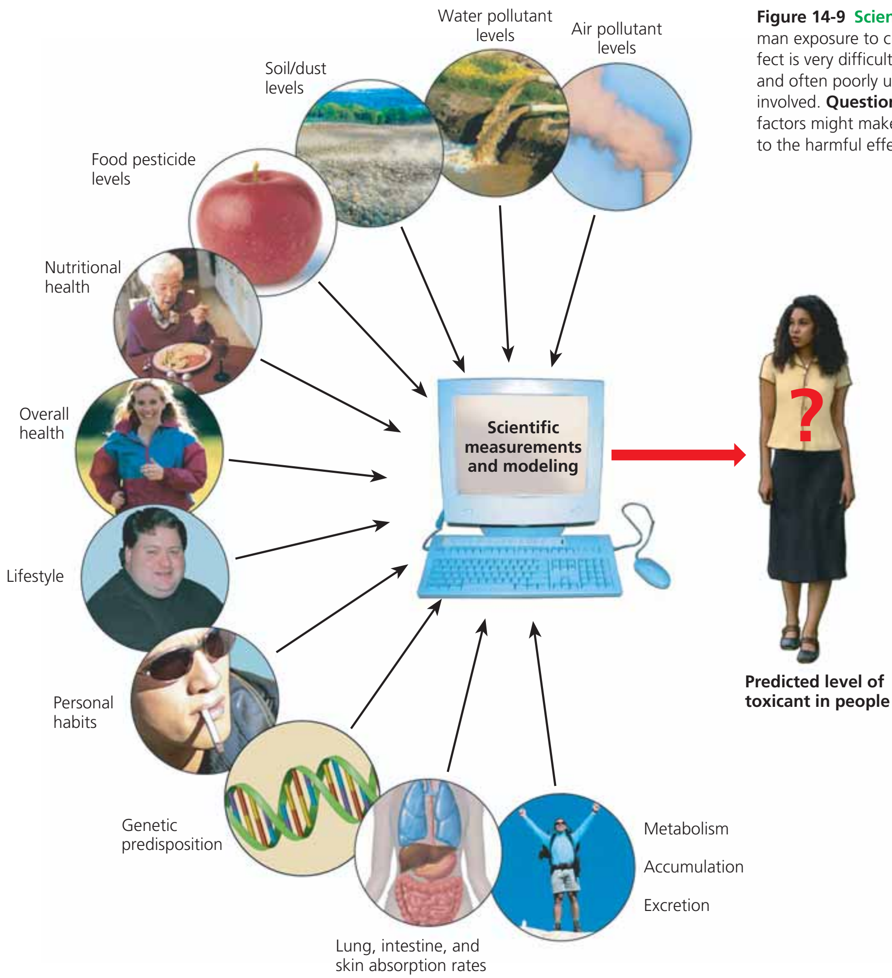


Figure 14-9 **Science:** estimating human exposure to chemicals and their effect is very difficult because of the many and often poorly understood variables involved. **Question:** What three of these factors might make you more vulnerable to the harmful effects of chemicals?

Chemists are able to detect increasingly smaller amounts of potentially toxic chemicals in air, water, and food. This is good news, but it can give the false impression that dangers from toxic chemicals are increasing. In reality, we may simply be uncovering levels of chemicals that have been around for a long time.

RESEARCH FRONTIER

Learning more about the long-term health effects of trace amounts of potentially harmful chemicals

Some people also have the mistaken idea that all natural chemicals are safe and all synthetic chemicals are harmful. In fact, many synthetic chemicals are quite safe if used as intended, and many natural chemicals are deadly.

Why Do We Know So Little about the Harmful Effects of Chemicals?

All methods for estimating toxicity levels and risks have serious limitations, as discussed in Supplement 17 on pp. S71–S72. 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 10% of 85,000 registered synthetic

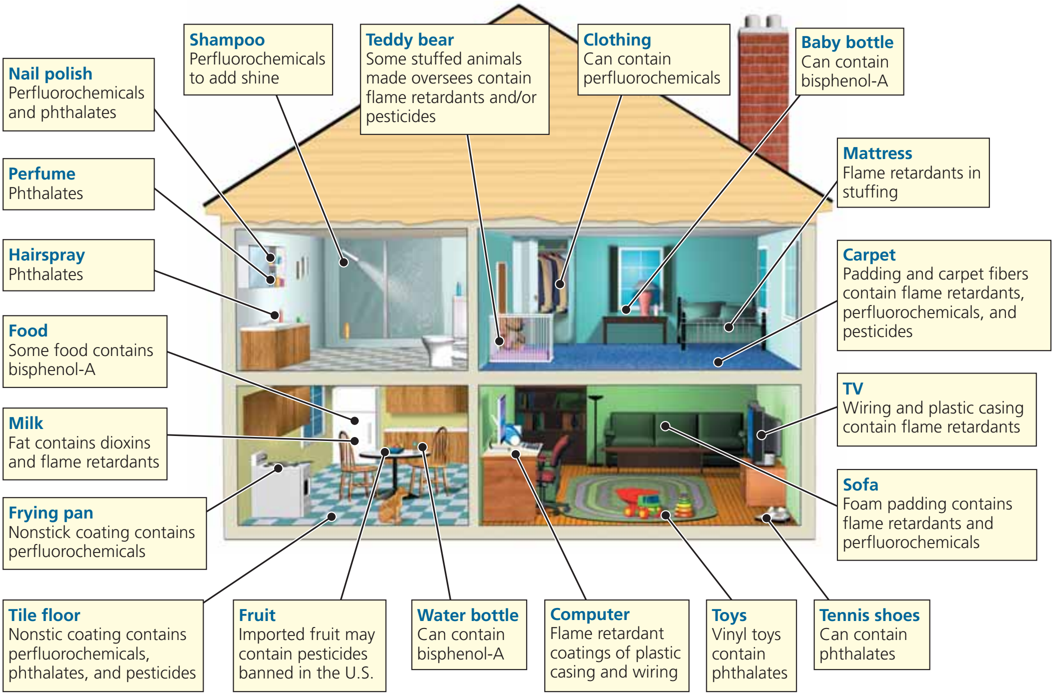


Figure 14-10 **Science:** some potentially harmful chemicals found in most homes. Most people have traces of these chemicals in their blood and body tissues. We do not know the long-term effects of exposure to low levels of such chemicals. (Data from U.S. Environmental Protection Agency, Centers for Disease Control and Prevention, and New York State Department of Health)

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 costs involved in 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?

So where does this leave us? We do not know a lot about the potentially toxic chemicals around us and inside of us, and estimating their effects is very difficult, time-consuming, and expensive. Is there a way to deal with this problem?

Some scientists and health officials, especially those in European Union countries, are pushing for much greater emphasis on *pollution prevention* (**Concept 1-4**, p. 14). 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 or recycling them within production processes to keep them from reaching the environment (**Concept 14-4B**), as the 3M company in the United States has been doing since 1975, and as the DuPont chemical giant has also begun doing.

CONCEPT LINK

Pollution prevention is based on the *precautionary principle* (p. 117). Recall that this means that when there is reasonable but incomplete scientific evidence (tentative scientific evidence) of significant 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. Our threat to the life-sustaining ozone layer (see Individuals Matter, at right) could have been prevented had we used the precautionary principle to delay releasing large quantities of ozone-depleting chemicals into the atmosphere until we carried out research to evaluate their possible harmful effects. But hindsight is often much clearer than foresight.

There is controversy over how far we should go in using the precautionary principle. With this approach, those proposing to introduce a new chemical or tech-

INDIVIDUALS MATTER

Ray Turner and His Refrigerator

Life as we know it could not exist on land or in the upper layers of the oceans and other bodies of water without the thin layer of ozone (O_3) found in the lower stratosphere (Figure 3-7, p. 44). In other words, a basic rule of sustainability based on pollution prevention should be: *Don't mess with the ozone layer.*

However, for decades we violated this principle of pollution prevention by releasing large amounts of chemicals such as chlorofluorocarbons (CFCs) into the troposphere. These chemicals have drifted into the stratosphere where they react with and destroy some of the ozone that protects life from harmful UV radiation.

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 the harmful ozone-destroying chemicals led scientists to use the principle of pollution prevention to search for less harmful alternatives.

Ray Turner, an aerospace manager at Hughes Aircraft in the U.S. state of California, found a solution to this problem by looking in his refrigerator. His concern for the environment led him to search for a cheap and simple substitute for the CFCs used as cleaning agents to remove films of oxidation from the electronic circuit boards manufactured at his plant.

He decided to put drops of some common kitchen substances on a corroded penny to see whether any of them removed the film of 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 Turner 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.

nology would bear the burden of establishing its safety. This requires two major changes in the way we evaluate risks. *First,* new chemicals and technologies would be assumed to be harmful until scientific studies can 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 can be established. For example, after decades of research established the harmful effects of lead, especially on children, lead-based paints and leaded gasoline were phased out in most developed countries.

Some further 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.* The list includes DDT and eight other persistent pesticides, PCBs, dioxins, and furans. 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. There is also concern that some of these chemicals may play a role in malformed penises in boys, increased testicular cancers, and a 50% decline in sperm counts and sperm quality in men in a number of countries. Because such evidence is tentative and controversial, these chemicals qualify for being phased out. 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.

In 2006, the European Union enacted new regulations, known as REACH, 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. Environmentalists applaud this use of the precautionary principle, but some say that the regulation does not go far enough and has too many loopholes.

Manufacturers and businesses contend that widespread application of the precautionary principle would make it too expensive and almost impossible to introduce any new chemical or technology. They argue that we can never have a risk-free society.

Proponents of increased reliance on the precautionary principle agree, but argue we have an ethical responsibility to make greater use of the precautionary principle to reduce known or potentially serious risks. 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 primarily on cleanup. Such solutions would reduce health risks for employees and society, free businesses from having to deal with pollution regulations, reduce the threat of lawsuits from harmed parties, possibly increase profits from sales of safer products and innovative technologies, and improve the public image of businesses operating in this manner.

HOW WOULD YOU VOTE? ✓

Should we rely more on the precautionary principle as a way to reduce the risks from chemicals and technologies? Cast your vote online at **www.thomsonedu.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 Risks Are Associated with 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 (see Supplement 17 on pp. S71–S72), are used to estimate risks from older technologies and chemicals. To evaluate new technologies and products, risk evaluators use more uncertain statistical probabilities, based on models rather than actual experience and testing.

Risk experts also seek to determine the most dangerous risks by doing *comparative risk analysis.* 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 14-11) and reduced life span (Figure 14-12), *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 the health risks associated with poverty and being born male, the greatest risks of premature death mostly result from choices people make relating to their lifestyles (Figures 14-11). The best ways to reduce one's risk of premature death and serious health risks are to avoid smoking and exposure to smoke, 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 per day), avoid excess sunlight (which ages skin and can cause skin cancer), and practice safe sex (**Concept 14-5**). A 2005 study by Majjid Ezzati with participation by 100 scientists around the world estimated that one-third of the 7 million annual

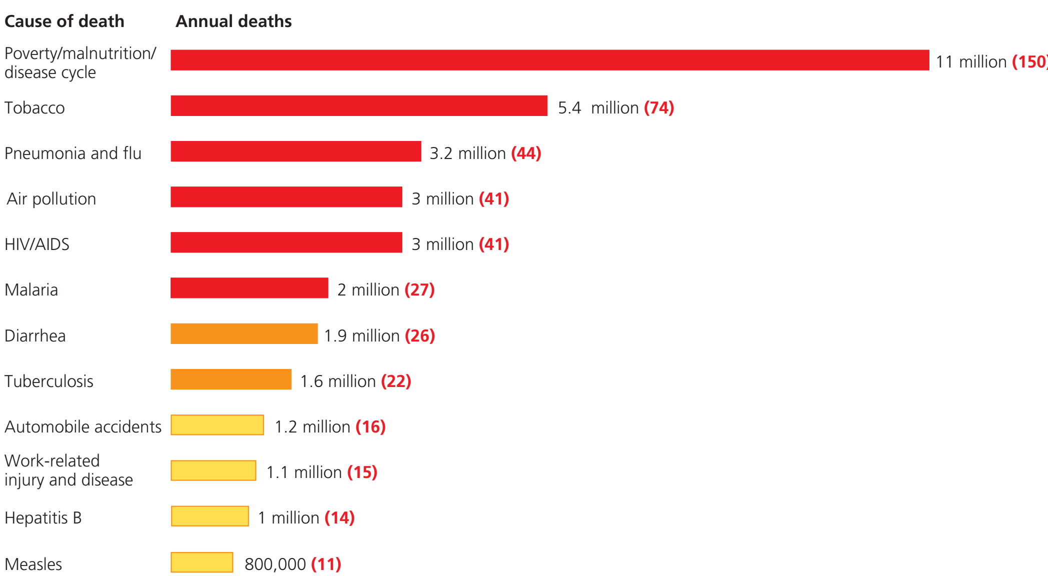


Figure 14-11 *Global outlook:* number of deaths per year in the world from various causes. Numbers in parentheses give these death tolls in terms of the number of fully loaded 200-passenger jets crashing *every day of the year* with no survivors. Because of sensational media coverage, most people are misinformed about the largest annual causes of death. **Question:** Which three of these items are most likely to shorten your life span? (Data from World Health Organization)

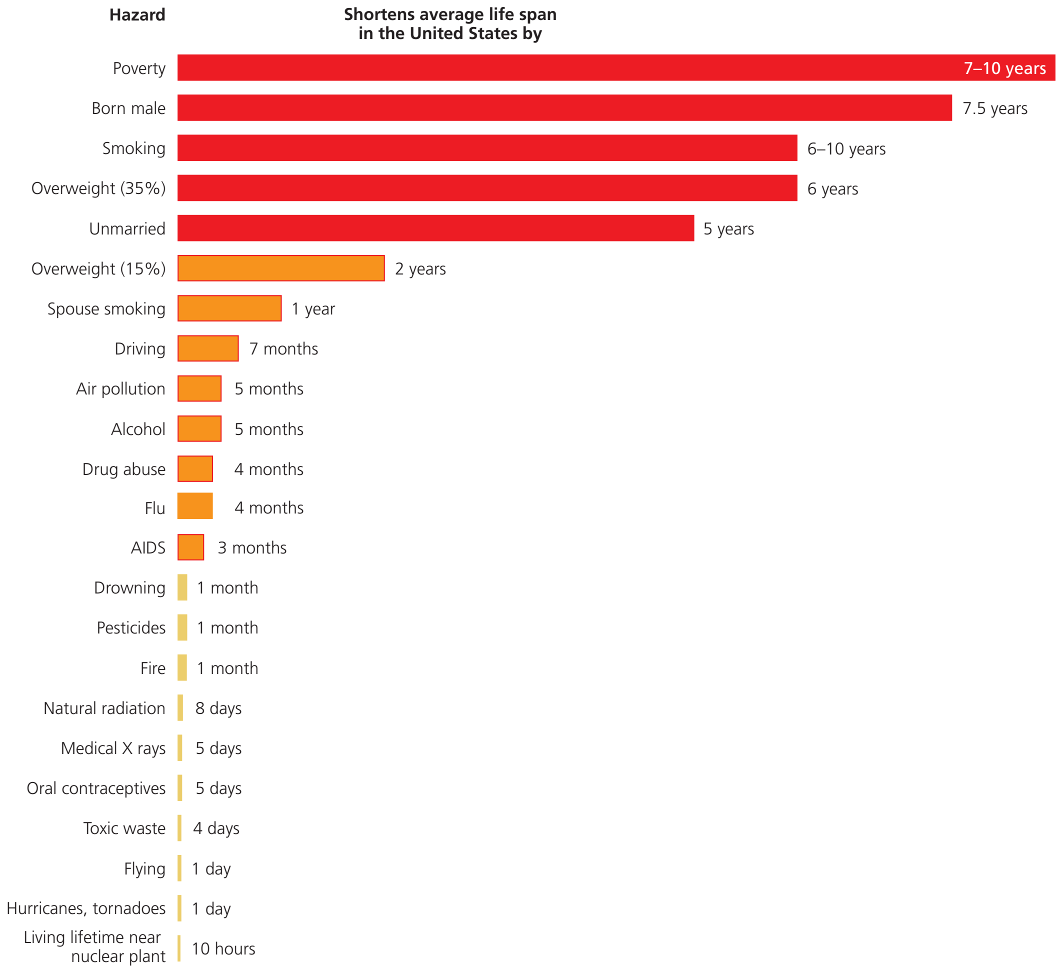


Figure 14-12 Comparison of risks people face in the United States, expressed in terms of shorter average life span. Excepting poverty and gender, the greatest risks people face come mostly from the lifestyle choices they make. These are generalized relative estimates. Individual responses to these risks can 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)

deaths from cancer could be prevented if individuals followed these guidelines.

Note that one of the top five causes of premature deaths worldwide (Figure 14-11) is air pollution—a factor that many people, especially in developing countries, cannot control. Other such problems are listed in Figure 14-13 (p. 340), which summarizes the results of a comparative risk analysis concerning the greatest ecological and health risks in the United States, identified by a panel of scientists acting as advisers to the U.S. Environmental Protection Agency. We discuss these problems, most of which apply worldwide, in more depth in later chapters. Here we focus more on preventable risks such as smoking (see Case Study that follows).

■ 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 about 13,700 people every day, or 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.*

According to the WHO, tobacco helped kill 90 million people between 1950 and 2006—three times the 30 million people killed in all wars since 1900!

The WHO estimates that each year, tobacco contributes to the premature deaths of 5.4 million people from 25 illnesses including *heart disease, lung cancer, other*

COMPARATIVE RISK ANALYSIS

Most Serious Ecological and Health Problems

High-Risk Health Problems
- Indoor air pollution
- Outdoor air pollution
- Worker exposure to industrial or farm chemicals
- Pollutants in drinking water
- Pesticide residues on food
- Toxic chemicals in consumer products

High-Risk Ecological Problems
- Global climate change
- Stratospheric ozone depletion
- Wildlife habitat alteration and destruction
- Species extinction and loss of biodiversity

Medium-Risk Ecological Problems
- Acid deposition
- Pesticides
- Airborne toxic chemicals
- Toxic chemicals, nutrients, and sediment in surface waters

Low-Risk Ecological Problems
- Oil spills
- Groundwater pollution
- Radioactive isotopes
- Acid runoff to surface waters
- Thermal pollution

Figure 14-13 **Science:** *comparative risk analysis* of the most serious ecological and health problems in the United States, according to scientists acting as advisers to the EPA. Risks under each category are not listed in rank order. **Question:** Which two risks in each of the two high-risk problem lists do you think are the most serious? Why? (Data from Science Advisory Board, *Reducing Risks,* Washington, D.C.: Environmental Protection Agency, 1990)

cancers, bronchitis, emphysema, and stroke. About half of these deaths occur in developed countries and the other half in developing countries. By 2030, the annual death toll from smoking-related diseases is projected to reach 8.3 million—an average of 22,700 preventable deaths per day or 1 death every 4 seconds. About 70% of these deaths are expected to occur in developing countries.

According to the CDC, smoking kills about 442,000 Americans per year prematurely—an average of 1,210 deaths per day (Figure 14-14). This death toll is roughly equivalent to six fully loaded 200-passenger jets crashing *every day* with no survivors! Yet, this ongoing major human tragedy in the United States and throughout the world rarely makes the news.

The overwhelming consensus in the scientific community is that the nicotine inhaled in tobacco smoke is highly addictive. Only 1 in 10 people who try to quit smoking succeeds. A British government study showed that adolescents who smoke more than one cigarette have an 85% chance of becoming smokers.

Passive smoking, or breathing secondhand smoke, also poses health hazards for children and adults. Children who grow up with smokers are more likely to develop allergies and asthma. Among adults, nonsmoking spouses of smokers face a 30% higher risk of both heart attack and lung cancer than do spouses of nonsmokers. 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. In 2006, California became the first state to classify secondhand smoke as a toxic air pollutant.

A 50-year 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 old—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.

Many health experts urge that a $3–$5 federal tax be added to the price of a pack of cigarettes in the United States (and in other countries). Then users of tobacco products would pay a much greater share of the $158 billion per year (an average of $301,000 per minute) in health, economic, and social costs associated with smoking in the United States.

Analysts also call for classifying and regulating the use of nicotine as an addictive and dangerous drug under the U.S. Food and Drug Administration, eliminating all federal subsidies and tax breaks to tobacco farmers and tobacco companies, and using cigarette tax revenue to finance an aggressive antitobacco advertising and education program. In 2005, activists left 1,210 pairs of empty shoes in front of the U.S. capital to remind lawmakers that *each day* tobacco kills that many people in the United States. So far, the U.S. Congress has not enacted such reforms.

Some other countries are enacting smoking bans. In 2004, Ireland, Norway, Scotland, and the United Kingdom enacted bans that will take place within a few years on smoking in all indoor workplaces, bars, and restaurants. And in 2004, India banned smoking in

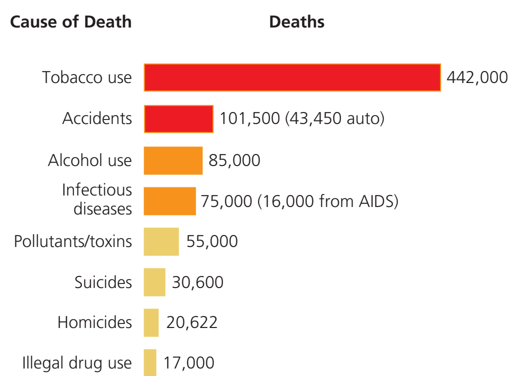


Figure 14-14 Annual deaths in the United States from tobacco use and other causes in 2004. Smoking is by far the nation's leading cause of preventable death, causing more premature deaths each year than all the other categories in this figure combined. (Data from U.S. National Center for Health Statistics and Centers for Disease Control and Prevention and U.S. Surgeon General)

public places, tobacco advertising in the mass media, and tobacco sales to minors, after studies showed that smoking was killing 2,200 people a day in India.

HOW WOULD YOU VOTE?

Do you favor classifying and regulating nicotine as an addictive and dangerous drug? Cast your vote online at **www.thomsonedu.com/biology/miller**.

Estimating Risks from Technologies Is Not Easy

The more complex a technological system and the more people needed to design and run it, the more difficult it is to estimate the risks of using the system. The overall *reliability* or the probability (expressed as a percentage) that a person or device 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 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 explain allegedly "almost impossible" tragedies such as the Chernobyl nuclear power plant explosion (Case Study, p. 293) and the *Challenger* and *Columbia* space shuttle 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 bolt 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. Also, 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 the possibility 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).

Several 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 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. In the United States, the risk of dying in a car accident while using your seatbelt is 1 in 6,070 whereas the risk of dying in a commercial airliner crash is 1 in 9 million.

Second is *fear of the unknown.* Most people fear a new, unknown product or technology more than they do an older, more familiar one. For example, some people fear genetically modified food and trust food produced by traditional plant-breeding techniques. Most people have greater fear of nuclear power plants than of more familiar and highly polluting coal-fired power plants.

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 higher death toll spread out over time. Other examples include a severe nuclear power plant accident, an industrial explosion, or an accidental plane crash, as opposed to coal-burning power plants, automobiles, or smoking.

Fourth, some people suffer from an *optimistic bias,* believing that risks that apply to other people do not apply to them. A driver might get upset seeing another person driving erratically while talking on a cell phone. Yet that driver may not believe that talking on the cell phone impairs his or her driving ability.

A fifth problem 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, lying in the sun, and practicing unsafe sex.

There is also concern about the *unfair distribution of risks* from the use of a technology or chemicals. Citizens are outraged when government officials decide to put a hazardous waste landfill or incinerator in or near their neighborhood. Even when the decision is based on careful risk analysis, it is usually seen as political, not a scientific, decision. Residents will not be satisfied by estimates that the lifetime risk of dying from cancer caused by living near the facility is not greater than, say, 1 in 100,000. Instead, they point out that they will have a much higher risk of dying from cancer than will people living farther away.

We Can Become Better at Evaluating Risks

You can do three things to become better at estimating risks (**Concept 14-5**). *First,* carefully evaluate news reports. Recognize that the media often give an exaggerated view of risks to capture our interest and sell newspapers or gain radio listeners or television viewers.

Second, compare risks. Do you risk getting cancer by eating a charcoal-broiled steak once or twice a week for a lifetime? Yes, because in theory, anything can harm you. The question is whether this danger is great enough for you to worry about. In evaluating a risk, the question is not "Is it safe?" but rather *"How risky is it compared to other risks?"*

Third, concentrate on the most serious risks to your life and health over which you have some control, and stop worrying about smaller risks and those over which you have no control. When you worry about something, the most important question to ask is, "Do I have any control over this?"

You have control over major ways to reduce risks from heart attack, stroke, and many forms of cancer because you can decide whether you smoke, what you eat, and how much alcohol you 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 in tanning booths. Concentrate on evaluating and carefully making these important choices, and you will have a much greater chance of living a longer, healthier, happier, and less fearful life.

REVISITING AIDS and Sustainability

CORE CASE STUDY

SUSTAINABILITY

In this chapter, we have seen that on a global basis, the greatest threat to human health is the tragic poverty-malnutrition-disease cycle, followed by the threats from smoking, pneumonia, flu, air pollution, and HIV/AIDS (**Core Case Study**). These five global threats prematurely kill about 25.2 million people a year—an average of 69,000 a day or 2,875 an hour—half of them children younger than age 5.

These major global risks are largely preventable if governments, under pressure from concerned citizens, choose to make them global priorities. We can use the four **scientific principles of sustainability** (see back cover) to help us reduce these major risks to human health. This involves shifting from nonrenewable fossil fuels to renewable energy, thereby reducing pollution and the threats from global warming; cutting down on waste of energy and matter resources by reusing and recycling them, thereby helping to provide enough resources for most people to avoid poverty; and emphasizing the use of diverse strategies for solving environmental and health problems, especially for reducing poverty and population growth.

Is this idealistic? Sure. But if creative and caring people throughout human history had not acted to improve the world by doing things 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 QUESTIONS

1. Describe the effect that the global HIV/AIDS epidemic has had on the life expectancies of people living in sub-Saharan African countries. How is this altering the age-structure of those countries?
2. Define risk. What is the difference between risk assessment and risk management?
3. Summarize the main types of hazards that people face.
4. Choose one type of infectious disease and fully explain the cause, method of spreading, symptoms and consequences, prevention and treatment strategies for this type of biological hazard.
5. Describe how a toxic chemical can cause harm or death to humans or animals.
6. Explain why it is often difficult to determine the effect of human exposure to chemicals.

7. Summarize at least ten examples of potentially harmful chemicals that you could be exposed to in your own home.

8. Using comparative risk analysis, explain how risks are ranked as high, medium, or low.

9. From a global perspective, discuss the risk that is the leading cause of deaths worldwide. What is the effect of this risk for people living in the United States?

10. Discuss the effect of smoking on the death rate of people in the United States. List four factors that can cause people to do a poor job of evaluating risks.

CRITICAL THINKING

1. List three ways in which you could apply **Concept 14-5** (p. 338) to make your lifestyle more environmentally sustainable while reducing the major risks you face.

2. How can changes in the age structure of a human population increase the spread of infectious diseases? How can the spread of infectious diseases such as HIV/AIDS affect the age structure of human populations (**Core Case Study** and Figure 14-2, p. 323?) CORE CASE STUDY

3. What three actions would you take to reduce the global threats to human health and life from **(a)** HIV/AIDS (**Core Case Study**), **(b)** tuberculosis, and **(c)** malaria. CORE CASE STUDY

4. 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.

5. Workers in a number of industries are exposed to higher levels of various toxic substances than is the general public. Should workplace levels allowed for such chemicals be reduced? What economic effects might this have?

6. 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. 340. Do you believe there should be a ban on smoking indoors in all public places? Explain.

7. What are the three major risks you face from **(a)** your lifestyle, **(b)** where you live, and **(c)** what you do for a living? Which of these risks are voluntary and which are involuntary? List the three most important things you can do to reduce these risks. Which of these things do you already do or plan to do?

8. Would you support legislation requiring the use of the precautionary principle for deciding what to do about risks from chemicals used in the United States or in the country where you live? Explain.

9. Congratulations! You are in charge of the world. List the three most important features of your program to reduce the risk from exposure to **(a)** infectious disease organisms and **(b)** toxic and hazardous chemicals.

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

LEARNING ONLINE

Log on to the Student Companion Site for this book at www.thomsonedu.com/biology/miller and choose Chapter 14 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Web links, information on Green Careers, and InfoTrac® College Edition articles.

For access to animations and additional quizzing, register and log on to ThomsonNOW! at **www.thomsonedu.com/thomsonnow** using the access code card in the front of your book. You can also explore the **Active Graphing** exercises that your instructor may assign.

15 Air Pollution, Climate Change, and Ozone Depletion

CORE CASE STUDY Studying a Volcano to Understand Climate Change

In June of 1991, after 600 years of slumber, Mount Pinatubo in the Philippines exploded (Figure 15-1). A huge amount of volcanic material blasted out of the mountain, sending a cloud of air pollutants and ash to a height of 35 kilometers (22 miles). Avalanches of hot gases and ash roared down the sides of the mountain, filling valleys with volcanic deposits. It was the second-largest volcanic eruption of the 20th century. (The largest took place in Alaska in 1912.)

Rick Hoblitt/U.S. Geological Service

Figure 15-1 An enormous cloud of air pollutants and ash rises above Mount Pinatubo in the Philippines on June 12, 1991. The volcano exploded in a catastrophic eruption, killing hundreds. Sulfur dioxide and other gases emitted into the atmosphere by the eruption circled the globe, polluted the air, reduced sunlight reaching the earth's surface, and cooled the atmosphere for 15 months.

The eruption of Mount Pinatubo killed hundreds of people, destroyed homes and farmland, and caused hundreds of millions of dollars in damage. At the same time, it enabled scientists to test whether they understood the global climate well enough to estimate how the eruption would affect temperatures on the earth.

By the late 1980s, most of the world's climate scientists had become concerned that human actions, especially fossil fuel use, were enhancing the world's natural greenhouse effect and contributing to a rise in the average temperature of the atmosphere. Some stated publicly that such global warming was likely to occur and could have disastrous ecological and economic effects. Their concerns were based in part on results from computer models of the global climate. But were these models reliable?

Although their complex global climate models mimicked past and present climates well, Mount Pinatubo provided scientists with an opportunity to perform a more rigorous test of such models. Soon after the volcano erupted, James Hansen, a U.S. National Aeronautics and Space Administration (NASA) scientist, estimated that the Pinatubo explosion would probably cool the average temperature of the earth by 0.5 C° (1 F°) over a 19-month period. The earth would then begin to warm, Hansen said, and by 1995 would return to the temperatures observed before the explosion. His projections turned out to be correct.

To make his forecasts, Hansen added the estimated amount of sulfur dioxide released by the volcano's eruption to a global climate model and then used the model to forecast how the earth's temperature would change. His model passed the test with flying colors. Its success helped convince most scientists and policy makers that climate model projections—including the impact of human actions—should be taken seriously.

Hansen's model and nineteen other climate models indicate that global temperatures are likely to rise several degrees during this century—mostly because of human actions—and affect the earth's global and regional climates, economies, and human ways of life. To many scientists and a growing number of business executives, **global climate change** (a broad term referring to changes in any aspects of the earth's climate, including temperature, precipitation, and storm activity) represents the biggest challenge that humanity faces during this century. The primary question is: What should we do about it?

Key Questions and Concepts

15-1 What are the major air pollution problems?

CONCEPT 15-1A Three major outdoor air pollution problems are *industrial smog* from burning coal, *photochemical smog* from motor vehicle and industrial emissions, and *acid deposition* from coal burning and motor vehicle exhaust.

CONCEPT 15-1B The most threatening indoor air pollutants are smoke and soot from wood and coal fires (in developing countries) and chemicals used in building materials and products (in developed countries).

15-2 How should we deal with air pollution?

CONCEPT 15-2 Legal, economic, and technological tools can help clean up air pollution, but scientists call for much greater emphasis on preventing air pollution.

15-3 How might the earth's temperature and climate change in the future?

CONCEPT 15-3 Evidence indicates that the earth's atmosphere is warming rapidly, mostly because of human activities, and that this will lead to significant climate change during this century with severe and long-lasting consequences for humans and many other forms of life.

15-4 What are some possible effects of a warmer earth?

CONCEPT 15-4 Some areas will benefit from a warmer climate and others will suffer from melting ice, rising sea levels, more extreme weather events, increased drought and floods, and shifts in locations of wildlife habitats and agricultural areas.

15-5 What can we do about global warming?

CONCEPT 15-5A We can slow the rate of warming and climate change by increasing energy efficiency, relying more on renewable energy resources, greatly reducing greenhouse gas emissions, and slowing population growth.

CONCEPT 15-5B Governments can subsidize energy efficiency and renewable energy use, tax greenhouse gas emissions, and cooperate internationally, and individuals and institutions can sharply reduce their greenhouse gas emissions.

15-6 How have we depleted ozone in the stratosphere and what can we do about it?

CONCEPT 15-6A Widespread use of certain chemicals has reduced ozone levels in the stratosphere, which allows more harmful ultraviolet radiation to reach the earth's surface.

CONCEPT 15-6B To reverse ozone depletion, we must stop producing ozone-depleting chemicals, and adhere to the international treaties that ban such chemicals.

Note: Supplements 7, 8, 10. 12, and 16 can be used with this chapter.

We are in the middle of a large, uncontrolled experiment on the only planet we have.

DONALD KENNEDY

15-1 What Are the Major Air Pollution Problems?

CONCEPT 15-1A Three major outdoor air pollution problems are *industrial smog* from burning coal, *photochemical smog* from motor vehicle and industrial emissions, and *acid deposition* from coal burning and motor vehicle exhaust.

CONCEPT 15-1B The most threatening indoor air pollutants are in smoke and soot from wood and coal fires (in developing countries) and chemicals used in building materials and products (in developed countries).

The Atmosphere Consists of Several Layers

We live at the bottom of a thin layer of gases surrounding the earth, called the *atmosphere*. It is divided into several spherical layers (Figure 15-2, p. 346), each characterized by abrupt changes in temperature caused by differences in the absorption of incoming solar energy.

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 to about 17 kilometers (11 miles) above sea level at the equator and to

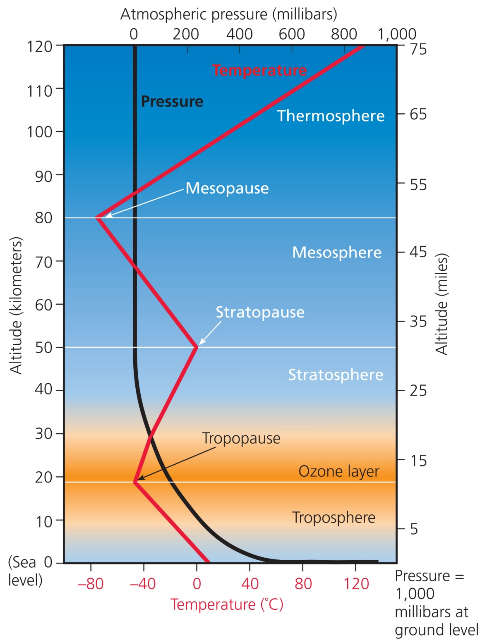


Figure 15-2 **Science:** The earth's atmosphere is a dynamic system that consists of four layers. The average temperature of the atmosphere varies with altitude (red line). Most UV radiation from the sun is absorbed by ozone (O_3), found primarily in the stratosphere in the *ozone layer* 17–26 kilometers (10–16 miles) above sea level.

8 kilometers (5 miles) over the poles. If the earth were the size of an apple, this lower layer containing the air we breathe would be no thicker than the apple's skin.

Take a deep breath. About 99% of the air you inhaled consists of two gases: nitrogen (78%) and oxygen (21%). The remainder is water vapor (varying from 0.01% at the frigid poles to 4% in the humid tropics), slightly less than 1% 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).

The troposphere is a dynamic system involved in the chemical cycling of the earth's vital nutrients (**Concept 3-6**, p. 54). And its rising and falling air currents and winds are largely responsible for the planet's short-term *weather* (see Supplement 10 on p. S43) and long-term *climate* (**Concept 5-1**, p. 76).

CONCEPT LINKS

The atmosphere's second layer is the **stratosphere,** which extends from about 17 to 48 kilometers (11–30 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 (Figure 15-2). Stratospheric ozone is produced when oxygen molecules interact with ultraviolet (UV) radiation emitted by the sun. This "global sunscreen" of ozone in the stratosphere keeps about 95% of the sun's harmful UV radiation (Figure 2-6, p. 33) from reaching the earth's surface.

The UV filter of "good" ozone in the lower stratosphere allows us and other forms of life to exist on land and helps protect us from sunburn, skin and eye cancer, cataracts, and damage to our immune systems. It also prevents much of the oxygen in the troposphere from being converted to photochemical ozone, a harmful air pollutant.

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 materials, or to alter climate. The effects of air pollution range from annoying to lethal.

Air pollutants come from natural and human sources. Natural sources include dust blown by wind (Figure 5-1, p. 75), pollutants from wildfires and volcanic eruptions (**Core Case Study**), 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. However, chemicals emitted from volcanic eruptions (Figure 15-1) and some natural forest fires can reach harmful levels.

CORE CASE STUDY

Human inputs of outdoor air pollutants occur mostly in industrialized and urban areas where people, motor vehicles, and factories are concentrated. Most of these pollutants enter the atmosphere from the burning of coal in power and industrial plants (*stationary sources,* Figure 1-9, p. 15, and photo 2, p. vi) and gasoline and diesel fuel 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 may react with one another or with the basic components of air to form new harmful chemicals, called **secondary pollutants** (Figure 15-3, right).

Indoor air pollution is considered by experts to be a higher-risk human health problem than outdoor air pollution. Some indoor air pollutants come from outdoors. But chemicals used or produced inside buildings in developed areas can be dangerous pollutants, as can smoke from poorly designed wood or coal stoves used to provide heat and cook food in many developing countries. We discuss this later in the chapter.

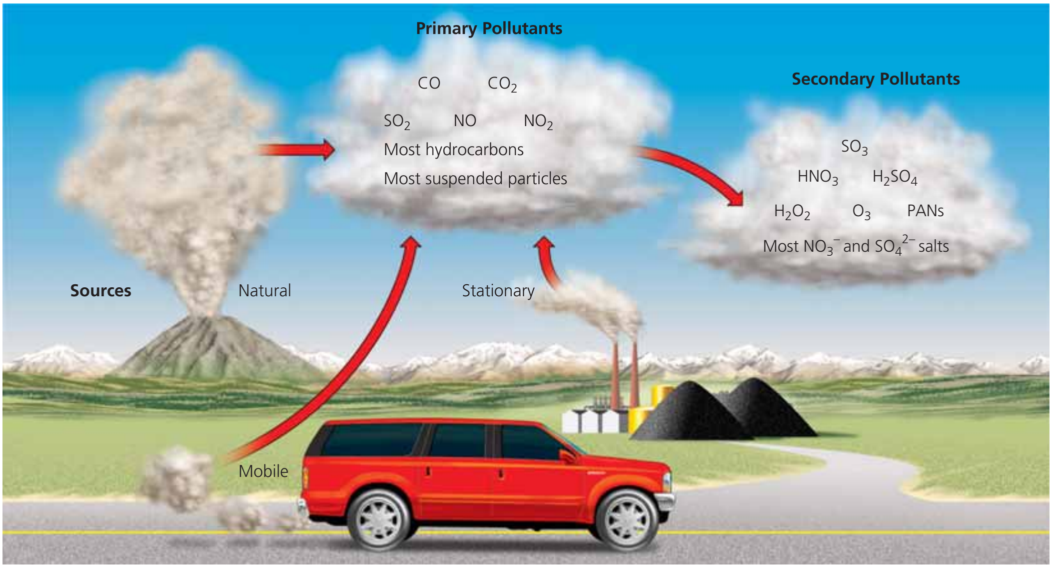


Figure 15-3 *Sources and types of air pollutants.* Human inputs of air pollutants may come from *mobile sources* (such as cars) and *stationary sources* (such as industrial and power plants). Some *primary air pollutants* may react with one another or with other chemicals in the air to form *secondary air pollutants.*

THINKING ABOUT
Air Pollutants

Explain how your daily lifestyle produces some of each of the primary air pollutants shown in Figure 15-3.

Let us look more closely at the major air pollutants.

Carbon Oxides. *Carbon monoxide* (CO) is a colorless, odorless, and highly toxic gas that forms, during the incomplete combustion of carbon-containing materials. Major sources are motor vehicle exhaust, clearing and burning of forests and grasslands, tobacco smoke, and cooking with open fires and inefficient stoves.

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 causes 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 3-19, p. 56). The rest comes from human activities, mostly burning fossil fuels and clearing forests and grasslands. Emissions from human activities have been rising sharply since the industrial revolution. Increasing levels of CO_2 can contribute to warming of the atmosphere and global climate change.

Nitrogen Oxides and Nitric Acid. *Nitrogen 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 plants. Lightning and certain bacteria in soil and water also produce NO as part of the nitrogen cycle (Figure 3-20, p. 57).

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.* Both NO and NO_2 play a role in the formation of *photochemical smog*—a mix of chemicals formed under the influence of sunlight in cities with heavy traffic. *Nitrous oxide* (N_2O), a greenhouse gas, is emitted from fertilizers and animal wastes and is produced by burning fossil fuels.

Nitrogen oxides can irritate the eyes, nose, and throat, aggravate lung ailments such as asthma and bronchitis, suppress plant growth, and reduce visibility.

Sulfur Dioxide and Sulfuric Acid. *Sulfur dioxide* (SO_2) is a colorless gas with an irritating odor. About one-third of the SO_2 in the atmosphere comes from natural sources as part of the sulfur cycle (see Supplement 8, pp. S39–S40). 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.

In the atmosphere, SO_2 can be converted to 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. These pollutants also reduce visibility and aggravate breathing problems. SO_2 and H_2SO_4 can damage crops, trees, soils, and aquatic life in lakes. They can corrode metals and damage paint, paper, leather, and stone on buildings and statues.

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. 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 plowed fields, road construction, unpaved roads, tobacco smoke, coal-burning electric power and industrial plants, and motor vehicles.

These particles can irritate the nose and throat, damage the lungs, aggravate asthma and bronchitis, and shorten life. Toxic particulates (such as lead, cadmium, and PCBs) can cause mutations, reproductive problems, and cancer. Toxic lead particles mostly from burning coal and leaded gasoline and smelting lead ores can accumulate in the body and cause nervous system damage, mental retardation (especially in children), and digestive and other health problems. In the United States, particulate air pollution is responsible for about 60,000 premature deaths a year, according to the EPA and the Harvard School of Public Health. Particulates also reduce visibility, corrode metals, and discolor clothes and paints.

Ozone. *Ozone* (O_3), a colorless and highly reactive gas, is a major component 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.

Volatile Organic Compounds (VOCs). Organic compounds that exist as gases in the atmosphere are called *volatile organic compounds* (VOCs). Most are hydrocarbons, such as *isoprene* (C_3H_8) and *terpenes* like $C_{10}H_{15}$ emitted by the leaves of many plants, and *methane* (CH_4, a greenhouse gas). 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, and oil and natural gas wells—and from cows (from belching and flatulence). Other VOCs, including benzene, vinyl chloride, and trichloroethylene (TCE), are used as industrial solvents, dry-cleaning fluids, and components of gasoline, plastics, drugs, synthetic rubber, and other products.

Radioactive Radon (Rn). *Radon-222* is a naturally occurring colorless and odorless radioactive gas found in some types of soil and rock. It can seep into homes and buildings sitting above such deposits. Long-term exposure can cause lung cancer, especially among smokers.

SCIENCE FOCUS

Using Lichens to Detect Air Pollution

Nineteenth-century coal miners took canaries with them into the mines—not to enjoy their songs but for the moment when they stopped singing. Then the miners knew it was time to get out of the mine because the air contained methane, which could ignite and explode.

Today we use sophisticated equipment and satellites to monitor air quality, but living things such as lichens (Figure 15-A) can also warn us of bad air. Lichens consist of a fungus and an alga living together, usually in a mutually beneficial (mutualistic) relationship (p. 114).

These hardy pioneer species are good biological indicators of air pollution because they continually absorb air as a source of nourishment. A highly polluted area around an industrial plant may have only gray-green crusty lichens or none at all. An area with moderate air pollution may have orange crusty lichens on outdoor walls. Walls and trees in areas with fairly clean air may support leafy lichens.

Because lichens are widespread, long lived, and anchored in place, they can also help track pollution to its source. Isle Royale, Michigan (USA) in Lake Superior is a place where no car or smokestack has ever intruded. The scientists who discovered sulfur dioxide pollution there used *Evernia* lichens to point the finger northward to coal-burning facilities in Thunder Bay, Ontario, Canada.

Gerald & Buff Corsi/Visuals Unlimited

Figure 15-A Red and yellow crusted lichens growing on slate rock in the foothills of the Sierra Nevada near Merced, California (USA). The vulnerability of various lichen species to specific air pollutants can help researchers detect levels of these pollutants and track down their sources.

Critical Thinking

Investigate rocks, trees, and buildings in the area where you live for the presence of various lichens. Use their presence, colors, and types to identify high- and low-pollution areas.

Biological indicators such as lichens (Science Focus, at left), chemical instruments, and satellites can detect levels of air pollutants. In addition, scientists are trying to develop inexpensive nanodetectors (see p. S38 in Supplement 7) for various air pollutants.

Burning Coal Produces Industrial Smog

Fifty years ago, cities such as London, England, and Chicago and Pittsburgh in the United States burned large amounts of coal in power plants and factories, for heating homes, and often for cooking food. During the winter, people in such cities were exposed to **industrial smog** consisting mostly of sulfur dioxide, suspended droplets of sulfuric acid, and a variety of suspended solid particles that give the resulting smog a gray color, explaining why it is sometimes called *gray-air smog* (**Concept 15-1A**). During the 1940s, the air over some industrialized cities in the United States (such as Chattanooga, Tennessee, Case Study, p. 18) was so polluted that people had to use their automobile headlights during the day.

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, India, Ukraine, and some eastern European countries, where large quantities of coal are burned in houses and in factories with inadequate pollution controls. Because of its heavy reliance on coal, China has some of the world's highest levels of industrial smog and 16 of the world's 20 most polluted cities. In 2006, China's Environmental Protection Administration estimated that each year, air pollution (mostly from coal burning) prematurely kills 358,000 Chinese—an average of 981 deaths per day.

In 2006, a U.S. satellite tracked the spread of a dense cloud of pollutants from northern China to Seoul, South Korea, and then across the Pacific Ocean to the United States. The EPA estimates that on certain days nearly one-fourth of the particulate matter in the skies above Los Angeles, California, can be traced to coal-fired power plants, smelters, diesel trucks, and dust storms (due to drought and deforestation) in China.

The history of air pollution control in Europe and the United States shows that industrial smog can be cleared up 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.

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,

VOCs + NO_x + heat + sunlight → ground level ozone (O_3)
+ other photochemical oxidants
+ aldehydes
+ other secondary air pollutants

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 other pollutants. The resulting *photochemical smog* is a mixture of pollutants, including ground-level ozone. Some pollutants, known as *photochemical oxidants,* can damage lung tissue.

Hotter days lead to higher levels of ozone and other components of smog. As traffic increases on a sunny day, photochemical smog (dominated by O_3) usually builds up to peak levels by late morning, irritating people's eyes and respiratory tracts.

All modern cities have some photochemical smog, but it is much more common in cities with sunny, warm, and dry climates and lots of motor vehicles. Examples are Los Angeles, Denver, and Salt Lake City in the United States; Sydney, Australia; São Paulo, Brazil; Buenos Aires, Argentina; Bangkok, Thailand; Jakarta, Indonesia; and Mexico City, Mexico (see photo 13 on p. xii). According to a 1999 study, if 400 million people in China drive conventional gasoline-powered cars by 2050 as projected, the resulting photochemical smog could regularly cover the entire western Pacific, extending to the United States.

ThomsonNOW™ See how photochemical smog forms and how it affects us at ThomsonNOW.

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 the earth's gravity. Second, *rain and snow* help cleanse the air of pollutants. Third, *salty sea spray from the oceans* can wash out much of the particulates and other water-soluble pollutants from air that flows over the oceans from land. Fourth, *winds* sweep pollutants away, diluting them by mixing them with cleaner air. Fifth, some pollutants are removed by *chemical reactions*. For example, SO_2 can react with O_2 in the atmosphere to form SO_3, which reacts with water vapor to form droplets of H_2SO_4 that fall out of the atmosphere as acid precipitation.

Six other factors can *increase* outdoor air pollution. First, *urban buildings* can slow wind speed and reduce dilution and removal of pollutants. Second, *hills and mountains* can reduce the flow of air in valleys below them and allow pollutant levels to build up at ground level. Third, *high temperatures* promote the chemical reactions leading to photochemical smog formation. Fourth, *VOC emissions from certain trees and plants* such as some oak species, sweet gums, poplars, and kudzu (Figure 9-10, p. 186) 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 volatile air pollutants are transported from tropical and temperate areas toward the earth's poles, especially during winter. This explains why polar bears, whales, sharks, and other top carnivores and native peoples in the Arctic have high levels of DDT and other long-lived pesticides, toxic metals (such as lead and mercury), and PCBs in their bodies, even in the absence of industrial facilities and cars.

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 and disperse the pollutants with the cooler air above it. 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. This allows pollutants to build up in the stagnant layer of cool air near the ground.

Two types of areas are especially susceptible to prolonged temperature inversions. The first is a town or city located in a valley surrounded by mountains where the weather turns cloudy and cold during part of the year. In such cases, the surrounding mountains and the clouds block much of the winter sunlight that causes air to heat and rise, and the mountains block the wind. As long as these stagnant conditions persist, pollutants in the valley below will build up to harmful and even lethal concentrations.

The other type of area vulnerable to temperature inversions is a city with several million motor vehicles in an area with a sunny climate, light winds, mountains on three sides, and the ocean on the other side. Here, the conditions are ideal for photochemical smog worsened by frequent thermal inversions, and the surrounding mountains prevent the polluted surface air from being blown away by sea breezes. This describes the U.S. state of California's heavily populated Los Angeles basin, which has prolonged temperature inversions, mostly during summer and fall.

ThomsonNOW™ Learn more about thermal inversions and what they can mean for people in some cities at ThomsonNOW.

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.

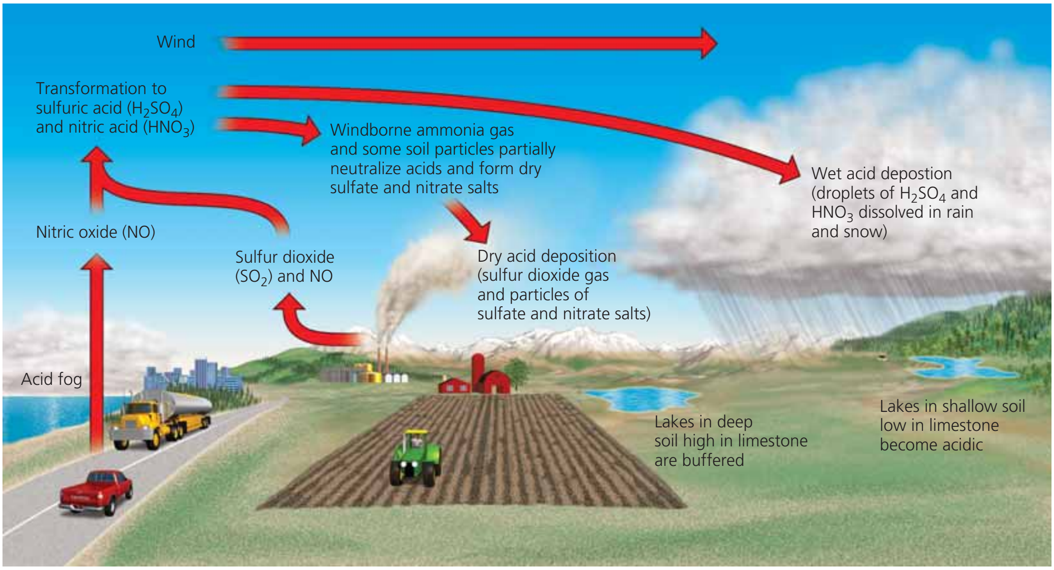
These tall smokestacks reduce *local* air pollution, but can increase *regional* air pollution downwind. The primary pollutants (sulfur dioxide and nitrogen oxides) emitted into the atmosphere above the inversion layer may be transported as far as 1,000 kilometers (600 miles) by prevailing winds. During their trip, they form secondary pollutants such as droplets of sulfuric acid, nitric acid vapor, and particles of acid-forming sulfate and nitrate salts.

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 15-4)—sometimes termed *acid rain*—with a pH below 5.6 (see Figure 6 on p. S34 in Supplement 7). Most dry 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 has been occurring since the industrial revolution. In 1872, British chemist Robert A. Smith coined the term *acid rain* after observing that rain was eating away stone in the walls of buildings in major industrial areas. Acid deposition occurs when human activities disrupt the natural nitrogen cycle (Figure 3-20, p. 57), by adding large amounts of nitrogen oxides to the atmosphere, and disrupt the sulfur cycle (Figure 1, p. S39, in Supplement 8) by adding excessive amounts of sulfur dioxide to the atmosphere.

Acid deposition is a *regional* air pollution problem (**Concept 15-1A**) in areas that lie downwind from coal-burning facilities and from urban areas with large numbers of cars. Such areas include the eastern United States and other parts of the world (Figure 15-5).

Older coal-burning power and industrial plants without adequate pollution controls in the midwestern United States emit the largest quantities of sulfur dioxide and other pollutants that can cause acid deposition. Because of these emissions, and those of other urban



ThomsonNOW™ **Active Figure 15-4** *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 buffer or remove excess acidity. *See an animation based on this figure at* ThomsonNOW. **Question:** What are three ways in which your daily activities contribute to acid deposition?

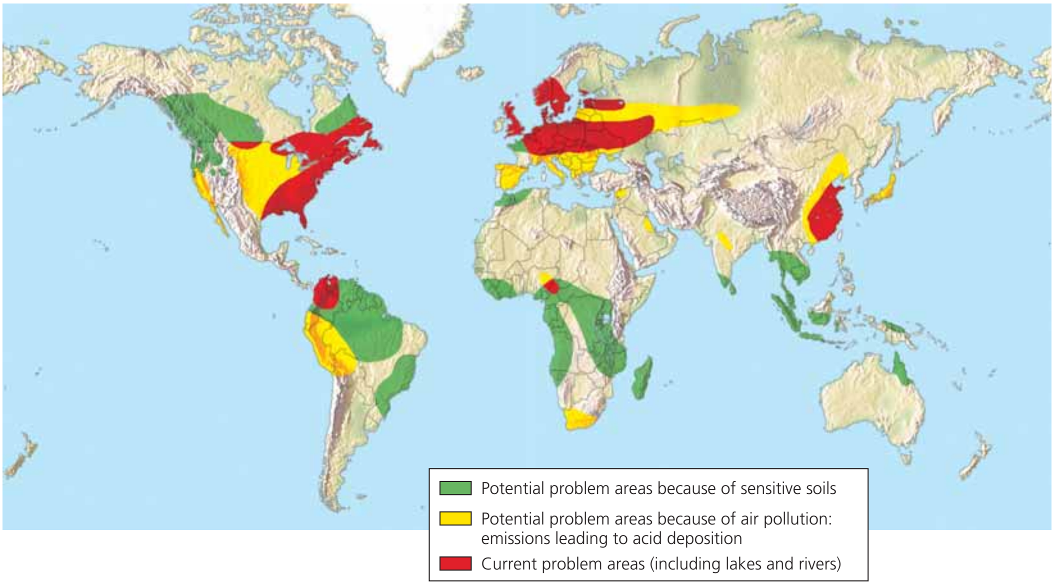


Figure 15-5 **Natural capital degradation:** regions where acid deposition is now a problem and regions with the potential to develop this problem (**Concept 15-1A**). Such regions have large inputs of air pollution (mostly from power plants, industrial plants, and ore smelters) or are sensitive areas 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 that is likely to be affected by acid deposition in the future? (Data from World Resources Institute and U.S. Environmental Protection Agency)

industries and motor vehicles, typical precipitation in the eastern United States is at least 10 times more acidic than natural precipitation. Some mountaintop forests in the eastern United States (see photo 14, p. xii) and east of Los Angeles, California, are bathed in fog and dews as acidic as lemon juice—about 1,000 times the acidity of normal precipitation.

THINKING ABOUT
Volcanoes and Acid Deposition

CORE CASE STUDY

Explain how volcanic eruptions (**Core Case Study**) can contribute to acid deposition.

In some areas, soils contain basic compounds such as calcium carbonate ($CaCO_3$) or limestone that can react with and neutralize, or *buffer,* some inputs of acids. The areas most sensitive to acid deposition are those with thin, acidic soils that provide no such natural buffering (Figure 15-5, green and most red areas) and those where the buffering capacity of soils has been depleted by decades of acid deposition.

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 Norway and neighboring countries. The worst acid deposition occurs in Asia, especially China, which gets 69% of its total energy and 75% of its electricity from burning coal. In addition, air pollution that contributes to acid deposition and enhanced global warming is produced by the greatly increased use of cheap diesel generators to provide electricity for rural villages and power for irrigation pumps in China, India, and other developing countries.

ThomsonNOW™ Learn more about the sources of acid deposition, how it forms, and what it can do to lakes and soils at ThomsonNOW.

Acid Deposition Has a Number of Harmful Effects

Acid deposition causes harm in several ways. It contributes to human respiratory diseases, and can leach toxic metals (such as lead and mercury) from soils and rocks into acidic lakes used as sources of drinking water. These toxic metals can accumulate in the tissues of fish eaten by people, other mammals, and birds. Currently 45 U.S. states have issued warnings to people (especially pregnant women) to avoid eating fish caught from some of their waters because of mercury contamination. Acid deposition also damages statues, national monuments, buildings, metals, and car finishes, and acidic particles in the air decrease visibility.

Because of excess acidity, several thousand lakes in Norway and Sweden contain no fish, and many more lakes there have lost most of their acid-neutralizing capacity. In Ontario, Canada, at least 1,200 acidified lakes contain few if any fish, and some fish populations in thousands of other lakes are declining because of increased acidity. In the United States, several hundred lakes (most in the Northeast) are threatened in this way. But some lakes are acidic because they are surrounded by naturally acidic soils.

Acid deposition (often along with other air pollutants such as ozone) can harm forests and crops by leaching essential plant nutrients such as calcium and magnesium from soils and releasing ions of aluminum, lead, cadmium, and mercury, which are toxic to the trees (Figure 15-6). This reduces plant productivity, tree growth, and the ability of soils to buffer acidic inputs. Acid deposition rarely kills trees directly, but can weaken them and leave them vulnerable to stresses such as severe cold, diseases, insect attacks, and drought.

Mountaintop forests are the terrestrial areas hardest hit by acid deposition (see photo 14, p. xii). These areas tend to have thin soils without much buffering capacity. And trees on mountaintops (especially conifers like red spruce and balsam fir) are bathed almost continuously in highly acidic fog and clouds.

Most of the world's forests and lakes are not being destroyed or seriously harmed by acid deposition. Rather, this regional problem is harming forests and lakes that lie downwind from coal-burning facilities and from large car-dominated cities without adequate pollution controls (Figure 15-5 and **Concept 15-1A**).

ThomsonNOW™ Examine how acid deposition can harm a pine forest and what it means to surrounding land and waters at ThomsonNOW.

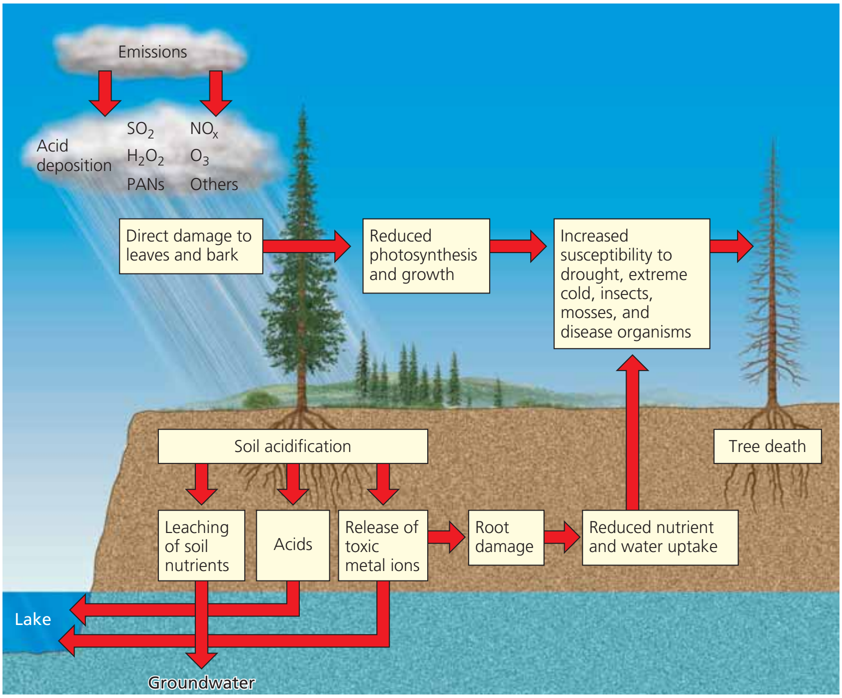
RESEARCH FRONTIER

Learning more about the extent and effects of acid deposition throughout the world

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.

Controlling acid deposition is politically difficult. One problem is that the people and ecosystems it affects often are quite distant from those that cause the problem. Also, countries with large supplies of coal (such as China, India, Russia, and the United States) have a strong incentive to use it as a major energy resource. Owners of coal-burning power plants say that adding the latest pollution control equipment, using low-sulfur coal, or removing sulfur from coal would increase the cost of electricity for consumers.



ThomsonNOW™ Active Figure 15-6 Air pollution is one of several interacting stresses that can damage, weaken, or kill trees and pollute surface and groundwater. *See an animation based on this figure at* ThomsonNOW.

Environmental scientists counter that affordable and much cleaner resources are available to produce electricity. They also point out that the largely hidden health and environmental costs of burning coal are up to five times its market price (Table 13-1, p. 309). Including these costs in market prices would reduce coal use, spur the use of cleaner ways to burn coal, and help prevent acid deposition.

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. Some 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 global warming, 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. Everything is connected.

THINKING ABOUT
Low-Sulfur Coal

Do you think that the advantages of burning low-sulfur coal outweigh the disadvantages? Explain. Are there better options?

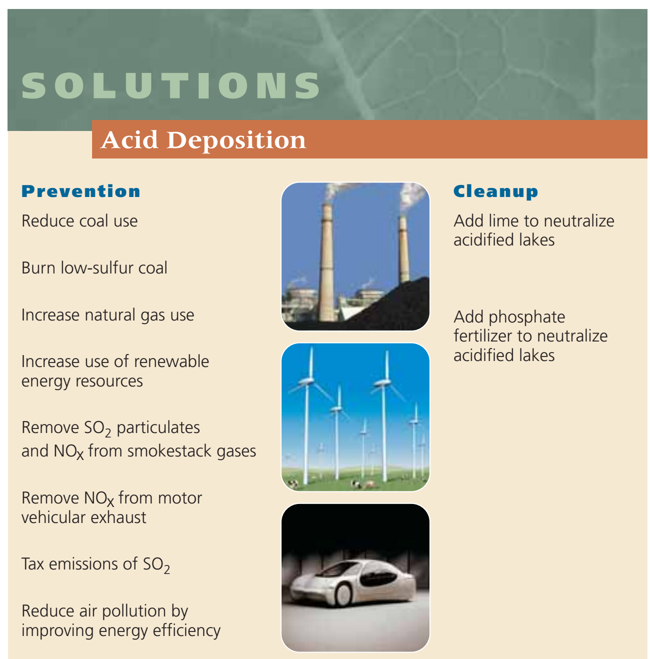


Figure 15-7 Methods for reducing acid deposition and its damage. **Question:** Which two of these solutions do you think are the most important? Why?

Indoor Air Pollution Is a Serious Problem

If you are reading this book indoors, you may be inhaling more air pollutants than you would if you were outside. Figure 15-8 shows some typical sources of indoor air pollution in a modern home.

Indoor air pollution usually poses a much greater threat to human health than does outdoor air pollution. EPA studies have revealed some alarming facts about indoor air pollution in the United States and in other developed countries. *First,* levels of 11 common pollutants generally are two to five times higher inside 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 as much as 18 times higher than outside levels. *Third,* the health risks from exposure to such chemicals are magnified because most people in developed countries spend 70–98% of their time indoors or inside vehicles.

Since 1990, the EPA has placed indoor air pollution at the top of the list of 18 sources of cancer risk. It causes as many as 6,000 premature cancer deaths per year in the United States. At greatest risk are smokers, infants and children younger than age 5, the old, the sick, pregnant women, people with respiratory or heart problems, and factory workers.

Danish and U.S. EPA studies have linked various air pollutants found in buildings to a number of health effects, a phenomenon known as the *sick-building syndrome* (SBS). Such effects include dizziness, headaches, coughing, sneezing, shortness of breath, nausea, burning eyes, chronic fatigue, irritability, skin dryness and

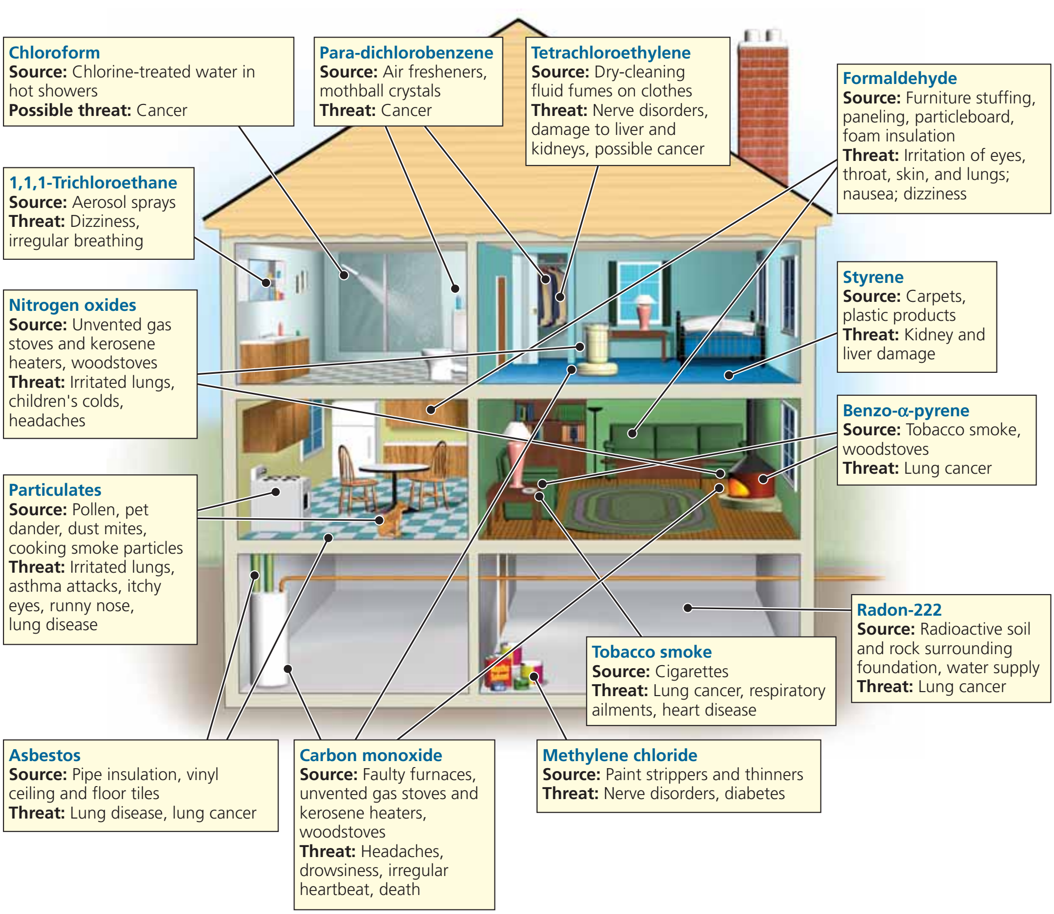


Figure 15-8 Some important indoor air pollutants (**Concept 15-1B**). **Question:** Which of these pollutants are you exposed to? (Data from U.S. Environmental Protection Agency)

irritation, flu-like symptoms, and depression. EPA and Labor Department studies indicate that almost one in five commercial buildings in the United States is considered "sick," exposing employees to these health risks. **GREEN CAREER:** Indoor air pollution specialist

According to the EPA and public health officials, the four most dangerous indoor air pollutants in developed countries are *tobacco smoke* (Case Study, p. 339); *formaldehyde* found in many building materials and household products; *radioactive radon-222 gas;* and *very small particles* (**Concept 15-1B**). *Formaldehyde,* a colorless, extremely irritating organic chemical, is a growing problem. According to the EPA and the American Lung Association, 20–40 million Americans suffer from chronic breathing problems, dizziness, rash, headaches, sore throat, sinus and eye irritation, skin irritation, wheezing, and nausea caused by daily exposure to this chemical.

In developing countries, the indoor burning of wood, charcoal, coal, and other fuels for cooking and heating in open fires or in unvented or poorly vented stoves exposes people to dangerous levels of particulate air pollution (**Concept 15-1B**). According to the WHO and the World Bank, *indoor air pollution for the poor is by far the world's most serious air pollution problem.*

RESEARCH FRONTIER

Learning more about indoor air pollutants and how to prevent them

Your Respiratory System Helps Protect You from Air Pollution

Your respiratory system (Figure 15-9) helps 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 hairlike structures called *cilia* line your upper respiratory tract. They continually wave 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 these natural defenses. Years of smoking and breathing air pollutants can lead to *lung cancer* and *chronic bronchitis.* Damage deeper in the lung can cause *emphysema,* in which irreversible damage to air sacs or alveoli leads to abnormal dilation of air spaces, loss of lung elasticity, and acute shortness of breath (Figure 15-10, p. 356).

Air Pollution Is a Big Killer

According to the WHO, at least 3 million people worldwide (most of them in Asia) die prematurely each year from the effects of air pollution—an average of 8,200

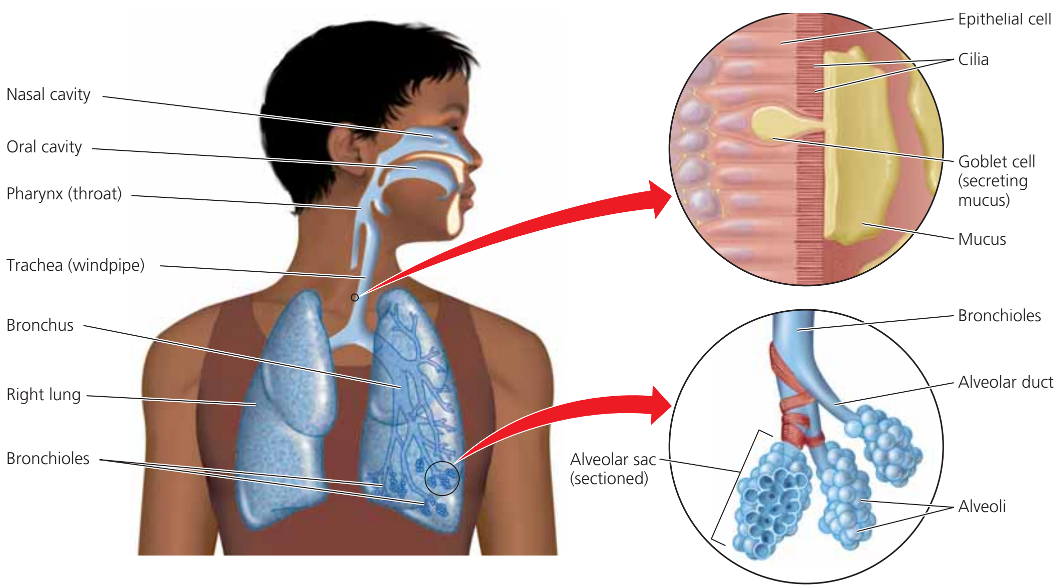


Figure 15-9 Major components of the human respiratory system. **Question:** Can you think of times when pollution might have affected your respiratory system?

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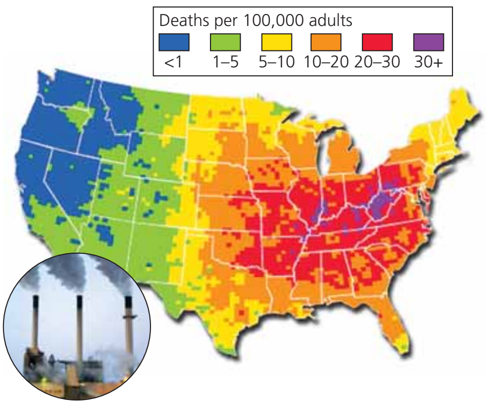


Figure 15-11 Premature deaths from air pollution in the United States, mostly from very small particles added to the atmosphere by coal-burning power plants. According to the American Lung Association, more that 2,000 scientific studies published since 1995 link particulate matter with adverse health effects. **Question:** What is the risk where you live or go to school? (Data from U.S. Environmental Protection Agency)

deaths per day. About 2.2 million of these deaths (73%) result from indoor air pollution, typically from heart attacks, respiratory diseases, and lung cancer related to daily breathing of polluted air.

In the United States, the EPA estimates that annual deaths related to indoor and outdoor air pollution range from 150,000 to 350,000 people—equivalent to 2–3 fully loaded 200-passenger airliners crashing *each day* with no survivors. Millions more suffer from asthma attacks and other respiratory disorders and lose work time. Most of the deaths are related to inhalation of very small particulates from coal-burning power plants (Figure 15-11).

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 from buses and trucks. Other sources of these fumes include tractors, bulldozers and other construction equipment, and trains. A large diesel truck emits as much particulate matter as 150 cars, and particulate emissions from a diesel train engine equal those from 1,500 cars.

15-2 How Should We Deal with Air Pollution?

CONCEPT 15-2 Legal, economic, and technological tools can help clean up air pollution, but scientists call for much greater emphasis on preventing air pollution.

Laws Have Reduced Outdoor Air Pollution in the United States

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 *national ambient air quality standards* (NAAQS) for six outdoor *criteria pollutants*—carbon monoxide, nitrogen oxides, sulfur dioxide, suspended particulate matter, ozone, and lead. One limit, called a *primary standard,* is set to protect human health. Each standard specifies the maximum allowable level, averaged over a specific period, for a certain pollutant in outdoor (ambient) air.

The EPA has also established national emission standards for more than 188 *hazardous air pollutants* (HAPs) that can cause serious health and ecological effects. Most of these chemicals are chlorinated hydrocarbons, volatile organic compounds, or compounds of toxic metals.

Great news. According to a 2005 EPA report, combined emissions of the six principal outdoor air pollutants decreased by 53% between 1970 and 2005, even with significant increases in gross domestic product, vehicle miles traveled, energy consumption, and population (**Concept 15-2**). The decreases for the six pollutants during this period were 99% for lead, 84% for suspended particulate matter, 55% for carbon monoxide, 52% for sulfur dioxide, 29% for nitrogen oxides, and 14% for ground-level ozone. Volatile organic compounds decreased 53% in this period.

The bad news is that although photochemical smog levels dropped in the 1980s, they have fallen very little since 1994. In 2004, the EPA found that 474 of the nation's 2,700 counties in 31 states had unacceptable levels of ground-level ozone, a major ingredient in unhealthy smog. Reducing smog will require much bigger cuts in emissions of nitrogen oxides from power and industrial plants and motor vehicles. According to the EPA, almost 60% of the U.S. population lives in areas where the air is unhealthy to breathe during part of the year because of high levels of smog pollutants, primarily ozone and very small particles.

U.S. Air Pollution Laws Can Be Improved

The reduction of outdoor air pollution in the United States since 1970 has been a remarkable success story. It occurred because of two factors. *First,* U.S. citizens insisted that laws be passed and enforced to improve air quality. *Second,* the country was affluent enough to afford such controls and improvements.

Environmental scientists applaud the success of U.S. air pollution control laws but suggest the following deficiencies.

- The United States *continues to rely mostly on pollution cleanup rather than prevention* (**Concept 15-2**). The power of prevention is clear. In the United States, the air pollutant with the largest drop in its atmospheric level was lead (99% between 1970 and 2005), which was largely banned in gasoline. This has prevented a generation of children from suffering lead poisoning.
- The U.S. Congress *has failed to increase fuel-efficiency (CAFE) standards for cars, SUVs, and light trucks.* CAFE standards have been shown to reduce air pollution from motor vehicles more quickly and effectively than any other method. Congress has also failed to enact a feebate program (p. 300).
- *Regulation of emissions from motorcycles and two-cycle gasoline engines remains inadequate.* Two-cycle engines used in lawn mowers, leaf blowers, chain saws, jet skis, outboard motors, and snowmobiles emit high levels of pollutants (although less-polluting versions are becoming available). According to the California Air Resources Board, a 1-hour ride on a typical jet ski creates more air pollution than the average U.S. car does in a year, and operating a 100-horsepower boat engine for 7 hours emits more air pollutants than driving a new car 160,000 kilometers (100,000 miles).
- *There is little or no regulation of air pollution from ocean-going ships in American ports.* According to the Earth Justice Legal Defense Fund, a single cargo ship emits more air pollution than 2,000 diesel trucks or 350,000 cars. Ships burn the dirtiest grades of diesel fuel and threaten the health of millions of dockworkers and other people living in port cities.
- *Major airports, which are among the top polluters in urban areas, are exempt from many air pollution regulations.*
- *As of 2007, the Clean Air Acts did not specifically regulate emissions of the greenhouse gas CO_2,* which can alter climate and cause numerous harmful ecological, health, and economic effects.
- *The acts have failed to deal seriously with indoor air pollution,* even though it is by far the most serious air pollution problem in terms of poorer health, premature death, and economic losses from lost work time and increased health costs.
- *There is a need for better enforcement of the Clean Air Acts.* Under the acts, state and local officials have primary responsibility for implementing federal clean air standards, based on federal funding. However, a 2006 study by the Center for American Progress found that since 1993, enforcement has become lax because of a sharp drop in federal grants to state and local air quality agencies and relaxed federal inspection standards. According to a 2002 government study, more rigorous enforcement would save about 6,000 lives and prevent 140,000 asthma attacks each year in the United States.

Executives of companies that would be affected by implementing stronger policies claim that correcting deficiencies in the Clean Air Acts would cost too much and harm economic growth. Proponents contend that most industry cost estimates for implementing U.S. air pollution control standards have been many times the actual costs. In addition, implementing such standards has boosted economic growth and created jobs by stimulating companies to develop new technologies for reducing air pollution emissions—many of which can be sold in the global marketplace. Without intense pressure from citizens, it is unlikely that the U.S. Congress will strengthen the Clean Air Acts. In recent years, in fact, Congress has weakened some air pollution regulations.

HOW WOULD YOU VOTE?

Should the 1990 U.S. Clean Air Act be strengthened? Cast your vote online at **www.thomsonedu.com/biology/miller**.

We Can Use the Marketplace to Reduce Outdoor Air Pollution

Allowing producers of air pollutants to buy and sell government air pollution allotments in the marketplace can help reduce emissions (**Concept 15-2**). To help reduce SO_2 emissions, the Clean Air Act of 1990 authorizes an *emissions trading,* or *cap-and-trade, program,* which enables the 110 most polluting power plants in 21 states (primarily in the midwestern and eastern United States) to buy and sell SO_2 pollution rights.

Each year, a coal-burning power plant is 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 it is allotted has a surplus of pollution credits. It can use these credits to avoid reductions in SO_2 emissions at another of its plants, keep them for future plant expansions, or sell them to other utilities, private citizens, or environmental groups.

Proponents argue that this approach is cheaper and more efficient than having the government dictate how to control air pollution. Critics of this plan contend that it allows utilities with older, dirtier power plants to buy their way out of their environmental responsibilities and continue polluting. This approach also can encourage cheating, because it is based largely on self-reporting of emissions.

Scientists warn that the ultimate success of any emissions trading approach depends on how low the initial cap is set and then on the annual lowering of the cap, which should promote continuing innovation in air pollution prevention and control. Without these elements, emissions trading programs mostly move air pollutants from one area to another without achieving any overall reduction in air quality.

Good news. Between 1990 and 2005, the emissions trading system helped reduce SO_2 emissions from electric power plants in the United States by 31% at a cost of less than one-tenth the cost projected by industry. The EPA estimates that by 2010, this approach will annually generate health and environmental benefits that are 60 times higher than the annual cost of the program.

Emissions trading is also being tried for NO_x and perhaps in the future for other air pollutants. However, environmental and health scientists strongly oppose using a cap-and-trade program to control emissions of mercury by coal-burning power plants and industries, because this pollutant is highly toxic and does not break down in the environment. Coal-burning plants choosing to buy permits instead of sharply reducing their mercury emissions would create toxic hot spots with unacceptably high levels of mercury.

In 2002, the EPA reported results from the country's oldest and largest emissions trading program, in effect since 1993 in southern California. According to the report, this cap-and-trade model fell far short of projected emissions reductions. The same study also found accounting abuses. This highlights the need for more careful government monitoring of all cap-and-trade programs.

HOW WOULD YOU VOTE?

Should emissions trading be used to help control emissions of all major air pollutants? Cast your vote online at **www.thomsonedu.com/biology/miller**.

Figure 15-12 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 15-2**). **Question:** Which two of these solutions do you think are the most important? Why?

There Are Many Ways to Reduce Outdoor Air Pollution

Figure 15-12 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 2002, emissions of SO_2 from U.S. electric power plants were decreased by 40%, emissions of NO_x by 30%, and soot emissions by 75%, mostly by using the first of two clean-up methods listed in Figure 15-12, 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 required for new facilities under the Clean Air Acts. Officials of states subject to pollution from such plants have been trying to get Congress to correct this shortcoming since 1970. But they have not been successful because of strong lobbying efforts by U.S. coal and electric power industries.

HOW WOULD YOU VOTE?

Should older coal-burning power and industrial plants in the United States (or the country where you live) have to meet the same air pollution standards as new facilities? Cast your vote online at **www.thomsonedu.com/biology/miller**.

Figure 15-13 lists ways to reduce emissions from motor vehicles, the primary culprits in producing photochemical smog.

Bad news. The already poor air quality in urban areas of many developing countries is worsening as their 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.

Good news. Because of the Clean Air Act, a new car today in the United States emits 75% less pollution than did pre-1970 cars. Over the next 10–20 years, technology will bring more gains through improved engine and emission systems, conventional hybrid-electric vehicles (Figure 13-21, p. 300), plug-in hybrids, and vehicles powered by hydrogen fuel cells (Figure 13-22, p. 301).

Reducing Indoor Air Pollution Should Be a Priority

Little effort has been devoted to reducing indoor air pollution even though it poses a much greater threat to human health than does outdoor air pollution. Air pollution experts suggest several ways to prevent or reduce indoor air pollution, as shown in Figure 15-14.

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

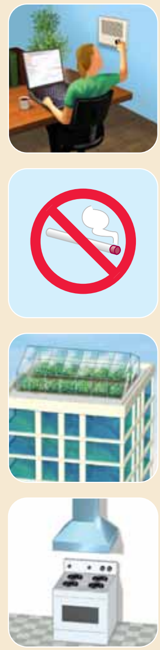
Figure 15-13 Methods for reducing emissions from motor vehicles. To find out how serious your car emissions are go to **www.cleancarsforkids.org**. **Question:** Which two of these solutions do you think are the most important? Why?

SOLUTIONS

Indoor Air Pollution

Prevention

- Cover ceiling tiles and lining of 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 15-14 Ways to prevent and reduce indoor air pollution (**Concept 15-2**). **Question:** Which two of these solutions do you think are the most important? Why?

In developing countries, indoor air pollution from open fires and leaky and inefficient stoves that burn wood, charcoal, or coal could be reduced. People could use inexpensive clay or metal stoves that burn biofuels more efficiently, while venting their exhaust to the outside, or stoves that use solar energy to cook food (Figure 13-28, p. 307). This would also reduce deforestation by cutting demand for fuelwood and charcoal.

Figure 15-15 (p. 360) lists some ways to reduce your exposure to indoor air pollution.

We Need More Emphasis on Pollution Prevention

Encouraging news. 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

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 15-15 **Individuals matter:** ways to reduce your exposure to indoor air pollution. **Questions:** Which three of these precautions do you think are the most important? Why? Which ones have you taken?

pollution by using *output approaches.* To environmental and health scientists, the next step is to shift to *preventing air pollution* (**Concept 1-4**, p. 14). 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?"*

CONCEPT LINK

Figure 15-16 shows ways to prevent outdoor and indoor air pollution over the next 30–40 years (**Concept 15-2**). Like the shift to controlling outdoor air pollution between 1970 and 2006, this new shift to preventing outdoor and indoor air pollution will not take place unless individual citizens and groups put political pressure on elected officials and economic pressure on companies through their purchasing decisions.

SOLUTIONS

Air Pollution

Outdoor

- Improve energy efficiency to reduce fossil fuel use
- Rely more on lower-polluting natural gas
- Rely more on renewable energy (especially solar cells, wind, and solar-produced hydrogen)
- Transfer energy efficiency, renewable energy, and pollution prevention technologies to developing countries

Indoor

- Reduce poverty
- Distribute cheap and efficient cookstoves or solar cookers to poor families in developing countries
- Reduce or ban indoor smoking
- Develop simple and cheap tests for indoor pollutants such as particulates, radon, and formaldehyde

Figure 15-16 Ways to prevent outdoor and indoor air pollution over the next 30–40 years (**Concept 15-2**). **Question:** Which two of these solutions do you think are the most important? Why?

15-3 How Might the Earth's Temperature and Climate Change in the Future?

CONCEPT 15-3 Evidence indicates that the earth's atmosphere is warming rapidly, mostly because of human activities, and that this will lead to significant climate change during this century with severe and long-lasting consequences for humans and many other forms of life.

Global Warming and Global Cooling Are Not New

Changes in the earth's climate are neither new nor unusual. Over the past 4.7 billion years, the planet's climate has been altered by volcanic emissions (**Core Case Study**), changes in solar input, continents moving slowly as a result of shifting tectonic plates (Figure 4-3, p. 67, and **Concept 4-2**, p. 66), impacts by large meteors, and other factors.

CORE CASE STUDY

CONCEPT LINK

Over the past 900,000 years, the atmosphere has experienced prolonged periods of *global cooling* and *global warming* (Figure 15-17, top left). These alternat-

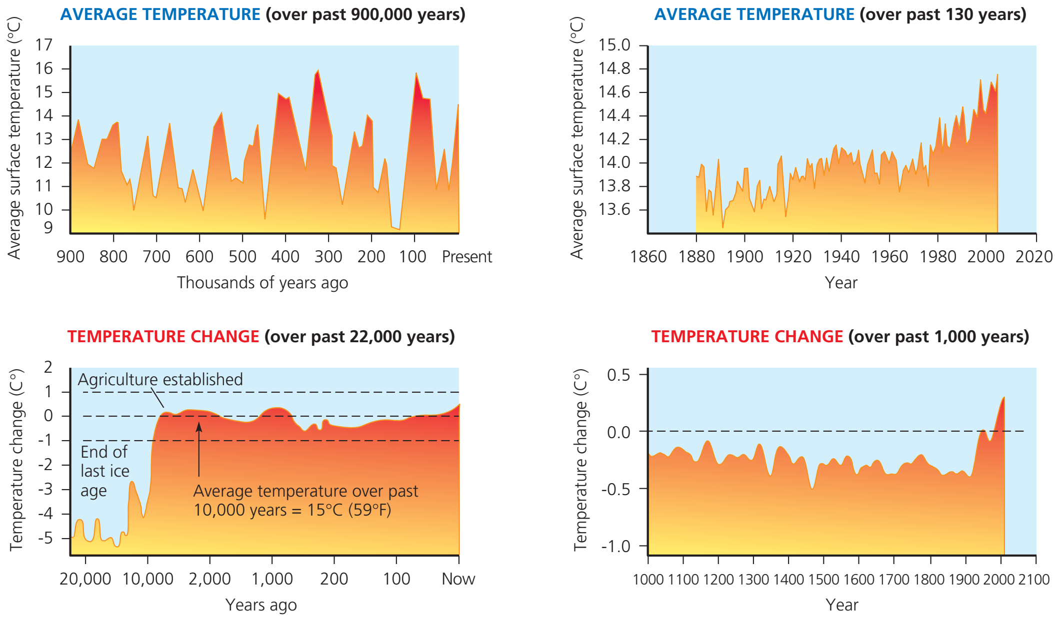


Figure 15-17 Science: estimated changes in the average global temperature of the atmosphere near the earth's surface over different periods of time. The graphs in the top half of this figure are rough estimates of global average temperatures, and the two graphs on the bottom are estimates of changes in the average temperature. They are based on limited evidence, but they do indicate general trends. **Question:** Assuming these estimates are correct, 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.*

Some analysts hypothesize that climate change after the last ice age ended about 13,000 years ago was an important factor leading nomadic hunter–gatherers to settle down and invent agriculture. 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 steady average global surface temperature (Figure 15-17, bottom left). These conditions allowed agriculture, and then cities, to flourish.

For the past 1,000 years, the average temperature of the atmosphere has remained fairly stable but began rising during the last century (Figure 15-17, bottom right) when people began clearing more forests and burning fossil fuels. Figure 15-17, top right, shows that most of the recent increase in temperature has taken place since 1975. (Also see Figure 9 on p. S47 in Supplement 10.)

Past temperature changes such as those depicted in Figure 15-17 are estimated by analysis of: radioisotopes in rocks and fossils; plankton and radioisotopes in ocean sediments; tiny bubbles of ancient air found in ice cores from glaciers (Figure 15-18); temperature measurements taken at different depths from boreholes drilled deep into the earth's surface; pollen from the bottoms of lakes and bogs; tree rings; historical records; insects, pollen, and minerals in different layers of bat dung

U.S. Geological Survey

Figure 15-18 Science: *ice cores* are extracted by drilling deep holes in ancient glaciers at various sites such as this one in Antarctica (the South Pole). Scientists analyze tiny air bubbles and layers of soot particles trapped in different segments of such ice cores to uncover information about past composition of the lower atmosphere, temperature trends such as those in Figure 15-17, greenhouse gas concentrations, solar activity, snowfall, and forest fire frequency.

deposited in caves over thousands of years; and temperature measurements taken regularly since 1861.

We Are Making the Earth's Natural Low-Grade Fever Worse

Along with solar energy, a natural process called the *greenhouse effect* (Figure 3-7, p. 44) warms the earth's lower atmosphere and surface. *Life on the earth and the world's economies are totally dependent on the natural greenhouse effect*—one of the planet's most important forms of natural capital. The oceans are another factor shaping the earth's climate because they remove carbon dioxide and heat from the atmosphere and move stored heat from one place to another in water currents (Figure 5-6, p. 79).

Swedish chemist Svante Arrhenius first recognized the natural greenhouse effect in 1896. Since then, numerous laboratory experiments and measurements of temperatures at different altitudes have confirmed this effect—now one of the most widely accepted theories in the atmospheric sciences. 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).

ThomsonNOW™ See how greenhouse gases trap heat in the lower atmosphere and raise the earth's temperature at ThomsonNOW.

Since the beginning of the Industrial Revolution about 275 years ago, human actions have led to significant increases in the concentration of earth-warming CO_2, CH_4, and N_2O in the lower atmosphere—mainly from agriculture, deforestation, and burning fossil fuels. There is considerable and growing evidence that these inputs of greenhouse gases from human activities are causing an **enhanced greenhouse effect,** popularly known as **global warming.**

In 2006, researchers at the British Antarctic Survey analyzed air bubbles in ice cores from Antarctica going back 800,000 years. Their data indicated that current levels of CO_2 are higher than at any other time during that period and are now increasing at an unprecedented rate.

In 2007, the largest CO_2 emitting countries in order were China, the United States, the European Union, Indonesia, Russia, Japan, and India. Global CO_2 emissions are growing exponentially at an increasing rate. The United States has been responsible for 25% of the world's cumulative CO_2 emissions, compared to China's 5% contribution. But coal-fired power plants provide over 70% of China's electricity compared to 50% in the United States. And China's oil consumption and use of coal to produce electricity are soaring.

Figure 11 in Supplement 16 (p. S70) shows average CO_2 emissions per person in various parts of the world. Although China's total CO_2 emissions are high and growing rapidly, its per capita emissions are low. For example, the United States emits about seven times more CO_2 per person than China does. China points out that current global warming has been caused mostly by the long-term historic emissions by developed countries and their high per capita emissions.

Critics respond that if China does not radically change to more sustainable forms of production, power generation, transport, and building design, its projected economic miracle will turn into an unsustainable eco-nightmare. Because CO_2 mixes freely in the atmosphere, every country's climate is affected by any one country's actions.

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 130 nations. In its 2007 report, based on more than 29,000 sets of data, the IPCC listed a number of findings indicating that it is *very likely* (a 90–99% probability) that the lower atmosphere is getting warmer (**Concept 15-3**) and that human activities are the primary cause of the recent warming (Science Focus, p. 364).

According to the 2007 IPCC report, here is some of the evidence that supports its conclusions.

- 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 15-17, top right, and Figure 10 on p. S47 in Supplement 10).
- Actual temperature measurements indicate that the 13 warmest years since 1861 (when temperature measurements began) have occurred since 1990 (Figure 15-17, top right). In order, the five hottest years since 1861 have been 2005, 1998, 2002, 2003, and 2006.
- Over the past 50 years, Arctic temperatures have risen almost twice as fast as temperatures in the rest of the world.
- In some parts of the world, glaciers (Figure 15-19) and floating sea ice (Figure 15-20) are melting and shrinking at increasing rates, rainfall patterns are changing, and extreme 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 increases.

HOW WOULD YOU VOTE? ✓

Do you think that we will experience significant global warming during this century? Cast your vote online at **www.thomsonedu.com/biology/miller**.

Enhanced Global Warming May Have Severe Consequences: Some Scary Scenarios

So what is the big deal? Why should we worry about a possible rise of only a few degrees in the earth's average surface temperature? We often have that much change between May and July, or even between yesterday and today. The key point is that we are talking not about normal swings in *local weather,* but about a projected *global change in climate*—weather measurements averaged over decades, centuries, and millennia.

Climate scientists warn that the concern is not just about how much the temperature changes but also about how rapidly it occurs. Most past changes in the temperature of the lower atmosphere took place over thousands to a hundred thousand years (Figure 15-17, top and bottom left). The next problem we face is a rapid increase in the average temperature of the lower atmosphere during this century (Figure 15-C, p. 365). In other words, according to the IPCC and other climate scientists, the earth's atmosphere is running a fever that is rising fast, mostly because of human activities.

Such rapid change could drastically affect life on earth. Humans have built a civilization adapted to the generally favorable climate we have had for the past 10,000 years. Climate models indicate that within only a few decades, we will have to deal with a rapidly changing climate.

A 2003 U.S. National Academy of Sciences report laid out a nightmarish *worst-case scenario* in which human activities, alone or in combination with natural factors, trigger new and abrupt changes. At that point, the global climate system would reach a *tipping point* after which it would be too late to reverse catastrophic change for tens of thousands of years.

The report describes ecosystems suddenly collapsing, low-lying cities being flooded, forests being consumed in vast fires, grasslands drying out and turning into dust bowls, premature extinction of up to half of the world's species, prolonged heat waves and droughts, more intense coastal storms and hurricanes, and tropical infectious diseases spreading rapidly beyond their current ranges. Climate change can also threaten peace and security as changing patterns of rainfall increase competition for water and food resources, cause destabilizing migrations of tens of millions of people, and lead to economic and social disruption.

National Snow and Ice Data Center at Boulder, CO (USA)

National Snow and Ice Data Center at Boulder, CO (USA)

Figure 15-19 Melting of Alaska's Muir Glacier in the popular Glacier Bay National Park and Preserve between 1948 and 2004. **Question:** How might melting glaciers in Alaska and other parts of the Arctic affect your lifestyle during this century?

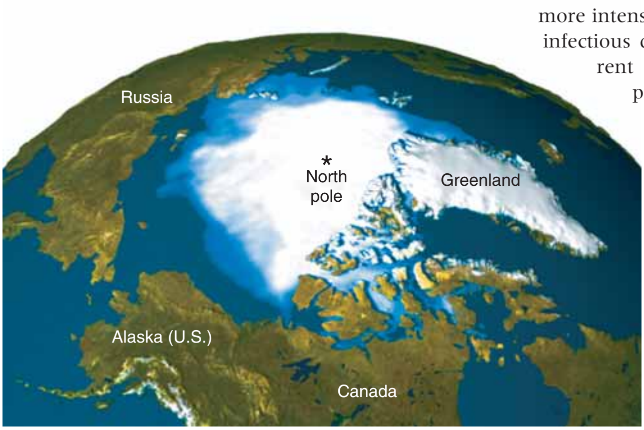


Figure 15-20 **Science:** satellite data showing a 20% drop in the average cover of summer Arctic sea ice between 1979 (dark blue) and 2005 (white)—a loss in area about the size of the U.S. state of Texas. Such summer ice may be gone in 20–50 years. (Data U.S. Goddard Space Flight Center, NASA)

What Is the Scientific Consensus about Future Global Temperature Changes?

To project the effects of increasing greenhouse gases on average global temperatures, scientists develop complex *mathematical models* to simulate interactions among the earth's sunlight, clouds, landmasses, oceans, ocean currents, concentrations of greenhouse gases and pollutants, and positive (runaway) and negative (corrective) feedback loops within the climate system. Then they run these elaborate and continually improving climate models on supercomputers and use the results to project future changes in the earth's average atmospheric temperature. Figure 15-B gives a greatly simplified summary of some of the interactions in the global climate system.

Such models provide scenarios or projections of what is *very likely* (90–99% level of confidence) or *likely* (66–89% level of confidence) 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

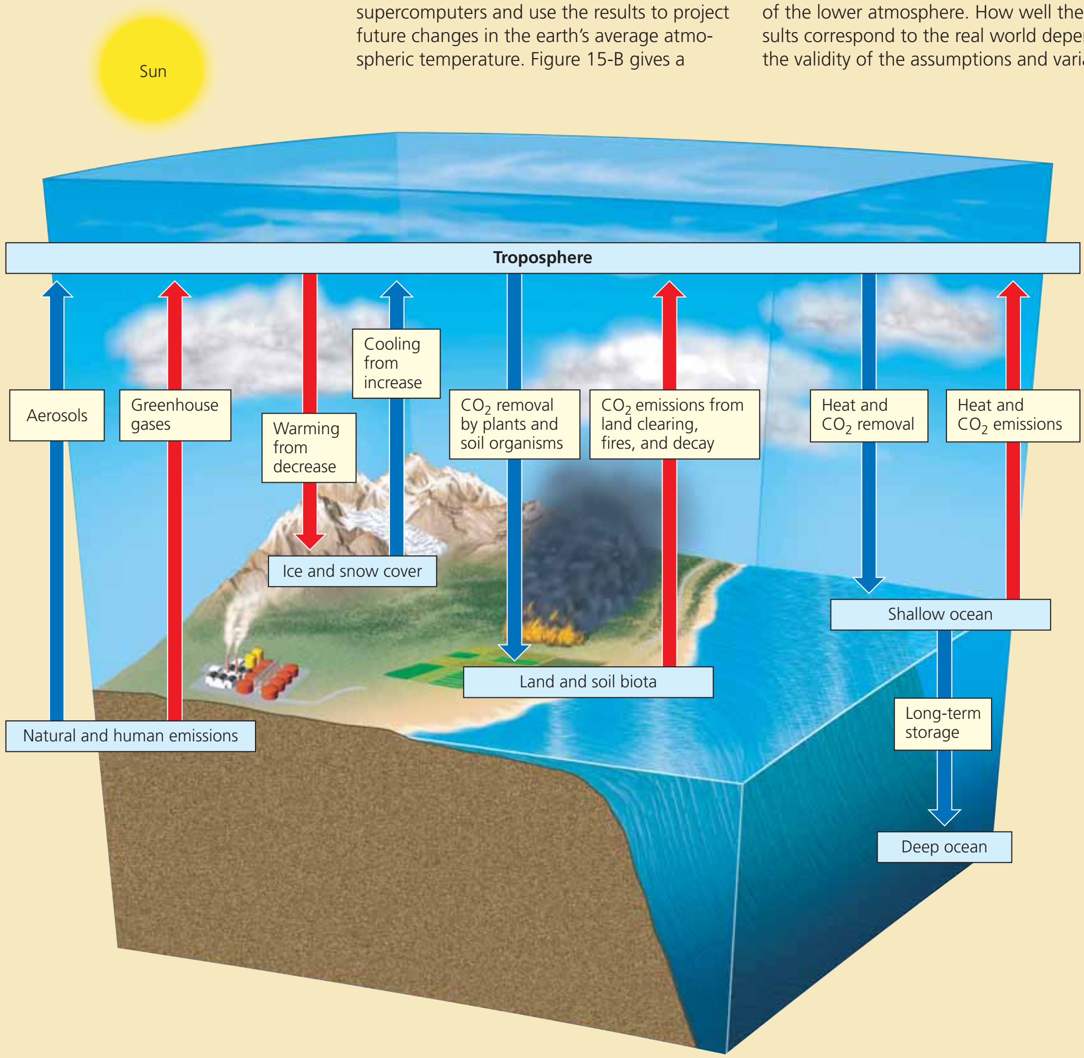


Figure 15-B Science: simplified model of some major processes that interact to determine the average temperature and greenhouse gas content of the lower atmosphere and thus the earth's climate. Red arrows show processes that warm the atmosphere and blue arrows show those that cool the atmosphere. **Question:** Why do you think a decrease in snow and ice cover would increase global warming?

built into the models and on the accuracy of the data used.

In 1990, 1995, 2001, and 2007, the Intergovernmental Panel on Climate Change (IPCC) published reports on how global temperatures have changed in the past (Figure 15-17) and made forecasts of how they are likely to change during this century. According to the 2007 report, based on analyzing past climate data and using 19 climate models, it is very likely (a 90–99% probability) that human activities, led by burning fossil fuels, have been the main cause of the observed atmospheric warming during the past 50 years.

The 2007 report and recent runs of 19 different climate models suggest that it is *very likely* that the earth's mean surface temperature will increase by 2–4.5 C° (3.6–8.1 F°) between 2005 and 2100 (Figure 15-C), with about 3 C° (5.4 F°) the most likely rise, unless the world makes drastic cuts in greenhouse gas emissions from power plants, factories, and cars that burn fossil fuels. This is a major increase in such a short period. The lower temperature in this range is likely only if global greenhouse gas emissions fall 50–85% by 2050—an unlikely assumption.

There is overwhelming consensus among the world's climate scientists that global warming is occurring at a rapid rate, that human activities are the major factor in this temperature increase since 1950, and that human activities will play an even greater role in the warming projected to take place during this century (**Concept 15-3**). Energy use accounts for about two-thirds of the CO_2 emitted by human activities, followed by agriculture (14%) and deforestation and other forms of land use (10%). In 2007, the leaders of the American Association for the Advancement of Science (AAAS)—the world's largest general science body—said that

> *Global warming is not a theory; it is a fact based on a growing torrent of information . . . . The pace of change and the evidence of harm have increased markedly over the last five years. The time to control greenhouse gas emissions is now. . . . Delaying action to address climate change will increase the environmental and social consequences as well as the costs.*

The global warming hypothesis is based on very reliable science. The question now is, what do we do about it?

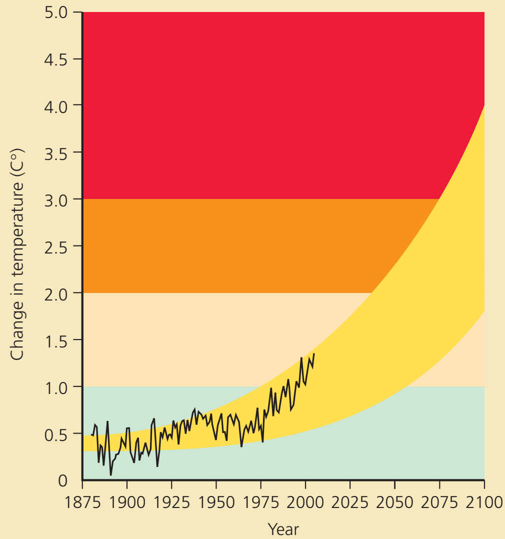


Figure 15-C **Science:** comparison of measured changes in the average temperature of the atmosphere at the earth's surface between 1860 and 2006 and the projected range of temperature increase during the rest of this century (**Concept 15-3**). (Data from U.S. National Academy of Sciences, National Center for Atmospheric Research, and Intergovernmental Panel on Climate Change, and Hadley Center for Climate Prediction and Research)

Critical Thinking

If projected temperature increases in Figure 15-C take place, list three ways in which this will affect your lifestyle.

These possibilities were supported by a 2003 analysis carried out by Peter Schwartz and Doug Randall for the U.S. Department of Defense. They concluded that global warming "must be viewed as a serious threat to global stability and should be elevated beyond a scientific debate to a U.S. national security concern." In 2004, the United Kingdom's chief science adviser, David A. King, wrote, "In my view, climate change is the most severe problem we are facing today—more serious even than the threat of terrorism."

This is not science fiction. Climate change scenarios are based on rigorous and continually improving scientific modeling. In 2006, NASA climate scientist, James Hansen (**Core Case Study**), warned that we probably have no longer than a decade to mount a global effort to prevent an irreversible change in the earth's climate that will produce a different planet and cause ecological and economic havoc. As a prevention strategy (**Concept 1-4**, p. 14), he and other prominent climate scientists urge policy makers and business leaders to mount a crash program to cut global carbon dioxide emissions in half over the next 50 years to slow down or avoid major climate changes that could last for thousands of years.

CORE CASE STUDY

CONCEPT LINK

The good news is that we know how to slow the rate of climate change. We can burn fossil fuels more cleanly and efficiently, greatly improve energy efficiency (Section 13-4, p. 298), and rely more on a mix of locally available solar, wind, flowing water, and biomass renewable energy resources (Section 13-5, p. 304).

Can the Oceans Save Us?

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 (Figure 15-C). The oceans, for example, help moderate the earth's average surface temperature by removing about 30% of the excess 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 of it to the deep ocean (Figure 5-6, p. 79), where it is removed from the climate system for unknown periods (Figure 15-B).

We do not know whether the oceans can continue to absorb more CO_2. But the solubility of CO_2 in ocean water decreases with increasing temperature. Thus, if the oceans heat up, some of their dissolved CO_2 could be released into the lower atmosphere—like CO_2 bubbling out of a warm carbonated soft drink. This could amplify global warming.

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. According to a 2007 study of the vast Southern Ocean around Antarctica, led by researcher Corinne Le Quere, 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 could reach very harmful levels by 2150. This happens because much of the CO_2 absorbed by the ocean reacts with water to produce carbonic acid (H_2CO_3)—the same weak acid found in carbonated drinks. The scientists involved in this study warn that this may reduce the ability of the oceans to remove CO_2 from the lower atmosphere and thus could accelerate global warming.

This increase in seawater acidity also threatens coral reefs and alters seawater life by impairing the ability of certain shellfish (including certain plankton and tiny snails) to produce shells, which like coral reefs, are made of calcium carbonate ($CaCO_3$). You can see this effect by dropping a piece of chalk (made of calcium carbonate) in a glass of vinegar (a weak acid) and watching it rapidly dissolve.

Extensive loss of these forms of plankton would disrupt food webs (Figure 3-15, p. 51), killing seals, whales, and fish and perhaps disrupting human food supplies from the ocean. This would also decrease the ability of such plankton to slow global warming by removing CO_2 from the atmosphere.

Bottom line: Changes in the temperature and acidity of the oceans as a result of human activities are likely to accelerate global warming.

There Is Uncertainty about the Effects of Cloud Cover on Global Warming

A major unknown in global climate models is the effect that changes in the global distribution of clouds might have on the temperature of the atmosphere. Warmer temperatures increase evaporation of surface water and create more clouds. Depending on their content and reflectivity, these additional clouds could have two effects. An increase in thick and continuous 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 can warm the lower atmosphere and *increase* surface warming. We need more research to understand which of these effects might predominate globally and in various parts of the world.

In addition, infrared satellite images indicate that the wispy condensation trails (contrails) left behind by jet planes might have a greater impact on atmospheric temperatures than scientists once thought. NASA scientists found that jet contrails expand and turn into large cirrus clouds that tend to release heat into the upper troposphere. If these preliminary results are confirmed, emissions from jet planes could be responsible for as much as half of the warming of the lower atmosphere in the northern hemisphere.

Outdoor Air Pollution Can Temporarily Slow Global Warming

Aerosols (microscopic droplets and solid particles) of various air pollutants are released or formed in the troposphere by volcanic eruptions (**Core Case Study**) and human activities (Figure 15-3). CORE CASE STUDY They can either warm or cool the air and hinder or enhance cloud formation depending on factors such as their size and reflectivity.

Most aerosols, such as light-colored sulfate particles produced by fossil fuel combustion, tend to reflect incoming sunlight and cool the lower atmosphere and thus temporarily slow global warming. On the other hand, a 2004 study by Mark Jacobson of Stanford University indicated that tiny particles of *soot* or *black carbon aerosols*—produced mainly from incomplete combustion in coal burning, diesel engines, and open fires—may be the second biggest contributor to global warming after the greenhouse gas CO_2.

Climate scientists do not expect aerosol and soot pollutants to counteract or enhance projected global warming very much in the next 50 years for two reasons. *First,* aerosols and soot fall back to the earth or are washed out of the lower atmosphere within weeks or months, whereas CO_2 remains in the lower atmosphere for about 120 years. *Second,* aerosol and soot inputs into the lower atmosphere are being reduced because of their harmful impacts on plants and human health—especially in developed countries.

Some scientists have suggested using balloons, large jet planes, or giant cannons to inject sulfate particles into the stratosphere as a possible way to slow global warming by reflecting some of the incoming sunlight into space and cooling the troposphere. The effect might be similar to the estimated 0.5 C° (0.9 F°) cooling effect that lasted about 15 months from the 1991 volcanic eruption of Mt. Pinatubo (**Core Case Study**). Huge amounts of SO_2 would have to be injected into the stratosphere about every two years at an average cost of about $1 billion a year—nearly 100 times cheaper than the estimated cost of cutting CO_2 emissions.

CORE CASE STUDY

Other scientists reject this idea as being too risky because of our limited knowledge about possible unknown effects. Such a scheme could increase ozone depletion by boosting levels of ozone-destroying chlorine in the stratosphere. This short-term technological fix could also destroy much of the life in the oceans and their ability to remove CO_2 by allowing CO_2 levels in the lower atmosphere to continue to rise and increase the acidity of the oceans. As the oceans become more acidic, they absorb less CO_2, which can accelerate global warming.

THINKING ABOUT
Tinkering with the Stratosphere

Explain why you agree or disagree with the proposal to inject large quantities of sulfate particles into the stratosphere every two years to help cool the troposphere.

Plants Can Remove More CO_2 from the Atmosphere but the Effect Is Temporary

Some studies suggest that larger amounts of CO_2 in the lower atmosphere could increase the rate of photosynthesis in some areas with adequate water and soil nutrients. This would remove more CO_2 from the lower atmosphere and help slow global warming.

However, recent studies indicate that this effect would be temporary for two reasons. *First,* the increase in photosynthesis would slow as the plants reach maturity and take up less CO_2. *Second,* carbon stored by the plants would return to the lower atmosphere as CO_2 when the plants die and decompose or burn. According to the 2007 IPCC report, plants now absorb more CO_2 than they release, but by 2050 will likely release more CO_2 than they take up.

Reducing the clear-cutting of rain forests in the Amazon and other tropical areas will preserve trees and other vegetation that remove some of the CO_2 we add to the atmosphere. However, even if we halted all clear-cutting, climate models forecast that global warming will convert much of the Amazon's wet forests into dry savannah during this century. This would reduce CO_2 uptake by tropical forests, further accelerate global warming, and greatly decrease tropical biodiversity.

15-4 What Are Some Possible Effects of a Warmer Atmosphere?

CONCEPT 15-4 Some areas will benefit from a warmer climate and others will suffer from melting ice, rising sea levels, more extreme weather events, increased drought and floods, and shifts in locations of wildlife habitats and agricultural areas.

Global Warming Can Have Harmful and Beneficial Effects

A warmer global climate could have a number of harmful and beneficial effects for humans, other species, and ecosystems, depending mostly on where they are located and on how rapidly the temperature changes. Some areas will benefit because of less severe winters, more precipitation in some dry areas, less precipitation in wet areas, and increased food production. Other areas will suffer harm from excessive heat, drought, and decreased food production (**Concept 15-4**). According to the IPCC, the world's poor, who are least responsible for global warming, and wild species in the tropics (especially Africa and parts of Asia) will suffer the most harm.

According to a recent study by Agiuo Dai and his colleagues, between 1979 and 2002, the area of the earth's land (excluding Antarctica) experiencing severe drought tripled and affected an area the size of Asia, mostly because of global warming. This browning of the land is expected to increase sharply and decrease water supplies and biodiversity in many areas. According to the 2007 IPCC report, hundreds of millions of people would suffer from water scarcity, with just a small rise in temperatures. However, if the average temperature rose by more that 4 C°(7 F°), 1.1 to 3.2 billion people might suffer from water shortages. According to the IPCC, areas projected to have increased drought by 2080–2099 include the western United States, the Mediterranean basin, southern Africa, southern and eastern Australia, and northeastern Brazil. The same report projected more days of heavy rain with increased flooding in areas of Canada, most of Europe, and the northern parts of the United States.

> **RESEARCH FRONTIER**
>
> Predicting the effects of global warming in different parts of the world

Ice and Snow Are Melting in the Arctic

Environmental scientists are alarmed by recent news that parts of the Arctic are warming two to three times faster than the rest of the earth. Over the past 30 years, snow cover in the Arctic has declined by about 10%, mountain glaciers are melting and retreating (Figure 15-19), and permafrost is beginning to thaw in some areas. The melting of such reflective ice and snow exposes much darker land and water, which absorb more solar energy, and accelerates global warming.

In 2006, the U.S. National Oceanic and Atmospheric Administration issued a *State of the Arctic* report in which researchers predicted Arctic summers without floating sea ice (Figure 15-20) by 2040 and perhaps much earlier. Because sea ice floats, it does not contribute to a rising sea level when it melts. However, open water reflects much less sunlight and absorbs more heat than do reflective ice or snow. Hence, floating ice turning to water during the Arctic summer will accelerate the warming of the lower atmosphere.

The Arctic's contribution to a rising sea level will come from land-based ice and snow that melts and runs into the sea. This is especially true in Greenland, a large mountainous island, which is covered almost completely by glaciers that are up to 3.2 kilometers (2 miles) deep. These glaciers contain about 10% of the world's freshwater—enough water to raise the global sea level by as much as 7 meters (23 feet) if the glaciers all melt. This would flood many coastal cities (Figure 7-13, p. 138) and large areas of farmland.

Until recently scientific models of Greenland assumed that this huge solid block of ice would take thousands of years to melt. But recent satellite measurements made by scientists at the University of Kansas Jet Propulsion Laboratory show that Greenland's net loss of ice more than doubled between 1996 and 2006 and is not being replaced by increased snowfall. Even partial melting will accelerate the projected average sea level rise during this century. Some climate scientists, such as James Hansen (**Core Case Study**), warn that once Greenland's glaciers starts to disintegrate they could reach a tipping point beyond which the breakup would occur very rapidly. CORE CASE STUDY

Mountaintop glaciers are affected by two climatic factors: snowfall that adds to their mass during the winter and warm temperatures that spur melting during the summer. As temperatures go up, melting exceeds snowfall and the glaciers begin receding. During the last 25 years, many of the world's mountaintop glaciers have been melting and shrinking at accelerating rates (Figure 15-19). For example, climate models predict that by 2070, Glacier National Park in the United States will have no glaciers. In 2007, scientists projected that at their current rate of melting most glaciers will disappear from Europe's Alps somewhere between 2037 and 2059. As mountain glaciers disappear, at least 300 million people in countries such as Bolivia, Peru, Ecuador, and India, who rely on meltwater from such glaciers could face severe water shortages.

Sea Levels Are Rising

According to the 2007 IPCC report, the world's average sea level is *very likely* (90–99% certainty) to rise 8–59 centimeters (0.6–1.9 feet) during this century—about two-thirds of it from the expansion of water as it warms, and the other third from the melting of land-based ice. However, larger rises in sea levels of up to 1 meter (39 inches) by 2100 cannot be ruled out if glaciers in Greenland reach a tipping point and continue melting at their current or higher rates as the atmosphere warms.

According to the IPCC, the projected increases in sea levels during this century could

- threaten at least one third of the world's coastal estuaries, wetlands, and coral reefs,
- disrupt many of the world's coastal fisheries,
- flood low-lying barrier islands and cause gently sloping coastlines (especially on the U.S. East Coast) to erode and retreat inland,
- flood agricultural lowlands and deltas in coastal areas where much of the world's rice is grown,
- contaminate freshwater coastal aquifers with saltwater,
- submerge some low-lying islands in the Pacific Ocean, the Caribbean Sea, and the Indian Ocean (Figure 15-21), and
- flood coastal areas, including some of the world's largest cities, and displace at least 100 million people, especially in China, India, Bangladesh, Vietnam, Indonesia, and Japan.

Permafrost Is Melting: Another Dangerous Scenario

Global warming could be accelerated by an increased release of methane (a greenhouse gas 23 times more potent, per volume, than carbon dioxide) from four major sources: natural decay in swamps and other freshwater wetlands, decay from garbage in landfills, melting permafrost in soils and lake beds, and ice-like compounds called *methane hydrates* trapped beneath arctic permafrost and on the deep ocean floor.

The amount of carbon locked up as methane in permafrost soils is 50–60 times the amount emitted as carbon dioxide from burning fossil fuels each year. Significant amounts of methane and carbon dioxide would be released into the atmosphere if the permafrost in arctic areas melts. This is already happening on a small scale in parts of North America and Asia, and as the earth gets warmer, it could accelerate. According to the 2004 Arctic Climate Impact Assessment, 10–20% of the Arctic's current permafrost might thaw during this century and decrease the area of Arctic tundra.

A warmer atmosphere could melt more permafrost and increase emissions of CH_4 and CO_2. This would cause more warming and more permafrost melting, which would cause still more warming.

Ocean Currents Are Changing but the Threat Is Unknown

Ocean currents, which on the surface and deep down are connected, act like a gigantic conveyor belt, moving CO_2 and heat to and from the deep sea, and transferring hot and cold water between the tropics and the poles (Figure 5-6, p. 79).

Scientists are concerned that melting of land-based glaciers from global warming (especially in Greenland) and increased rain in the North Atlantic could add enough freshwater to the ocean in the arctic area to slow or disrupt this conveyor belt. Reaching this tipping point would drastically alter the climates of northern Europe, northeastern North America, and probably Japan. The exact nature and likelihood of this possible threat is still unknown, but most climate scientists do not see it as a major threat in the near future.

Extreme Weather Will Increase in Some Areas

Global warming is projected to alter the hydrologic cycle (Figure 3-18, p. 54) and shift patterns of precipitation, causing some areas to get more water and other areas to get less. This could shift the locations of areas where crops could be grown and where people could live (**Concept 15-4**).

According to the IPCC, global warming will increase the incidence of extreme weather such as prolonged, intense heat waves and droughts, which can kill large numbers of people and expand deserts. At the same time, other areas will experience increased flooding from heavy and prolonged precipitation.

Researchers have not been able to establish that global warming will increase the frequency of tropical hurricanes and typhoons (Figure 8 on p. S46 in Supplement 10). But a 2005 statistical analysis by MIT climatologist Kerry Emmanuel and six other peer-reviewed studies published in 2006 indicated that global warming, on average, could increase the size and strength of such storms in the Atlantic by warming the ocean's surface water.

Massimo Borchi/Bruce Coleman, USA

Figure 15-21 For a low-lying island nation like the Maldives in the Indian Ocean, even a small rise in sea level could spell disaster for most of its 295,000 people. About 80% of the 1,192 small islands making up this country lie less than 1 meter (39 inches) above sea level. Rising sea levels and higher storm surges during this century could flood most of these islands and their coral reefs.

On the other hand, some researchers blame the recently increased ferocity of tropical Atlantic hurricanes on natural climate cycles. More research is needed to evaluate these opposing hypotheses. More research is needed to evaluate the scientific controversy over the effects of global warming on hurricane frequency and intensity.

Global Warming Is a Major Threat to Biodiversity

According to the 2007 IPCC report, changes in climate are now affecting physical and biological systems on every continent. A warmer climate could expand ranges and populations of some plant and animal species that can adapt to warmer climates, including certain weeds, insect pests such as fire ants and ticks, and disease-carrying organisms.

Changes in the structure and location of wildlife habitats could cause the premature extinction of as many as 1 million species during this century (**Concept 15-4**). One of the first mammal species to go may be the polar bear (see front cover), as arctic sea ice, on which the bears hunt seals and other marine mammals, diminishes. By 2050, polar bears may be found mostly in zoos.

The ecosystems *most likely* to suffer disruption and species loss are coral reefs, polar seas, coastal wetlands, arctic and alpine tundra, and high-elevation mountaintops. Forest fires may increase in some areas. Shifts in regional climate would also threaten many parks, wildlife reserves, wilderness areas, and wetlands—wiping out more biodiversity. In other words, slowing global warming would help sustain the earth's biodiversity.

Global Warming Will Change Locations of Areas Where Crops Can Be Grown

Farming depends on a stable climate, probably more than any other human endeavor. Global warming will upset this stability by shifting climates and speeding up the hydrologic cycle (**Concept 15-4**).

Agricultural productivity may increase in some areas and decrease in others. For example, models project that warmer temperatures and increased precipitation at northern latitudes may lead to a northward shift of some agricultural production from the breadbasket of the midwestern United States to midwestern Canada. But overall food production could decrease because soils in midwestern Canada are generally less fertile than those to the south. Crop production could also increase in Russia and Ukraine. In 2007, a panel of scientists from six Chinese government agencies warned that rising temperatures during the second half of this century could slash the country's grain production by over a third, melt glaciers, increase pressure on its already scarce water resources in many areas, change its forest industry, and cause flooding in coastal areas that include 21 of its 33 largest cities.

Models predict a decline in agricultural productivity in tropical and subtropical regions, especially in Southeast Asia and Central America, where many of the world's poorest people live. In addition, flooding of river deltas due to rising sea levels could reduce crop and fish production in these productive agricultural lands and coastal aquaculture ponds. According to the IPCC, for a time, food will be plentiful because of the longer growing season in northern regions. But by 2050, 200–600 million people could face starvation from decreased food production.

Global Warming Could Threaten the Health of Many People

According to the IPCC and a 2006 study by U.S National Center for Atmospheric Research, heat waves in some areas will be more frequent and prolonged, increasing death and illness, especially among older people, those with poor health, and the urban poor who cannot afford air conditioning. During the summer of 2003 (based on a detailed analysis in 2006 by Earth Policy Institute), such a heat wave killed about 52,000 people in Europe—almost two-thirds of them in Italy and France.

On the other hand, in a warmer world fewer people will die from cold weather. But a 2007 study by Mercedes Medin-Ramon and his colleagues suggested that increased heat-related deaths would be greater than the drop in cold-related deaths.

Incidences of tropical infectious diseases such as dengue fever and malaria (Figure 14-6, p. 328) are likely to increase if mosquitoes that carry them spread to temperate and higher elevation areas that are getting warmer. A 2006 study by Nils Stenseth at the University of Oslo found that the bacterium that causes bubonic plague, which killed more than 20 million people in the Middle Ages, could spread if the flea populations increase as temperatures rise. In addition, hunger and malnutrition will increase in areas where agricultural production drops.

A 2005 WHO study estimated that each year, climate change already prematurely kills more than 160,000 people—an average of 438 people a day—and that this number could double by 2030. In addition, the WHO estimates that climate change causes 5 million sicknesses each year. By the end of this century, the annual death toll from global warming could be in the millions.

15-5 What Can We Do about Global Warming?

CONCEPT 15-5A We can slow the rate of warming and climate change by increasing energy efficiency, relying more on renewable energy resources, greatly reducing greenhouse gas emissions, and slowing population growth.

CONCEPT 15-5B Governments can subsidize energy efficiency and renewable energy use, tax greenhouse gas emissions, and cooperate internationally, and individuals and institutions can sharply reduce their greenhouse gas emissions.

Dealing with Climate Change Is Difficult

What to do about climate change on the only planet we have should be one of the most urgent scientific, political, and ethical issues of this century. But the following characteristics of the problem make it difficult to deal with:

- *The problem is global.* Dealing with this threat will require unprecedented international cooperation.
- *The effects will last a long time.* Once climate change is set into motion, its effects will last hundreds to thousands of years.
- *The problem is a long-term political issue.* Voters and elected officials generally respond well to short-term

problems, but have difficulty acknowledging and coping with long-term threats.

- *The harmful and beneficial impacts of climate change are not spread evenly.* There will be winners and losers from moderate climate change. Winning nations are less likely to bring about controversial changes or spend large sums of money to slow down something that will benefit them. The catch: We will not know who will benefit and who will suffer until it is too late to avoid harmful effects, and at some temperature threshhold, essentially everyone will be harmed.
- *Many actions that might reduce the threat of climate change, such as phasing out fossil fuels, are controversial because they can disrupt economies and lifestyles.*

Despite these problems, most climate experts argue that the world must face up to the urgent problem of global climate change. This will require reaching a *political tipping point* in which individuals and elected officials shift from ignorance and denial to awareness and urgent action to deal with this serious threat.

What Are Our Options?

There are two basic approaches to global warming. One is to drastically reduce greenhouse gas emissions to slow down the rate of temperature increase and to shift to noncarbon-based energy options in time to prevent runaway positive feedback processes that set into motion major climate changes. The other is to recognize that some warming is unavoidable and to devise strategies to reduce its harmful effects. Most analysts believe we need a mix of both approaches.

In 2005, national academies of sciences from the United States, the United Kingdom, Germany, Italy, France, Russia, Japan, Canada, Brazil, China, and India joined together in an unprecedented statement saying that the scientific evidence on global climate change is clear enough for government leaders to commit to prompt action now. Any delay, they said, "will increase environmental damage and likely incur a greater cost."

In 2006, then U.N. Secretary General Kofi Annan said: "Let there be no more denial. Let no one say we cannot afford to act. It is increasingly clear that it will cost far less to cut greenhouse gas emissions now than to deal with the consequences later. And let there be no more talk of waiting until we know more. . . . The question is not whether climate change is happening or not, but whether, in the face of this emergency, we ourselves can change fast enough."

HOW WOULD YOU VOTE? ✓

Should we take serious action now to help slow global warming? Cast your vote online at **www.thomsonedu.com /biology/miller**.

We Can Reduce the Threat of Global Warming

The good news is that we know what to do to slow the rate and degree of global warming caused by our activities, as summarized in Figure 15-22.

These solutions come down to four major strategies: *improve energy efficiency to reduce fossil fuel use; shift from nonrenewable carbon-based fossil fuels to carbon-free renewable energy resources; stop cutting down tropical forests;* and *capture and store as much CO_2 as possible in soil, vegetation, underground, and in the deep ocean* (**Concept 15-5A**). The effectiveness of these strategies would be enhanced by *reducing population,* which would decrease the number of fossil fuel consumers and CO_2 emitters, and by *reducing poverty,* which would decrease the need of the poor to clear more land for crops and fuelwood. These strategies follow the four **scientific principles of sustainability** (see back cover).

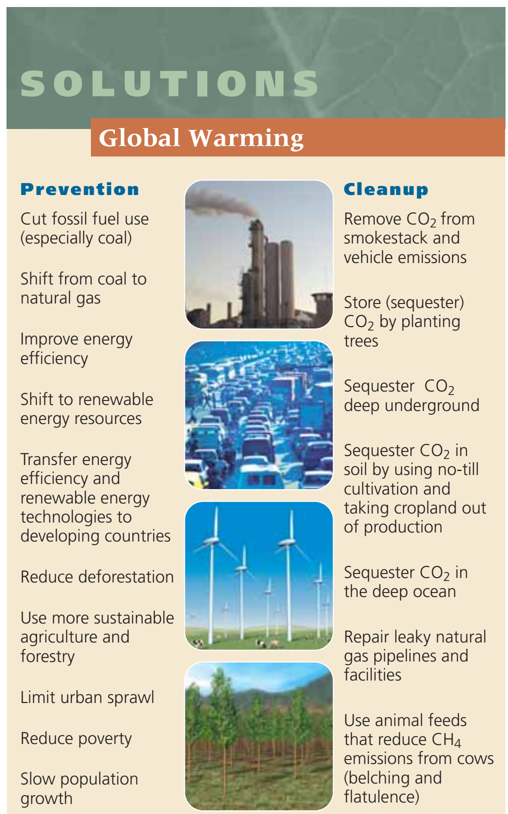


Figure 15-22 Methods for slowing atmospheric warming during this century (**Concept 15-5A**). **Question:** Which five of these solutions do you think are the most important? Why?

HOW WOULD YOU VOTE?

Should we phase out the use of fossil fuels over the next 50 years? Cast your vote online at **www.thomsonedu.com/biology/miller**.

Let us look more closely at some of these possible solutions.

Is Capturing and Storing CO_2 the Answer?

Figure 15-23 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 is to plant trees to store it in biomass while controlling insects and diseases that kill trees. But this is a temporary approach, because trees release their stored CO_2 back into the atmosphere when they die and decompose or if they burn.

Planting large numbers of carbon-storing trees in tropical areas and slowing tropical deforestation can help slow global warming by absorbing carbon dioxide and evaporating water into the atmosphere, which increases cloudiness and helps cool the atmosphere above them. But a 2006 study by a team of scientists from Lawrence Livermore Laboratory, Université Montpeller II, and the Carnegie Institution found that planting more trees in temperate regions such as the United States and Europe may enhance global warming. Their models showed that the less dense canopies of these temperate forests reflect less sunlight, absorb more heat, and evaporate much less cloud-forming water vapor than tropical forests. Thus, they can warm the ground below and contribute to global warming.

A second approach is to plant large areas with fast-growing plants such as switchgrass (Figure 13-37, p. 313) that can remove CO_2 from the air and store it in the soil. But warmer temperatures can increase decomposition in soils and return some of this CO_2 to the atmosphere.

A third strategy is to *reduce the release of carbon dioxide and nitrous oxide from soil.* This can be done through *no-till cultivation* (p. 207) and by setting aside degraded crop fields as conservation reserves.

A fourth approach is to remove some of the CO_2 from smokestacks and pump it deep underground into unmineable coal seams and abandoned oil fields or to liquefy it and inject it into thick sediments under the sea floor (Figure 15-23). Cleaner coal-fired power plants that could remove some of the CO_2 from smokestack emissions could be built within 5–10 years. But they are much more expensive to build and operate than conventional coal-burning plants are and thus would raise the price of electricity for consumers. Without strict government regulation of CO_2 emissions and carbon taxes or carbon-trading schemes, utilities and industries have no incentive to build such plants. According to the U.S. Department of Energy, the cur-

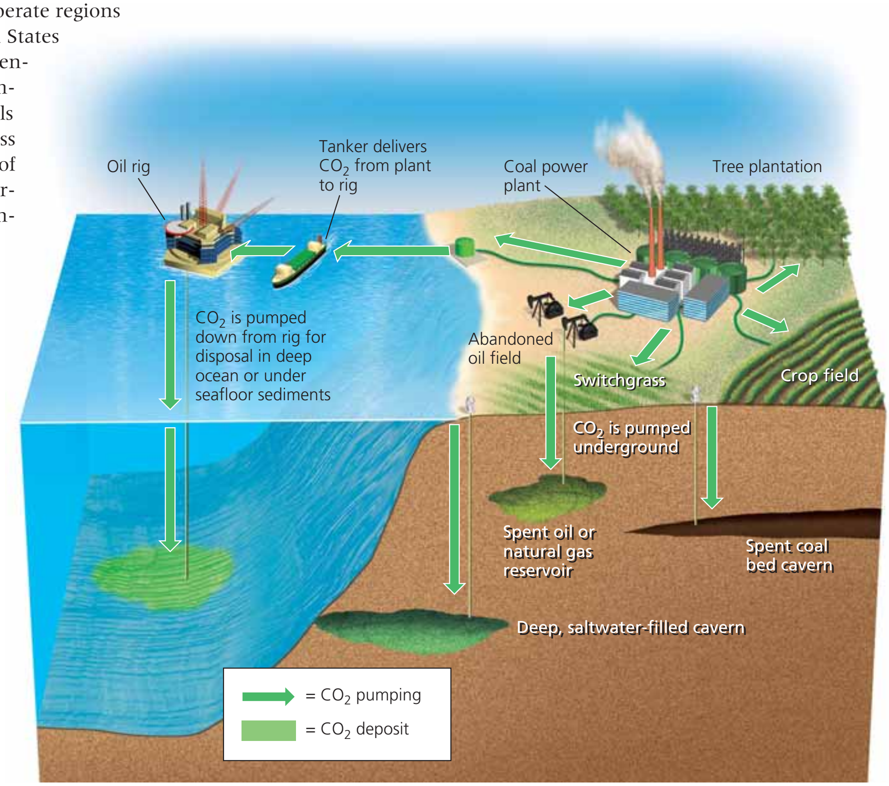


Figure 15-23 **Solutions:** methods for removing some of the carbon dioxide from the atmosphere or from smokestacks and storing it in plants, soil, deep underground reservoirs, and the deep ocean. **Question:** Which two of these solutions do you think are the most important? Why?

rent costs of carbon capture and storage systems have to be reduced by a factor of ten for these systems to be available and widely used.

Scientists say that no country should build any more traditional coal-burning power plants unless they are designed to be able to capture and store most of the CO_2 they emit. China and India worry that making a shift to cleaner technologies will slow their economic growth by raising costs. But Rob Watson, an expert on China's environmental problems, points out that leaders of China and India need to recognize that going green is an opportunity to save money by reducing pollution and resource waste and to make money by developing low-cost innovative solutions to environmental problems that can be sold in the global marketplace.

RESEARCH FRONTIER

Finding affordable and effective ways to remove and store carbon dioxide

Governments Can Help Reduce the Threat of Climate Change

Governments can use four major methods to promote the solutions listed in Figures 15-22 and 15-23 (**Concept 15-5B**). One is to *regulate carbon dioxide as a pollutant.*

Second, governments could phase in *carbon taxes* on each unit of CO_2 emitted by fossil fuel use or *energy taxes* on each unit of fossil fuel that is burned. Decreasing taxes on income, labor, and profits to offset such taxes could help make such a strategy more politically acceptable. In other words, *tax pollution, not payrolls.* In 2006, voters in the U.S. city of Boulder, Colorado, approved a plan to charge residences and businesses a carbon tax based on how much electricity they use. The tax revenues will fund energy audits for homes and businesses and visits by energy experts to provide information on ways to save energy. Residents choosing to use electricity produced by wind power will not have to pay the tax.

A related approach is to place a cap on total CO_2 emissions in a country or region, to *issue permits to release* CO_2, and then to let polluters trade their permits in the marketplace. This *cap-and-trade* strategy has a political advantage, but it would be difficult to manage because there are so many CO_2 emitters including industries, power plants, motor vehicles, buildings, and homes.

A third strategy is to *level the economic playing field* by greatly increasing government subsidies to businesses and individuals for using energy-efficiency technologies, carbon-free renewable-energy technologies, carbon capture and storage, and more sustainable agriculture. This would also include phasing out or sharply reducing subsidies and tax breaks for using fossil fuels, nuclear power (p. 297), and unsustainable agriculture.

A fourth strategy would focus on *technology transfer.* Governments of developed countries could help fund the transfer of the latest green technologies to developing countries, which can then bypass older energy-wasting and polluting technologies. Increasing the current tax on each international currency transaction by a quarter of a penny could finance this technology transfer, which would then generate wealth for developing countries and help stimulate a more environmentally sustainable global economy.

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 help slow global warming. The first phase of the resulting *Kyoto Protocol* went into effect in January 2005 with 189 countries (not including the United States and Australia) and the U.S states of California and Maine participating in the agreement. It requires 38 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 by 2012. Developing countries were excluded from having to reduce greenhouse gas emissions in this first phase because such reductions would curb their economic growth. In 2005, countries began negotiating a second phase that is supposed to go into effect after 2012.

The protocol also allows trading of greenhouse gas emissions among participating countries. For example, a country or business that reduces its CO_2 emissions or plants trees receives a certain number of credits. It can use these credits to avoid having to reduce its emissions in other areas, or it can bank them for future use or sell them to other countries or businesses.

Some analysts praise the Kyoto agreement as a small but important step in attempting to slow projected global warming. They hope that rapidly developing nations such as China, Brazil, and India will agree to reduce their greenhouse gases in the second phase of the protocol. Others see the agreement as a weak and slow response to an urgent global problem.

In 2001, President George W. Bush withdrew U.S. participation from the Kyoto Protocol, arguing that participation would harm the U.S. economy. He also objected to the agreement because it does not require emissions reductions by developing countries such as China and India, which produce large and increasing emissions of greenhouse gases.

Most analysts believe that the United States, which has the second highest CO_2 emissions and highest per capita emissions of any country, should use its influence to improve the treaty rather than to weaken and abandon it. A 2006 poll by the nonprofit, nonpartisan Civil Society Institute found that 83% of Americans want more leadership from the federal government in dealing with the threat of global warming.

In 2007, the European Union put climate change at the center of its foreign policy and began focusing on developing a new treaty with China that emphasizes sharp reductions in greenhouse gas emissions.

HOW WOULD YOU VOTE?

Should the United States participate in the Kyoto Protocol and try to strengthen it? Cast your vote online at **www.thomsonedu.com/biology/miller**.

We Can Move beyond the Kyoto Protocol

In 2004, environmental law experts Richard B. Stewart and Jonathan B. Wiener proposed that countries work together to develop a new strategy for slowing global warming. They concluded that the Kyoto Protocol will have little effect on future global warming without support and action by the United States, China, and India. In 2005, China, India, and other developing countries accounted for 37% of the world's greenhouse gas emissions. By 2050, the International Energy Agency projects that their share could be 55%.

Stewart and Wiener urge the development of a new climate treaty among the United States, China, India, Russia, Australia, Japan, South Korea, the European Union, and other major greenhouse gas emitters. The treaty would also create an emissions trading program that includes developing countries omitted from the trading plan under the first phase of the Kyoto Protocol. In addition, it would set achievable 10-year goals for reducing emissions over the next 40 years and evaluate global and national strategies for adapting to the harmful ecological and economic effects of global warming.

Some Governments, Businesses, and Schools Are Leading the Way

Some governments, businesses, and schools are tackling climate change problems on their own (**Concept 15-5B**). In 2005, the European Commission proposed a plan to increase the European Union's use of renewable energy to 12% by 2010 and cut energy use by 20% by 2020. Together these two achievements would cut EU carbon dioxide emissions by nearly one-third.

Since 1990, local governments in more than 600 cities around the world (including 330 U.S. cities) have established programs to reduce their greenhouse gas emissions. The first major U.S. city to tackle global warming was Portland, Oregon. Between 1993 and 2005, the city cut its greenhouse gas emissions back to 1990 levels, while national levels rose by 16%. The city promotes energy-efficient buildings and the use of electricity from wind and solar sources. It has also built bicycle trails and greatly expanded mass transit. Far from hurting its economy, Portland has experienced an economic boom, saving $2 million a year on city energy bills.

In 2006, California, with the world's sixth largest economy, passed a law to cut its greenhouse gas emissions to 1990 levels (a 25% reduction) by 2020 and to 80% below 1990 levels by 2050. The EPA sued California, arguing that EPA and thus the state had no legal right to regulate CO_2 emissions. But California won this Supreme Court case, and at least ten other states plan to adopt its standards.

In 2007, the premier of British Columbia, Canada, stated that he would cut CO_2 emissions by a third by building no more coal plants, embracing wind power, toughening car emission standards, reducing pollution by the powerful oil and gas industry, and leasing hybrid cars for government use. He proposed making British Columbia the continent's greenest spot. He also proposed forming an alliance with California to create a Pacific Coast bloc of provinces and states to deal with climate change without waiting for their federal governments to act.

A growing number of major global companies, such as Alcoa, DuPont, IBM, Toyota, General Electric, and British Petroleum (BP), have established targets to reduce their greenhouse gas emissions by 10–65% from 1990 levels by 2010. Since 1990, the chemical company DuPont has slashed its energy usage and cut its greenhouse emissions by 72%. In the process, it has saved $3 billion while increasing its business by 30%.

General Electric, BP America, Duke Energy, Caterpillar, Pacific Gas and Electric, Wal-Mart, and some firms managing large pension funds are among several major companies that in 2007 urged the U.S. Congress to regulate CO_2 as a pollutant and impose mandatory carbon-emission caps on all U.S. businesses. The goal would be to reduce U.S. greenhouse gas emissions by 60–90% from 1990 levels, mostly by using a cap-and-trade system. Such companies have established the Global Roundtable on Climate Change. Individuals can send a message to politicians and business leaders around the world by visiting the roundtable's website at **www.nextgenerationearth.org**.

These and many other major companies see an enormous profit opportunity by going green and developing energy-efficient and clean-energy technologies such as fuel-efficient cars, wind turbines, solar-cell panels, biofuels, and coal gasification and carbon removal and storage technologies (**Concept 13-5**, p. 304, and **Concept 13-6**, p. 317). A 2006 study found that companies lagging behind in these efforts are putting their stockholders at risk of losses and lawsuits for failure to take advantage of the rapidly growing international marketplace for green technologies.

CONCEPT LINKS

Some colleges and universities are also taking action. Students and faculty at Oberlin College in Ohio (USA) 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 carbon-free renewable energy. In 2005, the president of Yale University committed the school to cutting its considerable greenhouse gas emissions 44% by 2020. The student Task Force for Environmental Partnership handed out 2,000 compact fluorescent light bulbs in exchange for incandescent light bulbs. The program paid for itself in four months through the savings on electric bills.

You can go to sites like **gocarbonzero.org**, **nature.org/climatecalculator, carbonfootprint.com,** and **climatecrisis.net/takeaction/carboncalculator** to calculate your *carbon footprint:* the amount of carbon dioxide you generate. Most of these websites and others such as **climatecare.org, nativeenergy.com, myclimate.com, carbon-clear.com** and **clean-air-coolplanet.org** suggest ways for you to offset some of your carbon dioxide emissions.

However, critics of such carbon-offset schemes say that most of them are primarily ways to ease consumer guilt while encouraging individuals to continue producing greenhouse gases instead of making carbon-cutting lifestyle changes.

Figure 15-24 lists some ways in which you can cut your CO_2 emissions. This involves thinking globally and acting locally.

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 light bulbs
- 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 shower head
- Buy products from, or invest in, companies that are trying to reduce their impact on climate

Figure 15-24 **Individuals matter:** ways to reduce your annual emissions of CO_2. **Questions:** Which of these actions, if any, do you now take or plan to take?

We Can Prepare for Global Warming

According to the latest global climate models, the world needs to make a 60–80% cut in emissions of greenhouse gases by 2050 (some say by 2020) to stabilize their concentrations in the atmosphere.

However, because of the difficulty of making such large reductions, many analysts believe that, at the same time, we should begin to prepare for the possible harmful effects of long-term atmospheric warming and climate change. Figure 15-25 shows some ways to implement this strategy. However, critics fear that emphasizing this approach will decrease the more urgent need to reduce greenhouse gas emissions.

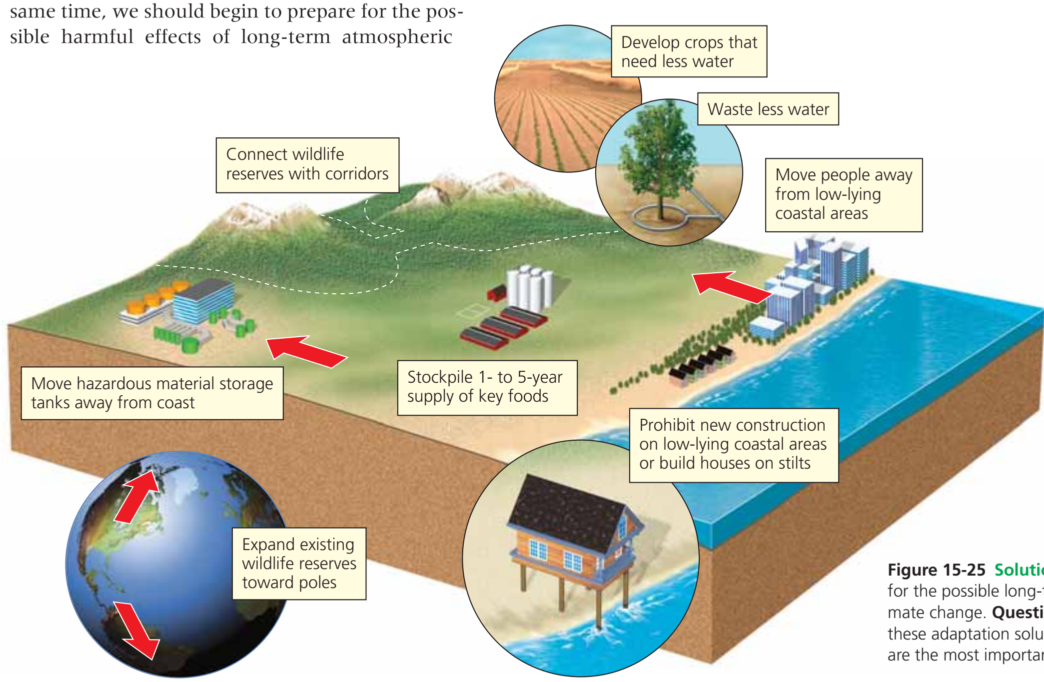


Figure 15-25 **Solutions:** ways to prepare for the possible long-term effects of climate change. **Question:** Which three of these adaptation solutions do you think are the most important? Why?

15-6 How Have We Depleted Ozone in the Stratosphere and What Can We Do about It?

CONCEPT 15-6A Widespread use of certain chemicals has reduced ozone levels in the stratosphere, which allows more harmful ultraviolet radiation to reach the earth's surface.

CONCEPT 15-6B To reverse ozone depletion, we must stop producing ozone-depleting chemicals, and adhere to the international treaties that ban such chemicals.

Human Activities Threaten the Ozone Layer

A layer of ozone in the lower stratosphere keeps about 95% of the sun's harmful UV radiation from reaching the earth's surface (Figure 15-2). Measurements made using balloons, aircraft, and satellites show considerable seasonal depletion (thinning) of ozone concentrations in the stratosphere above Antarctica and the Arctic. Similar measurements reveal a lower overall 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 15-6A**).

This situation began when Thomas Midgley, Jr., a General Motors chemist, discovered 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, fumigants for granaries and ship cargo holds, and bubbles in plastic foam used for 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 were caused by CFCs and other ozone-depleting chemicals (ODCs) released into the atmosphere by human activities beginning in the 1950s.

INDIVIDUALS MATTER

Sherwood Rowland and Mario Molina—A Scientific Story of Courage and Persistence

In 1974, calculations by chemists Sherwood Rowland and Mario Molina at the University of California–Irvine indicated that 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,* these persistent CFCs remain in the atmosphere. *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, a powerful, well-funded adversary with a lot of profits and jobs at stake (led by DuPont), 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.

In 1995, Rowland and Molina received the Nobel Prize in chemistry for their work. In awarding the prize, the Royal Swedish Academy of Sciences said that they contributed to "our salvation from a global environmental problem that could have catastrophic consequences."

Ozone Levels over the Earth's Poles Drop for a Few Months Each Year

In 1984, researchers analyzing satellite data discovered that 40–50% of the ozone in the upper stratosphere over Antarctica disappeared each year during October and November. This observed loss of ozone has been called an *ozone hole.* A more accurate term is *ozone thinning* because the ozone depletion varies with altitude and location.

When the southern hemisphere's winter ends and partial sunlight returns to Antarctica in October, huge masses of ozone-depleted air above Antarctica flow northward and linger for a few weeks over parts of Australia, New Zealand, South America, and South Africa. This raises biologically damaging UV-B levels in these areas by 3–10% and in some years by as much as 20%. In 2006, there was a record seasonal loss of ozone over an area of Antarctica about the size of North America.

In 1988, scientists discovered that similar but usually less severe ozone thinning occurs over the Arctic from February to June, resulting in a typical ozone loss of 11–38% (compared to a typical 40–50% loss above Antarctica). When the mass of air above the Arctic breaks up each spring, large masses of ozone-depleted air flow south to linger over parts of Europe, North America, and Asia.

Models indicated that the Arctic is unlikely to develop the large-scale ozone thinning found over the Antarctic. They also project that ozone depletion over the Antarctic and Arctic will be at its worst between 2010 and 2019.

Why Should We Worry about Ozone Depletion?

Why 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 15-6A**). This will give people worse sunburns, more eye cataracts, and more skin cancers.

The most dangerous type of skin cancer is *malignant melanoma.* It kills about one-fourth of its victims (most younger than age 40) within 5 years, despite surgery, chemotherapy, and radiation treatments. Each year it kills at least 48,000 people (including 7,700 Americans), mostly Caucasians, and the number of cases and deaths is rising in many countries. People who experience three or more blistering sunburns before age 20 are five times more likely to develop malignant melanoma than are those who have never had severe sunburns. Figure 15-27 (p. 378) lists ways in which you can protect yourself from harmful UV radiation.

The most serious threat from ozone depletion is that the resulting increase in UV radiation can impair or destroy phytoplankton, especially in Antarctic waters (Figure 3-15, p. 51). These tiny marine plants play a key role in removing CO_2 from the atmosphere and when they die and sink to the ocean floor, they take their carbon out of circulation for millions of years as a part of the carbon cycle (Figure 3-19, p. 56).

Furthermore, ozone depletion and global warming can interact to further decrease the vital populations of phytoplankton in Antarctic waters. Scientists project that global warming can slow down the upwelling of nutrients that support these populations of phytoplankton. In other words, populations of Antarctic phytoplankton could decrease sharply because of a combination of fewer nutrients and increased UV radiation.

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

Global Warming

- While in troposphere, CFCs act as greenhouse gases

Figure 15-26 Expected effects of decreased levels of ozone in the stratosphere (**Concept 15-6A**). **Question:** Which five of these effects do you think are the most important? Why?

WHAT CAN YOU DO?

Reducing Exposure to UV Radiation

- Stay out of the sun, especially between 10 A.M. and 3 P.M.
- Do not use tanning parlors or sunlamps.
- When in the sun, wear protective clothing and sunglasses that protect against UV-A and UV-B radiation.
- Be aware that overcast skies do not protect you.
- Do not expose yourself to the sun if you are taking antibiotics or birth control pills.
- When in the sun, use a sunscreen with a protection factor of at least 15.
- Examine your skin and scalp at least once a month for moles or warts that change in size, shape, or color and sores that keep oozing, bleeding, and crusting over. If you observe any of these signs, consult a doctor immediately.

Figure 15-27 **Individuals matter:** ways to reduce your exposure to harmful UV radiation as suggested by dermatologists (skin experts). **Question:** Which of these precautions do you take?

We Can Reverse Stratospheric Ozone Depletion

According to researchers in this field, we should immediately stop producing all ODCs (**Concept 15-6B**). However, even with immediate and sustained action, models indicate it will take about 60 years for the ozone layer to return to 1980 levels and about 100 years for recovery to pre-1950 levels. *Good news.* Substitutes are available for most uses of CFCs, and others are being developed (see Individuals Matter, p. 337).

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 ODCs) by about 35% between 1989 and 2000. After hearing more bad news about seasonal ozone thinning above Antarctica in 1989, representatives of 93 countries met in London in 1990 and then in Copenhagen, Denmark, in 1992. They adopted the *Copenhagen Protocol,* an amendment that accelerated phasing out key ODCs.

These landmark international agreements, now signed by 189 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 longer than originally projected) and to 1950 levels by 2100 (**Concept 15-6B**). The longer healing time results from a connection between global warming of the troposphere and repair of the ozone layer. Warming of the troposphere makes the stratosphere cooler, which slows down the rate of its ozone repair.

The ozone protocols set an important precedent by using *prevention* to solve a serious environmental problem (**Concept 1-4**, p. 14). Nations and companies agreed to work together to solve this global problem for three reasons. *First,* there was convincing and dramatic scientific evidence of a serious problem. *Second,* CFCs were produced by a small number of international companies. *Third,* 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. However, the most widely used substitutes cause some ozone depletion and must also be phased out.

CONCEPT LINK

REVISITING Volcanic Eruptions, Climate Change, and Sustainability

CORE CASE STUDY

SUSTAINABILITY

In this chapter, we have seen that human activities play a major role in warming the troposphere and depleting ozone in the stratosphere. Occasional large volcanic eruptions also emit CO_2 and other pollutants into the lower atmosphere (**Core Case Study**). But about three-fourths of current emissions of CO_2 come from human activities, especially the burning of fossil fuels. Thus, energy policy (Figure 13-43, p. 319) and climate policy (Figures 15-22, 15-23, and 15-25) are closely connected.

The four **scientific principles of sustainability** (see back cover) can be used to help reduce the problems of air pollution, global warming, and stratospheric ozone depletion. We can reduce inputs of air pollutants, greenhouse gases, and ODCs into the atmosphere by relying more on direct and indirect forms of solar energy than on fossils fuels; reducing the waste of matter and energy resources and recycling and reusing matter resources; mimicking biodiversity by using a diversity of carbon-free renewable energy resources based on local or regional availability; and reducing human population growth and wasteful resource consumption. We can also find substitutes for ODCs and emphasize pollution prevention.

Each of us has an important role to play in protecting the atmosphere that sustains life and supports our economies.

The atmosphere is the key symbol of global interdependence.
If we can't solve some of our problems in the face of threats to this global commons,
then I can't be very optimistic about the future of the world.

MARGARET MEAD

REVIEW QUESTIONS

1. Describe the global consequences of the eruption of Mount Pinatubo that occurred in June, 1991.
2. Identify the layers in the atmosphere and describe how the temperature and air pressure change with altitude.
3. Name and identify the sources of the primary and secondary air pollutants.
4. Explain the differences between industrial smog and photochemical smog in terms of their chemical composition and formation. Describe how lichens can be used to monitor and detect air pollution.
5. Discuss the main types of acid deposition and describe how sulfuric and nitric acids are formed in the atmosphere.
6. Summarize how air pollution can damage, weaken, or kill trees and pollute surface water and groundwater. Describe how we can reduce acid deposition.
7. Describe at least ten indoor air pollutants and explain why indoor air pollution is a serious problem.
8. Discuss the effect that legislation has had on air pollution in the United States and comment on what still needs to be done to prevent and control air pollution.
9. How have the earth's temperature and climate changed in the past? Discuss the current scientific consensus about future global temperature change. Describe the possible effects that a warmer climate will have on the earth. Summarize the methods for slowing and for adapting to atmospheric warming during this century.
10. Explain how human activities have caused a decrease in the levels of ozone in the stratosphere. Describe the expected environmental effects of these decreased levels of ozone. Discuss ways in which you can protect yourself from the harmful effects of ozone depletion.

CRITICAL THINKING

1. List three ways in which you could apply **Concept 15-2** (p. 356) and **Concept 15-5A** (p. 370) to making your lifestyle more environmentally sustainable.
2. Identify climate and topographic factors in your local community that **(a)** intensify air pollution and **(b)** help reduce air pollution.
3. Should all tall smokestacks be banned in an effort to promote greater emphasis on preventing air pollution and acid deposition? Explain.
4. Some radio and TV talk show hosts and a popular science fiction novelist have claimed that warnings of global warming and ozone depletion are false or overblown scare tactics that scientists and environmentalists are using to raise funds for their research and environmental organizations. Some have also claimed that natural factors such as occasional large volcanic eruptions also emit CO_2 and other pollutants into the lower atmosphere (**Core Case Study**) and are more responsible for emissions of greenhouse gases and ozone-depleting chemicals than human activities are. What is your response to such claims? CORE CASE STUDY
5. Explain why you agree or disagree with each of the proposals listed in **(a)** Figure 15-16 (p. 360) for shifting emphasis to pollution prevention over the next several decades and **(b)** Figure 15-22 (p. 371) for slowing atmospheric warming.
6. 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 Williamsburg. What was the flaw in his reasoning?
7. What changes might occur in **(a)** the global hydrologic cycle (Figure 3-18, p. 54) and **(b)** the global carbon cycle (Figure 3-19, p. 56) 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 slow global warming?
9. Congratulations! You are in charge of the world. List your three most important actions for dealing with the problems of **(a)** outdoor air pollution, **(b)** indoor air pollution, **(c)** global warming, and **(d)** depletion of ozone in the stratosphere.
10. List two questions that you would like to have answered as a result of reading this chapter.

LEARNING ONLINE

Log on to the Student Companion Site for this book at **www.thomsonedu.com/biology/miller** and choose Chapter 15 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Web links, information on Green Careers, and InfoTrac® College Edition articles.

For access to animations and additional quizzing, register and log on to Thomson NOW! at **www.thomsonedu.com/thomsonnow** using the access code card in the front of your book. You can also explore the **Active Graphing** exercises that your instructor may assign.

16 Solid and Hazardous Waste

CORE CASE STUDY E-Waste—An Exploding Problem

Electronic waste or e-waste consists of discarded television sets, cell phones, computers, e-toys, 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, 250 million personal computers, and many more millions of television sets, iPods, Blackberries, and other electronic products.

Most e-waste ends up in landfills and incinerators. It includes high-quality plastics and valuable metals such as aluminum, copper, nickel, platinum, silver, and gold. The concentration of copper in e-waste, for instance, is much higher than in currently mined copper ores. 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.

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Figure 16-1 *Rapidly growing electronic waste* (*e-waste*). Putting discarded computers and other electronic devices into a landfill or incinerator is a waste of resources and pollutes the air, water, and land with harmful compounds. **Question:** What are three things that could be done to reduce e-waste in the United States or in the country where you live?

According to a 2005 report by the Basel Action Network, about 50–80% of U.S. e-waste is shipped to China, India, Pakistan, Nigeria, and other developing countries where labor is cheap and environmental regulations are weak. Workers there, many of them children, dismantle such products to recover valuable metals like copper and gold and reusable parts and are exposed to the toxic metals. The remaining scrap is dumped in waterways and fields or burned in open fires, exposing many people to toxic dioxins. Transfer of hazardous waste from developed to developing countries is banned by the International Basel Convention, which the United States has refused to ratify.

The European Union (EU) has led the way in dealing with e-waste. In a *cradle-to-grave* approach, it 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. 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 10% of it, but that is changing. In 2000, Massachusetts became the first U.S. state to ban the disposal of computers and TV sets in landfills and incinerators, and five other states have established similar regulations. Some electronics manufacturers including Apple, Intel, Hewlett-Packard, Dell, Sharp, Panasonic, and Sony have free recycling programs. Some will arrange for pickups or pay shipping costs. A growing consumer awareness of the problem has spawned highly profitable *e-cycling* businesses. And, nonprofit groups, such as Free Geek in Portland, Oregon, are motivating many people to donate, recycle, and reuse old electronic devices.

But e-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 that gets toxic materials out of electrical and electronic products by using green design. For example, Sony Electronics has eliminated toxic lead solder used to attach electronic parts together and has also removed potentially hazardous flame retardants from virtually all of its electronic products. The company has replaced old cathode ray tubes (which contain large quantities of toxic lead) used in televisions and computers with liquid crystal displays, which are more energy efficient and contain few hazardous 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 What should we do about 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 eventually contribute to pollution and land degradation.

16-5 How should we deal with hazardous waste?

CONCEPT 16-5 A sustainable approach to hazardous waste is first to produce less of it, then to reuse or recycle it, then to convert it to less hazardous materials, and finally to safely store what is left.

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 businesses to reduce resource use and to reuse and recycle wastes at local, national, and global levels.

Note: Supplements 7, 14, and 17 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 and Dangerous Stuff

In nature, there is essentially no waste because the wastes of one organism become nutrients for others (Figure 3-15, p. 51, and **Concept 3-3**, p. 44). CONCEPT LINKS This recycling of nutrients is one of the four **scientific principles of sustainability** (see back cover). SUSTAINABILITY Humans, on the other hand, produce huge amounts of waste that go unused and pollute the environment. Because of the law of conservation of matter (**Concept 2-3**, p. 31) and the nature of human lifestyles, we will always produce some waste, but the amount can be drastically reduced (**Concept 2-5B**, p. 35, and Figure 2-9, p. 36).

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 is **municipal solid waste (MSW),** often called garbage or trash, which consists of the combined solid waste produced by homes and workplaces in a municipal area. 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

The other type is **industrial solid waste** produced by mines, agriculture, and industries that supply people with goods and services. 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% is municipal solid waste.

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 poor people eke out a living finding items they can sell for reuse or recycling (Figure 16-2, p. 382).

Jorgen Schytte/Peter Arnold, Inc.

Figure 16-2 Children looking for materials to sell in an open dump near Manila in the Philippines.

Figure 16-3 Harmful chemicals found in many homes. The U.S. Congress has exempted disposal of many of these materials from government regulation. **Question:** Which of these chemicals are in your home?

Another major category of waste is **hazardous,** or **toxic, waste,** which threatens human health or the environment because it is toxic, dangerously chemically reactive, corrosive, or flammable. Examples include industrial solvents, hospital medical waste, car batteries (containing toxic lead and acids), household pesticide products, dry-cell batteries (containing toxic mercury and cadmium), and incinerator ash. The two largest classes of hazardous wastes are *organic compounds* (such as various solvents, pesticides, PCBs, and dioxins) and *toxic heavy metals* (such as lead, mercury, chromium, and arsenic). Figure 16-3 lists some the harmful chemicals found in many homes.

According to the United Nations, developed countries produce 80–90% of the world's hazardous wastes. The United States produces more of such wastes than any other country, with the chemical and mining industries and the military being the top three producers. As China continues to industrialize, it may take over the number one spot. In 2007, a U.S. environmental group, the Blackstone Institute, listed the world's 10 most polluted places that threaten the health of more than 10 million people in eight countries, including Russia (3 sites), China, India, Ukraine, Peru, Dominican Republic, and Zambia.

Figure 16-3 lists some of the harmful chemicals found in many homes. There are two reasons to be concerned about the amount of solid and hazardous wastes we produce. *First,* at least three-fourths of these materials represent an unnecessary waste of the earth's resources. *Second,* in producing the products we use and often discard, we create huge amounts of air pollution, greenhouse gases, water pollution (Figure 16-4), and land degradation (**Concept 16-1**).

■ CASE STUDY
Solid Waste in the United States

The United States, with only 4.6% of the world's population, produces about one-third of the world's solid waste. About 98.5% of U.S. solid waste comes from mining, agricultural, and industrial activities.

The remaining 1.5% of U.S. solid waste is MSW. The largest categories of these wastes are paper and cardboard (37%), yard waste (12%), food waste (11%), plastics (11%), and metals (8%). This small percentage of the overall solid waste problem is still huge. Each year, the United States generates enough MSW to fill a bumper-to-bumper convoy of garbage trucks encircling the globe almost eight times!

The United States also leads the world in trash production (by weight) per person, followed by Canada. Each day the average American produces over 2.0 kilograms (4.5 pounds) of MSW, with three-fourths of it dumped in landfills or incinerated. That is about twice the amount of solid waste per person in other industrial countries such as Japan and Germany, and 5–10 times that amount in most developing countries.

Consider some of the solid wastes that consumers discard in the high-waste U.S. economy:

- Enough tires each year to encircle the planet almost three times
- Enough disposable diapers per year to, if linked end to end, 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 25 billion throwaway Styrofoam cups per year used mostly for drinking coffee
- 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 660 pieces per American) each year, about 45% of which are thrown away unopened
- Around 685,000 personal computers and 425,000 cell phones each day (**Core Case Study**)

CORE CASE STUDY

Lineair Fotochief/Peter Arnold, Inc.

Figure 16-4 **Natural capital degradation:** solid wastes polluting a river in Jakarta, Indonesia, a city of more than 11 million people. The man in the boat is looking for items to salvage or sell.

16-2 What Should We Do about 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*—a high-waste approach (Figure 2-8, p. 36) in which we attempt to manage wastes in ways that reduce their environmental harm without seriously trying to reduce the amount of waste produced. This approach begins with the question: "What do we do with solid waste?" It typically involves mixing wastes together and then transferring them from one part of the environment to another, usually by burying them, burning them, or shipping them to another location. This is the most common approach to dealing with e-waste (**Core Case Study**).

CORE CASE STUDY

The second approach is *waste reduction*—a low-waste approach in which much less waste and pollution are produced, and what *is* produced is viewed as potential resources that can be reused, recycled, or composted (Figure 2-9, p. 36, and **Concept 16-2**). It begins with the question: "How can we avoid producing so much solid waste?" With this prevention approach (**Concept 1-4**, 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 16-5, p. 384). Scientists call for much greater emphasis on waste reduction (Figure 16-6, p. 384). But this is not done in the United States (or in most industrialized countries) where 55% of the MSW is buried in landfills, 24% is recycled, 14% is incinerated, and 7% is composted.

Some scientists and economists estimate that of the solid waste we produce, 75–90% can be eliminated by a combination of the strategies shown in Figure 16-6. Let us look more closely at these options in the order of priorities suggested by scientists (Figure 16-6).

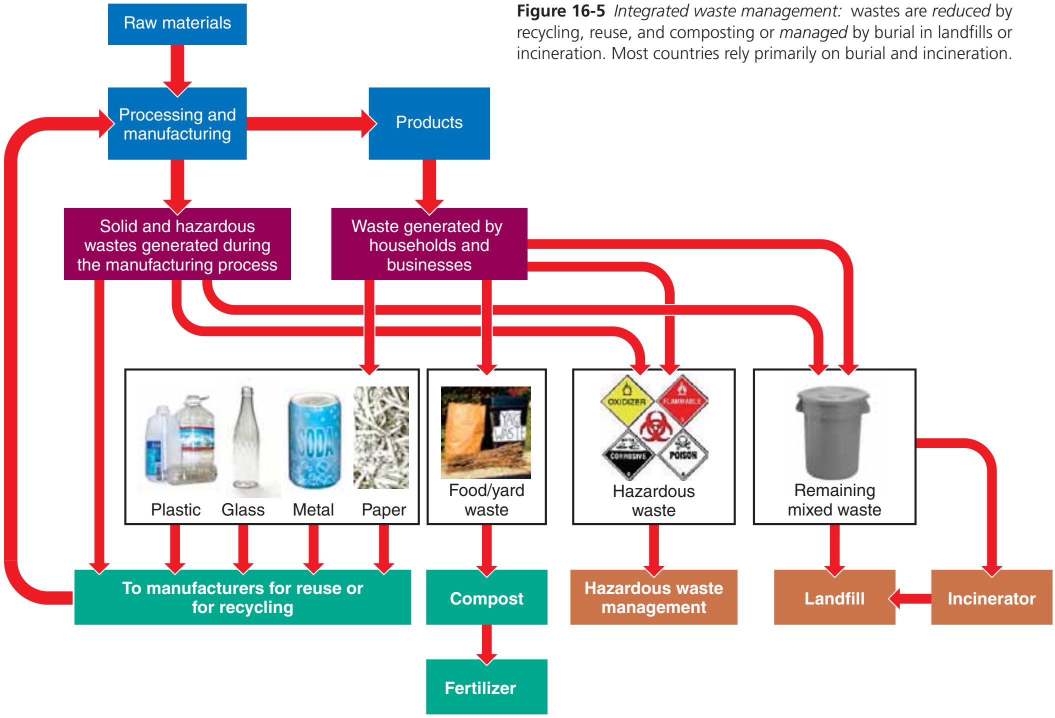


Figure 16-5 *Integrated waste management:* wastes are *reduced* by recycling, reuse, and composting or *managed* by burial in landfills or incineration. Most countries rely primarily on burial and incineration.

First Priority

Primary Pollution and Waste Prevention

- Change industrial process to eliminate use of harmful chemicals
- Use less of a harmful product
- Reduce packaging and materials in products
- Make products that last longer and are recyclable, reusable, or easy to repair

Second Priority

Secondary Pollution and Waste Prevention

- Reuse
- Repair
- Recycle
- Compost
- Buy reusable and recyclable products

Last Priority

Waste Management

- Treat waste to reduce toxicity
- Incinerate waste
- Bury waste in landfills
- Release waste into environment for dispersal or dilution

Figure 16-6 *Integrated waste management:* priorities suggested by the U.S. National Academy of Scientists 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, which are based on consensus science? (Data from U.S. Environmental Protection Agency and U.S. National Academy of Sciences)

We Can Cut Solid Wastes by Refusing, Reducing, Reusing, and Recycling

Waste reduction (**Concept 16-2**) is based on four Rs:

- **Refuse:** refuse to buy items that we really do not need. When deciding whether to purchase a product, consumers should ask themselves whether they really *need* it or merely *want* it,
- **Reduce:** consume less and live a simpler lifestyle.
- **Reuse:** rely more on items that can be used repeatedly instead of on throwaway items.
- **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 three Rs are preferred because they tackle the problem of waste production at the front end—before it occurs. This also saves matter and energy resources, reduces pollution (including greenhouse gas emissions), helps protect biodiversity, and saves money. Recycling is an important way to reduce waste and pollution. But it is an output approach based on dealing with wastes after they have been produced.

Figure 16-7 lists some ways you can use the 4Rs to reduce your output of solid waste.

Here are five ways in which industries and communities can also reduce resource use, waste, and pollution.

First, *redesign manufacturing processes and products to use less material and energy and to produce less waste and pollution*. The weight of a typical car has been reduced by about one-fourth since the 1960s by using lighter steel along with lightweight plastics and composite materials. Plastic milk jugs weigh 40% less than they did in the 1970s, and soft drink cans contain one-third less aluminum. In the *ecoindustrial revolution* (Case Study, p. 275), manufacturing processes are being redesigned to mimic how nature reduces and recycles wastes (Figure 12-15, p. 276, and **Concept 1-6**, p. 19). All these changes involve savings in energy use as well as materials and we know how to achieve such savings and more.

CONCEPT LINK

Second, *develop products that are easy to repair, reuse, remanufacture, compost, or recycle*. For example, a new Xerox photocopier with every part reusable or recyclable for easy remanufacturing should eventually save the company $1 billion in manufacturing costs.

RESEARCH FRONTIER

Green industrial design—inventing less wasteful and less polluting manufacturing processes and products

Third, *eliminate or reduce unnecessary packaging*. Use the following hierarchy for packaging: no packaging, minimal packaging, reusable packaging, and recyclable packaging. Canada has set a goal of using the first three of these priorities to cut excess packaging in half. The 37 European Union countries must recycle 55–80% of all packaging waste. In 2007, Wal-Mart asked its suppliers to cut down on packaging of products sold in its stores and introduced a scorecard to rate its vendors. In 2006, Great Britain's Environment Minister encouraged shoppers to dump what they consider to be excess product packaging at the checkout line to help force sellers and manufacturers to cut back on unnecessary packaging.

Fourth, *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.

Fifth, *establish cradle-to-grave responsibility laws* that require companies to take back various consumer products such as electronic equipment (**Core Case Study**), appliances, and motor vehicles, as Japan and many European countries do.

CORE CASE STUDY

WHAT CAN YOU DO?

Solid Waste

- Follow the four Rs of resource use: Refuse, Reduce, Reuse, and Recycle.
- Ask yourself whether you really need a particular item.
- Rent, borrow, or barter goods and services when you can.
- Buy things that are reusable, recyclable, or compostable, and be sure to reuse, recycle, and compost them.
- 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 in place of conventional paper mail.
- Read newspapers and magazines online.
- Buy products in concentrated form whenever possible.

Figure 16-7 **Individuals matter:** ways to save resources by reducing your output of solid waste and pollution. **Questions:** Which three of these actions do you think are the most important? Which of these things do you do?

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 Save Money

In today's high-throughput societies (Figure 2-8, p. 36), we have increasingly substituted throwaway items for reusable ones. *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 2-5B**, p. 35, and **Concept 16-3**).

CONCEPT LINK

Traditional forms of reuse include salvaging automobile parts from older cars in junkyards and recovering materials from old houses and buildings. About 75% of a car can be reused or recycled as secondhand parts, with the remaining 25% usually ending up in landfills. By 2015, the European Union will require that 95% of any discarded car must be reused or recycled.

Other reuse strategies involve yard sales, flea markets, secondhand stores, traditional and online auctions, and classified newspaper ads. An international website at **www.freecycle.org** links people who want to give away household belongings free to people in their area who want or need them.

Technology allows reuse of many items such as batteries. The latest rechargeable batteries come fully charged, can hold a charge for up to two years when they are not used, can be recharged in as few as 15 minutes, and greatly reduce toxic waste from discarded batteries. They cost more than conventional batteries but the extra cost is recovered quickly.

Reuse is alive and well in most developing countries (Figure 1-7, p. 12), but the poor who scavenge in open dumps for food scraps and items they can reuse or sell are often exposed to toxins and infectious diseases (Figure 16-2). Workers—many of them children—who dismantle e-wastes for parts that can be reused or recycled are often exposed to toxic chemicals (**Core Case Study**). CORE CASE STUDY

■ CASE STUDY

We Can Use Refillable Containers

Two examples of reuse are refillable glass beverage bottles and refillable soft drink bottles made of polyethylene terephthalate (PET) plastic. Typically, such bottles make 15 round-trips before they become too damaged for reuse and then are recycled. Reusing these containers saves energy, reduces pollution and wastes, and stimulates local economies by creating local jobs related to their collection and refilling. Moreover, studies by Coca-Cola and PepsiCo of Canada show that their soft drinks in 0.5-liter (16-ounce) bottles cost one-third less in refillable bottles than in throwaway bottles.

But big companies make more money by producing and shipping throwaway beverage and food containers at centralized facilities. This shift has put many small local bottling companies, breweries, and canneries out of business and hurt local economies.

Parts of Canada and 11 U.S. states have bottle laws that place a small deposit fee on all beverage containers. Retailers must accept the used containers and pass them on for recycling or reuse. Large beverage industries have used their political and financial clout to keep most U.S. states from passing bottle laws, arguing that they lead to a loss of jobs and higher beverage costs for consumers. But experience in Canada and states with bottle bills shows that more jobs are gained than lost, costs to consumers have not risen, resources are saved, and roadside litter decreases.

Some analysts call for a national bottle bill in the United States, while others would ban all beverage containers that cannot be reused, as Denmark, Finland, and Canada's Prince Edward Island have done. Ecuador levies a refundable beverage container deposit fee that amounts to 50% of the cost of the drink. In Finland, 95% of the soft drink, beer, wine, and spirits containers are refillable.

HOW WOULD YOU VOTE? ✓

Do you support banning all beverage containers that cannot be reused as Denmark has done? Cast your vote online at **www.thomsonedu.com/biology/miller**.

Cloth bags can be used instead of paper or plastic bags to carry groceries and other items. Both paper and plastic bags are environmentally harmful, and the question of which is more damaging has no clear-cut answer. To encourage people to bring reusable bags, stores in the Netherlands and Ireland charge for plastic shopping bags. Since 1992, Bangladesh, Bhutan, Rwanda, Australia, and the U.S. city of San Francisco, California, have banned the use of plastic shopping bags.

HOW WOULD YOU VOTE? ✓

Should consumers have to pay for plastic or paper bags at grocery and other stores? Cast your vote online at **www.thomsonedu.com/biology/miller**.

There are many other ways in which you can reuse items you buy (Figure 16-8). For example, an increasing number of coffeehouses and university food services offer discounts to customers who bring their own refillable mugs.

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, glass, aluminum, steel, and some plastics.

Such materials can be reprocessed in two ways. In *primary* or *closed-loop recycling,* these materials are recycled into new products of the same type—turning used aluminum cans into new aluminum cans, for example. 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. Engineer Henry Liu has developed a process that recycles fly ash produced by coal-burning power plants into bricks that save energy, reduce air pollution, and cost at least 20% less than conventional bricks.

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,* are the items separated for recycling actually recycled? Sometimes they are mixed with other wastes and sent to landfills or incinerated. *Second,* will businesses and individuals complete the recycling loop by buying products that are made from recycled materials? For example, about 424,000 trees would be saved if every U.S. household replaced just one roll of virgin fiber toilet paper (500 sheets) with a 100%-recycled one.

Switzerland and Japan recycle about half of their MSW. The United States recycles about 24% of its MSW—up from 6.4% in 1960. This increase was boosted by almost 9,000 curbside pickup recycling programs that serve about half of the U.S. population.

The United States recycles about 41% of its paper and cardboard, which is lower than the rate in many other developed countries. For example, Denmark recycles about 97% of its paper and cardboard. The United States recycles about 60% of its steel, 56% of its aluminum cans, 36% of its tires, 22% of its glass, and 5% of its plastics. Experts say that with education and proper incentives, the United States could recycle 60–70% of these and many other forms of solid waste in keeping with one of the four **scientific principles of sustainability** (see back cover)

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 waste to recover valuable materials for sale to manufacturers as raw materials (Figure 16-5). The remaining paper, plastics, and other combustible wastes are burned to produce steam or electricity to run the recovery plant or to sell to nearby industries or homes. There are about 480 MRFs operating in the United States.

Such plants are expensive to build, operate, and maintain. If not operated properly, they can emit 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 to produce more trash—the reverse of what prominent scientists believe we should be doing (Figure 16-6).

To many experts, it makes more environmental and economic sense for households and businesses to separate their trash into recyclable categories such as glass, paper, metals, certain types of plastics, and compostable materials. This *source separation* approach produces much less air and water pollution and has lower start-up costs than MRFs. It also saves more energy, provides more jobs per unit of material, and yields cleaner and usually more valuable recyclables. In addition, sorting material educates people about the need for recycling.

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. When residents of the U.S. city of Ft. Worth, Texas, were required to pay for the amount of garbage they produced, the proportion of households recycling 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.

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.
- Use reusable sponges and washable cloth napkins, dish towels, and handkerchiefs instead of throwaway paper ones.
- Buy used furniture, computers, cars, and other items instead of buying new.
- Give away or sell items you no longer use.

Figure 16-8 **Individuals matter:** ways to reuse some of the items you buy. **Question:** Which three of these actions do you think are the most important? Why?

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.thomsonedu.com/biology/miller**.

We Can Copy Nature and Recycle Biodegradable Solid Wastes

Composting is a simple process in which we copy nature (**Concept 1-6**, p. 19, and **Concept 3-3**, p. 44) by using decomposing bacteria to recycle some of the yard trimmings, food scraps, and other biodegradable organic wastes we produce. The organic material produced by composting can be added to soil to supply

CONCEPT LINKS

INDIVIDUALS MATTER

Recycling Plastics

Less than about 5% of the huge amount of plastics discarded each year in the United States is recycled. This is beginning to change.

In 1994, Mike Biddle (a former PhD engineer with Dow Chemical) and 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 20-step automated process that separates plastics from nonplastic items in mixed waste streams and then separates plastics from each other by type and grade into 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 are much lower than those resulting from making virgin plastics, and recycling plastics reduces the need to incinerate waste plastics 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 commercial plastics 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 was selected by the magazine *Inc.* as one of "America's Most Innovative Companies."

Those who grew up with Mike Biddle are not surprised that he played a major role in developing an innovative and money-making process that many scientists and engineers doubted could be done. As a kid growing up in Kentucky, he hated waste. He says he drove his parents crazy by following them around turning off unnecessary lights. Maybe you can be an environmental entrepreneur by using your brainpower to develop an environmentally beneficial and financially profitable process.

plant nutrients, slow soil erosion, retain water, and improve crop yields. Homeowners can compost such wastes in a simple backyard composting pile that must be turned over occasionally or in a small composting metal drum that can be rotated to mix the wastes to speed up the decomposition process. For details on composting, see the website for this chapter.

Organic wastes can be collected and composted in centralized community facilities. Some cities in Canada and many European Union countries compost more than 85% of their biodegradable wastes. The United States has about 3,300 municipal composting programs that recycle about 37% of country's yard wastes. This is likely to rise as the number of states (now 20) banning yard wastes from sanitary landfills increases. The resulting compost can be used as organic soil fertilizer, topsoil, or landfill cover. It can also be used to help restore eroded soil on hillsides and along highways, and on strip-mined land, overgrazed areas, and eroded cropland.

To be successful, a large-scale composting program must be located carefully, and odors must be controlled for the benefit of people living near them. Composting programs must also exclude toxic materials that can contaminate the compost and make it unsafe for fertilizing crops and lawns.

TRADE-OFFS

Recycling

Advantages	Disadvantages
Reduces air and water pollution	Can cost more than burying in areas with ample landfill space
Saves energy	May lose money for items such as glass and some plastics
Reduces mineral demand	Reduces profits for landfill and incinerator owners
Reduces greenhouse gas emissions	Source separation is inconvenient for some people
Reduces solid waste production and disposal	
Helps protect biodiversity	
Can save landfill space	
Important part of economy	

Figure 16-9 Advantages and disadvantages of recycling solid waste (**Concept 16-3**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

Recycling Has Advantages and Disadvantages

Figure 16-9 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 recycling does not make sense if it costs more to recycle materials than to send them to a landfill or incinerator. They concede 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, recycling is too expensive to be useful for most plastics, although this may be changing (Individuals Matter, at left). Critics also argue that recycling should pay for itself.

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 an uneven playing field? Proponents also point to studies showing that the net economic, health, and environmental benefits of recycling (Figure 16-9) 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 both the mining and the waste management industries together.

We Can Encourage Reuse and Recycling

Three factors hinder reuse and recycling. *First,* we have a faulty accounting system in which the market price of a product does not include the harmful environmental and health costs associated with the product during its life cycle.

Second, there is an uneven economic playing field, because in most countries, resource-extracting industries receive more government tax breaks and subsidies than recycling and reuse industries.

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. Governments can also pass laws requiring companies to take back and recycle or reuse packaging and electronic waste discarded by consumers (**Core Case Study**), as is done in Japan and European Union countries. By 2020, the European Union must recycle 50% of its MSW and ban recyclable wastes from landfills.

CORE CASE STUDY

HOW WOULD YOU VOTE?

Should governments pass laws requiring manufacturers to take back and reuse or recycle all packaging waste, appliances, electronic equipment (**Core Case Study**), and motor vehicles at the end of their useful lives? Cast your vote online at **www.thomsonedu.com/biology/miller**.

CORE CASE STUDY

Citizens can pressure governments to require labels on all products listing recycled content 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 soothe the conscience of 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 actually more effective ways to reduce 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 eventually contribute to pollution and land degradation.

Burning Solid Waste Has Advantages and Disadvantages

Globally, municipal solid waste is burned in more than 600 large *waste-to-energy incinerators* (98 in the United States), which 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 16-10 (p. 390).

Figure 16-11 (p. 390) lists the advantages and disadvantages of using incinerators to burn solid waste.

In addition to producing energy, mass burn incinerators reduce the volume of solid waste by 90%. However, without expensive air pollution control devices and careful monitoring, incinerators pollute the air with particulates, carbon monoxide, toxic metals such as mercury, and other toxic materials. They also add CO_2 to the atmosphere but produce about 38% less

Figure 16-10 **Solutions:** a *waste-to-energy incinerator* with pollution controls that burns mixed solid waste and uses some of the energy released to produce steam, used for heating or producing electricity. **Questions:** Would you invest in such a project? Why or why not?

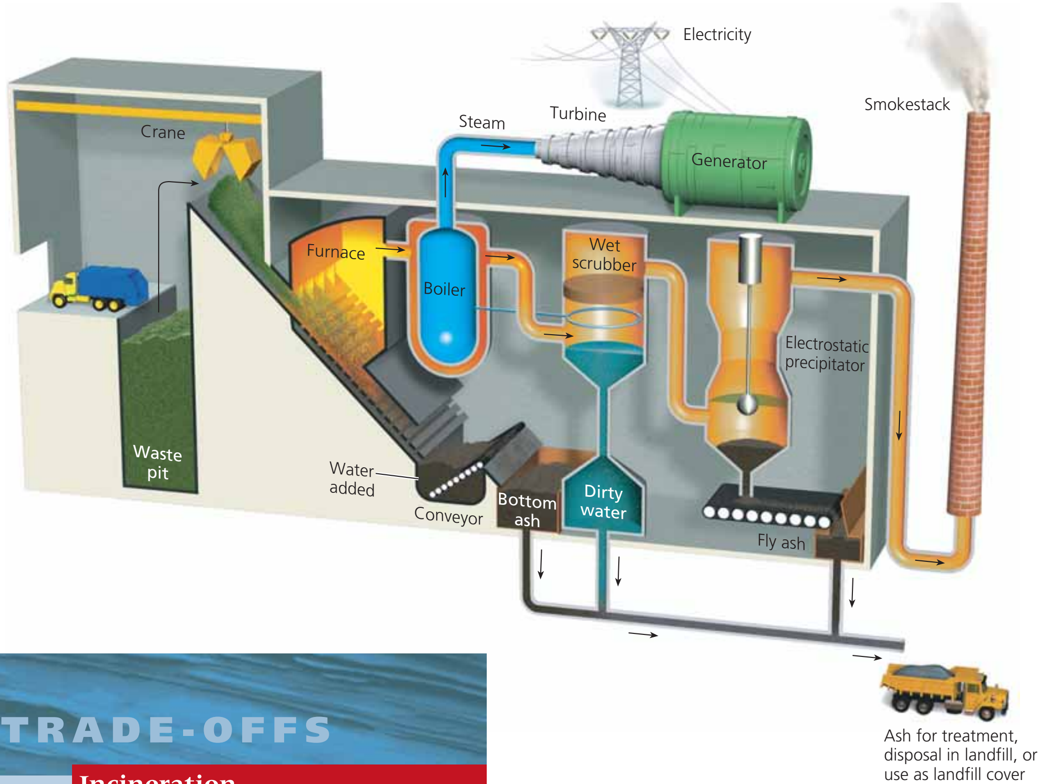


Figure 16-11 Advantages and disadvantages of incinerating solid waste (**Concept 16-4**). These trade-offs also apply to the incineration of hazardous waste. **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

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

CO_2 emissions per unit of energy than coal-burning power plants do. Incinerators also produce large quantities of toxic bottom ash and fly ash (removed by air pollution control devices), which must be disposed of safely, ideally in specially licensed hazardous waste landfills. 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.

HOW WOULD YOU VOTE? ✓

Do the advantages of incinerating solid waste outweigh the disadvantages? Cast your vote online at **www.thomsonedu.com/biology/miller**.

Burying Solid Waste Has Advantages and Disadvantages

About 55% 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 covered with soil. They are rare in developed countries, but are widely used in many developing countries (Figure 16-2)

In newer landfills, called **sanitary landfills** (Figure 16-12), solid wastes are spread out in thin layers, compacted, and covered daily with a fresh layer of clay or plastic foam, which helps keep the material dry and

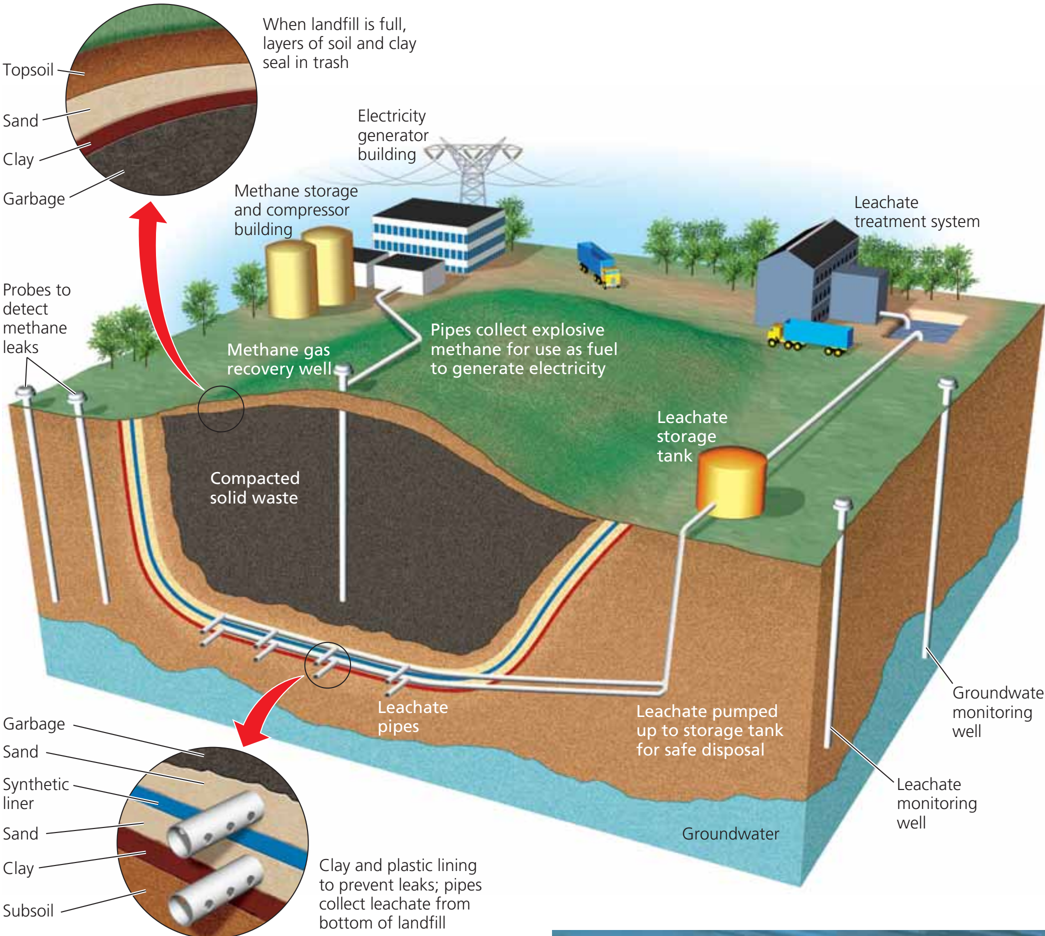


Figure 16-12 **Solutions:** state-of-the-art *sanitary landfill,* which is designed to eliminate or minimize environmental problems that plague older landfills. Even these landfills are expected to leak eventually, passing both the effects of contamination and clean-up costs on to future generations. Since 1997, only modern sanitary landfills are allowed in the United States. As a result, many small, older landfills have been closed and replaced with larger, modern, local and regional landfills. **Question:** How do you think such landfills could develop leaks?

reduces leakage of contaminated water (leachate) from the landfill. This covering also lessens the risk of fire, decreases odor, and reduces accessibility to vermin.

Figure 16-13 lists the advantages and disadvantages of using sanitary landfills to dispose of solid waste. According to the EPA, all landfills eventually leak.

HOW WOULD YOU VOTE?

Do the advantages of burying solid waste in sanitary landfills outweigh the disadvantages? Cast your vote online at **www.thomsonedu.com/biology/miller**.

TRADE-OFFS

Sanitary Landfills

Advantages

No open burning

Little odor

Low groundwater pollution if sited properly

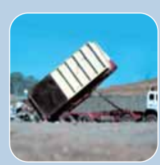
Can be built quickly

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 16-13 Advantages and disadvantages of using sanitary landfills to dispose of solid waste (**Concept 16-4**). **Question:** 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 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 16-14 shows an integrated management approach suggested by the U.S. National Academy of Sciences that establishes three levels of priorities for dealing with hazardous waste: produce less; convert as much if 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 (**Concept 14-4B**, p. 333, and p. 336) 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 12-15, p. 276). (See Science Focus, p. 394, and the Guest Essays on this topic by Lois Gibbs and Peter Montague at ThomsonNOW™.)

CONCEPT LINK

RESEARCH FRONTIER

Green chemistry: finding nontoxic substitutes for hazardous materials used in industries and homes

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 as the wave of the future. One approach is *bioremediation,* in which bacteria and enzymes help destroy toxic or hazardous substances or convert them to harmless compounds. See the Guest Essay by John Pichtel on this topic at at ThomsonNOW.

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 clean up soil and water contaminated with chemicals such as pesticides, organic solvents, and radioactive or toxic metals. For example, trees such as poplars can absorb toxic chemicals and break them down into less harmful compounds, which they store or release slowly into the air. Figure 16-15 lists advantages and disadvantages of phytoremediation.

HOW WOULD YOU VOTE?

Do the advantages of using phytoremediation to detoxify hazardous waste outweigh the disadvantages? Cast your vote online at **www.thomsonedu.com/biology/miller**.

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 mixture of advantages and disadvantages as

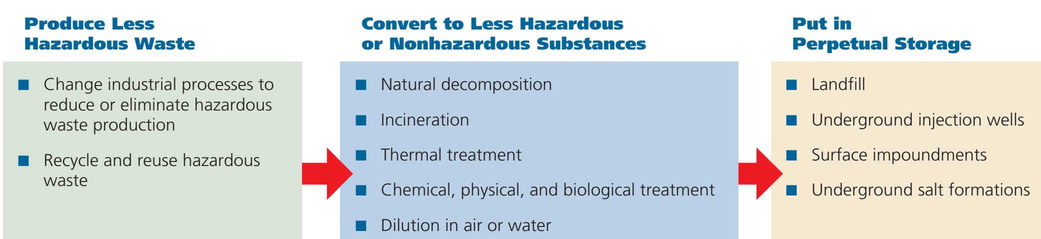


Figure 16-14 *Integrated hazardous waste management:* priorities suggested by the U.S. National Academy of Sciences for dealing with hazardous waste (**Concept 16-5**). To date, these priorities have not been followed in the United States and in most other countries. **Question:** Why do you think most countries do not follow these priorities? (Data from U.S. National Academy of Sciences)

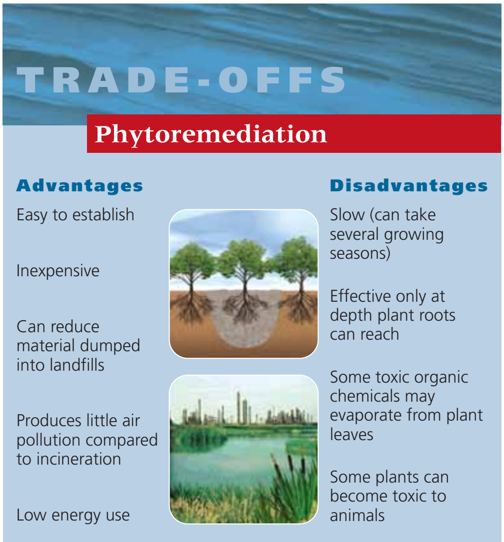


Figure 16-15 Advantages and disadvantages of using *phytoremediation* to remove or detoxify hazardous waste. **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

burning solid wastes (Figure 16-11). But 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

We Can Store Some Forms of Hazardous Waste

Ideally, land disposal and long-term storage of hazardous and toxic wastes should be used only as the third priority after the first two priorities have been exhausted (Figure 16-14 and **Concept 16-5**). But currently, land disposal is the most widely used method in the United States and most countries, largely because the market prices of goods do not include their harmful environmental costs. Such misleading pricing encourages hazardous waste production and discourages its reduction and prevention.

In *deep-well disposal,* liquid hazardous wastes are pumped under pressure through a pipe into dry, porous rock formations far beneath the aquifers tapped for drinking and irrigation water and separated from them by a layer of impervious clay. Theoretically, these liquids soak into the porous rock material and are isolated from overlying groundwater by essentially impermeable layers of clay and rock.

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. 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 are inadequate and should be improved. Figure 16-16 lists the advantages and disadvantages of deep-well disposal of liquid hazardous wastes.

HOW WOULD YOU VOTE?

Do the advantages of deep-well disposal of hazardous waste outweigh the disadvantages? Cast your vote online at **www.thomsonedu.com/biology/miller**.

Surface impoundments are ponds, pits, or lagoons into which liners are placed and liquid hazardous wastes are stored (Figure 11-25, p. 249). As water evaporates, the waste settles and becomes more concentrated. But inadequate seals can allow such wastes to percolate into the groundwater, volatile harmful chemicals can evaporate into the air, and powerful storms can cause these impoundments to overflow. Figure 16-17 (p. 395) lists the advantages and disadvantages of this method.

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, eventually all liners are likely to leak and can contaminate groundwater.

Figure 16-16 Advantages and disadvantages of injecting liquid hazardous wastes into deep underground wells. **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

Mercury

Mercury is a potent neurotoxin that interferes with the nervous system and brain function. 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 comes from human activities—mostly coal burning and chemical plants. Other lesser sources are incineration, gold and silver mining, smelting of metal ores, and the incineration or crushing of products such as mercury-containing batteries and electronic switches and relays.

Mercury is persistent and, because it is a chemical element, cannot be degraded. Therefore this global pollutant accumulates in soil, water, and the bodies of people and other animals that feed high on food chains, such as arctic polar bears, toothed whales, and seals. In 2007, scientists from the EPA and Oregon State University surveyed 2,707 fish randomly collected from 626 rivers in 12 U.S. states. They found mercury in every fish and every river but generally below the levels considered unsafe for people to eat occasionally.

In the atmosphere, some elemental mercury is converted to more toxic inorganic and organic mercury compounds that can be deposited in aquatic environments. In some aquatic systems—especially those made acidic from acid deposition (Figure 15-4, p. 351)—bacteria can convert inorganic mercury compounds to highly toxic methylmercury, which can be biologically magnified in food chains and webs (Figure 16-A). As a result, high levels of methylmercury are often found in the tissues of predatory fish such as large albacore (white) tuna, sharks, swordfish, king mackerel, tilefish, walleye, and marlin, which feed at high trophic levels in food chains and webs.

Humans are exposed to mercury in two ways. *First,* they may inhale vaporized elemental mercury (Hg) or particulates of inorganic mercury salts, such as HgS and $HgCl_2$. *Second,* they may eat fish contaminated with highly toxic methylmercury (CH_3Hg^+).

The greatest risk from exposure to low levels of methylmercury is brain damage in fetuses and young children. Scientists estimate that mercury exposure for a fetus in the womb can cause neurological problems, which can eventually lead to a lowered IQ and poor school performance. Roughly 7–15% of all children born each year in the United States are affected. In addition to harming infants, methylmercury may harm the heart, kidneys, and immune systems of adults.

Since 2004, the U.S. Food and Drug Administration (FDA) and the EPA have ad-

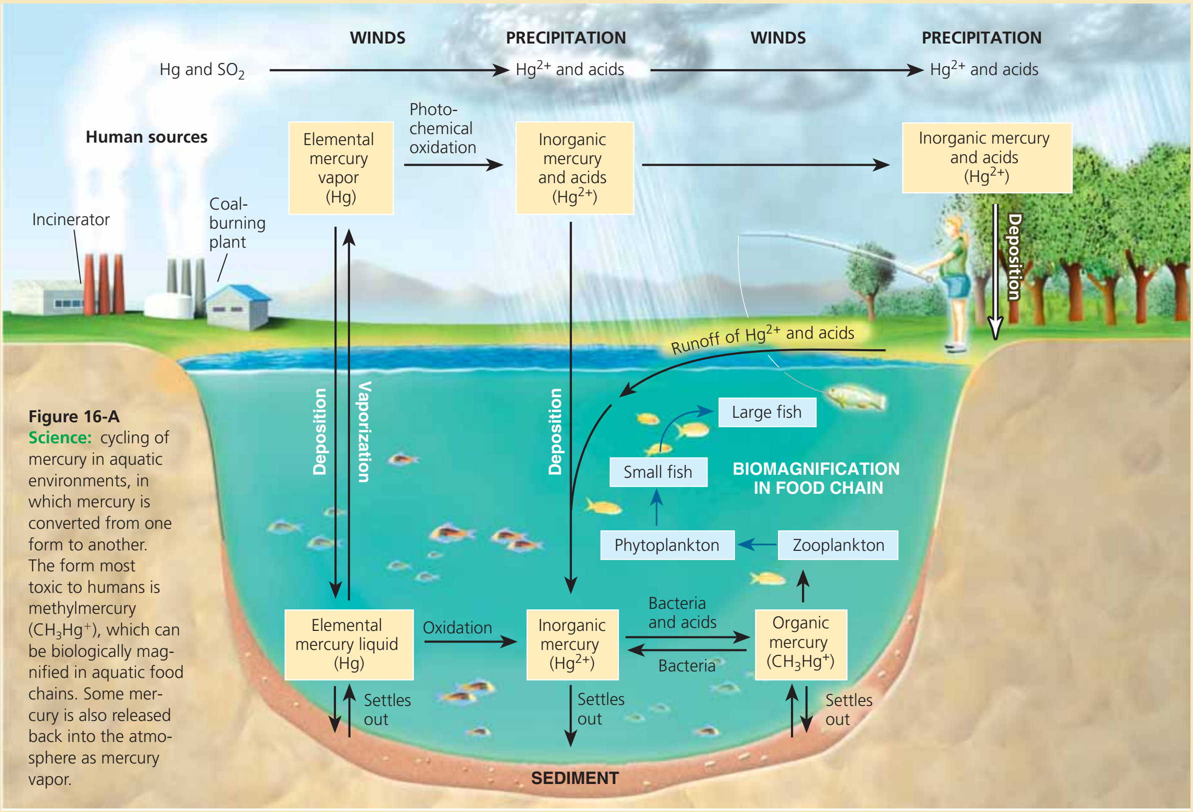


Figure 16-A **Science:** cycling of mercury in aquatic environments, in which mercury is converted from one form to another. The form most toxic to humans is methylmercury (CH_3Hg^+), which can be biologically magnified in aquatic food chains. Some mercury is also released back into the atmosphere as mercury vapor.

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 light bulbs, and all other products unless they are recycled

Control

Sharply reduce mercury emissions from coal-burning plants and incinerators

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, and dry-cell batteries

Figure 16-B Ways to prevent or control inputs of mercury into the environment from human activities—mostly through coal-burning plants and incinerators. **Question:** Which four of these solutions do you think are the most important? Why?

vised 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 and other pollutants. Figure 16-B lists ways to prevent or control human exposure to mercury.

In 2003, the U.N. Environment Programme recommended phasing out coal burning and waste incineration throughout the world as rapidly as possible. Other goals are to reduce or eliminate mercury in batteries, TVs, and paints and in factories that produce chlorine by no later than 2020. Substitute materials and processes are available for all of these uses. In 2007, Wal-Mart announced that its suppliers agreed to dramatically reduce the already small amount of mercury in energy-saving compact fluorescent light bulbs.

Critical Thinking

Should we phase out all coal burning and waste incineration as rapidly as possible as a way to sharply reduce mercury pollution, CO_2 emissions, and acid deposition? Explain. How might doing this change your lifestyle?

HOW WOULD YOU VOTE?

Do the advantages of storing hazardous wastes in surface impoundments outweigh the disadvantages? Cast your vote online at **www.thomsonedu.com/biology/miller**.

There are some highly toxic materials such as mercury (Science Focus, left) that we cannot destroy, detoxify, or safely bury. The best way to deal with these materials is to prevent or reduce their use and put what is produced in metal drums or other containers and place them aboveground in specially 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 are

TRADE-OFFS

Surface Impoundments

Advantages

Low construction costs

Low operating costs

Can be built quickly

Wastes can often be retrieved if necessary

Can store wastes indefinitely with secure double liners

Disadvantages

Groundwater contamination from leaking liners (or no lining)

Air pollution from volatile organic compounds

Overflow from flooding

Disruption and leakage from earthquakes

Output approach that encourages waste production

Figure 16-17 Advantages and disadvantages of storing liquid hazardous wastes in surface impoundments. **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

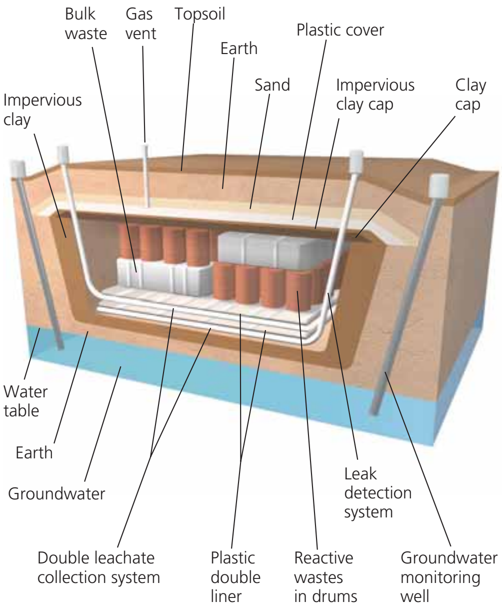


Figure 16-18 **Solutions:** secure hazardous waste landfill.

above aquifers used for drinking water. Storage structures are built to withstand storms and to prevent the release of toxic gases. Leaks are monitored and any leakage is 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 16-18). This is the least used method because of the expense involved. In the United States, there are only 23 commercial hazardous waste landfills, although the EPA licenses some companies to store their hazardous waste in approved landfill sites.

Some developed countries are careless with their hazardous wastes. In the United Kingdom, most such wastes are mixed with household garbage and stored in hundreds of conventional landfills throughout the country. Most developing countries do little to regulate and control what happens to the hazardous wastes they produce.

Figure 16-19 lists some ways in which you can reduce your output of hazardous waste—the first step in dealing with hazardous waste.

■ 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 firms 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 95% of the hazardous waste, including the growing mounds of e-waste (**Core Case Study**) produced in the United States, not regulated? Do you favor regulating such wastes? What are 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* (NPL) and scheduled for total cleanup using the most cost-effective method. In 2006, there were about 1,240 sites on the NPL. The Waste Management Research Institute estimates that there are at least 10,000 sites that should be on the priority list and that would cost about $1.7 trillion to clean up, not including legal fees. This shows 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, has virtually made illegal dump sites relics of the past. It has forced waste producers, fearful of future liability claims, to reduce their production of such waste and to recycle or reuse much more of it. However, facing pressure from polluters, the U.S. Congress refused to renew the tax on oil and chemical companies that 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 tax revenues from chemical, oil, mining, and smelting companies to reestablish a fund for cleaning up existing and new Superfund sites? Register your vote online at **www.thomsonedu.com/biology/miller**.

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. 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 12-15, p. 276), and neighborhoods. By 2006, 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**

Dealing with Lead Poisoning—The Legal Approach

Because it is a chemical element, lead (Pb) does not break down in the environment. This potent neurotoxin can harm the nervous system, especially in young children. Each year in the United States, 12,000–16,000 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 low blood levels of lead, are especially vulnerable to nervous system impairment, lowered IQ, 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.*

Good news. Between 1976 and 2000, the percentage of U.S. children ages 1–5 with blood lead levels above the safety standard dropped from 85% to 2.2%, meaning that at least 9 million childhood lead poisonings were prevented. The primary reason for this drop was that government regulations required the elimination of leaded gasoline by 1986 and lead-based paints by 1978. This is an excellent example of the power of pollution prevention implemented through regulations. In 2006, however, the EPA proposed relaxing the air pollution standards for lead, an idea strongly opposed by health and environmental scientists.

The U.S. Centers for Disease Control and Prevention (CDC) estimates that at least 400,000 U.S. children still have unsafe blood levels of lead caused by exposure from a number of sources. Major sources are peeling lead-based paint found in millions of houses built before 1960 and water pipes and faucets containing lead.

Health scientists have proposed a number of ways to help protect children from lead poisoning, as listed in Figure 16-20. Although the threat from lead has

WHAT CAN YOU DO?

Hazardous Waste

- Use pesticides and other hazardous chemicals in the smallest amounts possible.
- Use less harmful 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 household utensils, 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 16-19 **Individuals matter:** ways to reduce your output of hazardous waste (**Concept 16-5**). **Question:** What are two ways in which your habits might change if you apply these three pieces of advice?

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 16-20 Ways to help protect children from lead poisoning. **Question:** Which two of these solutions do you think are the most important? Why?

been reduced in the United States, it remains a danger in many developing countries, about 100 of which still use leaded gasoline. The WHO estimates that 130–200 million children around the world are at risk from lead poisoning, which has caused permanent brain damage in 15–18 million children—mostly due to use of leaded gasoline. *Good news.* China recently phased out leaded gasoline in less than three years.

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 businesses to reduce resource use and to reuse and recycle wastes at local, national, and global levels.

Grassroots Action Has Led to Better Solid and Hazardous Waste Management

In the United States, individuals have organized 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 these facilities are much higher.

Manufacturers and waste industry officials point out that something must be done with the toxic and hazardous wastes produced to provide people with 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 16-14). For such materials, they believe that the goal should be "not in anyone's back yard" (NIABY) or "not on planet Earth" (NOPE), which calls for emphasizing pollution prevention and using the precautionary principle (**Concept 14-4B**, p. 332, and p. 336).

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 topic by Robert Bullard at ThomsonNOW.)

Studies have shown that a disproportionate share of polluting factories, hazardous waste dumps, incinerators, and landfills in the United States are located in communities populated mostly by African Americans, Asian Americans, Latinos, and Native Americans, most of whom are low-income workers. Studies have also shown that, in general, toxic waste sites in white communities have been cleaned up faster and more completely than have such sites in African American and Latino communities.

Such discrimination all over the world has led to a growing grassroots movement known as the *environmental justice movement.* Members of this group have pressured governments, businesses, and environmental groups to become aware of environmental injustice and to act on it. They have made progress toward their goals, but there is a long way to go.

THINKING ABOUT
Environmental Injustice

Have you or anyone in your class ever been a victim of environmental injustice? If so, describe what happened. What would you do to help prevent environmental injustice?

Countries Have Developed International Treaties to Reduce Hazardous Waste

Environmental justice also applies at the international level. For decades, some developed countries shipped hazardous wastes to developing countries. In 1989, the U.N. Environment Programme 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 2007, this agreement had been ratified by 152 countries, but not by the United States.

In 2000, delegates from 122 countries completed a global treaty to control 12 *persistent organic pollutants* (POPs). These widely used toxic chemicals are persistent, insoluble in water, and soluble in fat. This means that they can accumulate in the fatty tissues of humans and other organisms feeding at high trophic levels to concentrations hundreds of thousands of times higher than in the general environment (Figure 9-14, p. 188). Because they are persistent, POPs can also be transported long distances by wind and water.

The list of 12 chemicals, called the *dirty dozen,* includes DDT and 8 other chlorine-containing persistent pesticides, PCBs, dioxins, and furans. The treaty seeks to ban or phase out use of these chemicals and to detoxify or isolate stockpiles of them. It allows 25 countries to continue using DDT to combat malaria until safer alternatives are available. The United States has not ratified this treaty.

Environmental scientists consider the POPs treaty to be an important milestone in international environmental law and pollution prevention because it uses the *precautionary principle* (p. 336) to manage and reduce the risks from toxic chemicals (**Concept 14-4B**, p. 333). This list is expected to grow. CONCEPT LINK

In 2000, the Swedish Parliament enacted a law that by 2020 will ban all chemicals that are persistent and can accumulate in living tissue. This law also requires industry to perform risk assessments on the chemicals they use and to show that these chemicals are safe to use, as opposed to requiring the government to show that they are dangerous. In other words, chemicals are assumed to be guilty until proven innocent—the reverse of the current policy in the United States and most countries. There is strong opposition to this approach in the United States, especially from most industries producing potentially dangerous chemicals. In 2006, the European Union was considering legislation that puts the burden of proof on manufacturers to show that about 30,000 industrial chemicals and substances are safe.

We Can Make the Transition to Low-Waste Societies

According to physicist Albert Einstein, "A clever person solves a problem, a wise person avoids it." According to many environmental scientists, making the transition to a low-waste society, means dramatically increasing our emphasis on preventing pollution and reducing waste and thus avoiding these problems in the first place. To do this, many environmental scientists urge us to understand and live by five key principles:

- Everything is connected.
- There is no "away," as in "to throw away," for the wastes we produce.
- Dilution is not always the solution to pollution.
- We should mimic nature by reusing, recycling, or composting at least 75% of the solid wastes we produce.
- The best and cheapest ways to deal with solid and hazardous wastes are waste reduction and pollution prevention.

The governments of Norway, Austria, and the Netherlands have committed to reducing their resource waste by 75%. Other countries are following their lead. In a pilot study, residents of the U.S. city of East Hampton, New York, cut their waste production by 85%.

ThomsonNOW™ 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 ThomsonNOW.

REVISITING E-Waste and Sustainability

CORE CASE STUDY SUSTAINABILITY

The growing problem of e-waste (**Core Case Study**) and other stories from this chapter illustrate the problems of maintaining a high-throughput, high-waste society (Figure 2-8, p. 36). The challenge is to make the transition from a high-waste, throwaway mode to a low-waste, reducing-reusing-recycling economy (Figure 2-9, p. 36) over the next two decades. This requires applying the four **scientific principles of sustainability** (see back cover). Shifting from reliance on fossil fuels and nuclear power (which produces long-lived, hazardous, radioactive wastes) to greater use of renewable solar energy in the form wind, flowing water, and sunlight (Figure 13-43, p. 319) will reduce our outputs of solid and hazardous waste, as will reusing and recycling materials by mimicking nature's chemical cycling processes. Integrated waste management, with emphasis on waste reduction and pollution prevention, is another useful way to mimic nature's biodiversity. Reducing the human population and the resources used 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 QUESTIONS

1. Explain why electronic waste, or e-waste, is the fastest growing solid waste problem in the United States and the world.
2. Explain why there is essentially no waste in natural ecosystems. Describe the components of municipal solid waste, industrial solid waste, and hazardous waste. Discuss the role that the United States plays in the global production of solid waste.
3. Describe the steps involved in the strategy of integrated waste management.
4. Discuss the additional priorities that have been suggested by scientists for dealing with solid waste. Comment on the implementation of these priorities.
5. Describe ways that homeowners, communities, and industrial operations can use the 4Rs to reduce the amount of solid waste they generate.
6. Discuss ways in which you could reuse some of the items that you buy. Discuss ways in which you could recycle some of the items that you buy.
7. Provide an argument for burning municipal solid waste in a waste-to-energy incinerator. What objections could be raised against it? Provide an argument for burying municipal solid waste in a sanitary landfill. What objections could be raised against it?
8. Describe the priorities that are involved in integrated hazardous waste management.
9. Describe the pollution problems caused by one of the neurotoxins mercury or lead, and explain how we can deal with such problems.
10. Describe how we can make the transition to a more sustainable low-waste society.

CRITICAL THINKING

1. List three ways in which you could apply **Concept 16-6** (p. 398) to making your lifestyle more environmentally sustainable.
2. Do you think that manufacturers of computers, television sets, and other forms of e-waste (**Core Case Study**) 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 a take-back program? If so, how much extra per purchase (as a percent) would you be willing to pay?
3. Find three items you regularly use that are designed to be used once and thrown away. Are there other alternative reusable products 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 buying the alternatives.
4. Would you oppose having a hazardous waste landfill, waste treatment plant, deep-injection well, or incinerator in your community? Explain. If you oppose these disposal facilities, how do you believe the hazardous waste generated in your community and your state or region should be managed?
5. 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? List three ways to improve your school's waste reduction and management system.
6. 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 encourage reuse, recycling, and treatment, and to protect air, water, and soil from contamination.
   - **c.** Provide low-interest loans, tax breaks, and other financial incentives to encourage industries producing hazardous waste to reduce, reuse, recycle, treat, and decompose such waste.
7. 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.
8. List two questions you would like to have answered as a result of reading this chapter.

LEARNING ONLINE

Log on to the Student Companion Site for this book at www.thomsonedu.com/biology/miller and choose Chapter 16 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Web links, information on Green Careers, and InfoTrac® College Edition articles.

For access to animations and additional quizzing, register and log on to Thomson NOW! at **www.thomsonedu.com/thomsonnow** using the access code card in the front of your book. You can also explore the **Active Graphing** exercises that your instructor may assign.

Environmental Economics, Politics, and Worldviews

17

Rescuing a River

CORE CASE STUDY

In the 1960s, Marion Stoddart (Figure 17-1) moved to Groton, Massachusetts, on the Nashua River, then considered one of the nation's filthiest rivers. For decades, industries and towns along the river had used it as a dump. Dead fish bobbed on its waves, and at times the water was red, green, or blue from pigments discharged by industries.

Instead of thinking that nothing could be done, Stoddart committed herself to restoring the Nashua and establishing public parklands along its banks. She did not start by filing lawsuits or organizing demonstrations. Instead, she created a careful clean-up plan and approached state officials with her ideas. They laughed, but she was not discouraged and began practicing the most time-honored skill of politics: one-on-one persuasion. She identified power brokers in the riverside communities and began to educate them, win them over, and gain their cooperation in cleaning up the river.

She also got the state to ban open dumping in the river. When federal matching funds promised for building a treatment plant failed to materialize, Stoddart gathered 13,000 signatures on a petition that was sent to President Richard Nixon. The funds arrived in a hurry.

Stoddart's next success was getting a federal grant to beautify the river. She hired unemployed young people to clear away mounds of debris. When the cleanup was completed, she persuaded communities along the river to create a riverside park and woodlands along both banks.

Now, more than four decades later, the Nashua River is still clean. Several new water treatment plants have been built, and a citizens' group founded by Stoddart keeps watch on water quality. The river supports many kinds of fish and other wildlife, and its waters are used for canoeing and recreation.

This success story is testimony to what a committed individual can do to bring about change from the bottom up by getting people to work together. For her efforts, the U.N. Environment Programme named Stoddart an outstanding worldwide worker for the environment.

Politics is concerned with who has power over the distribution of resources and who gets what, when, and how. Many people think of politics in national terms, but what happens in their own communities directly affects and often motivates people, as illustrated by the story of Marion Stoddart's work on the Nashua.

In this chapter you will learn about the importance of environmental economics, politics, and worldviews for helping us make the transition to more sustainable societies.

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Key Questions and Concepts

17-1 How are economic systems related to the biosphere?

CONCEPT 17-1 Ecological economists and most sustainability experts regard human economic systems as subsystems of the biosphere and subject to its limiting factors.

17-2 How can we use economic tools to deal with environmental problems?

CONCEPT 17-2A Using resources sustainably will require including the harmful environmental and health costs of resource use in the market prices of goods and services (*full-cost pricing*).

CONCEPT 17-2B Governments can help improve and sustain environmental quality by subsidizing environmentally beneficial activities and by taxing pollution and wastes instead of wages and profits.

17-3 How can reducing poverty help us deal with environmental problems?

CONCEPT 17-3 Reducing poverty can help us to reduce population growth, resource use, and environmental degradation.

17-4 How can we implement more sustainable and just environmental policies?

CONCEPT 17-4 Individuals can work with others, starting at the local level, to influence how environmental policies are made and whether or not they succeed.

17-5 How do the major environmental worldviews differ?

CONCEPT 17-5 Major environmental worldviews differ over what is more important—human needs and wants, or the overall health of ecosystems and the biosphere; different worldviews include varying mixes of both priorities.

17-6 How can we live more sustainably?

CONCEPT 17-6 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 4, 5, 14 and 16 can be used with this chapter.

The main ingredients of an environmental ethic are caring about the planet and all of its inhabitants, allowing unselfishness to control the immediate self-interest that harms others, and living each day so as to leave the lightest possible footprints on the planet.

ROBERT CAHN

17-1 How Are Economic Systems Related to the Biosphere?

CONCEPT 17-1 Ecological economists and most sustainability experts regard human economic systems as subsystems of the biosphere and subject to its limiting factors.

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 (demanders) and sellers (suppliers) interact in *markets* to make economic decisions about which goods and services are produced, distributed, and consumed. In an ideal free market system, the *prices* of goods and services are determined solely by their *supply* and *demand.* If the demand is greater than the supply, the price rises, and when supply exceeds demand, the price falls.

Three types of resources, or capital, are used to produce goods and services (Figure 17-2). **Natural resources,** or **natural capital,** include goods and services produced by the earth's natural processes, which support all economies and all life (**Concept 1-1A**, p. 6, and Figure 1-3, p. 8). CONCEPT LINK See the Guest Essay on natural capital by Paul Hawken at ThomsonNOW™.

Human resources, or **human capital,** include people's physical and mental talents that provide labor, innovation, organization, and culture. **Manufactured resources,** or **manufactured capital,** are things such as machinery, equipment, and factories, made from natural resources with the help of human resources.

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.

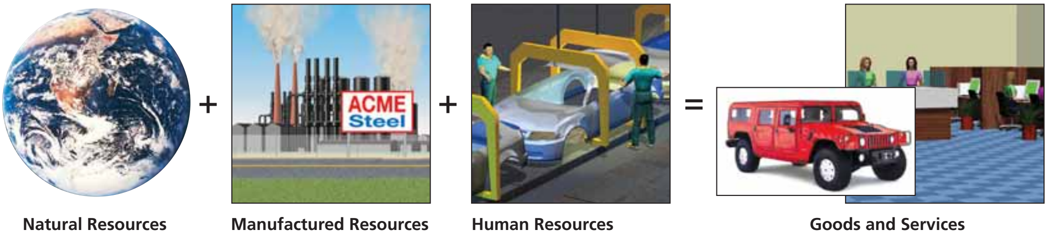
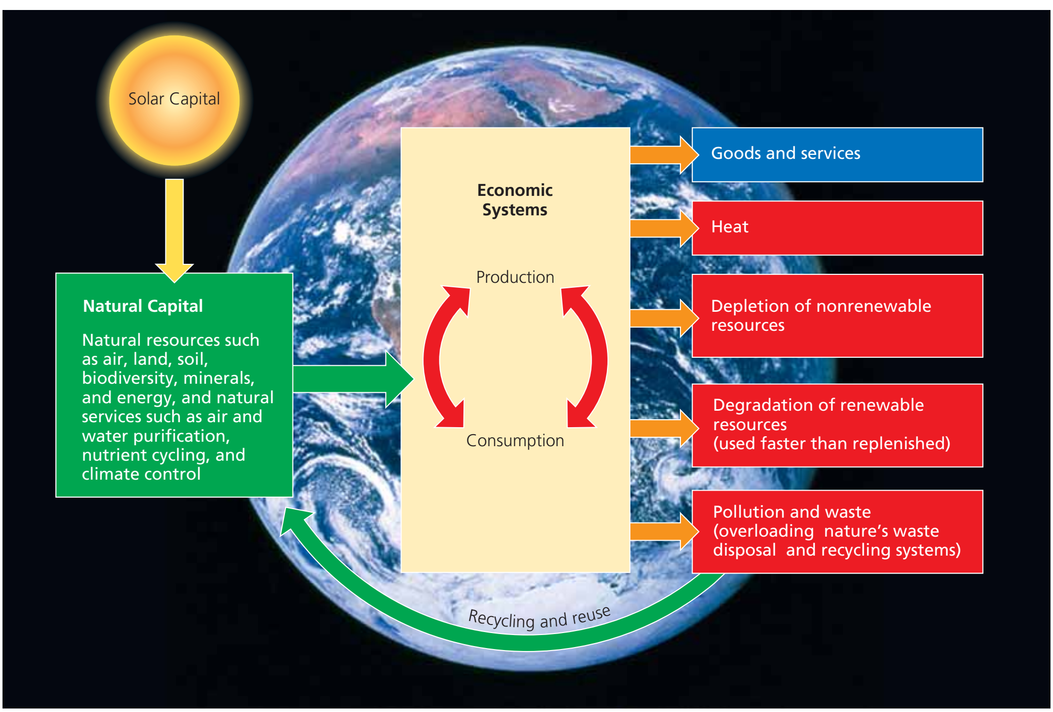


Figure 17-2 Three types of resources are used to produce goods and services. **Question:** In which of these categories can resources be recycled?

Economists Disagree over the Importance of Natural Resources

Neoclassical economists such as Robert Samuelson and the late Milton Friedman view natural resources as important but not indispensable because of our ability to find resource substitutes. They also contend that continuing economic growth is necessary, desirable, and essentially unlimited.

Ecological economists such as Herman Daly and Robert Costanza view economic systems as subsystems of the environment that depend heavily on irreplaceable natural resources (Figure 17-3) (**Concept 17-1**). They point out that there are no substitutes for many natural resources, such as air, water, fertile soil, and biodiversity. They also believe that conventional economic growth eventually will become unsustainable because it can deplete or degrade natural capital. They call for us to learn how to live off of the earth's natural income without depleting or degrading the natural capital that supplies it (**Concept 1-1B**, p. 6). To ecological economists, societies can grow economically



ThomsonNOW™ **Active Figure 17-3** *Ecological economists* see all economies as human subsystems that depend on natural resources and services provided by the sun and earth (**Concept 17-1**). The earth serves both as a source for raw materials and as a sink for the resulting wastes and pollution. *See an animation based on this figure at* ThomsonNOW. **Question:** Do you agree or disagree with this model? Explain.

and remain environmentally sustainable only if growth is based on environmentally beneficial economic development (**Concept 1-2**, p. 10).

CONCEPT LINK

Taking the middle ground in this debate are *environmental economists.* They generally agree with ecological economists that some forms of economic growth are not sustainable and should be discouraged.

Ecological economists and many environmental economists call for making a shift from our current economy based on unlimited economic growth to a more *environmentally sustainable economy,* or *eco-economy,* over the next several decades. See the Guest Essay on this topic by Herman Daly at ThomsonNOW. Figure 17-4 shows some of the goods and services these economists would encourage in an eco-economy.

ThomsonNOW™ Learn more about how ecological economists view market-based systems and contrast their views with those of conventional economists at ThomsonNOW.

THINKING ABOUT
Economic Growth

Do you think that the economy of the country where you live is on a sustainable path or on an unsustainable path? Explain.

Ecological and environmental economists have suggested several strategies to help make the transition to an eco-economy over the next several decades:

- Use and widely publicize indicators that monitor economic and environmental health.
- Include the estimated harmful environmental and health costs of resource use in the market prices of goods and services (*full-cost pricing*).
- Use *eco-labeling* to identify products produced by environmentally sound methods and thus help consumers make informed choices.

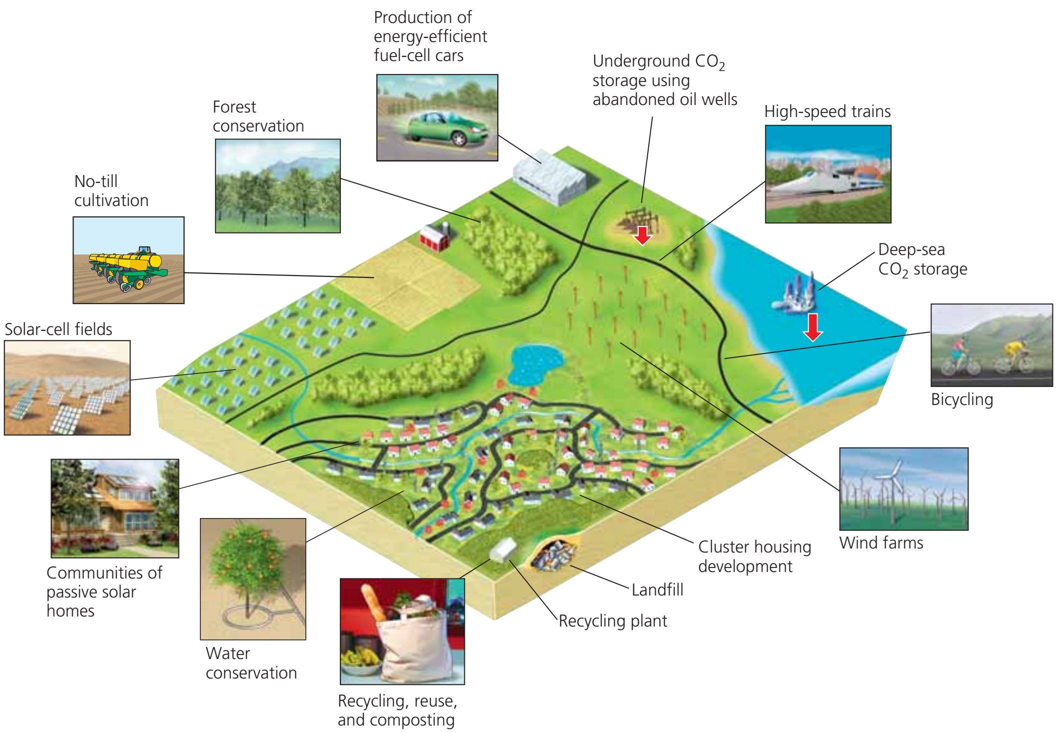


Figure 17-4 **Solutions:** some components of more environmentally sustainable economic development favored by ecological and environmental economists. The goal is to have economic systems put more emphasis on conserving and sustaining the air, water, soil, biodiversity, and other natural resources that sustain all life and all economies. Such a shift toward more efficient resource use, cleaner energy, cleaner production, and natural capital preservation can save money, create jobs, and be profitable. **Question:** What are three new types of jobs that could be generated by such an economy?

- Phase out environmentally harmful government subsidies and tax breaks while increasing subsidies and tax breaks for environmentally beneficial goods and services (*subsidy shifting*).
- Decrease taxes on income and wealth while increasing taxes on pollution, resource waste, and environmentally harmful goods and services (*tax shifting*).
- Pass laws and develop innovation-friendly regulations to prevent or reduce pollution and resource depletion (**Concept 14-4B**, p. 333).
- Use tradable permits to encourage the marketplace to reduce pollution and resource use and waste.
- Sell services instead of things to reduce resource use, waste, and pollution, while increasing profits.

Let's look at some of these proposed solutions in more detail.

17-2 How Can We Use Economic Tools to Deal with Environmental Problems?

CONCEPT 17-2A Using resources sustainably will require including the harmful environmental and health costs of resource use in the market prices of goods and services (*full-cost pricing*).

CONCEPT 17-2B Governments can help improve and sustain environmental quality by subsidizing environmentally beneficial activities and by taxing pollution and wastes instead of wages and profits.

Most Things Cost a Lot More Than You Might Think

The *market price*, or *direct price*, that you pay for something does not include most of the environmental, health, and other harmful costs associated with its production and use. For example, if you buy a car, the direct price you pay includes the costs of raw materials, labor, and shipping, as well as a markup to allow the car company and its dealers to make a profit. Once you buy the car, you must pay additional direct costs for gasoline, maintenance, repair, and insurance.

Making, distributing, and using any economic good or service also involve harmful *external costs* that are not included in their market prices. These harmful environmental and social costs affect people other than the buyer and seller. 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, and pollute the air and water. These 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 land used for highways and parking. The pollution of the Nashua River described in the **Core Case Study** that opens this chapter is a good example of such hidden costs.

CORE CASE STUDY

Excluding the harmful environmental costs from the market prices of goods and services has three major impacts. It hides these costs from consumers, hinders the development of more environmentally beneficial or green goods and services, and promotes pollution, resource waste, and environmental degradation. Many economists and environmental experts cite this failure in today's market-based economic systems as one of the major causes of the environmental problems we face (Figure 1-10, p. 16).

THINKING ABOUT
Hidden Costs

Were you aware of the harmful external costs involved in producing, buying, and owning a car (or any other item)? Do you believe that such usually hidden costs should be included in the prices of all goods and services? Explain.

Using Environmental Economic Indicators Can Reduce Our Environmental Impact

Gross domestic product (GDP) and *per capita GDP* indicators (p. 10) provide a standardized and useful method for measuring and comparing the economic outputs of nations. The GDP is deliberately designed to measure the annual economic value of all goods and services produced within a country without distinguishing between goods and services that are environmentally or socially beneficial and those that are harmful.

Currently, we have misleading national and corporate accounting systems that give natural capital little or no value. As a result, its huge economic value is not included in the prices of goods and services. For example, fishing companies pay for the cost of catching fish, but not for the depletion of fish stocks. Timber companies pay for the timber they clear-cut, often with government subsidies and tax breaks, but they do not pay for the resulting loss in forest biodiversity and other ecological services forests provide (Figure 8-3, p. 153).

Critics contend that it is difficult to determine precise values for natural capital. However, ecological economists and scientists have made a number of such estimates (Science Focus, p. 153). Proponents counter that any realistic estimates of various types of natural capital are better than treating it as having little or no value.

Environmental and ecological economists and environmental scientists call for the development and widespread use of new indicators to help monitor environmental quality and human well-being. One such indicator is the *genuine progress indicator* (GPI). Redefining Progress, a nonprofit organization that develops economics and policy tools to help promote environmental sustainability, introduced the GPI in 1995. (This group also developed the concept of ecological footprints, Figure 1-8, p. 13)

Within the GPI, the estimated value of beneficial transactions that meet basic needs, but in which no money changes hands, are added to the GDP. Examples include unpaid volunteer work, health care for family members, childcare, and housework. Then the estimated harmful environmental costs (such as pollution and resource depletion and degradation) and social costs (such as crime) are subtracted from the GDP.

Genuine progress indicator = GDP + benefits not included in market transactions − harmful environmental and social costs

Figure 17-5 compares the per capita GDP and GPI for the United States between 1950 and 2002 (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 between 1975 and 2002.

China has begun phasing in a "Green GDP" indicator that subtracts pollution and resource depletion costs from its GDP. If fully implemented, this new indicator could help China follow a more environmentally sustainable path and put pressure on Japan, the European Union, and the United States to rely more on such environmental indicators.

The GPI and other environmental economic indicators under development are far from perfect. But without such 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 policies. According to ecological and environmental economists, without these indicators, we are steering national and global economies through treacherous economic and environmental waters at ever increasing speeds without a good radar system.

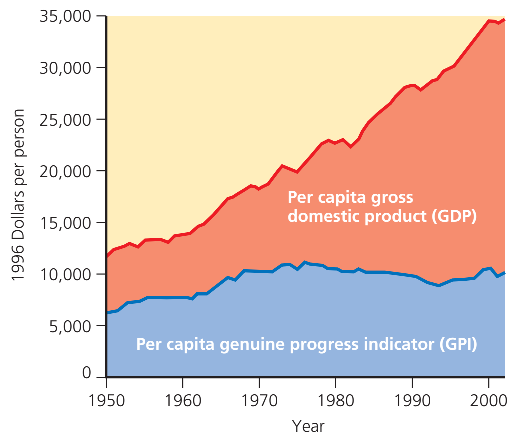


Figure 17-5 *Monitoring environmental progress:* Comparison of the per capita gross domestic product (GDP) and the per capita genuine progress indicator (GPI) in the United States between 1950 and 2002 (latest data available). **Questions:** Would you favor making widespread use of this or similar indicators? Why hasn't this been done? (Data from Redefining Progress, 2004)

RESEARCH FRONTIER

Developing and refining environmental economic indicators

We Can Include Harmful Environmental Costs in the Prices of Goods and Services

For most economists, an *environmentally honest market system* would include the harmful environmental and health costs of goods and services in their market prices to reflect as close as possible their **full costs**—internal costs plus external costs (**Concept 17-2A**).

Full-cost pricing would reduce resource waste, pollution, and environmental degradation and improve human health by encouraging producers to invent more resource-efficient and less-polluting methods of production. It would also allow consumers to make more informed choices. Jobs and profits would be lost in environmentally harmful businesses as consumers more often chose green products, but jobs and profits would be created in environmentally beneficial businesses. If a shift to full-cost pricing were phased in over two decades, most environmentally harmful businesses would have time to transform themselves into environmentally beneficial businesses.

Full-cost pricing seems to make a lot of sense. So why is it not used more widely?

First, many producers of harmful and wasteful products 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 to ecological and environmental economists, making the best possible estimates is far better than continuing with the current misleading and eventually unsustainable system, which excludes such costs.

Third, because these harmful costs are not included in the market prices of goods and services, most consumers do not connect them with the things they buy. Solving this problem requires consumer education.

RESEARCH FRONTIER

Refining methods for estimating and implementing full-cost pricing

HOW WOULD YOU VOTE?

Should full-cost pricing be used in setting market prices for goods and services? Cast your vote online at **www.thomsonedu.com/biology/miller**.

Phasing in such a system would require government action prodded by bottom-up citizen pressure. Few if any companies will volunteer to reduce their short-term profits to become more environmentally responsible unless it eventually becomes more profitable for them to do so. Governments can use several strategies to encourage producers to work toward full-cost pricing: certifying and labeling environmentally beneficial goods and services; phasing out environmentally harmful subsidies; levying taxes on environmentally harmful goods and services; passing laws to regulate pollution and resource depletion; and using tradable permits for reducing pollution and resource use.

Environmentally Informed Consumers Can Vote with Their Wallets

Eco-labeling can encourage companies to develop green products and services and help consumers to select more environmentally beneficial products and services. Eco-labeling programs have been developed in Europe, Japan, Canada, and the United States. The U.S. *Green Seal* labeling program has certified more than 300 products as environmentally friendly.

Eco-labels are also being used to identify fish caught by sustainable methods (certified by the Marine Stewardship Council) and to certify timber produced and harvested by sustainable methods (evaluated by organizations such as the Forest Stewardship Council; see Science Focus, p. 158). However, without intense consumer pressure, the World Trade Organization (WTO) may ban the use of such labels because some of its member countries view them as unfair barriers to international trade.

We Can Reward Environmentally Sustainable Businesses

One way to encourage a shift to full-cost pricing is to *phase out* environmentally harmful subsidies and tax breaks, which according to Norman Myers cost the world's governments (taxpayers) at least $2 trillion a year—an average $3.8 million a minute! (See Myers's Guest Essay on perverse subsidies at ThomsonNOW.). Such subsidies create a huge economic incentive 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.

A typical American taxpayer unknowingly pays at least $2,500 a year to provide these and other subsidies and then pays another $1,000 for environmental degradation, pollution cleanup, and higher health and insurance costs related to these subsidies. According to a 1997 study by the Earth Council, "There is something unbelievable about the world spending hundreds of billions of dollars annually to subsidize its own destruction."

On paper, phasing out such subsidies may seem like a great idea. In reality, the economically and politically powerful interests receiving them want to keep, and if possible increase, these mostly hidden benefits provided to them by taxpayers. They often lobby against proposed subsidies and tax breaks for their more environmentally beneficial competitors. Such opposition could be overcome if enough individuals work together to force elected officials to stop such practices.

Some countries have begun reducing environmentally harmful subsidies. Japan, France, and Belgium have phased out all coal subsidies, and Germany plans to do so by 2010. China has cut coal subsidies by about 73% and has imposed a tax on high-sulfur coals. New Zealand has eliminated virtually all of its agricultural subsidies.

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 conservation and renewable energy, and slowing global warming (**Concept 17-2B**). Making such subsidy shifts over two decades would encourage the rise of new environmentally beneficial businesses. It would also give current environmentally harmful businesses enough time to transform themselves into profitable operations that benefit the environment and their stockholders. This is capitalism at its best.

THINKING ABOUT
Subsidies

Do you favor phasing out environmentally harmful government subsidies and tax breaks and phasing in environmentally beneficial ones? Explain. What are three things you could do to help bring this about? How might doing this affect your lifestyle?

We Can Tax Pollution and Wastes instead of Wages and Profits

Another way to discourage pollution and resource waste is to use *green taxes,* or *ecotaxes,* to help include many of the harmful environmental costs of production and consumption in market prices (**Concept 17-2B**). 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, and minerals. Figure 17-6 lists advantages and disadvantages of using green taxes.

HOW WOULD YOU VOTE?

Do the advantages of green taxes and fees outweigh the disadvantages? Cast your vote online at **www.thomsonedu.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 system would *lower* taxes on labor, income, and wealth and *raise* taxes on environmentally harmful activities that produce pollution, wastes, and environmental degradation.

With such a *tax shift,* for example, a tax on coal would cover the health costs of breathing polluted air and costs of damage from acid deposition. Then taxes on wages and wealth could be reduced by an equal amount. Some 2,500 economists, including eight Nobel Prize winners, have endorsed the concept of tax shifting.

Proponents point out three requirements for successful implementation of green taxes. *First,* they would have to be phased in over 15 to 20 years to allow businesses to plan for the future. *Second,* they should reduce or replace income, payroll, or other taxes. *Third,* the poor and middle class need a safety net to reduce the regressive nature of any new taxes on essentials such as food and fuel.

In Europe and the United States, polls indicate that, once such tax shifting is explained to them, 70% of voters support the idea. The U.S. Congress has not enacted green taxes, mostly because politically powerful auto, oil, coal, and other industries claim that such taxes will reduce their competitiveness and harm the economy.

Meanwhile, 15 European countries have green taxes on activities such as waste disposal, air and water pollution, CO_2 emissions, energy consumption, and vehicles entering congested cities. Germany's ecological tax on fossil fuels, introduced in 1999, has reduced pollution and greenhouse gas emissions, created up to 250,000 new jobs, and lowered taxes on wages. Several European countries have found that green taxes can increase economic competitiveness by stimulating industries to come up with environmentally beneficial technologies that can be sold in their own countries and worldwide.

HOW WOULD YOU VOTE?

Do you favor shifting taxes from wages and profits to pollution and waste? Cast your vote online at **www.thomsonedu.com/biology/miller**.

TRADE-OFFS

Environmental Taxes and Fees

Advantages	Disadvantages
Help bring about full-cost pricing	Penalize low-income groups unless safety nets are provided
Encourage businesses to develop environmentally beneficial technologies and goods to save money	Hard to determine optimal level for taxes and fees
Easily administered by existing tax agencies	Governments may use money as general revenue instead of improving environmental quality and reducing taxes on income, payroll, and profits
Fairly easy to detect cheaters	


Figure 17-6 Advantages and disadvantages of using green taxes to help reduce pollution and resource waste (**Concept 17-2B**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

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 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 require that certain irreplaceable or slowly replenished resources be protected 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. Regulations often set compliance deadlines that are too short to allow companies to find innovative solutions. Or they may require use of specific technologies where less costly but equally effective alternatives are 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 create jobs, increase company profits, and make the companies more competitive in national and international markets.

For years, many companies mostly resisted environmental regulation and developed an adversarial relationship with government regulators. But in recent years, a growing number of companies have realized the economic and competitive advantages of making environmental improvements. They now recognize that their shareholder value depends in part on having a good environmental record. In other words, environmental stewardship is a source of business value for firms. At the same time, many consumers have begun buying green products, which further reinforces this trend.

We Can 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. It then sets limits or *caps* to maintain these levels and gives companies a certain number of *tradable pollution* and *resource-use permits* governed by the caps.

With this *cap-and-trade* approach, a permit holder not using its entire allocation can save credits for future expansion, use them in other parts of its operation, or sell them to other companies. In the United States, this approach has been used to reduce the emissions of sulfur dioxide (p. 358) and several other air pollutants. Tradable rights can also be established among countries to help preserve biodiversity and 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 promote further reductions in pollution.

TRADE-OFFS

Tradable Environmental Permits

Advantages	Disadvantages
Flexible	Big polluters and resource wasters can buy their way out
Easy to administer	May not reduce pollution at dirtiest plants
Encourage pollution prevention and waste reduction	Can exclude small companies from buying permits
Permit prices determined by market transactions	Caps can be too high and not regularly reduced to promote progress
Confront ethical problem of how much pollution or resource waste is acceptable	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. **Question:** Which two advantages and which two disadvantages do you think are the most important? Why?

INDIVIDUALS MATTER

Ray Anderson

Ray Anderson (Figure 17-A) is CEO of Interface, a company based in Atlanta, Georgia (USA) that he founded in 1973. The company is the world's largest commercial manufacturer of carpet tiles, with 26 factories in six countries, customers in 110 countries, and more than $1 billion in annual sales.

Anderson changed the way he viewed the world—and his business—after reading Paul Hawken's book *The Ecology of Commerce.* In 1994, he announced plans to develop the nation's first totally sustainable green corporation by applying some of the four **scientific principles of sustainability** (see back cover) to the carpet business. Since then, he has implemented hundreds of projects with goals such as zero waste, greatly reduced energy use, zero use of fossil fuels, and reliance on solar energy. Between 1996 and 2005, his company had

Interface

Figure 17-A Ray Anderson

reduced solid waste by 63%, cut greenhouse gas emissions by 46%, lowered energy use by 28%, obtained 13% of its energy from renewable resources, and saved more than $100 million. It has also invented a variety of recyclable and compostable carpet fabrics. One of Interface's factories in California runs on solar cells and produced the world's first solar-made carpet.

To achieve the goal of zero waste, Interface plans to stop selling carpet and to lease it. The company will install, clean, and inspect the carpet on a monthly basis, repair worn carpet tiles overnight, and recycle worn-out tiles into new carpeting. As Anderson says, "We want to harvest yesterday's carpets and recycle them with zero scrap going to the landfill and zero emissions into the ecosystem—and run the whole thing on sunlight."

Anderson is one of a growing number of business leaders committed to finding more economically and ecologically sustainable, yet profitable, ways to do business. Between 1993 and 1998, the company's revenues doubled and profits tripled, mostly because the company saved $130 million in material costs with an investment of less than $40 million. Andersen says he is having a blast.

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.thomsonedu.com/biology/miller**.

We Can Reduce Pollution and Resource Waste by Selling Services instead of Things

In the mid-1980s, German chemist Michael Braungart and Swiss industry analyst Walter Stahel independently proposed a new economic model that would provide profits while greatly reducing resource use and waste. Their idea for more sustainable economies focuses on shifting from the current *material-flow economy* (Figure 2-8, p. 36) to a *service-flow economy.* Instead of buying most 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, 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, machines are designed 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 using 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 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, above). This reduces his company's resource use and harmful environmental impacts and can 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 three services that you would be willing to lease.

17-3 How Can Reducing Poverty Help Us Deal with Environmental Problems?

CONCEPT 17-3 Reducing poverty can help us to reduce population growth, resource use, and environmental degradation.

The Gap between Rich and Poor Is Getting Wider

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—almost four times the entire U.S. population—struggle to survive on an income of less than $1 a day. About half of the world's people live on a daily income of $1–2.

Poverty has numerous harmful health and environmental effects (Figure 1-11, p. 16, and Figure 14-12, p. 339) and has been identified as one of the five major causes of the environmental problems we face (Figure 1-10, p. 16). Thus, reducing poverty benefits individuals, economies, and the environment and helps us to slow population growth (**Concept 17-3**).

Most neoclassical economists believe that a growing economy can help poor people by creating more jobs and providing greater tax revenues, which can be used to help the poor help themselves. Economists call this the *trickle-down effect.* However, since 1960, most of the benefits of global economic growth, as measured by income, have been *flowing up* to the rich, rather than trickling down to workers at the bottom fifth of the economic ladder (Figure 17-8). Since 1980, this *wealth gap* between the rich and the poor has grown. In 2005, the world's three richest people had a combined wealth greater than that of the world's 48 poorest countries.

South African President Thabo Mbeki told delegates at the 2003 Johannesburg World Summit on Sustainable Development, "A global human society based on poverty for many and prosperity for a few, characterized by islands of wealth, surrounded by a sea of poverty, is unsustainable."

We Can Reduce Poverty

Some nations have climbed out of abject 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 two decades by focusing on education, hard work, and discipline, all of which attracted investment capital. China and India are on a similar path.

Analysts point out that reducing poverty will require the governments of most developing countries to make policy changes. This includes emphasizing education to develop a trained workforce that can participate in an increasingly global economy.

Analysts have suggested that developed countries and international lending agencies forgive at least 60% of the massive debt that developing countries owe them, and all of the debt of the poorest, most heavily indebted countries. This could be done on the condition that money saved on debt interest be devoted to meeting basic human needs. Currently, developing countries pay an average of about $571,000 a minute in interest to developed countries. In 2005, the heads of the eight major industrial countries agreed to cancel

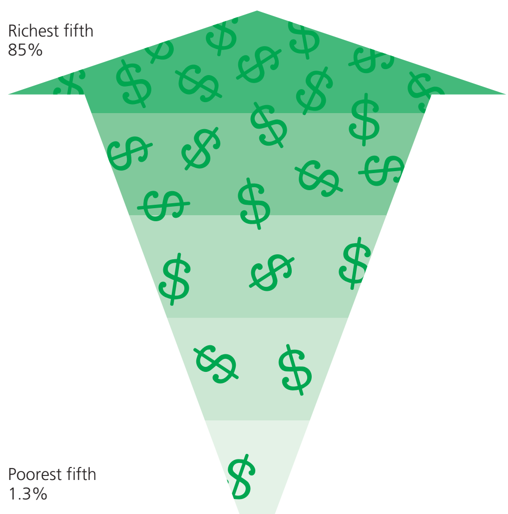


Figure 17-8 *Global outlook:* the *global distribution of income* shows that most of the world's income flows up; the richest 20% of the world's population receive more of the world's income than all of the remaining 80%. Each horizontal band in this diagram represents one-fifth of the world's population. This upward flow of global income has accelerated since 1960, and especially since 1980. This trend can increase environmental degradation by increasing average per capita consumption for the richest 20% of the population and by forcing the poorest 20% to survive by using renewable resources faster than they are replenished. **Question:** How do you think this concentration of wealth can hinder or enhance protection of biodiversity? (Data from U.N. Development Programme and Ismail Serageldin, "World Poverty and Hunger—A Challenge for Science," *Science,* volume 296 (2002): pp. 54–58)

the debts of 18 of the poorest debt-ridden countries (14 of them in Africa).

Governments, businesses, international lending agencies, and wealthy individuals in developed countries could also:

- Increase nonmilitary government and private aid, with mechanisms to assure that most of it is used directly to help the poor become more self-reliant, to help provide social safety nets, and to guarantee access to health care.
- Mount a massive global effort to combat malnutrition and the infectious diseases that kill millions of people prematurely (Figure 14-11, p. 338).
- Make large investments in small-scale infrastructure such as solar-cell power facilities in villages (Figure 13-30, p. 308) and sustainable agriculture projects that would allow developing nations to leapfrog over the conventional development path to more eco-efficient economies.
- Encourage lending agencies to make small loans to poor people who want to increase their income (see the following Case Study).

■ **CASE STUDY**

Microloans to the Poor

Most of the world's poor want to earn more, become more self-reliant, and have a better life. But they have no credit record and lack the assets needed for collateral to secure a loan to buy seeds and fertilizer for farming or tools and materials for a small business.

For almost three decades, an innovation, called *microlending* or *microcredit,* has helped people to deal with this problem. For example, since 1983, when economist Muhammad Yunus started the Grameen (Village) Bank in Bangladesh, the bank has provided microloans ranging from $50 to $500 to more than 6.6 million Bangladeshi villagers. About 97% of the loans are used by women to plant crops, buy cows, or start their own small businesses as seamtresses, weavers, bookbinders, vendors, and phone service providers.

To stimulate repayment and provide support, the Grameen Bank organizes microborrowers into five-member "solidarity" groups. If one member of the group misses a weekly payment or defaults on the loan, the other members of the group must make the payments.

The Grameen Bank's microlending has been successful and profitable. The repayment rate on these microloans is an astounding 99% compared to 45–50% of loans made by traditional banks in Bangladesh. About half of Grameen's borrowers move above the poverty line within 5 years, and domestic violence, divorce, and birth rates are lower among most borrowers. These microloans have helped more than 5 million borrowers work their way out of poverty by empowering them and giving them a sense of dignity and hope.

Grameen Bank microloans are also being used to develop daycare centers, health care clinics, reforestation projects, drinking water supply projects, literacy programs, group insurance programs, and small-scale solar and wind power systems in rural villages. Grameen's 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.

In 2006, Muhammad Yunus and his Grameen Bank jointly won the Nobel Peace Prize for their pioneering use of microcredit to help millions of people lift themselves out of poverty. This award recognized that attacking poverty is essential to peace and that private enterprises can play a key role in reducing poverty.

We Can Achieve the World's Millennium Development Goals

In 2000, the world's nations set goals—called Millennium Development Goals (MDGs)—for sharply reducing hunger and poverty, improving health care, and moving toward environmental sustainability by 2015. Developed countries agreed to devote 0.7% of their annual national income toward achieving the goals.

However, the average amount donated in most years has been 0.25% of national income. The United States—the world's richest country—gives only 0.16% of its national income to help poor countries. Meeting the MDGs by increasing aid to 0.7% is an ethical decision that requires developed countries and individuals to reevaluate their priorities (Figure 17-9).

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.

We Can Make the Transition to an Eco-Economy and Make Money Doing It

Figure 17-10 (p. 414) summarizes suggestions by Paul Hawken and other environmental and business leaders for using the economic tools discussed in this chapter

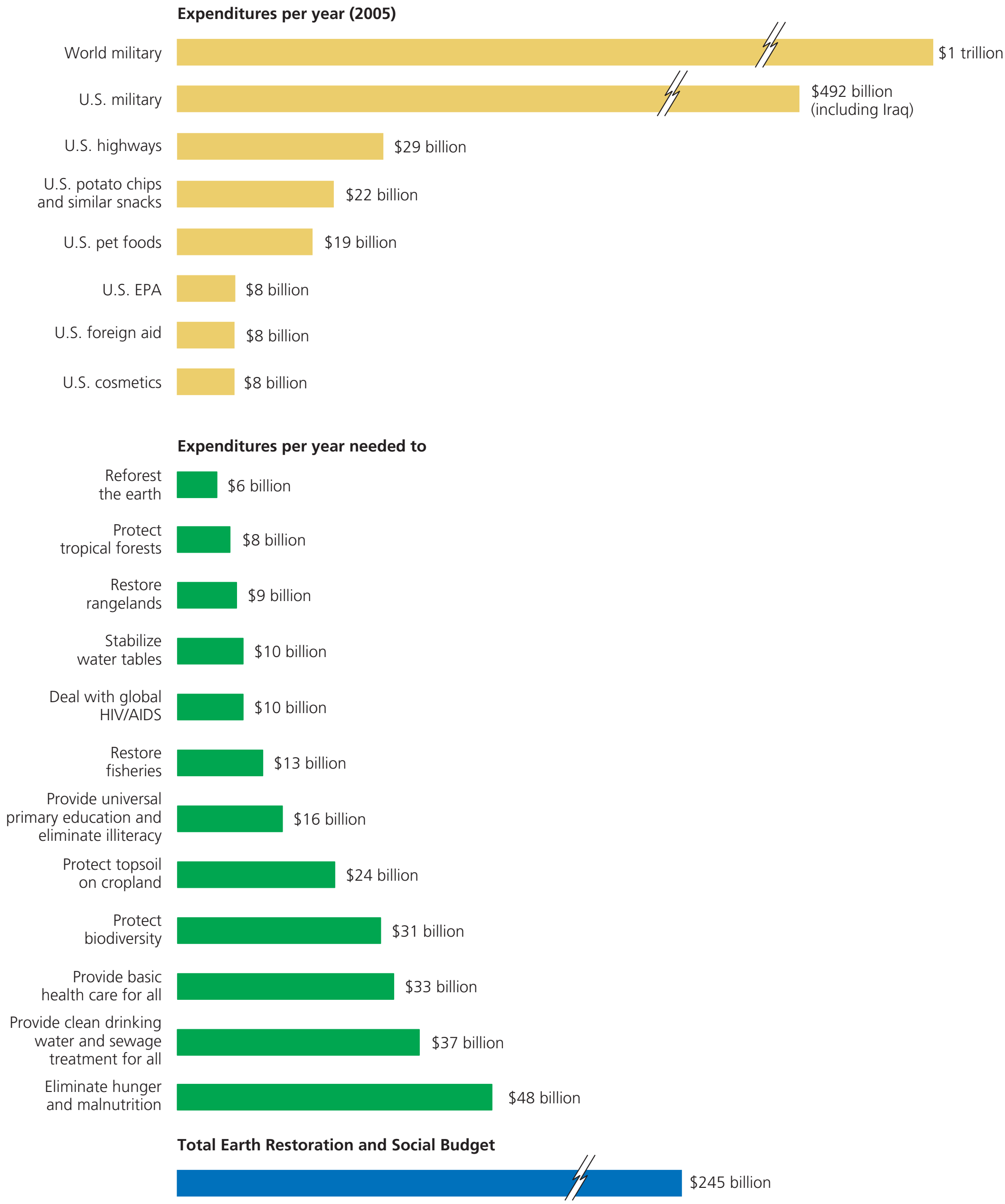


Figure 17-9 *Ethics:* what should our priorities be? **Questions:** Which one or more of the expenditures in the top part of the figure would you reduce to pay for solving some of the problems listed in the lower part of the figure? Which three of the problems in the bottom half of the figure do you think are the most important priorities? Why? (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)

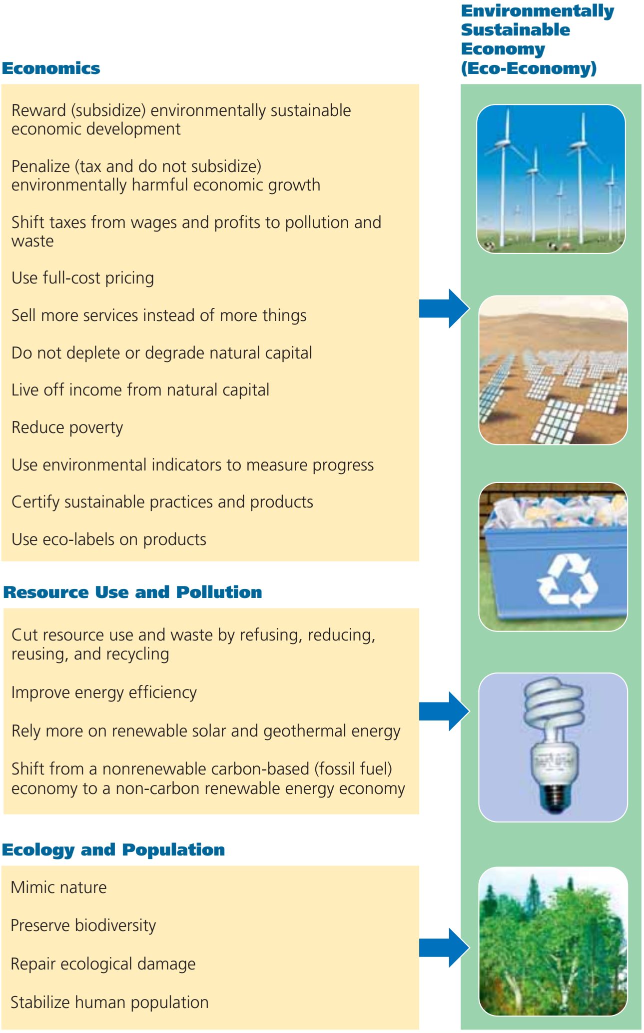


Figure 17-10 **Solutions:** principles for shifting to more environmentally sustainable economies, or *eco-economies,* during this century. **Question:** Which five of these solutions do you think are the most important? Why?

to make the transition to more environmentally sustainable economies over the next several decades. Such strategies would apply the four **principles of sustainability** (see back cover). Hawken has a simple golden rule for such an economy: *"Leave the world better than you found it, take no more than you need, try not to harm life or the environment, and make amends if you do."*

In making the shift to an eco-economy, some industries and businesses will disappear or remake themselves, and new ones will appear—a normal and healthy process in a dynamic capitalist economy. Improving environmental quality is a major growth industry that is creating new jobs. For example, on the Nashua River (**Core Case Study**), recreation-oriented commerce takes place now where it did not before the river was cleaned up.

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. According to Worldwatch Institute estimates, sales in global environmental industries average about \$1.3 million per minute—on a par with the global car industry. Green businesses employ more than 11 million people—2 million in the United States—and these numbers will grow. Figure 17-11 might give you some ideas for a green career choice.

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.

17-4 How Can We Implement More Sustainable and Just Environmental Policies?

CONCEPT 17-4 Individuals can work with others, starting at the local level, to influence how environmental policies are made and whether or not they succeed.

Dealing with Environmental Problems in Democracies Is Not Easy

Politics is the process by which individuals and groups try to influence or control the policies and actions of governments at local, state, national, and international levels. One important application of this process is the development of **environmental policy**—environmental laws, rules, and regulations that are developed, implemented, and enforced by one or more government agencies.

Democracy is government by the people through elected officials and representatives. In a *constitutional democracy,* a constitution provides the basis of government authority, limits government power by mandating free elections, and guarantees 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 the three branches of government—*legislative, executive,* and *judicial*—and among federal, state, and local governments.

In passing laws, developing budgets, and formulating regulations, elected and appointed government officials must deal with pressure from many competing *special-interest groups.* Each group advocates passing laws, providing subsidies or tax breaks, or establishing regulations favorable to its cause, and weakening or repealing laws and regulations unfavorable to its position. Some special-interest groups such as corporations are *profit-making organizations.* Others are *nonprofit nongovernmental organizations* (NGOs), such as labor unions and environmental organizations.

The design for stability and gradual change in democracies is highly desirable. But several features of democratic governments hinder their ability to deal with environmental problems. For example, many problems such as climate change and biodiversity loss are complex and difficult to understand. Such problems also have long-lasting effects, are interrelated, and require integrated, long-term solutions that emphasize prevention. But because elections are held every few years, most politicians seeking reelection tend to focus on short-term, isolated issues rather than on complex, time-consuming, and long-term problems. One of our greatest challenges is to place more emphasis on long-term thinking and policies. Another problem is that too many political leaders have too little understanding of how the earth's natural systems work and how those systems support all life, economies, and societies.

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:

- *The humility principle:* Our understanding of nature and how our actions affect nature is quite limited.
- *The reversibility principle:* Try to avoid doing something that cannot be reversed later if the decision turns out to be wrong.
- *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 fully established scientifically.
- *The prevention principle:* Whenever possible, make decisions that help 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 the pollutants and wastes they produce.
- *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 human rights principle:* All people have a right to an environment that does not harm their health and well-being.
- *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 topic by Robert D. Bullard at ThomsonNOW.

Individuals Can Influence Environmental Policy

A major theme of this book is that *individuals matter.* History shows that significant change usually comes from the *bottom up* when individuals join with others to bring about change (**Concept 17-4**). 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 have disappeared.

Figure 17-12 lists ways in which you can influence and change local, state, and national government policies in constitutional democracies. Many people recycle, buy eco-friendly products, and do other important things to help the environment. But to influence environmental policy, people must work together actively, starting at the local level, just as Marion Stoddart did (**Core Case Study**).

CORE CASE STUDY

At a fundamental level, all politics is local. And what we do to improve environmental quality in our own neighborhoods often 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 four ways. First, we can *lead by example,* using our own lifestyles and values to show others that change is possible and beneficial.

Second, we can *work within existing economic and political systems to bring about environmental improvement* by campaigning and voting for eco-friendly candidates and by communicating with elected officials. We can also send a message to companies that 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 an environmental career. (See Figure 17-11 and information on green careers found on the website for this book.)

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, as did Marion Stoddart (**Core Case Study**) and Wangari Maathai (Individuals Matter, p. 163).

CORE CASE STUDY

THINKING ABOUT

Environmental Leadership

CORE CASE STUDY

What types of environmental leadership did Marion Stoddart (**Core Case Study**) practice? What type of environmental leadership interests you?

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
- 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 17-12 **Individuals matter:** ways in which you can influence environmental policy (**Concept 17-4**). **Questions:** Which three of these actions do you think are the most important? Why? Which ones, if any, do you take?

Developing Environmental Policy Is a Controversial Process

The major function of government in democratic countries is to develop and implement *policy* for dealing with various issues. The first step is law making, which can be a complex process. But passing a law is not enough to make policy. The next step involves trying to get enough funds appropriated to implement and enforce each law. Indeed, developing and adopting a budget is the most important and controversial activity of the executive and legislative branches of a government.

Once a law has been passed and funded, the appropriate government department or agency must draw up regulations or rules for implementing it. An affected group may take the agency to court for failing to implement and enforce the regulations or for enforcing them too rigidly.

Politics plays an important role in the policies and staffing of environmental regulatory agencies. Regulated industries often exert political pressure to have their own people appointed to high positions in regulatory agencies. Such appointments have been described as "putting foxes in charge of the henhouse."

In addition, people in regulatory agencies work closely with officials in the industries they are regulating, often developing friendships with them. Some industries and other groups offer high-paying jobs to regulatory agency employees in an attempt to influence their regulatory decisions. This can create a *revolving door,* as employees move back and forth between industry and government.

CASE STUDY

Managing Public Lands in the United States—Politics in Action

No nation has set aside as much of its land for public use, resource extraction, enjoyment, and wildlife 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 17-13).

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 *National Resource Lands.* These lands are used primarily for mining, oil and gas extraction, and livestock grazing.

The U.S. Fish and Wildlife Service (USFWS) manages 544 *National Wildlife Refuges.* Most refuges protect habitats and breeding areas for waterfowl and

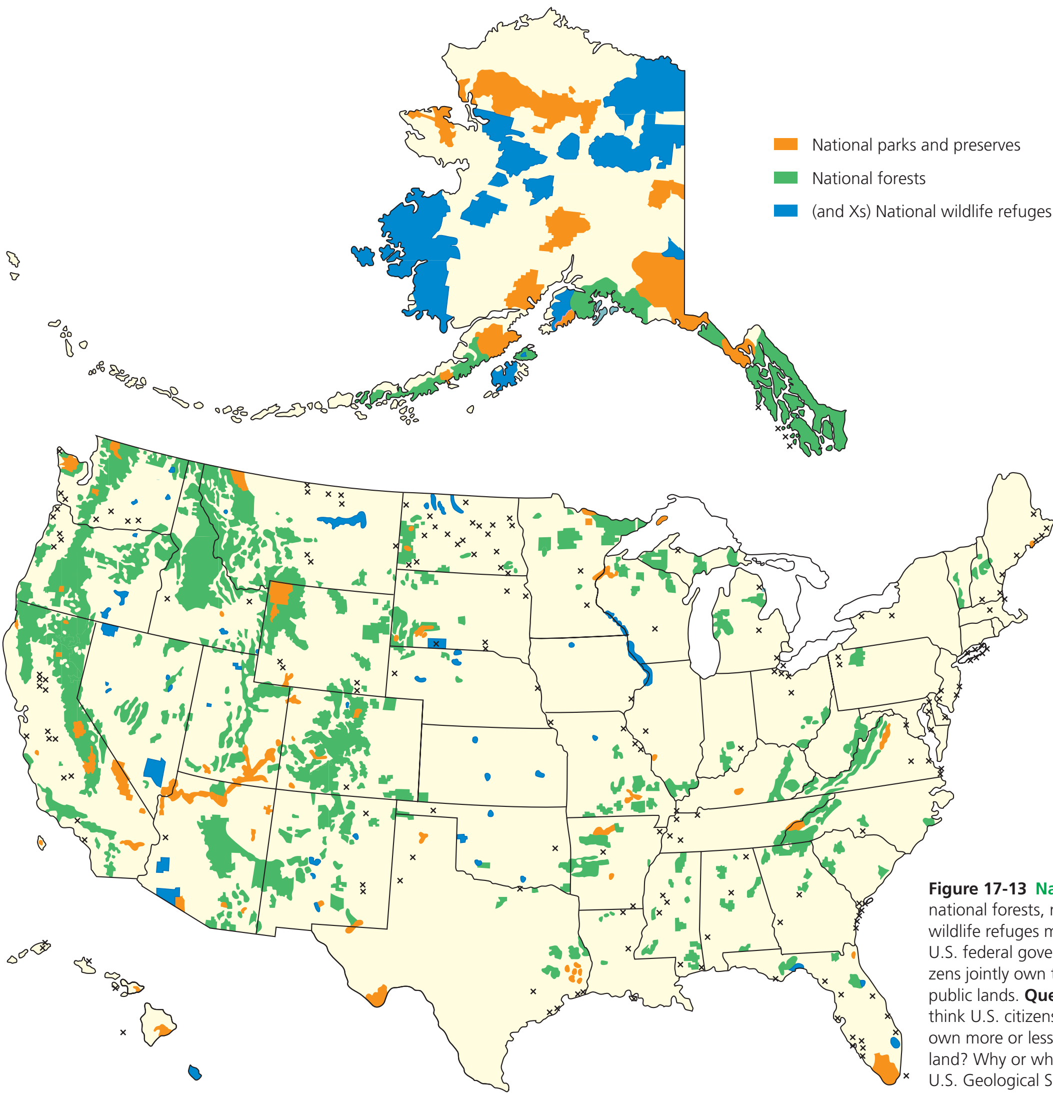


Figure 17-13 Natural capital: national forests, national parks, and wildlife refuges managed by the U.S. federal government. U.S. citizens jointly own these and other public lands. **Questions:** Do you think U.S. citizens should jointly own more or less of the nation's land? Why or why not? (Data from U.S. Geological Survey)

big game to provide a harvestable supply for hunters. A few protect endangered species from extinction. Permitted activities in most refuges include hunting, trapping, fishing, oil and gas development, mining, logging, grazing, some military activities, and farming.

Uses of some other public lands are more restricted. The *National Park System,* managed by the National Park Service (NPS), includes 58 major parks and 331 national recreation areas, monuments, historic sites, parkways, 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 660 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, timber, and mineral resources (see Supplement 14 on p. S14 and maps on pp. S62–S70 in Supplement 16). The use and management of the resources on these lands has been debated since the 1800s.

Many conservation biologists, environmental economists, and some 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 has been a strong and effective opposition to these ideas. Developers, resource extractors, and many economists tend to view public lands in terms of their usefulness in providing mineral, timber, and other resources and in terms of increasing short-term economic growth. They have succeeded in blocking implementation of the four principles listed above. For example, in recent years, the government has given an average of $1 billion a year—more than $114,000 an hour—in subsidies 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, mounting a campaign to get the U.S. Congress to pass laws that would do the following:

- Sell public lands or their resources to corporations or individuals, usually at less than market value, or turn over their management to state and local governments (the sagebrush rebellion discussed on p. S28 in Supplement 5).
- Slash federal funding for administration of regulations over public lands.
- Cut all old-growth forests in the national forests and replace them with tree plantations.
- Open all national parks, national wildlife refuges, and wilderness areas to oil drilling, mining, off-road vehicles, and commercial development. Do away with the National Park Service and launch a 20-year construction program of new concessions and theme parks run by private firms in the national parks.
- Continue mining on public lands under the provisions of the 1872 Mining Law, which allows mining interests to pay no royalties to taxpayers for hard-rock minerals they remove and to avoid responsibility for any damage they cause. (See Supplement 14, p. S60.)
- Repeal the Endangered Species Act or modify it to allow economic factors to override protection of endangered and threatened species.
- Redefine government-protected wetlands so that about half of them would no longer be protected.
- Prevent individuals and groups from legally challenging these uses of public lands owned jointly by all citizens for private financial gain.

Since 2002, the U.S. Congress has 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. Conservation biologists and environmental scientists argue that these eventually unsustainable policies degrade and deplete the country's irreplaceable natural capital.

HOW WOULD YOU VOTE? ✓

Should much more of U.S. public lands (or government-owned lands in the country where you live) be opened up to the extraction of timber, mineral, and energy resources? Cast your vote online at **www.thomsonedu.com/biology/miller**.

U.S. Environmental Laws and Regulations Are under Attack

Since 1980, a well-organized and well-funded movement has mounted a strong campaign in the United States to weaken or repeal existing environmental laws and regulations, change the way in which public lands (Figure 17-13) are used, and destroy the reputation and effectiveness of the U.S. environmental movement.

Three major groups are strongly opposed to environmental regulation: some corporate leaders and other powerful people who see environmental laws and regulations as threats to their wealth and power; citizens who see these laws and regulations as threats to their private property rights and jobs; and state and local government officials who resent having to implement federal laws and regulations with little or no federal funding (unfunded mandates) or who disagree with certain regulations.

One problem is that the focus of environmental issues has shifted from easy-to-see dirty smokestacks and filthy rivers to more complex, controversial, and often invisible environmental problems such as climate change and biodiversity loss. Explaining such complex issues to the public and mobilizing support for often controversial, long-range solutions to such problems is difficult. See the Guest Essay on environmental reporting by Andrew C. Revkin at ThomsonNOW.

In recent years, most major U.S. federal environmental laws and regulatory agencies have been weakened by a combination of executive orders and congressional actions. In some cases, regulatory agencies have been staffed largely with officials who favor weakening them, decreasing their funding, ignoring reliable scientific consensus (p. 26), and stifling dissent. Environmental leaders warn that the entire environmental legal and regulatory structure, built with bipartisan consensus between 1965 and 1980 (see Supplement 5, pp. S27–S28), is being systematically undermined, much like the structural foundation of a house being silently eaten away by termites. Most U.S. citizens are unaware that the increasingly weakened foundation of the nation's environmental laws and regulations could crumble.

Independent polls show that more than 80% of the U.S. public strongly support environmental laws and regulations and do not want them weakened. But polls also show that less than 10% of the U.S. public views the environment as one of the nation's most pressing problems. As a result, environmental concerns often do not get transferred to the ballot box.

Citizen Environmental Groups Play Important Roles

The spearheads of the global conservation, environmental, and environmental justice movements are the more than 100,000 nonprofit NGOs working at the international, national, state, and local levels—up from about 2,000 such groups in 1970. The growing influence of these organizations is one of the most important changes influencing environmental decisions and policies (**Concept 17-4**).

NGOs range from grassroots groups with just a few members to global organizations like the 5-million-member World Wildlife Fund (WWF) with offices in 48 countries. Other international groups with large memberships include Greenpeace, the Nature Conservancy, Conservation International, and the Grameen Bank (see Case Study, p. 412).

In the United States, more than 8 million citizens belong to more than 30,000 NGOs dealing with environmental issues. 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

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. More details can be found in Supplement 5, pp. S23–S30.

Supplement 5, pp. S27–S28), 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. According to political analyst Konrad von Moltke, "There isn't a government in the world that would have done anything for the environment if it weren't for the citizen groups." Taken together, a loosely connected worldwide network of grassroots NGOs working for bottom-up political, social, economic, and environmental change can be viewed as an emerging citizen-based *global sustainability movement.*

These groups have worked with individuals and communities to oppose harmful projects such as landfills, waste incinerators, and nuclear waste dumps, as well as to fight against the clear-cutting of forests and pollution from factories and power plants. They have also taken action against environmental injustice. See the Guest Essay on this topic by Robert D. Bullard at ThomsonNOW.

Some industries and environmental groups are working together to find solutions to environmental problems. For example, Environmental Defense worked with McDonald's to redesign its packaging system to eliminate its plastic hamburger containers. Environmental Defense also worked with FedEx to lower the air pollution emissions of its planes and trucks.

Grassroots groups have organized land trusts and other efforts to save wetlands, forests, farmland, and ranchland from development. They have helped restore forests, wetlands, and rivers (**Core Case Study**). CORE CASE STUDY

Some grassroots environmental groups use the nonviolent and nondestructive tactics of protest marches, tree sitting (see Individuals Matter, p. 155), 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 to achieve their ends. Most environmentalists strongly oppose such tactics.

Students Can Play Important Environmental Roles

Since 1988, there has been a boom in environmental awareness on college campuses and in public 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.

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, usually saving money in the process. As a result, students have helped convince almost 80% of universities and colleges in the United States to develop recycling programs.

Students at Oberlin College in Ohio helped design a more sustainable environmental studies building. At Northland College in Wisconsin, students helped design a "green" dorm that features a large wind generator, panels of solar cells, recycled furniture, and waterless (composting) toilets. At Minnesota's St. Olaf College, students have carried out sustainable agriculture and ecological restoration projects. And students at Brown University studied the impacts of lead and other toxic pollutants in low-income neighborhoods in nearby Providence, Rhode Island.

Environmental audits reveal that most college campuses are major polluters. A recent Yale University study reported that the school emits more greenhouse gases than do 32 developing countries. Students at Columbia University have pressured the university to make more socially and environmentally responsible investments with its endowment funds.

Many MBA students are calling for a more holistic approach to studying business. In 2005, 54% of the U.S. business schools required students to take at least one course with an emphasis on sustainability, ethics, and corporate and social responsibility. And in California, San Francisco's Presidio School of Management integrates sustainability into every aspect of its MBA curriculum.

THINKING ABOUT
Environmental Groups

What environmental groups exist at your school? Do you belong to such a group? Why or why not?

Corporations Can Play a Key Role in Achieving Environmental Sustainability

In a healthy democratic free-enterprise system, there is a delicate, dynamic balance between capitalism and democracy. Capitalism thrives on change and innovations that lead to new technologies, products, and opportunities for profits. This can lead to higher living standards for many people, but it can also result in environmental, economic, and human injustices when based on profits without responsibility. Democracy strives for equilibrium by resisting drastic change, and it can act to help curtail such injustices caused by capitalism.

Achieving the right balance between capitalism and democracy is not easy. Too much government intervention can strangle capitalism and innovation; too little can lead to excessive political power among business interests, and can result in unchecked environmental degradation.

Governments can set environmental standards and goals through legislation and regulations but corporations generally have highly efficient ways of accomplishing such goals. Making a transition to more sustainable societies and economies will require huge amounts of investment capital and research and development. Most of this money is likely to come from profitable corporations, including banks and other lending agencies. Thus corporations have a vital role in achieving a more sustainable future.

The good news is that a growing number of CEOs and investors are increasingly aware that there is much money to be made from developing and selling green products and services during this century. This is guided by the concept of *eco-efficiency,* which is about finding ways to create more economic value with less environmental impact. In shifting to more eco-efficient and environmentally sustainable business practices, business leaders can meet their responsibilities to stockholders and investors while helping to make the world a better place for all.

In the early 1990s, Stephan Schmidheiny, a Swiss billionaire, organized a group made up of the CEOs of 48 of the world's largest corporations. It eventually became the World Business Council for Sustainable Development (WBCSD), which is dedicated to promoting sustainable development built around improving eco-efficiency. Today, the WBSCD is a highly influential coalition of more than 150 international companies, involving some 700 global business leaders.

In 2006, the WBSCD and three highly respected conservation organizations published a study called "Ecosystem Challenges and Business Implications," based on data and forecasts by the 2005 United Nations Millennium Ecosystem Assessment. It stated that there is an urgent need to attach economic values to natural resources. The report also warned that businesses need to understand and take into account the values of the earth's natural resources and ecosystem services (Figure 1-3, p. 8). In other words, businesses need to get serious about protecting the natural capital that supports them and all life.

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 1-3, p. 8, and Figure 17-3).

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 the Guest Essay by Norman Myers on this topic at ThomsonNOW.

Research by Thomas Homer-Dixon, director of Canada's Trudeau Center for Peace and Conflict Studies, has revealed a strong correlation between growing scarcities of resources, such as cropland, water, forests, and fish, and the spread of civil violence and dysfunctional governments. The research also shows how civil violence can further degrade such resources and lead to a cycle of civil violence and resource scarcity.

Studies also show that terrorism and violence (sometimes the result of a long history of disputes between various cultures and religions) are bred and fueled by poverty, injustice, and inequality. Today, more than 1 billion young adults—more than three times the population of the United States—are without jobs.

Some analysts call for all countries to make environmental security a major focus of diplomacy and government policy at all levels. This perspective would be implemented by a council of advisers made up of highly qualified experts in environmental, economic, and military security who integrate all three security concerns in making major decisions.

HOW WOULD YOU VOTE?

Is environmental security just as important as economic and military security? Cast your vote online at **www.thomsonedu.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 (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 reducing poverty through sustainable economic development

TRADE-OFFS

Global Efforts to Solve Environmental Problems

Good News

Environmental protection agencies in 115 nations

Over 500 international environmental treaties and agreements

UN Environment Programme (UNEP) created in 1972 to negotiate and monitor international environmental treaties

1992 Rio Earth Summit adopted key principles for dealing with global environmental problems

2002 Johannesburg Earth Summit attempted to implement 1992 Rio summit policies and goals and reduce poverty

Bad News

Most international environmental treaties lack criteria for evaluating their effectiveness

1992 Rio Earth Summit led to nonbinding agreements with inadequate funding

By 2007 there was little improvement in the major environmental problems discussed at the 1992 Rio summit

2002 Johannesburg Earth Summit failed to deal with global environmental problems such as climate change, biodiversity loss, and poverty

Figure 17-15 Good and bad news about international efforts to deal with global environmental problems. **Question:** What single piece of good news and what single piece of bad news do you think are the most important? Why?

- Helping more than 100 nations to develop environmental laws and institutions

Since the 1972 U.N. Conference on the Human Environment in Stockholm, Sweden, progress has been made in addressing environmental issues at the global level. Figure 17-15 lists some of the good and bad news about international efforts to deal with global environmental problems such as poverty, climate change, biodiversity loss, and ocean pollution.

In 2004, environmental leader Gus Speth argued that global environmental problems are getting worse and that international efforts to solve them are inadequate. This analysis was confirmed by the 2006 Global Governance Initiative Report, which gave the world's governments and businesses a score of 2 out of 10 in dealing with environmental issues, especially in addressing declining biodiversity and climate change and providing clean water and sanitation. Speth and other environmental leaders propose the creation of a World Environmental Organization (WEO), on the order of the World Health Organization and the World Trade Organization, to deal with global environmental challenges.

The Yale Center for Environmental Law and Policy and the Center for International Earth Science Information Network have developed an Environmental Performance Index (EPI), which evaluates 133 countries on a scale of 0 to 100 in terms of their ecosystem health and environmental stresses on human health (See Figure 8 on p. S22 in Supplement 4 for a map of EPIs by country). In 2006, the top five countries in order were New Zealand, Sweden, Finland, the Czech Republic, and Great Britain. Canada ranked eighth. India ranked number 118. The five lowest ranked countries were Ethiopia, Mali, Mauritania, Chad, and Niger. Mid-ranked countries included the United States (28), Russia (32), Brazil (34), Mexico (66), and China (94).

We Can Shift to More Environmentally Sustainable Societies

According to business leader Paul Hawken, making a cultural shift to more environmentally sustainable societies over the next 50 years

> *means thinking big and long into the future. It also means doing something now. It means electing people who really want to make things work, and who can imagine a better world. It means writing to companies and telling them what you think. It means never forgetting that the cash register is the daily voting booth in democratic capitalism.*

Several guidelines have been suggested for fostering cooperation instead of confrontation as we struggle to make such a transition.

First, emphasize preventing or minimizing environmental problems instead of letting them build up to crisis levels.

Second, use well-designed and carefully monitored marketplace solutions to help prevent or reduce the impacts of most environmental problems.

Third, cooperate and innovate to find *win–win* solutions or *trade-offs* to environmental problems and injustices.

Fourth, stop exaggerating. People on both sides of thorny environmental issues should take a vow not to exaggerate or distort their positions in attempts to play win–lose or winner-take-all games.

The story of Marion Stoddart (**Core Case Study**) illustrates how these guidelines for cooperation can be applied. She did not confront businesses and government as enemies, but approached them with positive persistence and enlisted them as

CORE CASE STUDY

partners. She worked hard with them to build social capital (p. 18), and together they arrived at a win–win solution (**Concept 17-4**).

Making the transition to sustainability during your lifetime will require governments and their citizens to rethink their priorities. Figure 17-9 (p. 413) shows that it would take about $245 billion a year for the world to meet basic social goals and to provide environmental security. This is equal to about one-fourth of the annual global military budget and one-half of the annual U.S. military budget (including expenditures in Iraq). It also amounts to about one-eighth of what countries spend each year on environmentally harmful subsidies. Converting that portion of the world's environmentally harmful subsidies to environmentally beneficial subsidies and other forms of aid would go a long way toward solving the social and environmental problems listed in Figure 17-9.

The world has the knowledge, technologies, and financial resources to eradicate poverty and malnutrition, eliminate illiteracy, sharply reduce infectious diseases, stabilize human populations, and protect the earth's natural capital by restoring the planet's soils, forests, and fisheries and relying more on renewable energy. Making the shift to a more equitable and environmentally sustainable global society is primarily a political and ethical decision.

17-5 How Do the Major Environmental Worldviews Differ?

CONCEPT 17-5 Major environmental worldviews differ over what is more important—human needs and wants, or the overall health of ecosystems and the biosphere; different worldviews include varying mixes of both priorities.

What Is an Environmental Worldview?

People disagree about how serious our environmental problems are and what we should do about them. These conflicts arise mostly out of differing **environmental worldviews:** ways in which people think the world works, what they believe their roles in the world should be, and their **environmental ethics**—what they believe is right and wrong environmental behavior. Such worldviews can lead to beliefs, behavior, and lifestyles that can work for or against achieving environmental sustainability.

Worldviews, including one's religious beliefs, are built from the answers to fundamental questions: Who am I? Why am I here? What should I do with my life? These views provide key principles or values that help us to understand and to accept or reject the daily flood of information and misinformation that bombards us; they give us a sense of meaning and purpose. 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.

There are many different environmental worldviews. Some of these are *human-centered* (anthropocentric), focusing on needs and wants of people; others are *life-centered* (biocentric), focusing on individual species, the entire biosphere, or some level in between (**Concept 17-5**). Some are based on environmental knowledge and understanding and some are guided more by one's moral or spiritual beliefs.

Most People Have Human-Centered Environmental Worldviews

One human-centered worldview held by many people is the **planetary management worldview.** According to this view, we 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 only *instrumental value* based on how useful they are to us.

According to environmental leader Gus Speth, "This view of the world—that nature belongs to us rather than we to nature—is powerful and pervasive, and it has led to much mischief." Figure 17-16 (left, p. 424) summarizes the four major beliefs or assumptions of one version of this worldview.

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 17-16 (center) summarizes the major beliefs of this worldview. It holds that, when 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 we now enjoy.

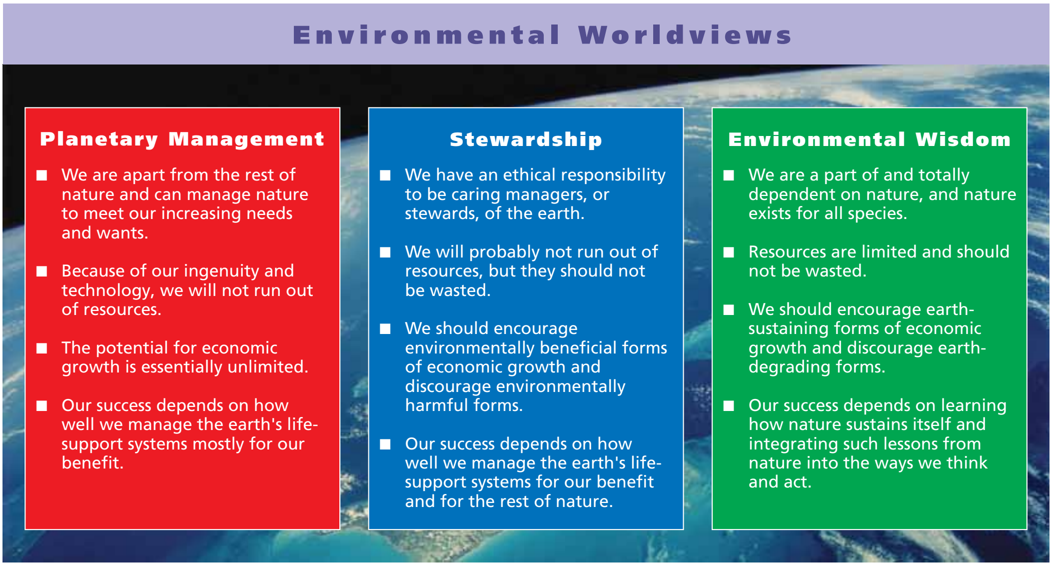


Figure 17-16 Comparison of three major environmental worldviews (**Concept 17-5**). **Questions:** Which of these descriptions most closely fits your worldview? Which of them most closely fits the worldviews of your parents?

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. The image of the earth as a spaceship or an island in space (Figure 4-1, p. 63) has played an important role in raising global environmental awareness. But critics argue that thinking of the earth as a spaceship that we can manage is an oversimplified, arrogant, misleading way to view an incredibly complex and ever-changing planet. This criticism was supported by the failure of an experiment called Biosphere 2 (Science Focus, below).

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. We have only an inkling of what goes on in a handful of soil, a meadow, or any other part of the earth.

SCIENCE FOCUS

Biosphere 2—A Lesson in Humility

In 1991, eight scientists (four men and four women) were sealed inside Biosphere 2, a glass and steel enclosure designed to be a self-sustaining life-support system with which they hoped to increase our understanding of Biosphere 1: the earth's life-support system.

The 1.3-hectare (3.2-acre) 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. They were 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.

From the beginning, many unexpected problems arose and the life-support system began unraveling. Large amounts of oxygen disappeared when soil organisms converted it to carbon dioxide. Additional oxygen had to be pumped in from the outside to keep the Biospherians from suffocating.

Other systems failed. 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 experiment was finished, all plant-pollinating insects became extinct, thereby dooming to extinction most of the plant species.

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.

Some People Have Life-Centered and Earth-Centered Environmental Worldviews

Critics of human-centered environmental worldviews 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 such a life-centered worldview believe we have an ethical responsibility to avoid causing the premature extinction of species, 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 represents a potential economic good for human use (*instrumental value*) and also plays a specific role in its ecosystem.

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 biosphere. This *earth-centered* environmental worldview is devoted to preserving the earth's biodiversity and the functioning of its life-support systems for all forms of life now and in the future.

One earth-centered worldview is called the **environmental wisdom worldview.** Figure 17-6 (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 instead of trying to conquer and manage it mostly for our own benefit (Figure 17-17). In many respects, this is the opposite of the planetary management worldview (Figure 17-16, left).

Courtesy of Earth Flag Co.

Figure 17-17 The earth flag is a symbol of commitment to promoting environmental sustainability by working with the earth at the individual, local, national, and international levels.

This worldview suggests that the earth does not need us managing it in order to go on, whereas we do need the earth in order to survive. *It is futile to try to save the earth, because it does not need saving.* What we need to save is our own species and cultures 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 ThomsonNOW.

17-6 How Can We Live More Sustainably?

CONCEPT 17-6 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

Learning how to live more sustainably (**Concept 1-6**, p. 19, and **Concept 2-5B**, p. 35) requires a foundation of environmental education. Here are some key goals for each person seeking *environmental literacy:*

CONCEPT LINKS

- Develop respect or reverence for all life.
- Understand as much as we can about how life on the earth sustains itself, and use such knowledge to guide our lives, communities, and societies.
- See the big picture by looking for connections within the biosphere and between our actions and the biosphere.
- Use critical thinking skills to become seekers of environmental wisdom, rather than overfilled vessels of environmental information.
- Understand and evaluate our environmental worldviews and see this as a lifelong process.
- Learn how to evaluate the beneficial and harmful consequences for the earth resulting from our lifestyles and professional and personal choices, today and in the future.
- Foster a desire to make the world a better place, and act on this desire.

Specifically, an ecologically literate person should have a basic comprehension of the items listed in Figure 17-18 (p. 426).

According to environmental educator Mitchell Thomashow, four basic questions lie at the heart of environmental literacy. *First,* where do the things I consume come from? *Second,* what do I know about the place where I live? *Third,* how am I connected to the earth and other living things? *Fourth,* what is my purpose and responsibility as a human being? How we answer these questions determines our *ecological identity.*

THINKING ABOUT
Environmental Literacy

How would you answer the four questions listed above?

Becoming environmentally literate and acting on such knowledge requires that we move beyond blame, guilt, fear, and apathy. Some analysts urge us to recognize and avoid common mental traps, which 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* (which some political leaders tend to offer)

Avoiding these traps helps us to hold on to empowering feelings of realistic hope, rather than giving in to immobilizing feelings of despair.

It is also important to recognize that there is no single correct or best solution to each of the environmental problems we face. Indeed, one of nature's **scientific principles of sustainability** holds that preserving diversity—in this case, being flexible and adaptable in trying a variety of solutions to our problems—is the best way to adapt to the earth's largely unpredictable, ever-changing conditions.

Major Components of Environmental Literacy

- Concepts such as environmental sustainability, natural capital, exponential growth, carrying capacity, risk, and risk analysis
- Four 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 17-18 Major components of environmental literacy (**Concept 17-6**). **Question:** After taking this course do you feel that you have a basic understanding of each of these items?

We Can Learn from Nature

Formal environmental education is important, but is it enough? Many analysts say no. They call for us to appreciate not just the economic value of nature, but also its ecological, aesthetic, and spiritual value. To these analysts, the problem is not just a lack of environmental literacy but also a lack of intimacy with nature and how it sustains us. They urge us to escape the cultural and technological body armor we use to insulate ourselves from nature and to experience and learn directly from nature (**Concept 17-6**).

They suggest we kindle a sense of awe, wonder, mystery, and humility by standing under the stars, sitting in a forest, or taking in the majesty and power of an ocean. We might pick up a handful of soil and try to sense the teeming microscopic life within it. We might look at a tree, mountain, rock, or bee and try to sense how they are a part of us and we a part of them as interdependent participants in the earth's life-sustaining recycling processes.

Many psychologists believe that, consciously or unconsciously, we spend much of our lives searching for roots—something to anchor us in a bewildering and frightening sea of change. As philosopher Simone Weil observed, "To be rooted is perhaps the most important and least recognized need of the human soul."

Earth-focused philosophers say that to be rooted, each of us needs to find a *sense of place*—a stream, a mountain, a yard, a neighborhood lot—any piece of the earth with which we feel at one, as a place we know, experience emotionally, and love. According to biologist Stephen Jay Gould, "We will not fight to save what we do not love." When we become part of a place, it becomes a part of us. Then we are driven to defend it from harm and to help heal its wounds.

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 Aldo Leopold called "the green fire that burns in our hearts" and use it as a force for respecting and working with the earth and with one another.

Some Affluent People Are Choosing to Live More Simply

For poor people, income and well-being are connected, because they have to use most of their meager income to meet their basic survival needs. This is not the case for many affluent people who are more often concerned about meeting an expanding list of wants beyond their basic needs.

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.

Polls reveal that too many people are working too many hours to buy too much stuff that gives them too little true happiness. According to research by psychologists, deep down, what most people really want is more community, not more stuff. They want greater and more fulfilling interactions among family, friends, and neighbors and a greater opportunity to express their creativity.

In general, research indicates that money buys happiness up to an annual income of about $10,000 per person. After that, studies in a number of nations show that there is little correlation between increasing happiness or life satisfaction as incomes rise.

Some affluent people in developed countries are adopting a lifestyle of *voluntary simplicity,* learning to live more simply and sustainably and spending more time with their loved ones, friends, and neighbors (**Concept 17-6**). Voluntary simplicity applies Mahatma Gandhi's *principle of enoughness:* "The earth provides enough to satisfy every person's need but not every person's greed. . . . When we take more than we need, we are simply taking from each other, borrowing from the future, or destroying the environment and other species."

Most of the world's major religions have similar teachings: "You cannot be the slave both of God and money" (Christianity: Matthew, 6:24); "Eat and drink, but waste not by excess" (Islam: Q'uran 7.31); "One should abstain from acquisitiveness" (Hinduism: Acarangasutra 2.119); "He who knows he has enough is rich" (Taoism: Tao Te Ching, Chapter 33); "Give me neither poverty nor riches" (Judaism: Proverbs, 30.8); "Whosoever in this world overcomes his selfish cravings, his sorrows fall away from him" (Buddhism: Dhammapada, 336).

Implementing this principle means asking ourselves, "How much is enough?" This is not easy, because people in affluent societies are conditioned to want more and more. And as a result of a lifetime of exposure to commercial advertising they often think of such wants as needs. But some affluent people are downsizing their lives by learning how to do with less and to reuse and share things.

Some communities have established tool libraries where people can check out hand and power tools and garden and lawn equipment. In the U.S. city of Philadelphia, Pennsylvania, a local nonprofit organization gives city employees access to fuel-efficient hybrid vehicles (Figure 13-21, p. 300). In Europe, thousands of people have signed up for car-sharing programs.

A growing number of religious leaders and members of all faiths are calling for governments and individuals to focus on the environmental problems we face. They point out that these problems bring a sense of urgency and shared purpose matched by few other issues, and that the teachings of the world's great religions remind us of our moral and spiritual obligations to help sustain the earth for current and future generations. According to Gary T. Gardner, Director of Research at the Worldwatch Institute and author of *Inspiring Progress: Religions' Contributions to Sustainable Development* (Norton, 2006), "Without ethics, without a deep spiritual respect for life and for the planet that supports us, progress over the next 50 years will likely be little more than progressive decline."

Some People Are Choosing to Live More Lightly on the Earth

Throughout this text, you have encountered lists of things you can do to reduce the *size* and *force* of our environmental footprints on the earth. None of us can do all of these things, so which ones are the most important?

The aspects of our lifestyles that have the greatest harmful impacts on the environment are *agriculture, transportation, home energy use, water use,* and our *overall resource consumption and waste.* Figure 17-19 (p. 428) lists the *sustainability dozen*—key ways in which some people are choosing to walk more lightly on the earth.

We Can Bring About a Sustainability Revolution during Your Lifetime

The industrial revolution took place during the past 275 years. Now in the 21st century, environmental leaders say it is time for an *environmental* or *sustainability revolution.* It would have several interrelated components:

- *Biodiversity protection*—dedication to protecting and sustaining the genes, species, natural systems, and

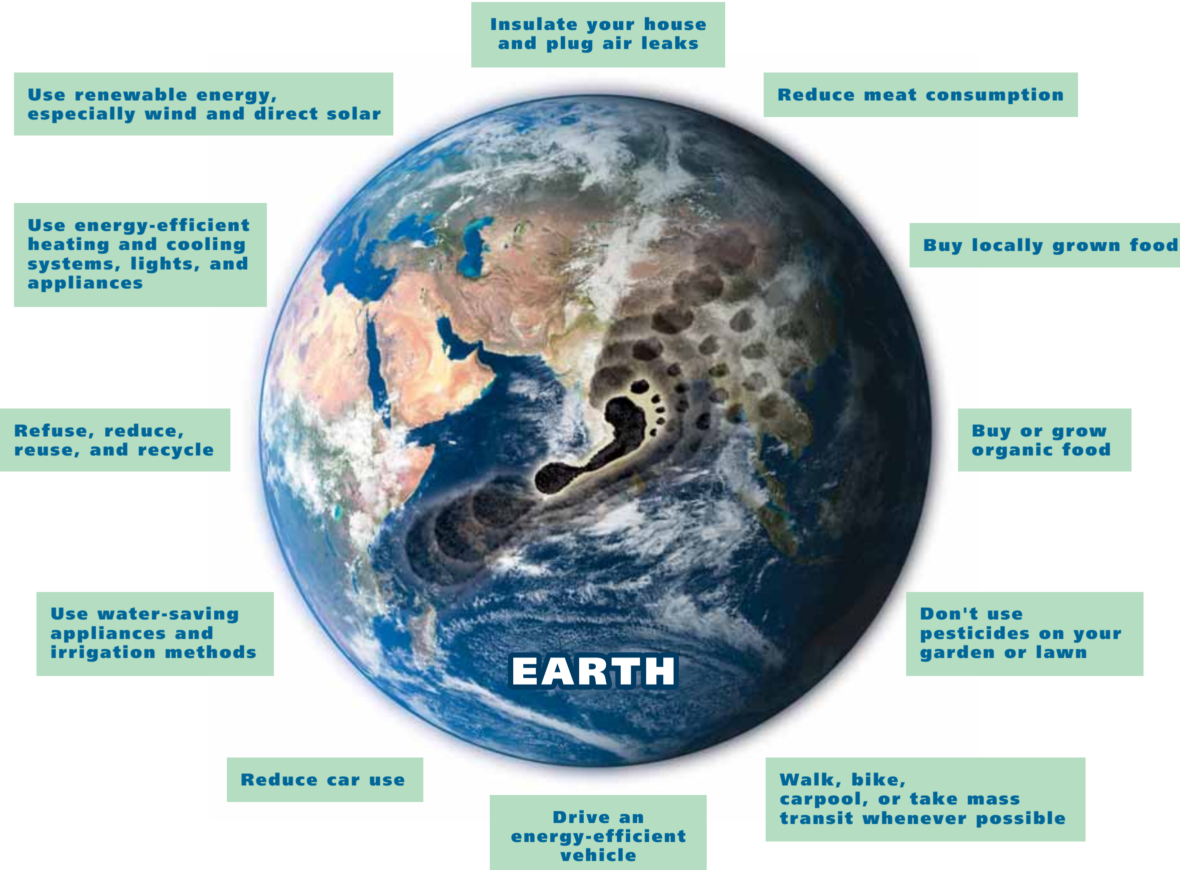


Figure 17-19 **Solutions:** *the sustainability dozen*—12 ways in which people can live more lightly on the earth (**Concept 17-6**). **Questions:** Which of these things do you already do? Which, if any, do you hope to do?

chemical and biological processes that make up the earth's biodiversity

- A *commitment to efficiency,* sharply reducing our waste of matter and energy resources
- An *energy transformation,* decreasing our dependence on carbon-based, nonrenewable fossil fuels and increasing our reliance on renewable energy from the sun, wind, flowing water, biomass, and geothermal sources
- *Pollution prevention*—a commitment to reducing pollution and environmental degradation by applying the precautionary principle
- 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 with less
- A *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 systems to reward environmentally beneficial behavior and to discourage environmentally harmful behavior

Science fiction writers have spun stories about humans living in space or on other planets. But the immediate reality is that this beautiful planet with its diverse life and incredibly complex life-support system is all we have for the foreseeable future. We are at the end of ecological childhood, and during your lifetime we would be wise to achieve ecological adulthood and use ecological wisdom to respect and sustain the life-support systems on this unique and marvelous planet that is our home.

Currently, we have the natural and financial wealth to make such a transition. But waiting any longer to deal with our environmental problems could drain these forms of wealth.

REVISITING The Nashua River and Sustainability

The work of Marion Stoddart and her colleagues in the Nashua River watershed (**Core Case Study**) is a model for how to bring about environmentally beneficial changes that could be applied on a global scale. Such efforts can be guided by the four **scientific principles of sustainability** (see back cover).

Because the environmental and social problems we face are interrelated, the solutions to these problems also are interrelated. For example, reducing oil and coal use by improving energy efficiency and relying more on renewable energy also reduces air pollution, can slow climate change by reducing greenhouse gas emissions, and helps protect biodiversity.

Likewise, reforestation increases aquifer recharge, reduces soil erosion, helps protect biodiversity, and slows climate change by removing carbon dioxide from the atmosphere. And efforts to eradicate poverty help us to stabilize population, sharply reduce hunger and malnutrition, and decrease environmental degradation. Once we begin these environmentally positive trends, they will reinforce one another and speed up the transition to more sustainable societies. Environmentally beneficial changes can occur much more rapidly than we think.

In working to make the earth a better and more sustainable place to live, we should be guided by George Bernard Shaw's reminder that "indifference is the essence of inhumanity" and 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 in dealing with the environmental challenges we face.

Those challenges are awesome, but they can be overcome. What an exciting time to be alive!

When there is no dream, the people perish.

PROVERBS 29:18

REVIEW QUESTIONS

1. Explain why some people would consider Marion Stoddart to be an environmental hero.
2. Provide an argument to support the view that the world economy is directly linked to, and dependent upon, the earth's natural resources.
3. Summarize the potential strategies put forward by ecological and environmental economists that could be used to help make the transition to an eco-economy over the next twenty years.
4. Explain how phasing in full-cost pricing would benefit the environment. Discuss the pros and cons of imposing specific taxes and fees in order to help protect the environment.
5. Describe the links between poverty and environmental degradation. Discuss ways that could be implemented to help alleviate global poverty.
6. Summarize the principles that have been suggested for shifting to a more environmentally sustainable economy.
7. Give examples of how an individual could positively influence environmental policy. Provide an argument for strengthening current environmental laws and regulations. How would opponents respond to your viewpoint?
8. Compare and contrast three major environmental worldviews.
9. Explain how raising global environmental literacy would effect sustainability.
10. Discuss how individuals could reduce their ecological footprints by implementing the sustainability dozen.

CRITICAL THINKING

1. List three ways in which you could apply **Concept 17-6** (p. 425) to making your lifestyle more environmentally sustainable.
2. If you could, would you work to improve some aspect of the environment in your local community as Marion Stoddart did? (**Core Case Study**) Would you do anything differently from the way that she did it?
3. Suppose that over the next 20 years, the environmental and health costs of goods and services are internalized until their market prices reflect their total costs. What harmful and beneficial effects might such full-cost pricing have on your lifestyle?
4. List all the goods you use, and then identify those that meet your basic needs and those that satisfy your wants.

Identify any economic wants that **(a)** you would be willing to give up and **(b)** you believe you should give up but are unwilling to give up. Relate the results of this analysis to your personal impact on the environment. Compare your results with those of your classmates.

5. Explain why you agree or disagree with each of the eight principles listed on p. 415, recommended by some analysts for use in making environmental policy decisions.
6. Explain why you agree or disagree with
   - **a.** each of the four principles that some biologists and economists have suggested for deciding how to use public lands in the United States (p. 418) or in the country where you live.
   - **b.** each of the eight suggestions made by some developers and resource extractors for managing and using U.S. public land (p. 418).
7. Do you believe that we have an ethical responsibility to leave the earth's natural systems in as good a condition as they are now or better? Explain. List three aspects of your lifestyle that hinder implementing this ideal and three aspects that promote this ideal.
8. This chapter summarized several different environmental worldviews. Go through these worldviews and find the beliefs you agree with, and then describe your own environmental worldview. Which of your beliefs were added or modified as a result of taking this course? Compare your answer with those of your classmates.
9. 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 anything they want with land they own, regardless of whether such actions harm the environment, 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 consistent with the beliefs making up your environmental worldview, which you described in Question 8?
10. List two questions that you would like to have answered as a result of reading this chapter.

LEARNING ONLINE

Log on to the Student Companion Site for this book at **www.thomsonedu.com/biology/miller** and choose Chapter 17 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Web links, information on Green Careers, and InfoTrac® College Edition articles.

For access to animations and additional quizzing, register and log on to ThomsonNOW! at **www.thomsonedu.com/thomsonnow** using the access code card in the front of your book.

Supplements

SUPPLEMENT

1 Measurement Units, Precision, and Accuracy (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) = 1,000,000,000 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):
$°F = (°C \times 1.80) + 32.0$

Uncertainty, Accuracy, and Precision in Scientific Measurements

How do we know whether a scientific measurement is correct? All scientific observations and measurements have some degree of *uncertainty* because people and measuring devices are not perfect.

However, scientists take great pains to reduce the errors in observations and measurements by using standard procedures and by testing (calibrating) measuring devices. They also repeat their measurements several times, and then find the average value of these measurements.

It is important to distinguish between accuracy and precision when determining the uncertainty involved in a measurement. *Accuracy* is how well a measurement conforms to the accepted correct value for the measured quantity, based on careful measurements by many people over a long time. *Precision* is a measure of *reproducibility,* or how closely a series of measurements of the same quantity agree with *one another.*

Figure 1 The distinction between accuracy and precision. In scientific measurements, a measuring device that has not been calibrated to determine its accuracy may give precise or reproducible results that are not accurate.

The dartboard analogy shown in Figure 1 shows the difference between precision and accuracy. *Accuracy* depends on how close the darts are to the bull's-eye. *Precision* depends on how close the darts are to each other. Note that good precision is necessary for accuracy but does not guarantee it. Three closely spaced darts may be far from the bull's-eye.

SUPPLEMENT

2 Graphing

In science, graphs convey information that can be summarized numerically. This information, called *data*, is collected in experiments, surveys, historical studies, and other information gathering activities. In this textbook and accompanying web-based Active Graphing exercises, we use three types—line graphs, bar charts, and pie charts.

Line graphs usually represent data that falls 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* (see Figure 1). The possible measurements of some variable, such as temperature, which changes over time or distance, usually lie on the vertical *y-axis*. The curving line on the graph represents the measurements taken at certain time or distance intervals. A good example of this application is the bottom graph in Figure 1-8, p. 13.

Another important use of the line graph is to show experimental results such as changes in a dependent variable in response to changes in an independent variable. For example, we measure

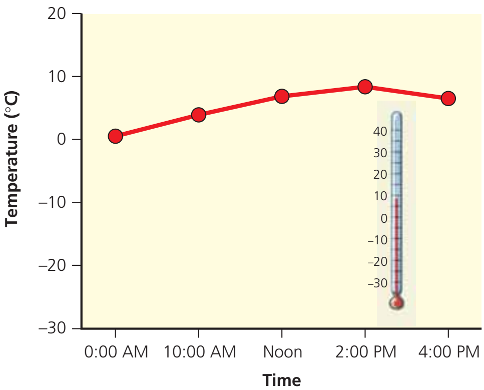


Figure 1 Temperature changes on a winter day (in Centigrade degrees).

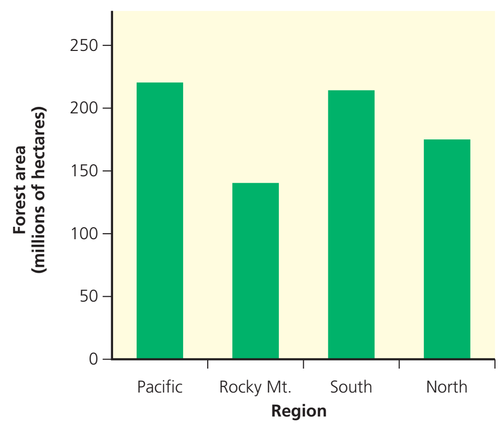


Figure 2 Forest area in four regions of the United States in 2002.

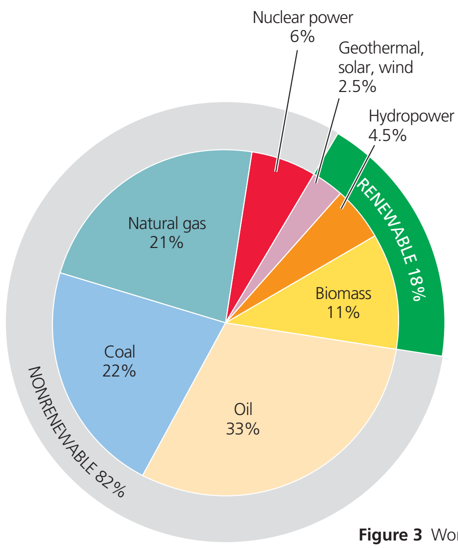


Figure 3 World energy use by source.

changes in toxicity of a chemical (dependent variable) with increases in the dosage of the chemical (independent variable). See Figure 1 on p. S71 in Supplement 17, and the Active Graphing exercise for Chapter 14.

The *bar chart* is used to compare measurements for one or more variables across categories. For instance, we could compare the amount of forested land in four regions of the United States, as in Figure 2.

See also the Active Graphing exercise for Chapter 9, which includes the data in Figure 2 along with similar data sets for other years. This enables us to compare not only the regional forest coverage but also how that coverage has changed over time across the regions.

In these examples, the categories are laid out on the x-axis, while the range of measurements for the variable under consideration lies along the y-axis. This is usually the case, although the information on the axes can be reversed. See for example Figures 7-8 (p. 131) and 7-10 (p. 132) depicting age structure diagrams, in which the bars are placed horizontally. This is another way to compare two data sets (in this case, for males and females) across categories.

Like bar charts, *pie charts* illustrate numerical values for more than one category. But in addition to that, they show each category's proportion of the total of all measurements. For example, Figure 3 shows how much each major energy source contributes to the world's total amount of energy used. Usually, the categories are ordered on the chart from largest to smallest, for ease of comparison, although this is not always the case.

Figure 13-3, p. 281, shows this and other data in more detail, revealing how pie charts can be used to compare different groups of categories and different data sets. Also, see the Active Graphing exercise for Chapter 13.

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 ThomsonNOW™ 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.

SUPPLEMENT 3

Maps of Global Economic, Population, and Hunger Data

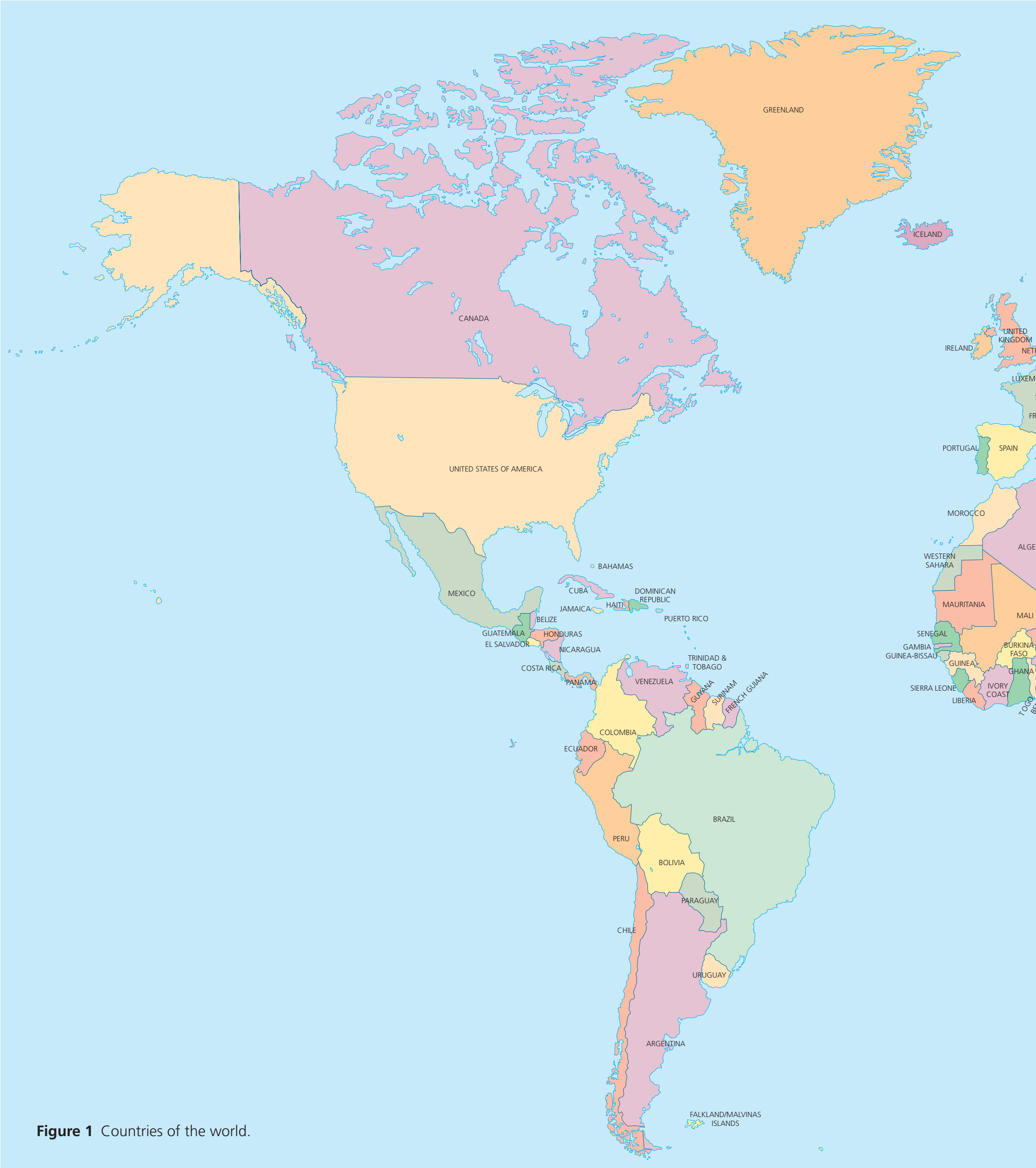


Figure 1 Countries of the world.


RUSSIA
FINLAND
SWEDEN
NORWAY
ESTONIA
LATVIA
LITHUANIA
DENMARK
BELARUS
BELGIUM
GERMANY
POLAND
CZECH REP.
SLOVAKIA
AUSTRIA
HUNGARY
UKRAINE
MOLDOVA
SLOVENIA
CROATIA
ROMANIA
YUGOSLAVIA
BOSNIA-HERZEGOVINA
BULGARIA
MACEDONIA
ITALY
ALBANIA
GREECE
GEORGIA
ARMENIA
AZERBAIJAN
TURKEY
KAZAKHSTAN
UZBEKISTAN
TURKMENISTAN
KYRGYZSTAN
TAJIKISTAN
MONGOLIA
NORTH KOREA
SOUTH KOREA
JAPAN
CHINA
CYPRUS
SYRIA
LEBANON
ISRAEL
IRAQ
IRAN
AFGHANISTAN
JORDAN
KUWAIT
PAKISTAN
NEPAL
BHUTAN
TUNISIA
LIBYA
EGYPT
SAUDI ARABIA
QATAR
UNITED ARAB EMIRATES
BANGLADESH
INDIA
TAIWAN
HONG KONG
MYANMAR
LAOS
OMAN
NIGER
CHAD
ERITREA
YEMEN
THAILAND
VIETNAM
PHILIPPINES
CAMBODIA
SUDAN
NIGERIA
ETHIOPIA
CENTRAL AFRICAN REPUBLIC
CAMEROON
SRI LANKA
BRUNEI
MALAYSIA
SOMALIA
UGANDA
EQUATORIAL GUINEA
GABON
CONGO
DEMOCRATIC REPUBLIC OF CONGO
KENYA
RAWANDA
BARUNDI
TANZANIA
INDONESIA
PAPUA NEW GUINEA
SOLOMON ISLANDS
ANGOLA
MALAWI
ZAMBIA
MOZAMBIQUE
VANUATU
FIJI
NAMIBIA
ZIMBABWE
MADAGASCAR
MAURITIUS
RÉUNION
BOTSWANA
NEW CALEDONIA
AUSTRALIA
SWAZILAND
LESOTHO
SOUTH AFRICA
NEW ZEALAND

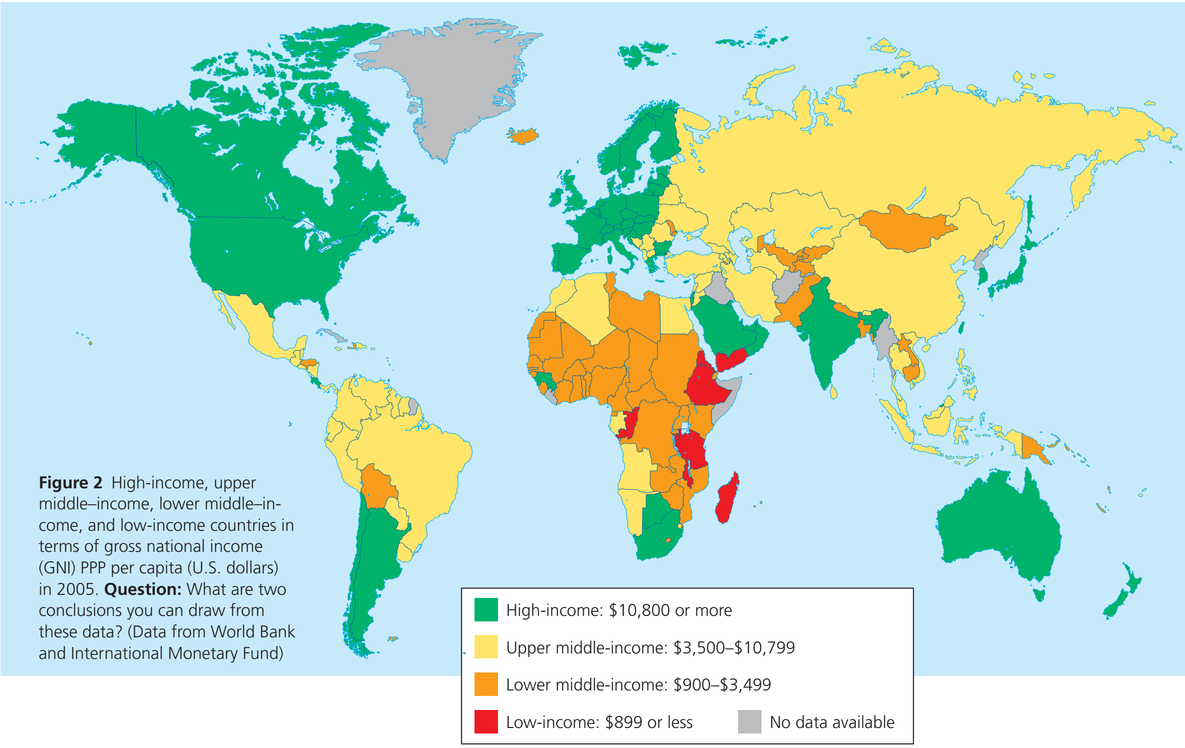


Figure 2 High-income, upper middle–income, lower middle–income, and low-income countries in terms of gross national income (GNI) PPP per capita (U.S. dollars) in 2005. **Question:** What are two conclusions you can draw from these data? (Data from World Bank and International Monetary Fund)

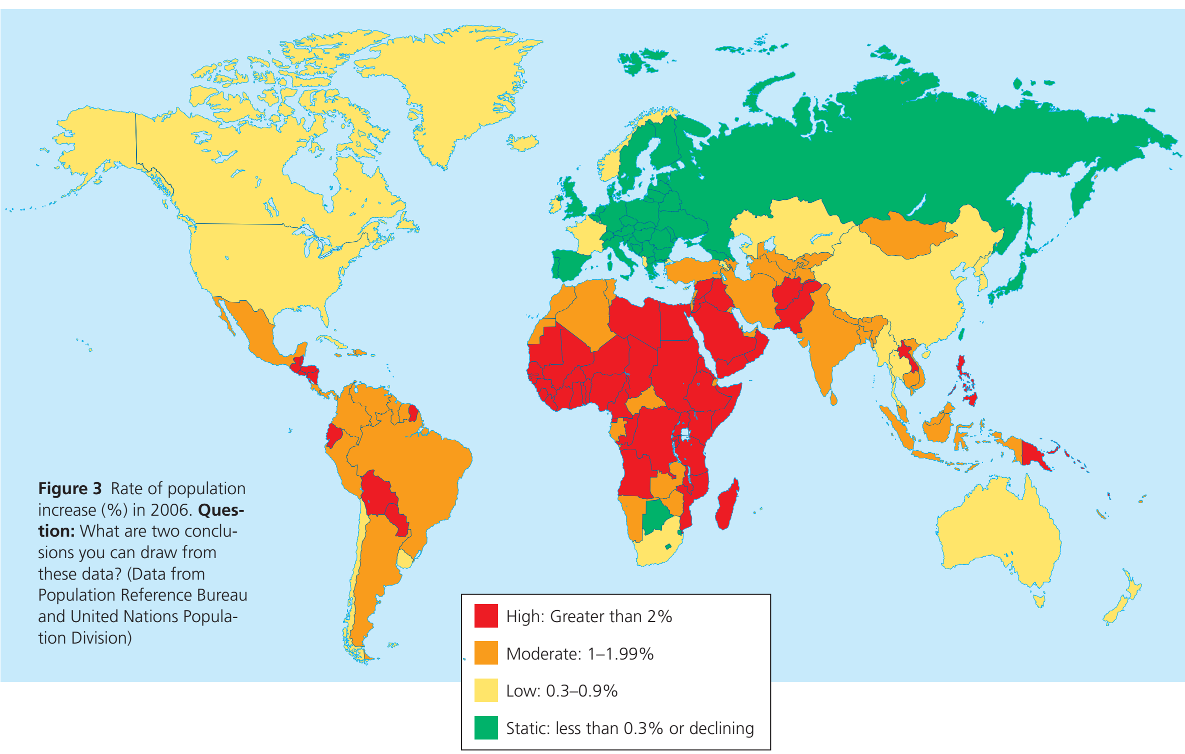


Figure 3 Rate of population increase (%) in 2006. **Question:** What are two conclusions you can draw from these data? (Data from Population Reference Bureau and United Nations Population Division)

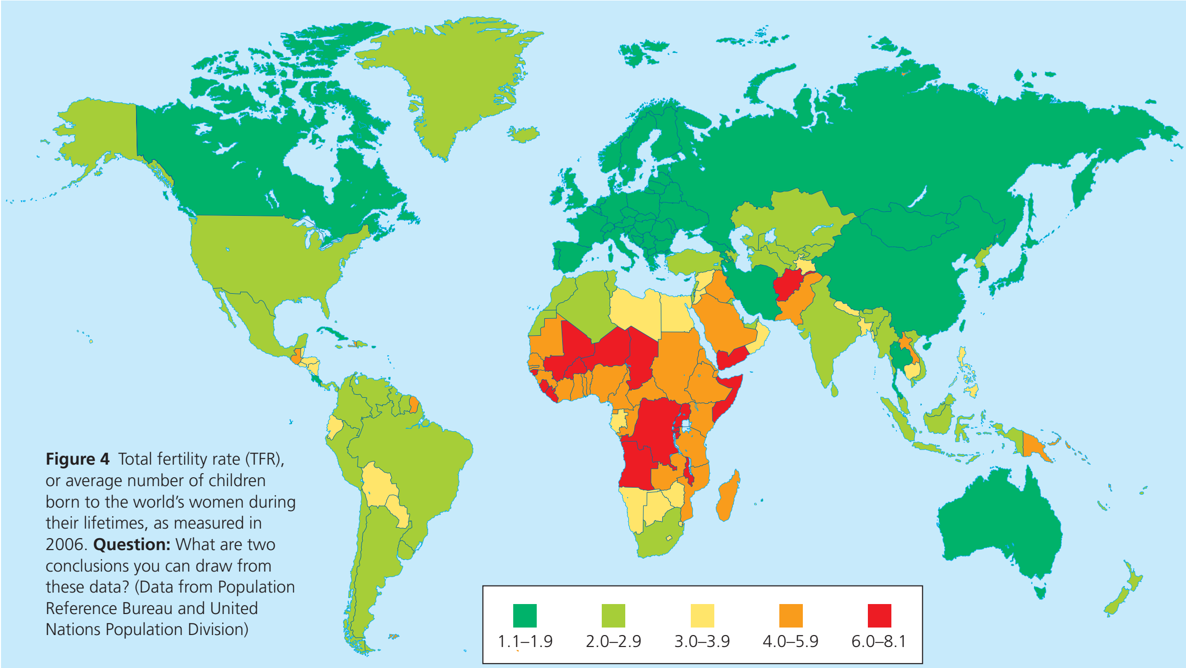


Figure 4 Total fertility rate (TFR), or average number of children born to the world's women during their lifetimes, as measured in 2006. **Question:** What are two conclusions you can draw from these data? (Data from Population Reference Bureau and United Nations Population Division)

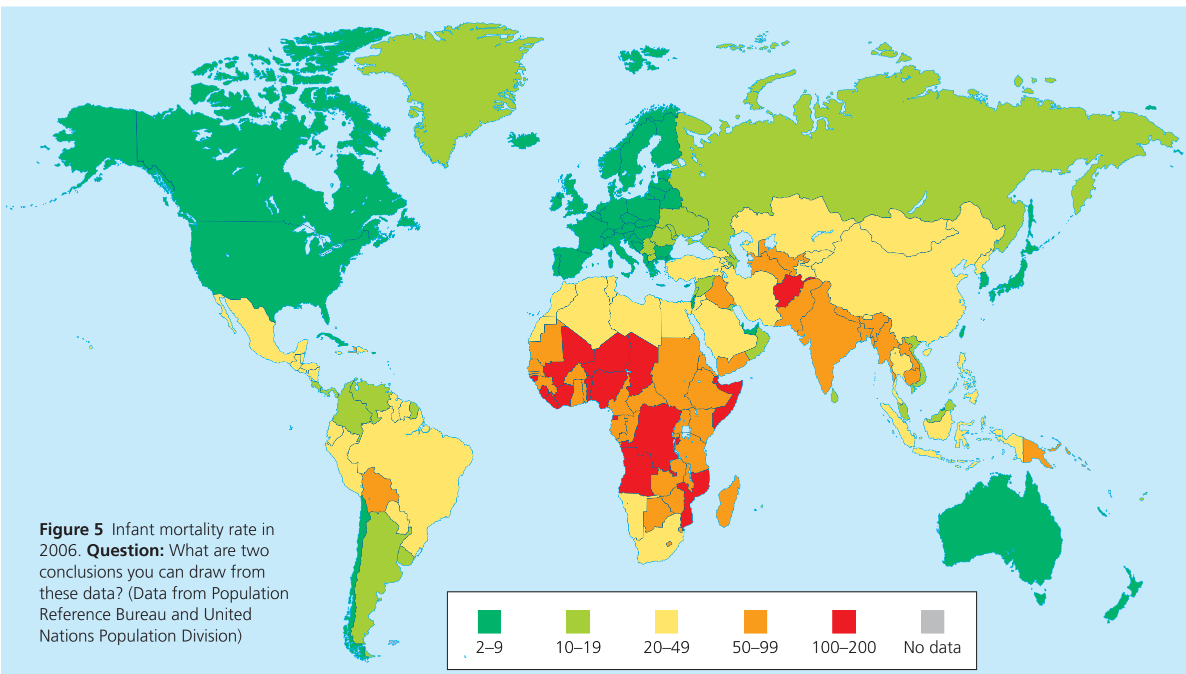


Figure 5 Infant mortality rate in 2006. **Question:** What are two conclusions you can draw from these data? (Data from Population Reference Bureau and United Nations Population Division)

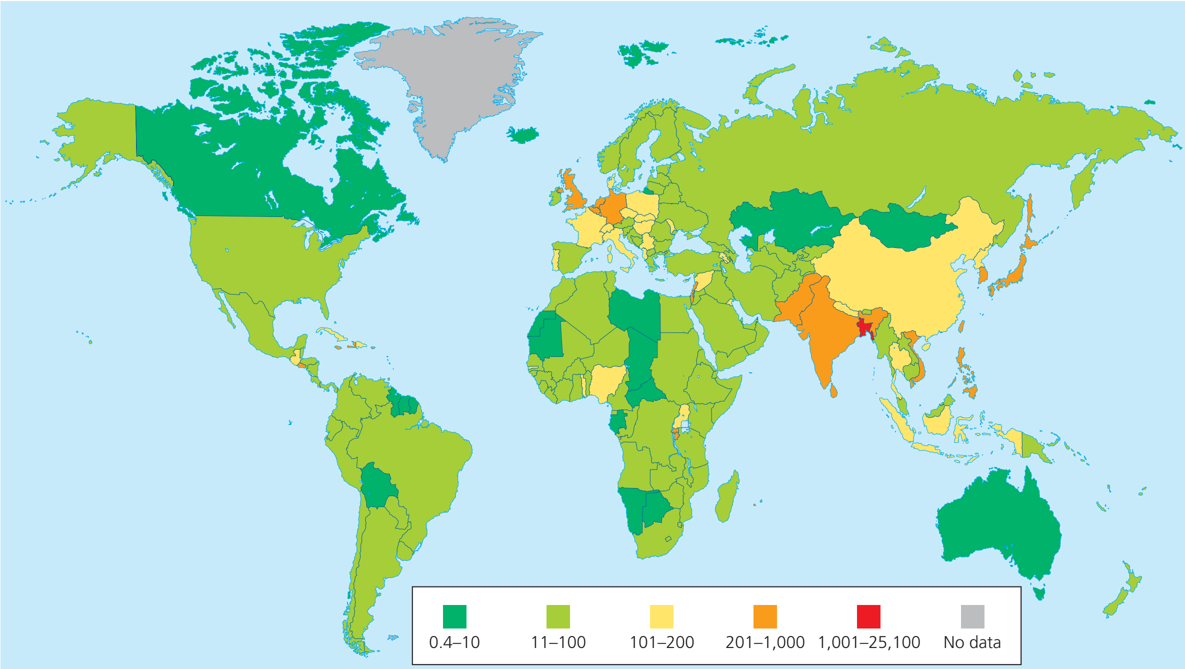


Figure 6 Population density per square kilometer (0.4 square miles) in 2006. **Question:** What are two conclusions you can draw from these data? (Data from Population Reference Bureau and United Nations Population Division)

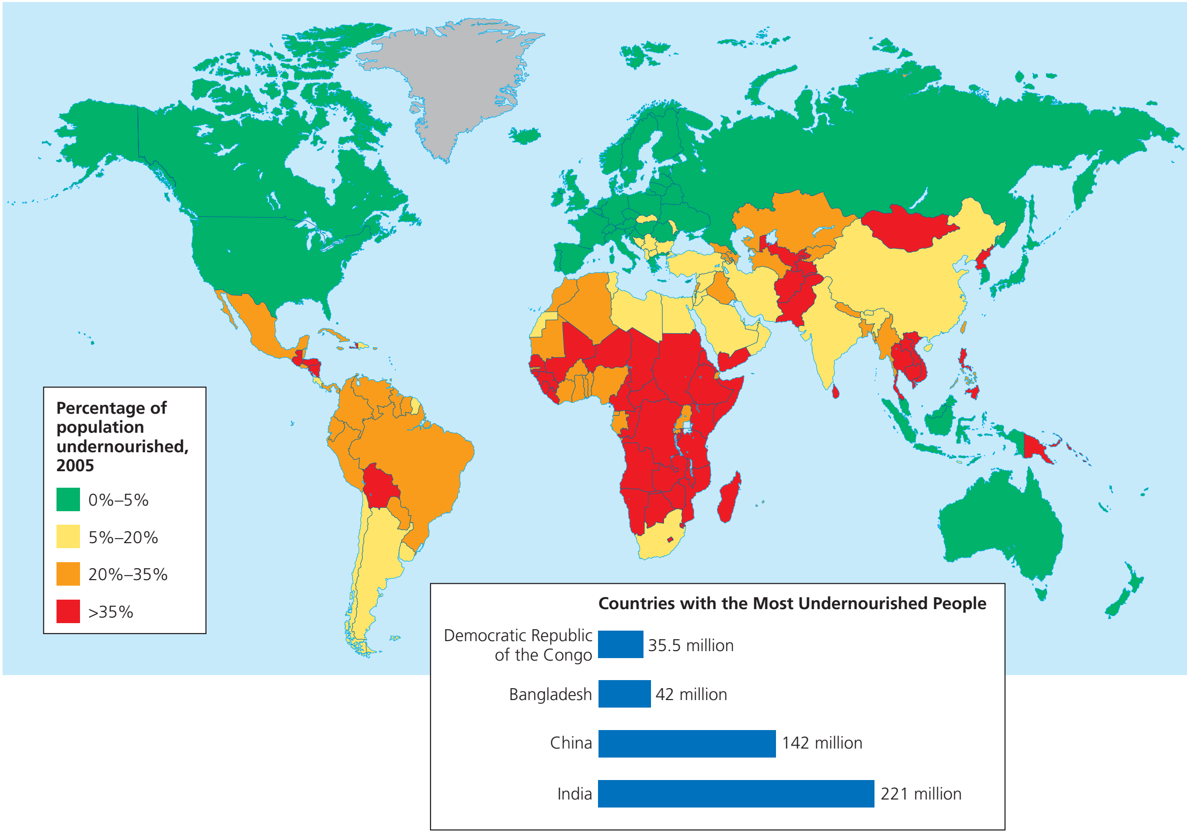


Figure 7 World hunger shown as a percentage of population suffering from chronic hunger and malnutrition in 2005. **Question:** What are two conclusions you can draw from these data? (Data from Food and Agriculture Organization, United Nations)

SUPPLEMENT 4

Maps of Biodiversity, Ecological Footprints, and Environmental Performance

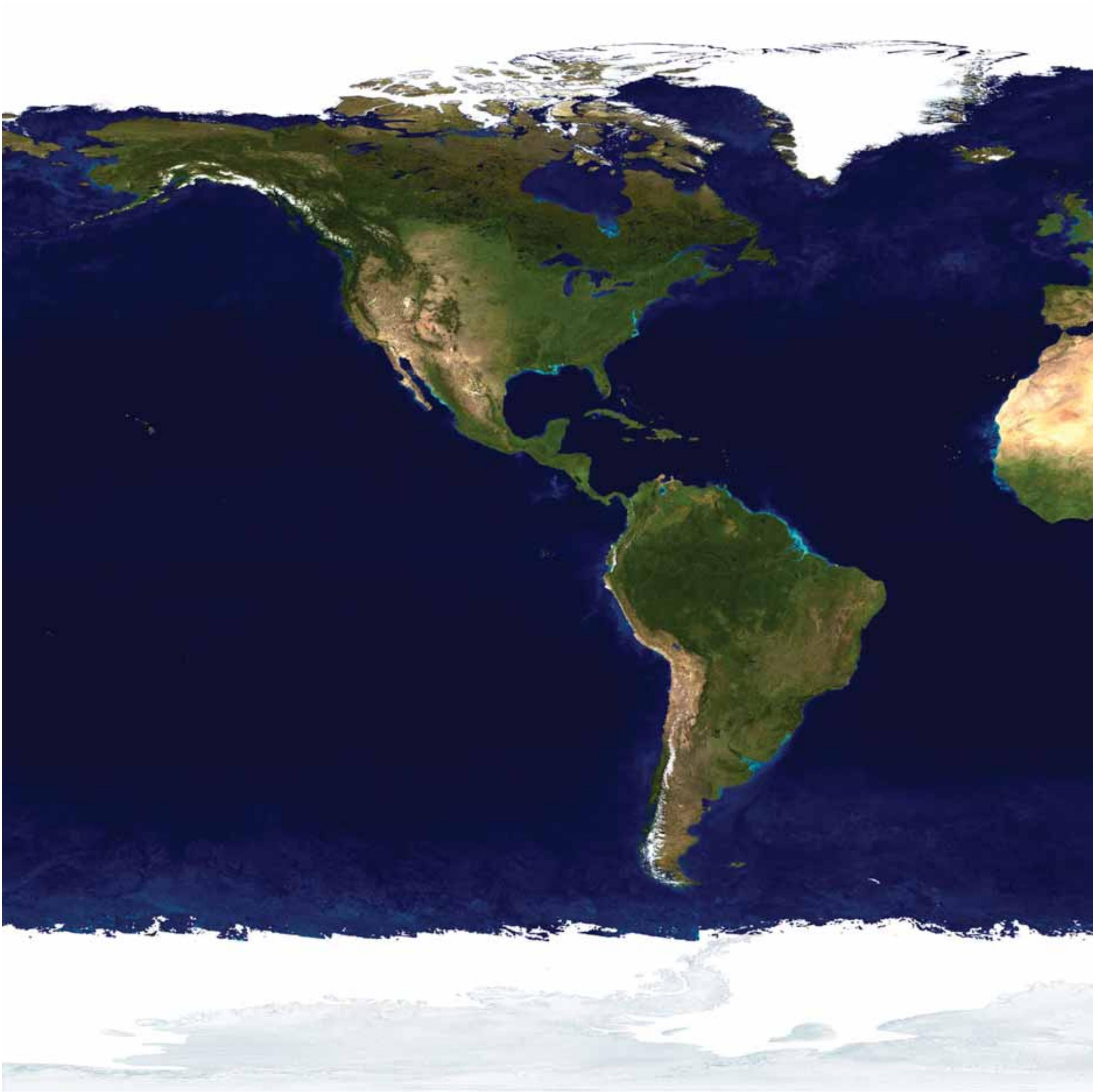
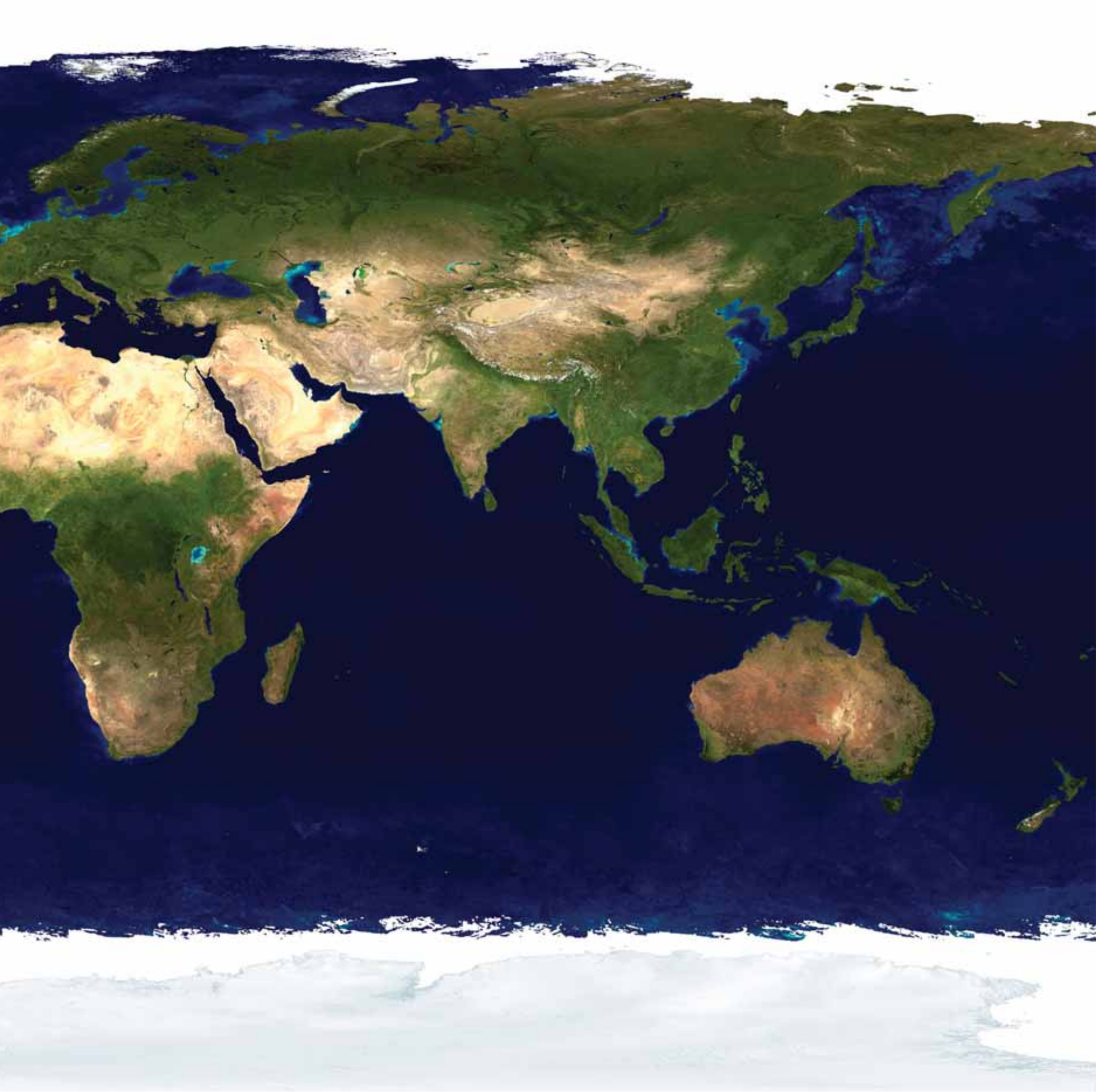


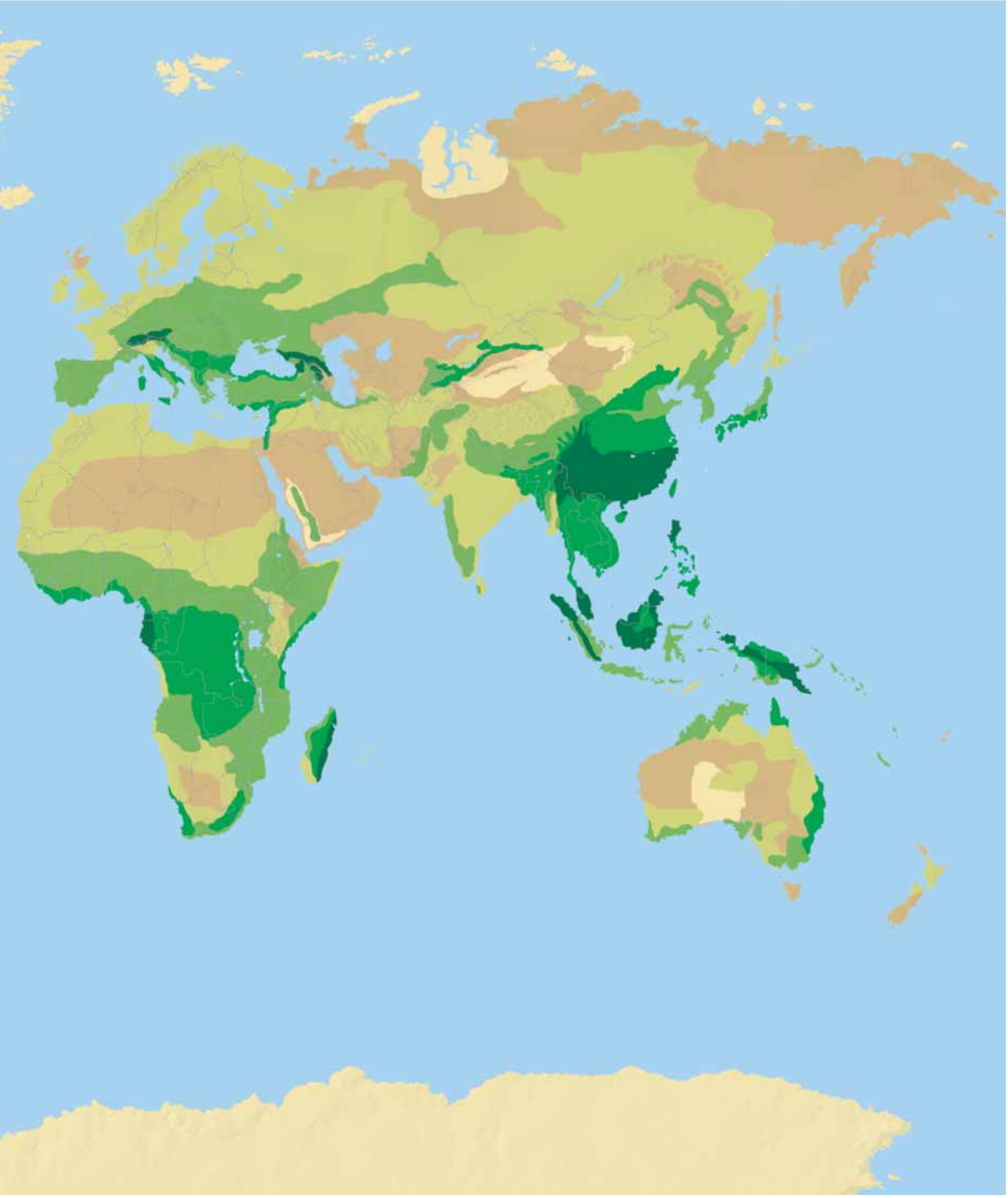
Figure 1 Composite satellite view of the earth showing its major terrestrial and aquatic features.

(Chapters 1, 3–11, 17)



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 **Natural capital:** global map of plant biodiversity. **Question:** What are two conclusions you can draw from these data? (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)



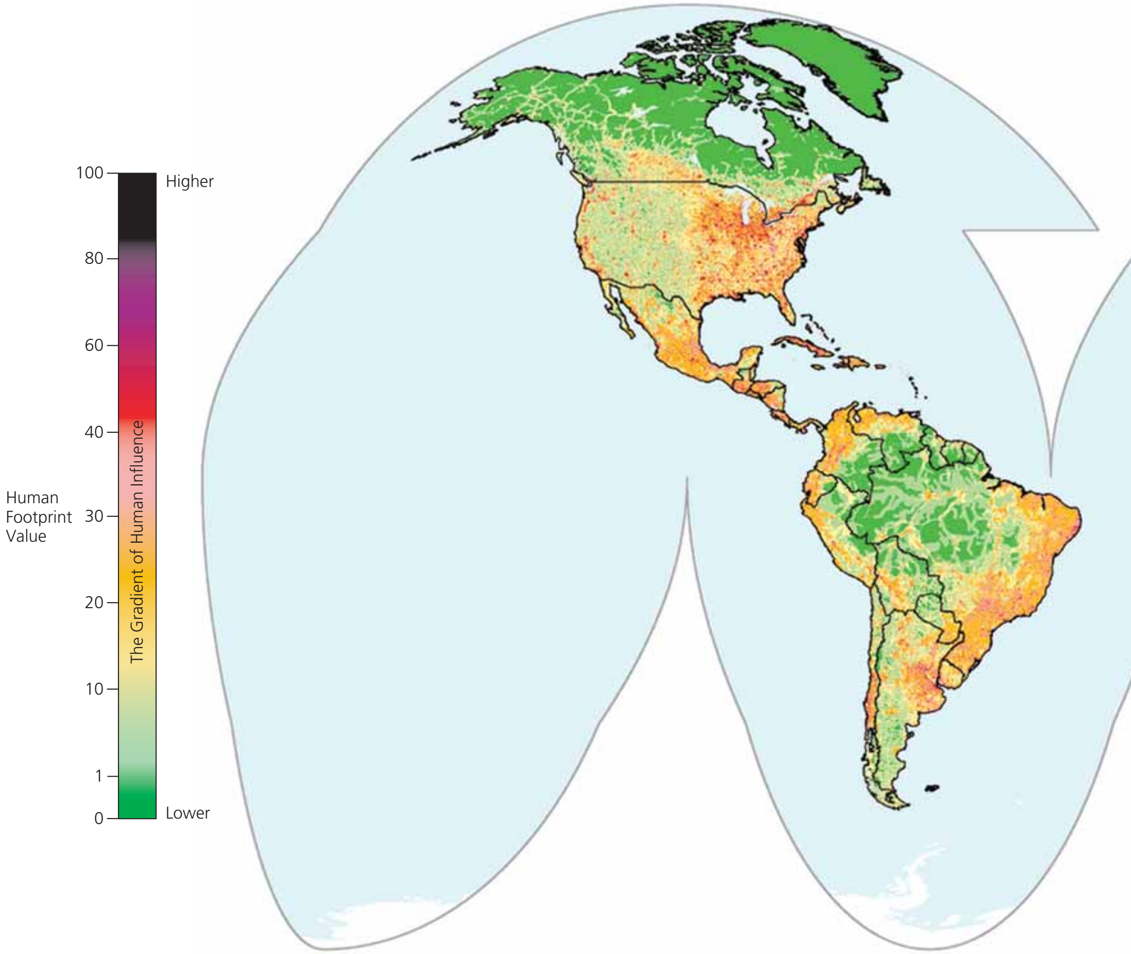
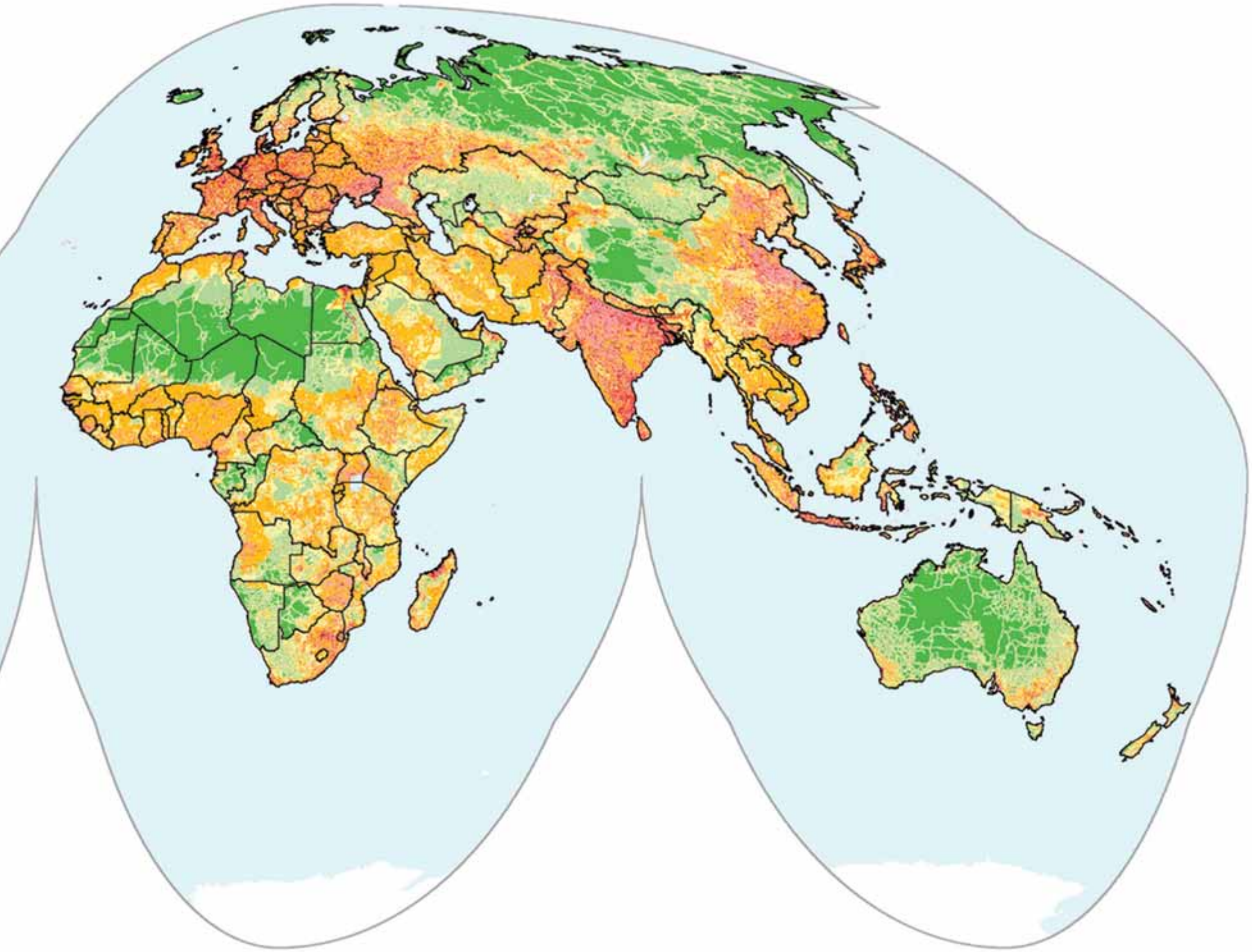


Figure 3 **Natural capital degradation:** the human footprint on the earth's land surface—in effect the sum of all ecological footprints (Figure 1-8, p. 13) of the human population. Colors represent the percentage of each area influenced by human activities. Excluding Antarctica and Greenland, human activities have directly affected to some degree about 83% of the earth's land surface and 98% of the area where it is possible to grow rice, wheat, or maize. **Question:** What are two conclusions you can draw from these data? (Data from Wildlife Conservation Society and the Center for International Earth Science Information Network at Columbia University)



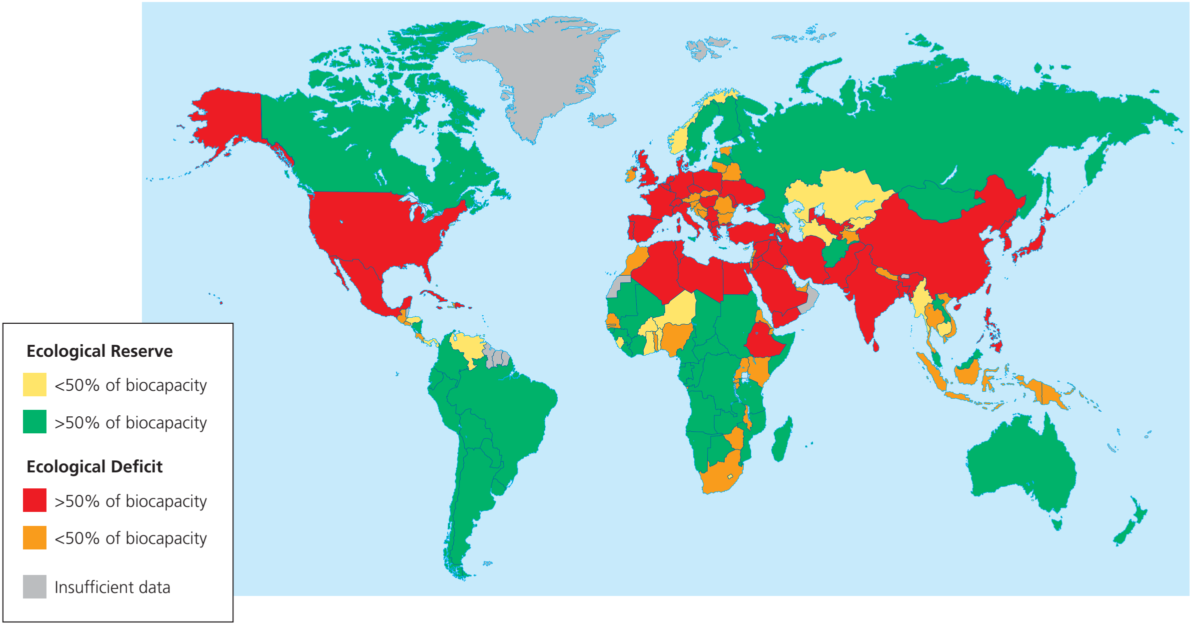


Figure 4 *Ecological debtors and creditors:* the ecological footprints of some countries exceed their biocapacity, while others still have ecological reserves. **Question:** What are two conclusions you can draw from these data? (Data from Global Footprint Network)

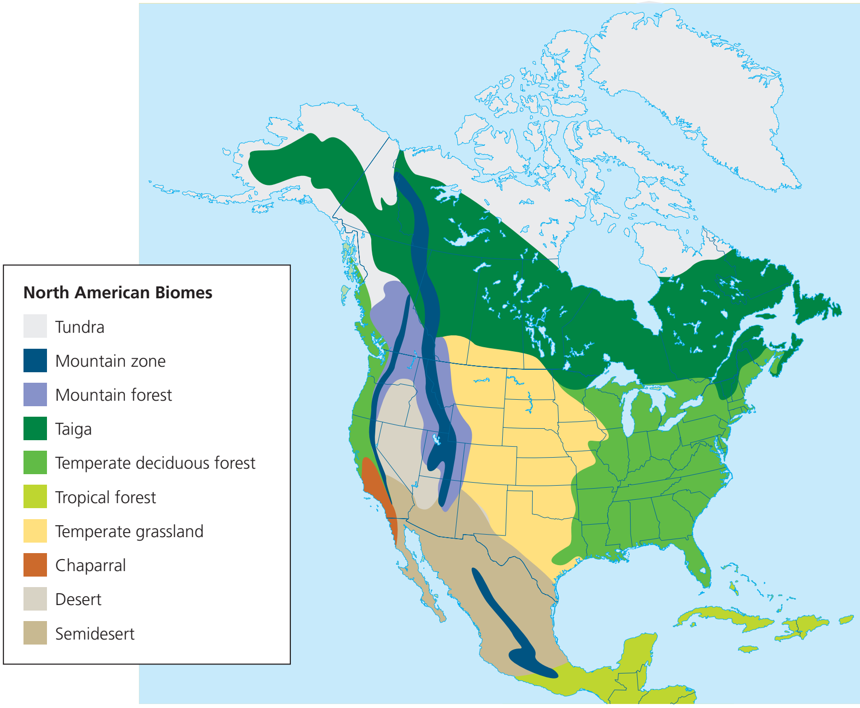
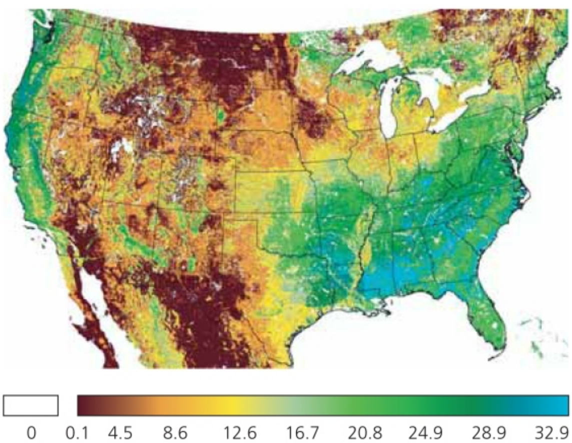
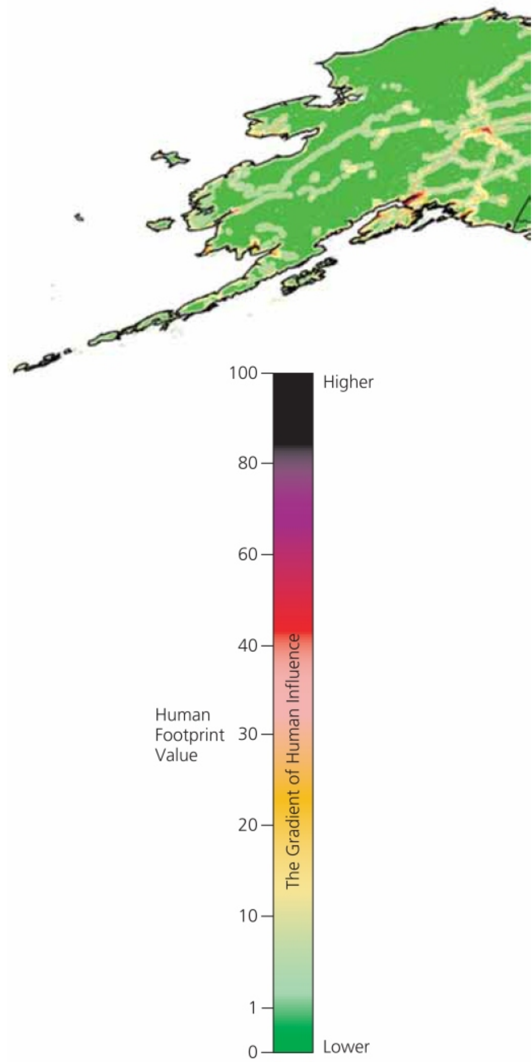


Figure 5 **Natural capital:** biomes of North America.



Gross primary productivity
(grams of carbon per square meter)

Figure 6 Gross primary productivity across the continental United States, based on remote satellite data. The differences roughly correlate with variations in moisture and soil types. **Question:** What are two conclusions you can draw from these data? (NASA's Earth Observatory)



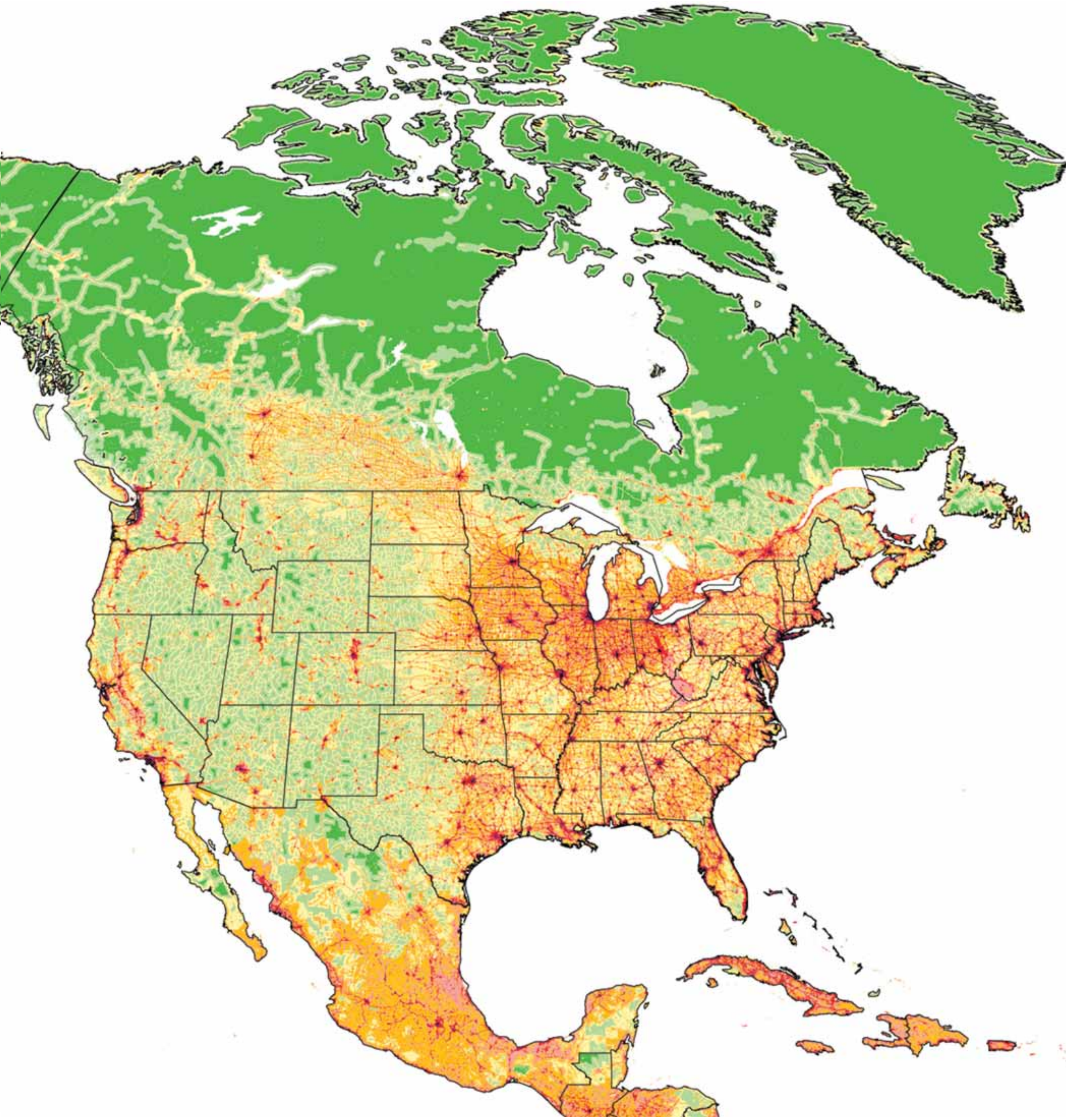


Figure 7 **Natural capital degradation:** the human ecological footprint in North America. Colors represent the percentage of each area influenced by human activities. This is an expanded portion of Figure 3 showing the human footprint on the earth's entire land surface. **Question:** What are two conclusions you can draw from these data? (Data from Wildlife Conservation Society and the Center for International Earth Science Information Network at Columbia University)

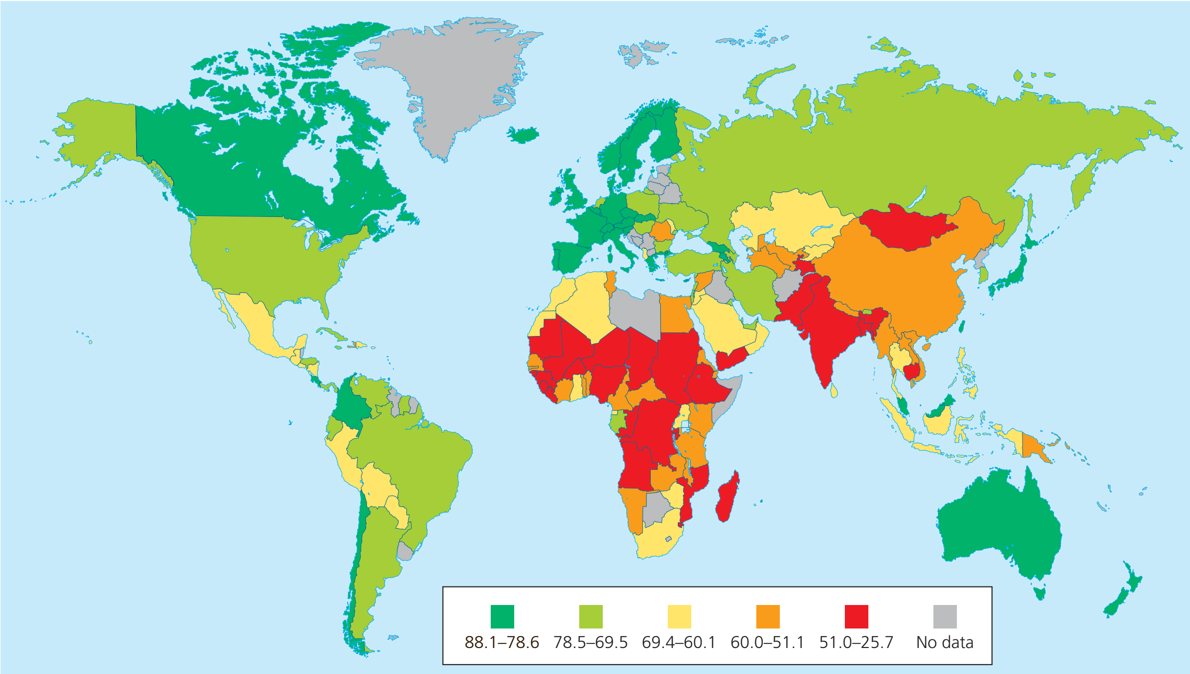


Figure 8 The Pilot 2006 Environmental Performance Index (EPI) uses 16 indicators of environmental health, air quality, water resources, biodiversity and habitat quality, renewable natural resources, and sustainable energy resources to evaluate countries in terms of their ecosystem health and environmental stresses on human health. This map shows the scores by quintiles. **Question:** In what quintile is the country where you live? (Data from Yale Center for Environmental Law and Policy and the Center for International Earth Science Information Network at Columbia University)

SUPPLEMENT

5

Overview of U.S. Environmental History (Chapters 1, 5, 8, 10, 17)

Four Eras of Environmental History in the United States

The environmental history of the United States can be divided into tribal, frontier, early conservation, and modern environmental eras. During the *tribal era,* 5–10 million tribal people (now called Native Americans) occupied North America for at least 10,000 years before European settlers began arriving in the early 1600s. These hunter–gatherers generally had sustainable, low-impact ways of life because of their low numbers and low resource use per person.

Next was the *frontier era* (1607–1890) when European colonists began settling North America. Faced with a continent offering seemingly inexhaustible resources, the early colonists developed a **frontier environmental worldview.** They saw a wilderness to be conquered and managed for human use.

Next came the *early conservation era* (1832–70), which overlapped the end of the frontier era. During this period some people became alarmed at the scope of resource depletion and degradation in the United States. They urged that part of the unspoiled wilderness on public lands be protected as a legacy to future generations. Most of these warnings and ideas were not taken seriously.

This period was followed by an era—lasting from 1870 to the present—featuring an increased role of the federal government and private citizens in resource conservation, public health, and environmental protection.

The Frontier Era (1607–1890)

During the frontier era, European settlers spread across the land, clearing forests for cropland and settlements and displacing the Native Americans who generally had lived on the land sustainably for thousands of years.

The U.S. government accelerated this settling of the continent and use of its resources by transferring vast areas of public land to private interests. Between 1850 and 1890, more than half of the country's public land was given away or sold cheaply by the government to railroad, timber, and mining companies, land developers, states, schools, universities, and homesteaders to encourage settlement. This era came to an end when the government declared the frontier officially closed in 1890.

Early Conservationists (1832–70)

Between 1832 and 1870, some people became alarmed at the scope of resource depletion and degradation in the United States. They urged the government to preserve part of the unspoiled wilderness on public lands owned jointly by all people (but managed by the government) and to protect it as a legacy to future generations.

Two of these early conservationists were Henry David Thoreau (1817–62) and George Perkins Marsh (1801–82). Thoreau (Figure 1) was alarmed at the loss of numerous wild species from his native eastern Massachusetts. To gain a better understanding of nature, he built a cabin in the woods on Walden Pond near Concord, Massachusetts, lived there alone for 2 years, and wrote *Life in the Woods,* an environmental classic.*

Figure 1 Henry David Thoreau (1817–62) was an American writer and naturalist who kept journals about his excursions into nature throughout parts of the northeastern United States and Canada and at Walden Pond in Massachusetts. He sought self-sufficiency, a simple lifestyle, and a harmonious coexistence with nature.

In 1864, George Perkins Marsh, a scientist and member of Congress from Vermont, published *Man and Nature,* which helped legislators and citizens see the need for resource conservation. Marsh questioned the idea that the country's resources were inexhaustible. He also used scientific studies and case studies to show how the rise and fall of past civilizations were linked to the use and misuse of their soils, water supplies, and other resources. Some of his resource conservation principles are still used today.

What Happened between 1870 and 1930?

Between 1870 and 1930, a number of developments increased the roles of the federal government and of private citizens in resource conservation and public health (Figure 2, p. S24). The *Forest Reserve Act of 1891* was a turning point in establishing the responsibility of the federal government for protecting public lands from resource exploitation.

In 1892, nature preservationist and activist John Muir (Figure 3, p. S24) founded the Sierra Club. He became the leader of the *preservationist movement* that called for protecting large areas of wilderness on public lands from human exploitation, except for low-impact recreational activities such as hiking and camping. This idea was not enacted into law until 1964. Muir also proposed and lobbied for creation of a national park system on public lands.

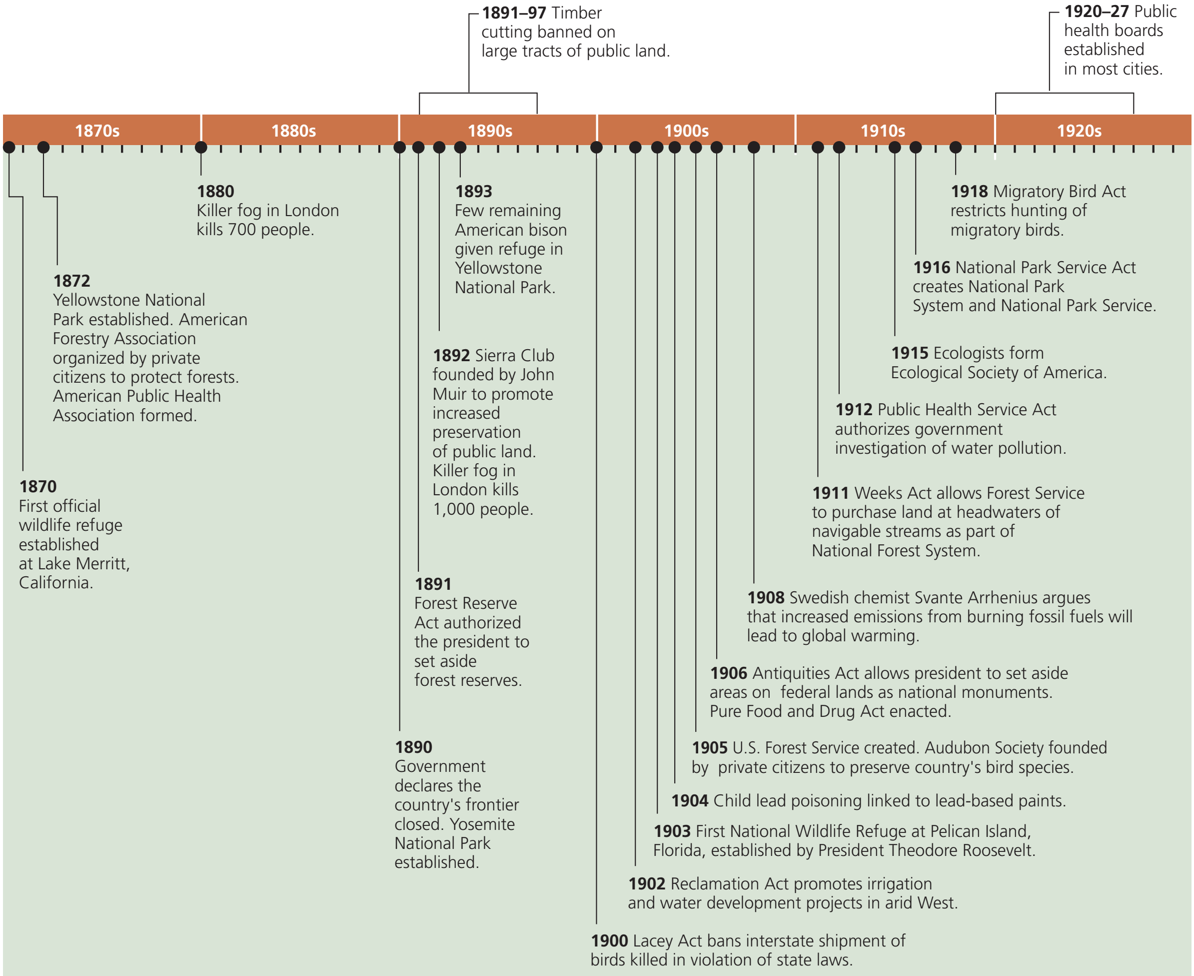
Mostly because of political opposition, effective protection of forests and wildlife did not begin until Theodore Roosevelt (Figure 4, p. S25), an ardent conservationist, became president. His term of office, 1901–09, has been called the country's *Golden Age of Conservation.*

While in office he persuaded Congress to give the president power to designate public land as federal wildlife refuges. In 1903, Roosevelt established the first federal refuge at Pelican Island off the east coast of Florida for preservation of the endangered brown pelican, and he added 35 more reserves by 1904. He also more than tripled the size of the national forest reserves.

In 1905, Congress created the U.S. Forest Service to manage and protect the forest reserves. Roosevelt appointed Gifford Pinchot (1865–1946) as its first chief. Pinchot pioneered scientific management of forest resources on public lands. In 1906, Congress passed the *Antiquities Act,* which allows the president to protect areas of scientific or historical interest on federal lands as national monuments. Roosevelt used this act to protect the Grand Canyon and other areas that would later become national parks.

Congress became upset with Roosevelt in 1907, because by then he had added vast tracts to the forest reserves. Congress passed a law banning further executive withdrawals of public forests. On the day before the bill became law, Roosevelt defiantly reserved another large block of land. Most environmental historians view Roosevelt (a Republican) as the country's best environmental president.

*I (Miller) can identify with Thoreau. I spent 15 years living in the deep woods studying and thinking about how nature works and writing early editions of the book you are reading. I lived in a remodeled school bus with an attached greenhouse. I used it as a scientific laboratory for evaluating things such as passive and active solar energy technologies for heating the bus and water, waste disposal (composting toilets), natural geothermal cooling (earth tubes), ways to save energy and water, and biological control of pests. It was great fun and I learned a lot. In 1990, I came out of the woods to find out more about how to live more sustainably in urban areas, where most people live.



1870–1930

Figure 2 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 these events do you think were the most important?

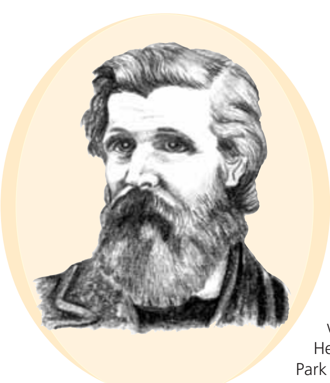


Figure 3 John Muir (1838–1914) was a geologist, explorer, and naturalist. He spent 6 years studying, writing journals, and making sketches in the wilderness of California's Yosemite Valley and then went on to explore wilderness areas in Utah, Nevada, the Northwest, and Alaska. He was largely responsible for establishing Yosemite National Park in 1890. He also founded the Sierra Club and spent 22 years lobbying actively for conservation laws.

Early in the 20th century, the U.S. conservation movement split into two factions over how public lands should be used. The *wise-use,* or *conservationist,* school, led by Roosevelt and Pinchot, believed all public lands should be managed wisely and scientifically to provide needed resources. The *preservationist* school, led by Muir wanted wilderness areas on public lands to be left untouched. This controversy over use of public lands continues today.

In 1916, Congress passed the *National Park Service Act.* It declared that parks are to be maintained in a manner that leaves them unimpaired for future generations. The act also established the National Park Service (within the Department of the Interior) to manage the system. Under its first head, Stephen T. Mather (1867–1930), the dominant park policy was to encourage tourist visits by allowing private concessionaires to operate facilities within the parks.

After World War I, the country entered a new era of economic growth and expansion. During the Harding, Coolidge, and Hoover administrations, the federal government promoted increased sales of timber, energy, mineral and other resources found on public lands at low prices to stimulate economic growth.

President Herbert Hoover (a Republican) went even further and proposed that the federal government return all remaining federal lands to the states or sell them to private interests for economic development. But the Great Depression (1929–41) made owning such lands unattractive to state governments and private investors. The depression was bad news for the country. But some say that without it we might have little if any of the public lands that make up about one-third of the country's land today.

What Happened between 1930 and 1960?

A second wave of national resource conservation and improvements in public health began in the early 1930s (Figure 5) as President Franklin D. Roosevelt (1882–1945) strove to bring the country out of the Great Depression. He persuaded Congress to enact federal government programs to provide jobs and to help restore the country's degraded environment.

During this period the government purchased large tracts of land from cash-poor landowners, and established the *Civilian Conservation Corps* (CCC) in 1933. It put 2 million unemployed people to work planting trees and developing and maintaining parks and recreation areas. The CCC also restored silted waterways and built levees and dams for flood control.

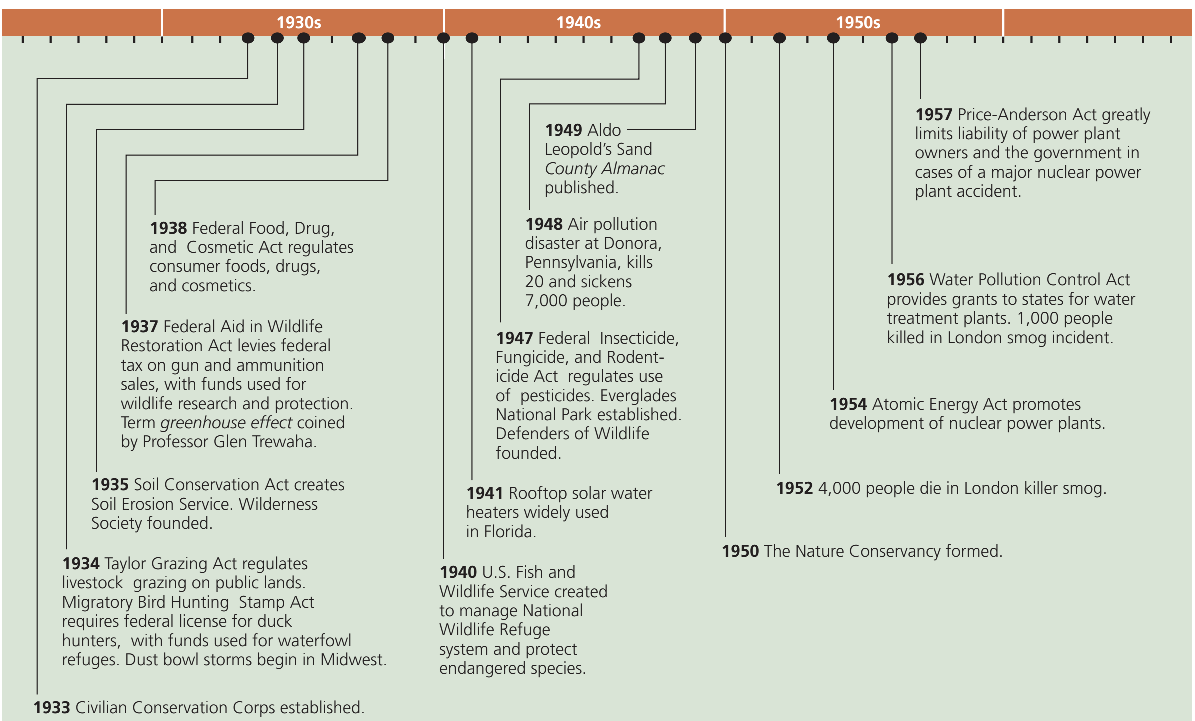
The government built and operated many large dams in the Tennessee Valley and in the arid western states, including Hoover Dam on the Colorado River. The goals were to provide jobs, flood control, cheap irrigation water, and cheap electricity for industry.

In 1935, Congress enacted the Soil Conservation Act. It established the *Soil Erosion Service* as part of the Department of Agriculture to correct the enormous erosion problems that had ruined many farms in the Great Plains states during the depression, as discussed in the Case Study on p. S30. Its name was later changed to the *Soil Conservation Service,* now called the *Natural Resources Conservation Service.* Many environmental historians praise Roosevelt (a Democrat) for his efforts to get the country out of a major economic depression and to help restore some environmentally degraded areas.

Federal resource conservation and public health policy during the 1940s and 1950s changed little, mostly because of preoccupation with World War II (1941–45) and economic recovery after the war.

Between 1930 and 1960, improvements in public health included establishment of public health boards and agencies at the municipal, state, and federal levels; increased public education about health issues; introduction of vaccination programs; and a sharp reduction in waterborne infectious disease mostly because of improved sanitation and garbage collection.

Figure 4 Theodore (Teddy) Roosevelt (1858–1919) was a writer, explorer, naturalist, avid bird-watcher, and twenty-sixth president of the United States. He was the first national political figure to bring the issues of conservation to the attention of the American public. According to many historians, he has contributed more than any other president to natural resource conservation in the United States.



1930–1960

Figure 5 Some important conservation and environmental events, 1930–60. **Question:** Which two of these events do you think were the most important?

INDIVIDUALS MATTER

Rachel Carson

Rachel Carson (Figure A) began her professional career as a biologist for the Bureau of U.S. Fisheries (later the U.S. Fish and Wildlife Service). In that capacity, she carried out research in oceanography and marine biology and wrote articles about the oceans and topics related to the environment.

Throughout the 1950s, DDT and related compounds were increasingly used to kill insects that ate food crops, attacked trees, bothered people, and transmitted diseases such as malaria. In 1958, 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 that independent research on the environmental effects of pesticides was almost nonexistent. As a well-trained scientist, she surveyed the scientific literature and methodically developed information about the harmful effects of widespread use of pesticides.

In 1962, she published her findings in popular form in *Silent Spring,* whose title alluded to the 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 viewed the book as a serious threat to their booming pesticide sales and mounted a campaign to discredit Carson. A parade of critical reviewers and industry scientists claimed 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 a hysterical woman and a radical nature lover trying to scare the public in an effort to sell books.

During these intense attacks, Carson was suffering from terminal 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 consider her work an important contribution to the modern environmental movement then emerging in the United States and to the eventual banning of a number of pesticides.

It has been correctly noted that Carson made some errors in *Silent Spring.* But her critics concede that the threat to some birds and ecosystems—one of Carson's main messages—was real and that her errors were due largely to the primitive stage of research on the topics she covered in her day.


U.S. Fish and Wildlife Service

Figure A Biologist Rachel Carson (1907–64) greatly increased our understanding of the importance of nature and the harmful effects from widespread use of pesticides.

What Happened during the 1960s?

A number of milestones in American environmental history occurred during the 1960s (Figure 6). In 1962, biologist Rachel Carson (1907–64) published *Silent Spring,* which documented the pollution of air, water, and wildlife from pesticides such as DDT (see Individuals Matter, above). This influential book helped broaden the concept of resource conservation to include preservation of the *quality* of the air, water, soil, and wildlife.

Many environmental historians mark Carson's wake-up call as the beginning of the modern **environmental movement** in the United States. It flourished when a growing number of citizens organized to demand that political leaders enact laws and develop policies to curtail pollution, clean up polluted environments, and protect unspoiled areas from environmental degradation.

In 1964, Congress passed the *Wilderness Act,* inspired by the vision of John Muir more than 80 years earlier. It authorized the government to protect undeveloped tracts of public land as part of the National Wilderness System, unless Congress later decides they are needed for the national good. Land in this system is to be used only for nondestructive forms of recreation such as hiking and camping.

Between 1965 and 1970, the emerging science of *ecology* received widespread media attention. At the same time, the popular writings of biologists such as Paul Ehrlich, Barry Commoner, and Garrett Hardin awakened people to the interlocking relationships among population growth, resource use, and pollution.

During that period, a number of events increased public awareness of pollution (Figure 6). The public also became aware that pollution and loss of habitat were endangering well-known wildlife species such as the North American bald eagle, grizzly bear, whooping crane, and peregrine falcon.

During the 1969 U.S. Apollo mission to the moon, astronauts photographed the earth from space. This allowed people to see the earth as a tiny blue and white planet in the black void of space and led to the development of the *spaceship-earth environmental worldview.* It reminded us that we live on a planetary spaceship (Terra I) that we should not harm because it is the only home we have.

What Happened during the 1970s? The Environmental Decade

During the 1970s, media attention, public concern about environmental problems, scientific research, and action to address environmental concerns grew rapidly. This period is sometimes called the *first decade of the environment* (Figure 7).

The first annual *Earth Day* was held on April 20, 1970. During this event, proposed by Senator Gaylord Nelson (1916–2005), some 20 million people in more than 2,000 communities took to the streets to heighten awareness and to demand improvements in environmental quality.

Republican President Richard Nixon (1913–94) responded to the rapidly growing environmental movement. He established the *Environmental Protection Agency* (EPA) in 1970 and supported passage of the *Endangered Species Act of 1973.* This greatly strengthened the role of the federal government in protecting endangered species and their habitats.

In 1978, the *Federal Land Policy and Management Act* gave the *Bureau of Land Management* (BLM) its first real authority to manage the public land under its control, 85% of which is in 12 western states. This law angered a number of western interests whose use of these public lands was restricted for the first time.

In response, a coalition of ranchers, miners, loggers, developers, farmers, some elected officials, and others launched a political campaign known as the *sagebrush rebellion.* It had two major goals. *First,* sharply reduce government regulation of the use of public lands. *Second,* remove most public lands in the western United States from federal ownership and management and turn them over to the states. Then the plan was to persuade state legislatures to sell or lease the resource-rich lands at low prices to ranching, mining, timber, land development, and other private interests. This represented a return to President Hoover's plan to get rid of all public land, which was thwarted by the Great Depression.

Jimmy Carter (a Democrat), president between 1977 and 1981, was very responsive to environmental concerns. He persuaded Congress to create the Department of Energy to develop a long-range energy strategy to reduce the country's heavy dependence on imported oil. He

1960s

1961 World Wildlife Fund founded.

1962 Rachel Carson publishes *Silent Spring* to alert the public about harmful effects of pesticides. 750 people die in London smog incident.

1963 300 deaths and thousands of illnesses in New York City from air pollution. Clean Air Act begins regulation of air pollution with stricter amendments in 1965, 1970, and 1990.

1964 Wilderness Act establishes National Wilderness System.

1965 Land and Water Conservation Act authorizes federal funds for local, state, and federal purchase of open space and parkland.

1965–69 Severe pollution of Lake Erie kills fish and closes beaches.

1967 Environmental Defense Fund formed.

1968 Biologist Paul Ehrlich publishes *The Population Bomb*. Biologist Garrett Hardin publishes *Tragedy of the Commons* article. UN Biosphere Conference to discuss global environmental problems.

1969 Oil-polluted Cuyahoga River, flowing through Cleveland, Ohio, catches fire. Leaks from offshore oil well off coast of Santa Barbara, California, kill wildlife and pollute beaches. Environmental Policy Act requires federal agencies to evaluate environmental impact of their actions. *Apollo* mission photo of the earth from space leads to spaceship-earth environmental worldview.

1960s

Figure 6 Some important environmental events during the 1960s. **Question:** Which two of these events do you think were the most important?

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 7 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?

appointed respected environmental leaders to key positions in environmental and resource agencies and consulted with environmental interests on environmental and resource policy matters.

In 1980, Carter helped create a *Superfund* as part of the *Comprehensive Environment Response, Compensation, and Liability Act* to clean up abandoned hazardous waste sites, including the Love Canal housing development in Niagara Falls, New York, which was abandoned when hazardous wastes began leaking into yards, school grounds, and basements.

Carter also used the *Antiquities Act of 1906* to triple the amount of land in the National Wilderness System and double the area in the National Park System (primarily by adding vast tracts in Alaska). He used the Antiquities Act to protect more public land, in all 50 states, than any president before him had done.

What Happened during the 1980s? Environmental Backlash

Figure 8 summarizes some key environmental events during the 1980s that shaped U.S. environmental policy. During this decade, farmers and ranchers and leaders of the oil, coal, automobile, mining, and timber industries strongly opposed many of the environmental laws and regulations developed in the 1960s and 1970s. They organized and funded a strong *anti-environmental movement* that persists today.

In 1981, Ronald Reagan (a Republican, 1911–2004), a self-declared *sagebrush rebel* and advocate of less federal control, became president. During his 8 years in office, he angered environmentalists by appointing to key federal positions people who opposed most existing environmental and public land-use laws and policies.

Reagan greatly increased private energy and mineral development and timber cutting on public lands. He also drastically cut federal funding for research on energy conservation and renewable energy resources and eliminated tax incentives for residential solar energy and energy conservation enacted during the Carter administration. In addition, he lowered automobile gas mileage standards and relaxed federal air and water quality pollution standards.

Although Reagan was immensely popular, many people strongly opposed his environmental and resource policies. This resulted in strong opposition in Congress, public outrage, and legal challenges by environmental and conservation organizations, whose memberships soared during this period.

In 1988, an industry-backed, anti-environmental coalition called the *wise-use movement* was formed. Its major goals were to weaken or repeal most of the country's environmental laws and regulations and destroy the effectiveness of the environmental movement in the United States. Politically powerful coal, oil, mining, automobile, timber, and ranching interests helped back this movement.

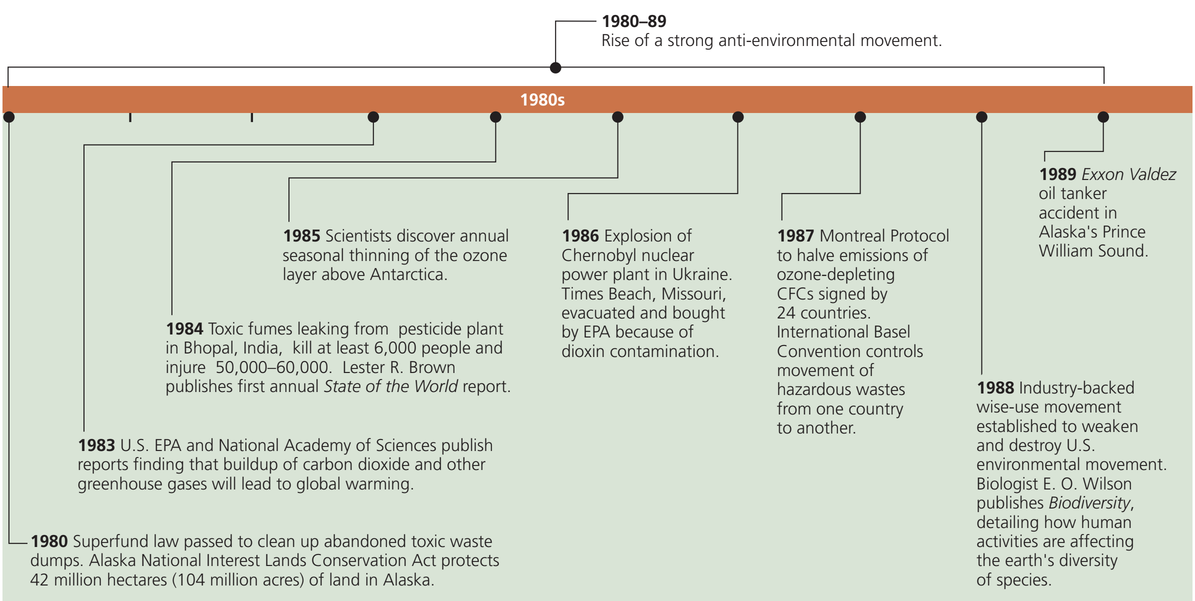
Upon his election in 1988, George H. W. Bush (a Republican) promised to be "the environmental president." But he received criticism from environmentalists for not providing leadership on such key environmental issues as population growth, global warming, and loss of biodiversity. He also continued support of exploitation of valuable resources on public lands at giveaway prices. In addition, he allowed some environmental laws to be undercut by the political influence of industry, mining, ranching, and real estate development interests. They argued that environmental laws had gone too far and were hindering economic growth.

What Happened from 1990 to 2007?

Figure 9 summarizes some key environmental events that took place between 1990 and 2007. In 1993, Bill Clinton (a Democrat) became president and promised to provide national and global environmental leadership. During his 8 years in office, he appointed respected environmental leaders to key positions in environmental and resource agencies and consulted with environmental interests about environmental policy, as Carter did.

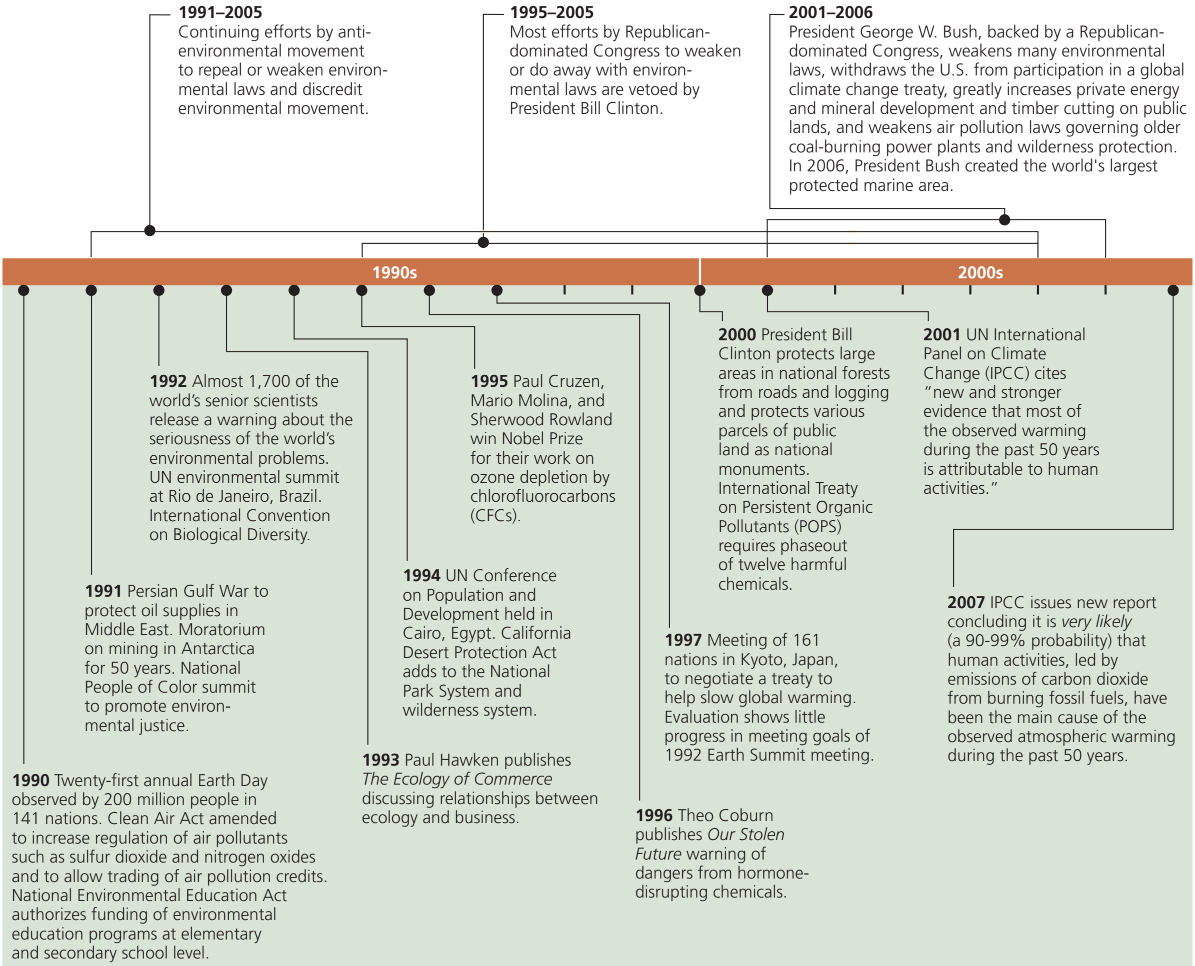
In addition, he vetoed most of the anti-environmental bills passed by a Republican-dominated Congress between 1995 and 2000. He announced regulations requiring sport utility vehicles (SUVs) to meet the same air pollution emission standards as cars. Clinton also used executive orders to make forest health the primary priority in managing national forests and to declare many roadless areas in national forests off limits to the building of roads and to logging.

In addition, he used the Antiquities Act of 1906 to protect various parcels of public land in the West from development and resource exploitation by declaring them national monuments. He protected more public land as national



1980s

Figure 8 Some important environmental events during the 1980s. **Question:** Which two of these events do you think were the most important?



1990–2007

Figure 9 Some important environmental events, 1990–2007. **Question:** Which two of these events do you think were the most important?

monuments in the lower 48 states than any other president, including Teddy Roosevelt and Jimmy Carter. However, environmental leaders criticized Clinton for failing to push hard enough on key environmental issues such as global warming and global and national biodiversity protection.

The anti-environmental movement gained strength between 1990 and 2007. This occurred because of continuing political and economic support from corporate backers, who argued that environmental laws were hindering economic growth, and because federal elections gave Republicans (many of whom were generally unsympathetic to environmental concerns) a majority in Congress.

Since 1990, leaders and supporters of the environmental movement have had to spend much of their time and funds fighting efforts to discredit the movement and weaken or eliminate most environmental laws passed during the 1960s and 1970s. They also have had to counter claims by anti-environmental groups that problems such as global warming and ozone depletion are hoaxes or not very serious and that environmental laws and regulations were hindering economic growth.

During the 1990s, many small and mostly local grassroots environmental organizations sprang up to deal with environmental threats in their local communities. Interest in environmental issues increased on many college campuses, and environmental studies programs at colleges and universities expanded. In addition, awareness of important, complex environmental issues, such as sustainability, population growth, biodiversity protection, and threats from global warming, increased.

In 2001, George W. Bush (a Republican) became president. Like Reagan in the 1980s, he appointed to key federal positions people who opposed or wanted to weaken many existing environmental and public land-use laws and policies because they were alleged to threaten economic growth. Also like Reagan, he did not consult with environmental groups and leaders in developing environmental policies, and he greatly increased private energy and mineral development and timber cutting on public lands.

Bush also opposed increasing automobile gas mileage standards as a way to save energy and reduce dependence on oil imports, and he supported relaxation of various federal air and water quality standards. Like Reagan, he developed an energy policy that emphasized use of fossil fuels and nuclear power with much less real support for reducing energy waste and relying more on renewable energy resources.

In addition, he withdrew the United States from participation in the international Kyoto treaty, designed to help reduce carbon dioxide emissions that can promote global warming. He also repealed or tried to weaken most of the pro-environmental measures established by Clinton. On the other hand, in 2006 he created the world's largest marine reserves in waters around some of the Hawaiian Islands.

In 2003, leaders of a dozen major environmental organizations charged that Bush, backed by a Republican-dominated Congress, was well on the way to compiling the worst environmental record of any president in the history of the country. By 2006, many of the country's environmental and public land-use laws and regulations had been seriously weakened.

A few moderate Republican members of Congress have urged their party to return to its environmental roots, put down during Teddy Roosevelt's presidency, and shed its anti-environmental approach to legislation. Most Democrats agree and assert that the environmental problems we face are much too serious to be held hostage to political squabbling. They call for cooperation, not confrontation. These Democrats and Republicans urge elected officials, regardless of party, to enter into a new pact in which the United States becomes the world leader in making this the *environmental century.* This would help sustain the country's rich heritage of natural capital and provide economic development, jobs, and profits in rapidly growing businesses such as solar and wind energy, energy efficient vehicles and buildings, ecological restoration, and pollution prevention.

In 2007, the Intergovernmental Panel on Climate Change (IPCC), which includes more than 2,500 of the world's climate experts, issued its third report on global climate change. According to this overwhelming consensus among the world's climate scientists, global warming is occurring, and it is *very likely* (a 90–99% probability) that human activities, led by burning fossil fuels, have been the main cause of the observed atmospheric warming during the past 50 years.

NOAA George E. Marsh Album

Figure 10 Dust storm of eroded soil approaching Stratford, Texas (USA) in 1935.

■ CASE STUDY

The U.S. Dust Bowl: An Environmental Lesson from Nature

In the 1930s, Americans learned a harsh environmental lesson when much of the topsoil in several dry and windy midwestern states was lost through a combination of poor cultivation practices and prolonged drought. This threatened to turn much of the U.S. plains into a vast desert.

Before settlers began grazing livestock and planting crops there in the 1870s, the deep and tangled root systems of native prairie grasses anchored the fertile topsoil firmly in place. But plowing the prairie tore up these roots, and the crops that settlers planted annually in their place had less extensive root systems.

After each harvest, the land was plowed and left bare for several months, exposing it to high winds. Overgrazing by livestock in some areas also destroyed large expanses of grass, denuding the ground.

The stage was set for severe wind erosion and crop failures; all that was needed was a long drought. It came between 1926 and 1937 when the annual precipitation dropped by about two-thirds. In the 1930s, dust clouds created by hot, dry windstorms blowing across the barren exposed soil darkened the sky at midday in some areas (Figure 10). Rabbits and birds choked to death on the dust.

During May 1934, a cloud of topsoil blown off the Great Plains traveled some 2,400 kilometers (1,500 miles) and blanketed most of the eastern United States with dust. Laundry hung out to dry by women in the state of Georgia quickly became covered with dust blown in from the Midwest. Journalists gave the most eroded part of the Great Plains a new name: the *Dust Bowl* (Figure 11).

Figure 11 The *Dust Bowl* of the Great Plains, where a combination of extreme drought and poor soil conservation practices led to severe wind erosion of topsoil in the 1930s.

During the "dirty thirties," large areas of cropland were stripped of topsoil and severely eroded. This triggered one of the largest internal migrations in U.S. history. Thousands of farm families from the states of Oklahoma, Texas, Kansas, and Colorado abandoned their dust-choked farms and dead livestock and migrated to California or to the industrial cities of the Midwest and East. Most found no jobs because the country was in the midst of the Great Depression.

In May 1934, Hugh Bennett of the U.S. Department of Agriculture (USDA) went before a congressional hearing in Washington to plead for new programs to protect the country's topsoil. Lawmakers took action when Great Plains dust began seeping into the hearing room. As Hugh Bennett put it, "This nation and civilization is founded upon nine inches of topsoil. And when that is gone there will no longer be any nation or any civilization."

In 1935, the United States passed the *Soil Erosion Act,* which established the Soil Conservation Service (SCS) as part of the USDA. With Bennett as its first head, the SCS (now called the Natural Resources Conservation Service) began promoting sound soil conservation practices, first in the Great Plains states and later elsewhere. Soil conservation districts were formed throughout the country, and farmers and ranchers were given technical assistance in setting up soil conservation programs.

In 1985, the U.S. Congress created the Conservation Reserve Program (CRP), which paid farmers to cover highly erodible land with vegetation under 10-year contracts. Since 1982, this program has cut soil erosion on cropland by about 40% and has provided a model to the world for soil conservation.

THINKING ABOUT
The Dust Bowl

What is the ecological lesson from the Dust Bowl? Has the United States learned this lesson?

Norse Greenland, Sumerian, and Icelandic Civilizations (Chapters 1, 2, 8, 10, 13)

SUPPLEMENT 6

The Norse Greenland Civilization Destroyed Its Resource Base

Greenland is a vast and mostly ice-covered island about three times the size of the U.S. state of Texas. During the 10th century, Viking explorers settled a small, flat portion of this island that was covered with vegetation and located near the water.

In his 2005 book, *Collapse: How Societies Choose to Fail or Succeed,* biogeographer Jared Diamond describes how this 450-year-old Norse settlement in Greenland collapsed in the 1400s from a combination of colder weather in the 1300s and abuse of its soil resources.

Diamond suggests the Norse made three major errors. First, they cut most of the trees and shrubs to clear fields, make lumber, and gather firewood. Without that vegetation, cold winds dried and eroded the already thin soil. The second error was overgrazing, which meant the depletion of remaining vegetation and trampling of the fragile soil.

Finally, when wood used for lumber was depleted, the Norse removed chunks of their turf and used it to build thick walls in their houses to keep out cold winds. Because they removed the turf faster than it could be regenerated, there was less land for grazing so livestock numbers fell. As a result, their food supply and civilization collapsed. Archeological evidence suggests the last residents starved or froze to death.

After about 500 years, nature healed the ecological wounds the Norse caused and Greenland's meadows recovered. In the 20th century, Danes who settled in Greenland reintroduced livestock. Today, more than 56,000 people make their living there by mining, fishing, growing crops, and grazing livestock.

But there is evidence that Greenland's green areas—about 1% of its total land area—are again being overused and strained to their limits. Now Greenlanders have the scientific knowledge to avoid the tragedy of the commons by reducing livestock numbers to a sustainable level, not cutting trees faster than they are replenished, and practicing soil conservation. Time will tell whether they will work together to avoid the environmental tragedy suffered by their ancestors.

The Sumerian Civilization Collapsed Because of Unsustainable Farming

During the 4th century B.C., a highly advanced urban and literate Sumerian civilization emerged on the flood plains of the lower reaches of the Tigris and Euphrates Rivers in parts of what is now Iraq. This civilization developed science and mathematics, and to grow food, built a well-engineered irrigation system, which used dams to divert water from the Euphrates River through a network of gravity-fed canals.

The irrigated cropland produced a food surplus and allowed Sumerians to develop the world's first cities and written language (the cunneiform script). But the Sumerians also learned the painful lesson that long-term irrigation can lead to salt buildup in soils and sharp declines in food production.

Poor underground drainage slowly raised the water table to the surface, and evaporation of the water left behind salts that sharply reduced crop productivity—a form of environmental degradation we now call *soil salinization* (Figure 10-10, p. 207). As wheat yields declined, the Sumerians slowed the salinization by shifting to more salt-tolerant barley. But as salt concentrations continued to increase, barley yields declined and food production was undermined.

Around 2000 B.C., this once-great civilization disappeared as a result of such environmental degradation, economic decline, and invasion by Semitic peoples.

Iceland's Environmental Struggles and Triumphs: Learning a Lesson from Natural Capital Degradation

Iceland is a Northern European island country slightly smaller than the U.S. state of Kentucky. This volcanic island is located in the North Atlantic Ocean just south of the Arctic Circle between Greenland and Norway. Glaciers cover about 10% of the country, and it is subject to earthquakes and volcanic activity.

Immigrants from Scandinavia, Ireland, and Scotland began settling the country during the late 9th and 10th centuries A.D. Since these settlements began, most of the country's trees and other vegetation have been destroyed and about half of its original soils have eroded into the sea. As a result, Iceland suffers more ecological degradation than any other European country.

The early settlers saw what appeared to be a country with deep and fertile soils, dense forests, and highland grasslands similar to those in their native countries. They did not realize that the soils built up by ash from volcanic eruptions were replenished very slowly and were highly susceptible to water and wind erosion when protective vegetation was removed for growing crops and grazing livestock. Within a few decades, the settlers degraded much of this natural capital that had taken thousands of years to build up.

When the settlers realized what was happening, they took corrective action by trying to save remaining trees and not raising ecologically destructive pigs and goats. The farmers joined together to slow soil erosion and preserve their grasslands. They estimated how many sheep the communal highland grasslands could sustain and divided the allotted quotas among themselves.

Icelanders also learned how to tap into an abundance of fish, geothermal power from the numerous hot springs and heated rock formations, and hydroelectric power from the many rivers. Renewable hydropower and geothermal energy provide about 95% of the country's electricity and geothermal energy is used to heat 80% of its buildings and to grow most of its fruits and vegetables in greenhouses.

In terms of per capita income, Iceland is one of the world's ten richest countries, and in 2005, it had the world's fifth highest Environmental Sustainability Index. By 2050, Iceland plans to become the world's first country to run its entire economy on renewable hydropower, geothermal energy, and wind, and to use these sources to produce hydrogen for running all of its motor vehicles and ships (Case Study, p. 316).

THINKING ABOUT
Past Civilizations

List two ecological lessons that we could learn from these three stories.

SUPPLEMENT 7

Some Basic Chemistry (Chapters 2, 3, 11, 12, 13, 14, 16)

Atoms Have an Internal Structure

In Chapter 2 (pp. 28–31), you learned that an atom of an element has a nucleus that contains protons and neutrons with one or more electrons moving around somewhere outside the nucleus. The number of protons in the nucleus of an atom is called its *atomic number* and the number of electrons outside the nucleus equals the number of protons inside its nucleus. The total number of protons and neutrons inside an atom is called its *mass number.*

For example, each atom of carbon, with an atomic number of 6, has 6 protons inside its nucleus and 6 electrons outside the nucleus. The number of protons inside the nucleus of an atom can vary, which results in different *isotopes.* For example, one isotope of carbon, called carbon-12 or C-12, has a mass number of 12. This means it has six protons and six neutrons inside its nucleus and 6 electrons outside, as shown in Figure 1.

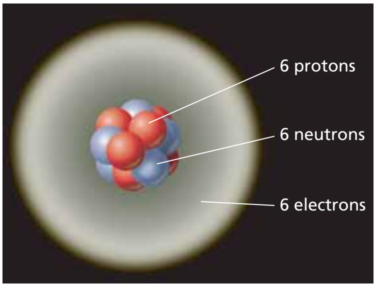


Figure 1 Greatly simplified model of a carbon-12 atom. It consists of a nucleus containing 6 positively charged protons and 6 neutral neutrons. There are 6 negatively charged electrons found outside its nucleus. We cannot determine the exact location of the electrons. Instead, we can estimate the *probability* that they will be found at various locations outside the nucleus—sometimes called an *electron probability cloud.* This is somewhat like saying that there are six airplanes flying around inside a cloud. We don't know their exact location, but the cloud represents an area where we can probably find them. **Question:** How would a model of an atom of carbon-14 differ from that of carbon-12?

Chemists Use the Periodic Table to Classify Elements on the Basis of Their Chemical Properties

Chemists have developed a way to classify the elements according to their chemical behavior, in what is called the *periodic table of elements* (Figure 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

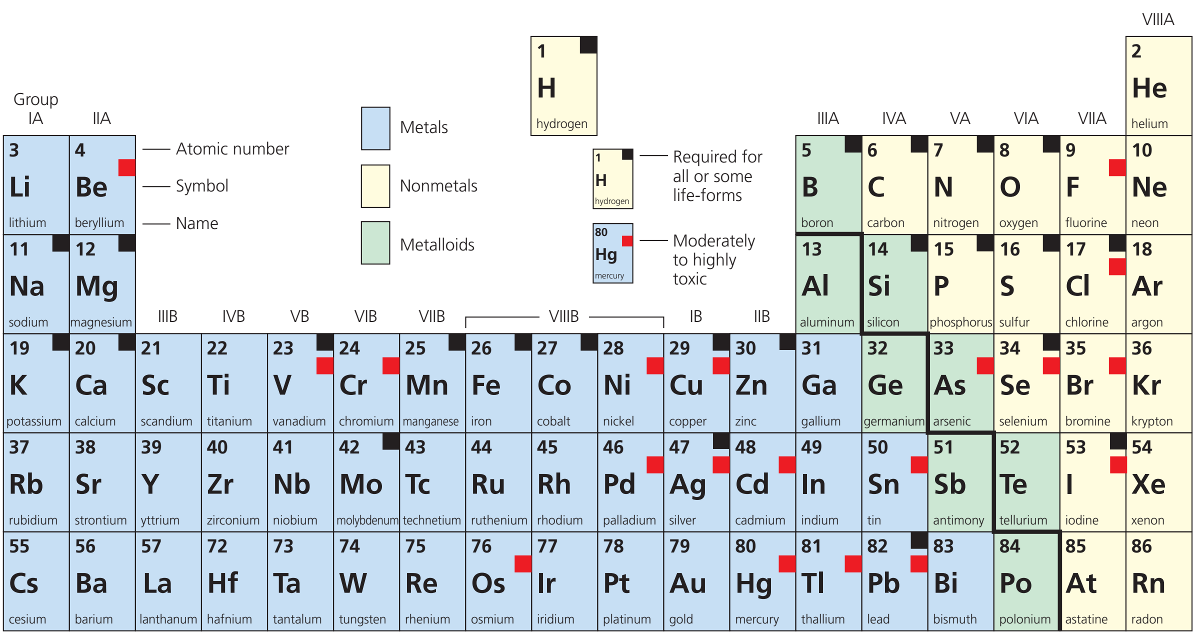


Figure 2 Abbreviated periodic table of elements. Elements in the same vertical column, called a *group,* have similar chemical properties. To simplify matters at this introductory level, only 72 of the 118 known elements are shown. **Question:** What are four elements with chemical properties similar to chlorine (Cl)?

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 and usually are not shiny. Examples are hydrogen (H), carbon (C), nitrogen (N), oxygen (O), phosphorus (P), sulfur (S), chlorine (Cl), and fluorine (F).

Atoms of some nonmetals such as chlorine, oxygen, and sulfur tend to gain one or more electrons lost by metallic atoms to form negatively charged ions such as O^{2-}, S^{2-}, and Cl^-. For example, an atom of the nonmetallic element chlorine (Cl, with an atomic number of 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 to all or most forms of life (red squares). 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.

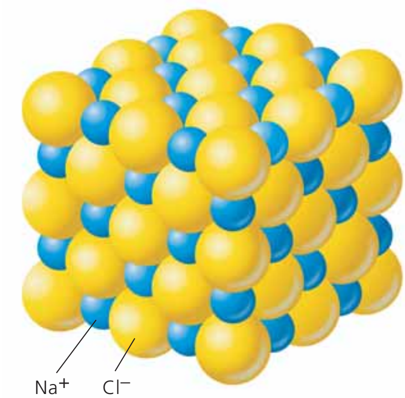


Figure 3 A solid crystal of an ionic compound such as sodium chloride consists of a three–dimensional array of opposite charged ions held together by *ionic bonds* resulting from the strong forces of attraction between opposite electrical charges. They are formed when an electron is transferred from a metallic atom such as sodium (Na) to a nonmetallic element such as chlorine (Cl).

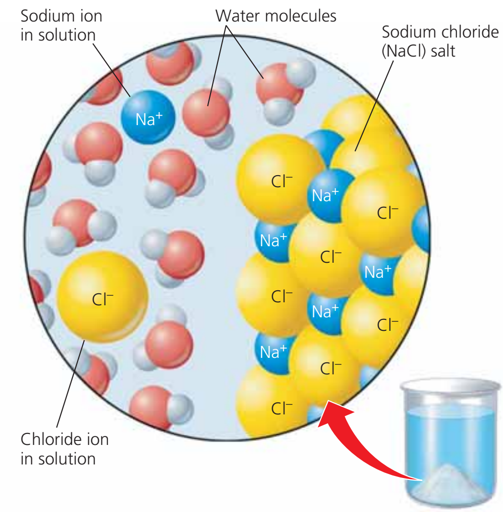


Figure 4 How a salt dissolves in water.

THINKING ABOUT
The Periodic Table

Use the periodic table to identify by name and symbol two elements that should have similar chemical properties to those of **(a)** Ca, **(b)** potassium, **(c)** S, **(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.*

Sodium chloride and many other ionic compounds tend to dissolve in water and break apart into their individual ions (Figure 4).

$$NaCl \longrightarrow Na^+ + Cl^-$$

sodium chloride in water → sodium ion + chloride ion

Water, a *covalent compound,* consists of molecules made up of uncharged atoms of hydrogen (H) and oxygen (O). Each water molecule consists of two hydrogen atoms chemically bonded to an oxygen atom, yielding H_2O molecules. The bonds between the atoms in such molecules are called *covalent bonds* and form when the atoms in the molecule share one or more pairs of their electrons. Because they are formed from atoms of nonmetallic elements (Figure 1), covalent compounds can be described as *nonmetal–nonmetal compounds.* Figure 5 (p. S34) shows the chemical formulas and shapes of the molecules that are the building blocks for several common *covalent compounds.*

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 10-fold increase or decrease in the concentration of hydrogen ions per liter. For example, an acidic solution with a pH of 3 is 10 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?

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). 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.

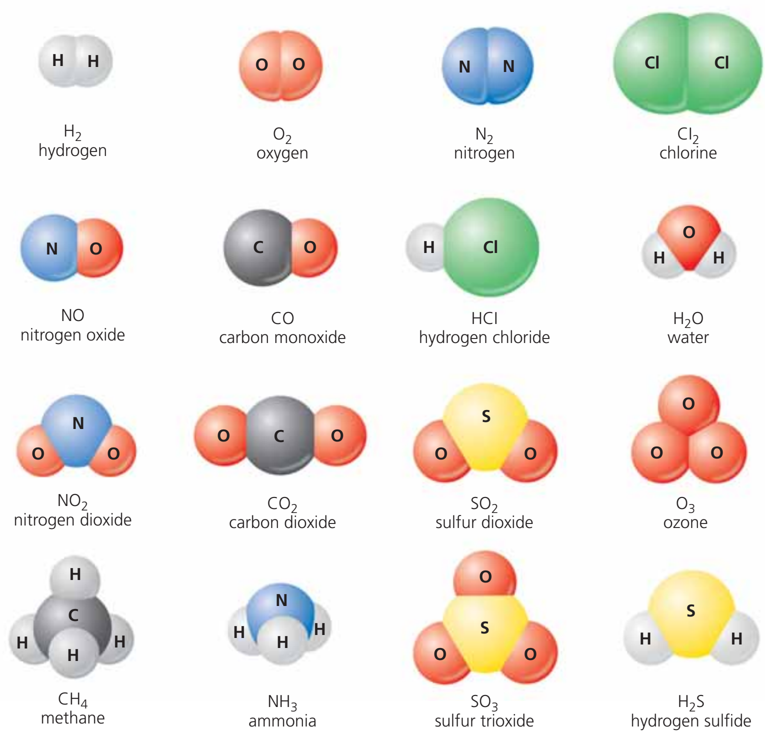


Figure 5 Chemical formulas and shapes for some *covalent compounds* formed when atoms of one or more nonmetallic elements combine with one another. The bonds between the atoms in such molecules are called *covalent bonds.*

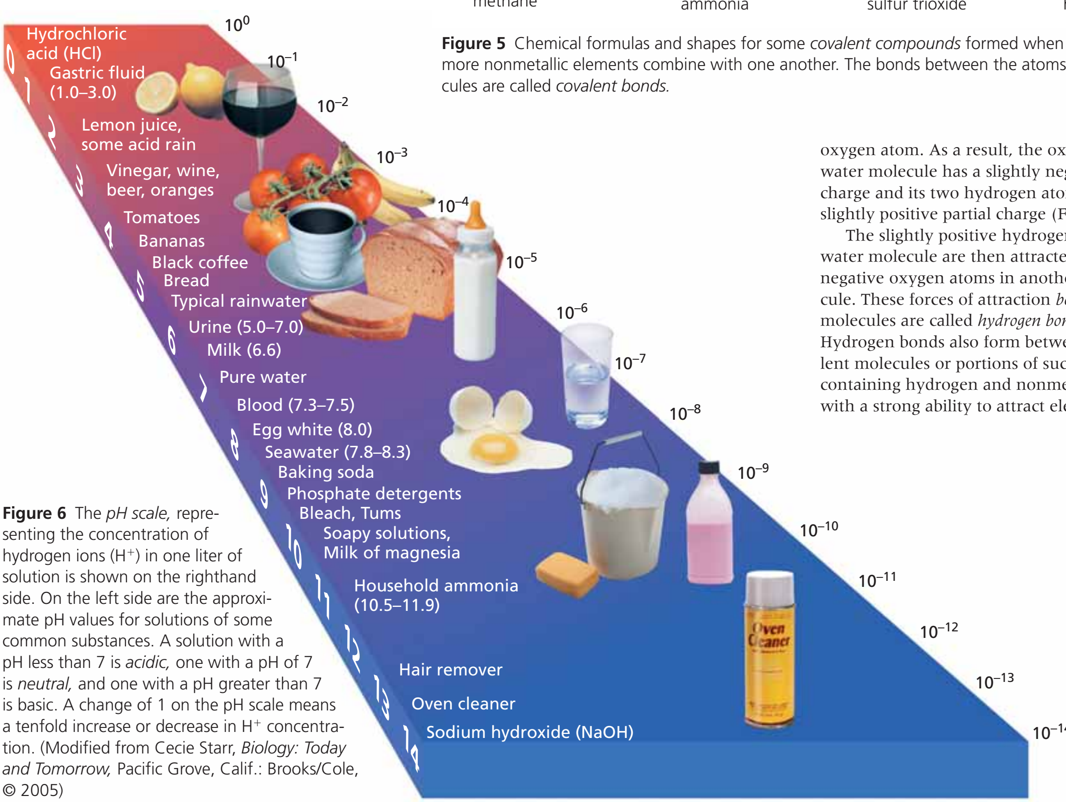


Figure 6 The *pH scale,* representing the concentration of hydrogen ions (H^+) in one liter of solution is shown on the righthand side. On the left side are the approximate pH values for solutions of some common substances. A solution with a pH less than 7 is *acidic,* one with a pH of 7 is *neutral,* 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)

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, that 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 store energy. Some are components of the *immune system* that helps protect the body against disease and harmful substances by forming antibodies that make invading agents harmless. Others are *hormones* that are used as chemical messengers in the bloodstreams of animals to turn various bodily functions on or off. In animals, proteins are also components of hair, skin, muscle, and tendons. In addition, some proteins act as *enzymes* that catalyze or speed up certain chemical reactions.

Nucleic acids are large polymer molecules made by linking hundreds to thousands of four types of monomers called *nucleotides*. Two nucleic acids—DNA (**d**eoxyribo**n**ucleic **a**cid) and RNA (**r**ibo**n**ucleic **a**cid)—participate in the building of proteins and carry hereditary information used to pass traits from parent to offspring. Each nucleotide consists of a *phosphate group,* a *sugar molecule* containing five carbon atoms (deoxyribose in DNA molecules and ribose in RNA molecules), and one of four different *nucleotide bases* (represented by A, G, C, and T, the first letter in each of their names, or A, G, C, and U in RNA)

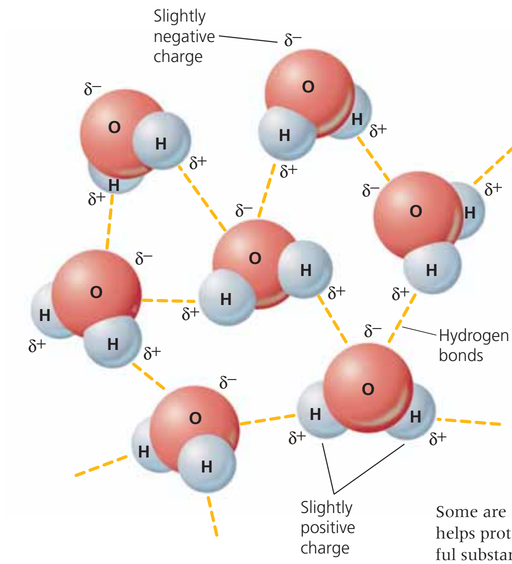


Figure 7 *Hydrogen bond:* slightly unequal sharing of electrons in the water molecule creates a molecule with a slightly negatively charged end and a slightly positively charged end. Because of this electrical polarity, the hydrogen atoms of one water molecule are attracted to the oxygen atoms in other water molecules. These fairly weak forces of attraction *between* molecules (represented by the dashed lines) are called *hydrogen bonds.*

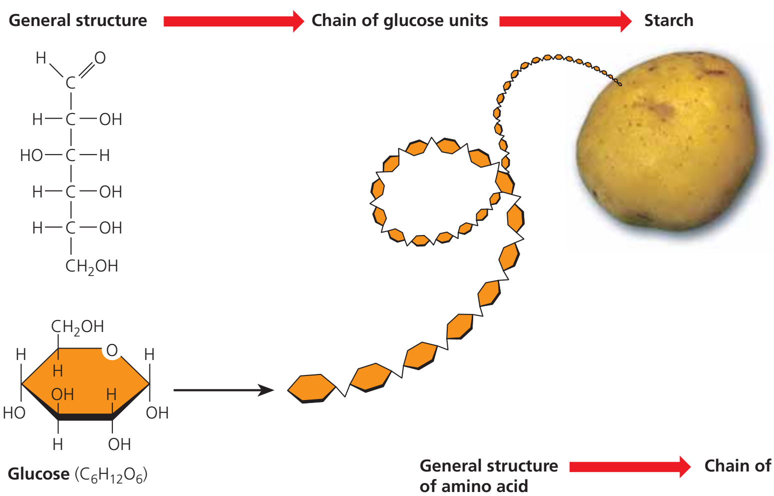


Figure 8 Straight-chain and ring structural formulas of glucose, a simple sugar that can be used to build long chains of complex carbohydrates such as starch and cellulose.

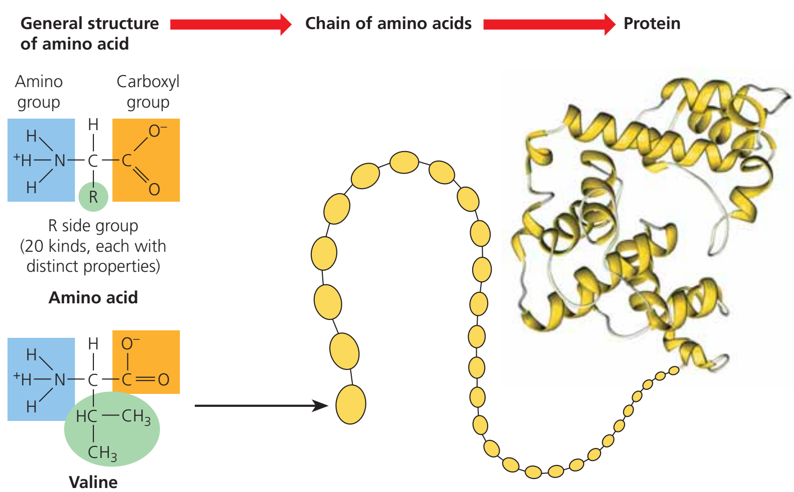
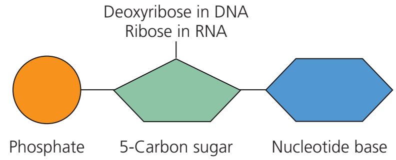


Figure 9 General structural formula and a specific structural formula of one of the 20 different amino acid molecules that can be linked together in chains to form proteins that fold up into more complex shapes.

Figure 10 Generalized structure 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, U, occurs instead of thymine 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).

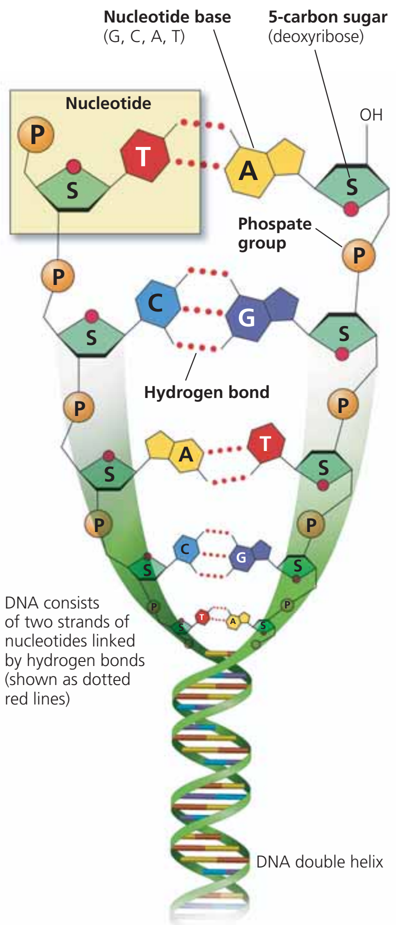


Figure 11 Portion of the double helix of a DNA molecule. The double helix is composed of two spiral (helical) strands of nucleotides. Each nucleotide contains a unit of phosphate (P), deoxyribose (S), and one of four nucleotide bases: guanine (G), cytosine (C), adenine (A), and thymine (T). The two strands 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).

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 the world's 6.9 billion people is only about 50 milligrams—the weight of a small match. Yet, 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.

Certain Molecules Store and Release Energy in Cells

Chemical reactions occurring in photosynthesis (p. 46) release energy that is absorbed by adenosine diphosate (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).

Photosynthesis: A Closer Look

In photosynthesis, sunlight powers a complex series of chemical reactions that combine water taken up by plant roots and carbon dioxide from the air to produce sugars such as glucose. This process converts solar energy into chemical energy in sugars for use by plant cells, with the solar energy captured, stored, and released as chemical energy in ATP and ADP molecules (Figure 14). Figure 15 (p.S38) is a greatly simplified summary of the photosynthesis process.

Photosynthesis takes place within tiny enclosed structures called *chloroplasts* found within plant cells. Chlorophyll, a special compound in chloroplasts, absorbs incoming visible light mostly in the violet and red wavelengths. The green light that is not absorbed is reflected back, which is why photosynthetic plants look green. The absorbed wavelengths of solar energy initiate a sequence of chemical reactions

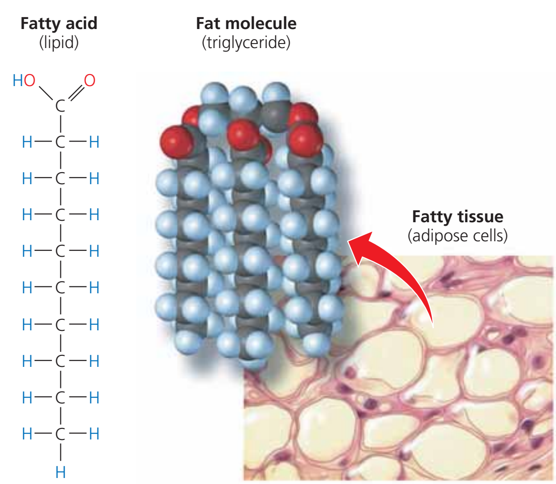


Figure 12 Structural formula of fatty acid that is one form of lipid (left). Fatty acids are converted into more complex fat molecules that are stored in adipose cells (right).

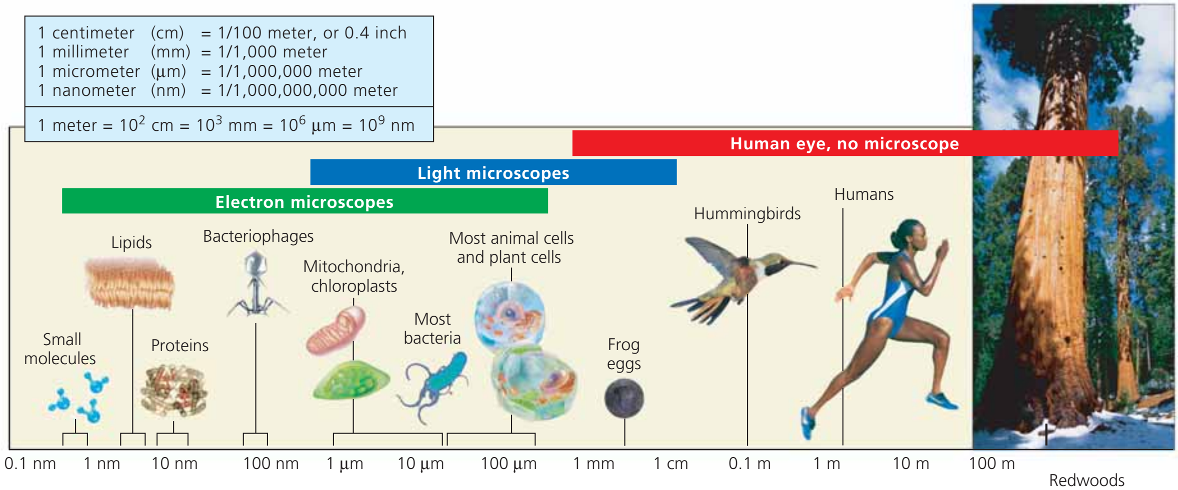


Figure 13 Relative size of simple molecules, complex molecules, cells, and multicellular organisms. This scale is exponential, not linear. Each unit of measure is 10 times larger than the unit preceding it. (Used by permission from Cecie Starr and Ralph Taggart, *Biology,* 11th ed, Belmont, Calif.: Thomson Brooks/Cole, © 2006)

with other molecules in what are called *light-dependent reactions.*

This series of reactions splits water into hydrogen ions (H^+) and oxygen (O_2) which is released into the atmosphere. Small ADP molecules in the cells absorb the energy released and store it as chemical energy in ATP molecules (Figure 14). The chemical energy released by the ATP molecules drives a series of *light-independent* (*dark*) *reactions* in the plant cells. In this second sequence of reactions, carbon atoms stripped from carbon dioxide combine with hydrogen and oxygen to produce sugars such as glucose ($C_6H_{12}O_6$) that plant cells can use as a source of energy and carbon.

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 conservation of matter (p. 31, and **Concept 2-3**, p. 31). 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 ($C + O_2 \longrightarrow CO_2$) is balanced because one atom of carbon and two atoms of oxygen are on both sides of the equation.

Consider the following chemical reaction: When electricity passes through water (H_2O), the latter can be broken down into hydrogen (H_2) and oxygen (O_2), as represented by the following equation:

$$H_2O \longrightarrow H_2 + O_2$$

H_2O	H_2	O_2
2 H atoms 1 O atom	2 H atoms	2 O atoms

This equation is unbalanced because one atom of oxygen is on the left side of the equation but two atoms are on the right side.

We cannot change the subscripts of any of the formulas to balance this equation because that would change the arrangements of the atoms, leading to different substances. Instead, we must use different numbers of the molecules involved to balance the equation. For example, we could use two water molecules:

$$2\,H_2O \longrightarrow H_2 + O_2$$

$2\,H_2O$	H_2	O_2
4 H atoms 2 O atoms	2 H atoms	2 O atoms

This equation is still unbalanced. Although the numbers of oxygen atoms on both sides of the equation are now equal, the numbers of hydrogen atoms are not.

We can correct this problem by having the reaction produce two hydrogen molecules:

$$2\,H_2O \longrightarrow 2\,H_2 + O_2$$

$2\,H_2O$	$2\,H_2$	O_2
4 H atoms 2 O atoms	4 H atoms	2 O atoms

Now the equation is balanced, and the law of conservation of matter has been observed. For every two molecules of water through which we pass electricity, two hydrogen molecules and one oxygen molecule are produced.

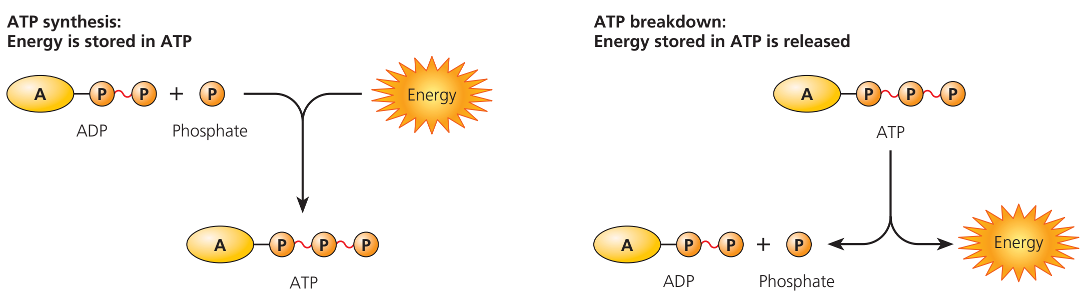


Figure 14 Energy storage and release in cells.

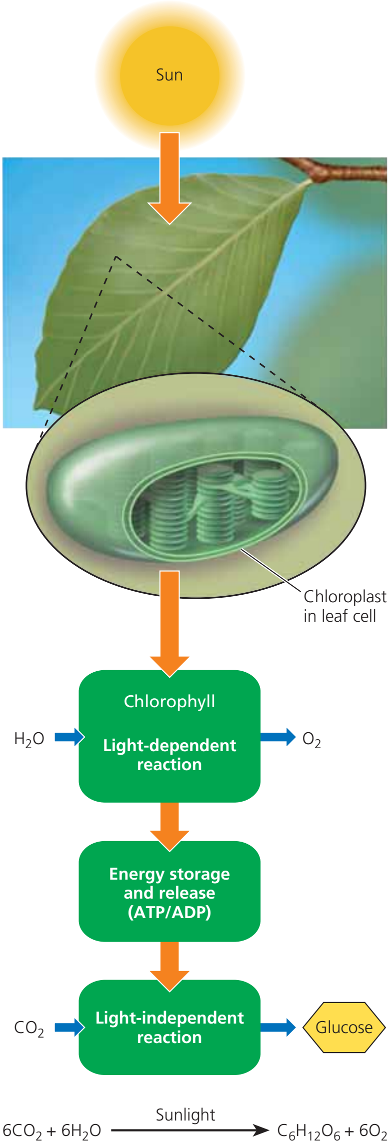


Figure 15 Simplified overview of *photosynthesis.* In this process, chlorophyll molecules in the chloroplasts of plant cells absorb solar energy. This initiates a complex series of chemical reactions in which carbon dioxide and water are converted to sugars such as glucose and oxygen.

THINKING ABOUT
Chemical Equations

Try to balance the chemical equation for the reaction of nitrogen gas (N_2) with hydrogen gas (H_2) to form ammonia gas (NH_3).

Scientists Are Learning How to Build Materials from the Bottom Up

Nanotechnology (Core Case Study, p. 261) uses atoms and molecules to build materials from the bottom up using atoms of the elements in the periodic table as its raw materials. A *nanometer* (nm) is one billionth of a meter—equal to the length of about 10 hydrogen atoms lined up side by side. A DNA molecule (Figure 11) is about 2.5 nanometers wide. A human hair has a width of 50,000 to 100,000 nanometers.

Below about 100 nanometers on a nanoscale, the properties of materials change dramatically. At the nanoscale level, materials can exhibit new properties such as extraordinary strength or increased chemical activity that they do not exhibit at the much larger macroscale of everyday items.

For example, scientists have learned how to make tiny tubes of carbon atoms linked together in hexagons. Experiments have shown that these carbon nanotubes are the strongest material ever made with strength 60 times that of high-grade steel. Such nanotubes have been linked together to form a rope so thin it is invisible, but it is strong enough to suspend a pickup truck. At the macroscale, zinc oxide (ZnO) can be rubbed on the skin as a white paste to protect against the sun's harmful UV rays; at the nanoscale it becomes transparent and is being used as invisible coatings to protect the skin and fabrics from UV damage. Because silver can kill harmful bacteria, silver (Ag) nanocrystals are being incorporated into bandages for wounds.

Researchers hope to incorporate nanoparticles of hydroxyapatite, with the same chemical structure as tooth enamel, into toothpaste to put coatings on teeth that prevent bacteria from penetrating. Nanotech coatings now being used on cotton fabrics form an impenetrable barrier that causes liquids to bead and roll off. Such stain-resistant fabrics used to make clothing, rugs, and furniture upholstery could eliminate the need to use harmful chemicals for removing stains.

Self-cleaning window glass coated with a layer of nanoscale titanium dioxide (TiO_2) particles is now available. As the particles interact with UV rays from the sun, dirt on the surface of the glass loosens and washes off when it rains. Similar products can be used for self-cleaning sinks and toilet bowls.

Scientists are working on ways to replace the silicon in computer chips with carbon-based nanomaterials that greatly increase the processing power of computers. Biological engineers are working on nanoscale devices to deliver drugs and to penetrate cancer cells and deliver nanomolecules that kill the cancer cells from the inside. Researchers also hope to develop nanoscale crystals that can change color when they detect parts per trillion amounts of harmful substances such chemical and biological warfare agents and food pathogens. For example, a color change in food packaging could alert a consumer when a food is contaminated or has begun to spoil. The list of possibilities goes on.

By 2007, more than 800 products containing nanoscale particles were commercially available and thousands more are in the pipeline. Examples are found in cosmetics, sunscreens, fabrics, pesticides, and food additives.

So far, these products are largely unregulated and unlabeled. This concerns many health and environmental scientists because the tiny size of nanoparticles can allow them to penetrate the natural defenses of the body against invasions by foreign and potentially harmful chemicals and pathogens. Nanoparticles of a chemical tend to be much more chemically reactive than macroparticles of the chemical, largely because the tiny nanoparticles have relatively large surface areas for their small mass. This means that a chemical that is harmless at the macroscale may be hazardous at the nanoscale when they are inhaled, ingested, or absorbed through the skin.

We know little about such effects and risks at a time when the use of a variety of untested and unregulated nanoparticles is increasing exponentially. A few toxicological studies are sending up red flags.

- In 2004, Eva Olberdorster, an environmental toxicologist at Southern Methodist University, found that fish swimming in water loaded with a certain type of carbon nanomolecules called buckyballs experienced brain damage within 48 hours.
- In 2005, NASA researchers found that injecting commercially available carbon nanotubes into rats caused significant lung damage.
- A 2005 study by researchers at the U.S. National Institute of Occupational Safety and Health found substantial damage to the heart and aortic arteries of mice exposed to carbon nanotubes.
- In 2005, researchers at New York's University of Rochester found increased blood clotting in rabbits inhaling carbon buckyballs.

In 2004, the British Royal Society and Royal Academy of Engineering recommended that we avoid the environmental release of nanoparticles and nanotubes as much as possible until more is known about their potential harmful impacts. They recommended as a precautionary measure that factories and research laboratories treat manufactured nanoparticles and nanotubes as if they were hazardous to their workers and to the general public. **GREEN CAREER:** Nanotechnology

THINKING ABOUT
Nanotechnology

Do you think that the benefits of nanotechnology outweigh its potentially harmful effects? Explain. What are three things you would do to reduce its potentially harmful effects?

RESEARCH FRONTIER

Learning more about nanotechnology and how to reduce its potentially harmful effects

SUPPLEMENT

8

The Sulfur Cycle (Chapters 3, 12, 13, 15)

The Sulfur Cycle

Sulfur circulates through the biosphere in the **sulfur cycle,** shown in Figure 1. 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 in flooded swamps, bogs, and tidal flats broken down by anaerobic decomposers. Sulfur dioxide (SO_2), a colorless and suffocating gas, also comes from volcanoes.

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

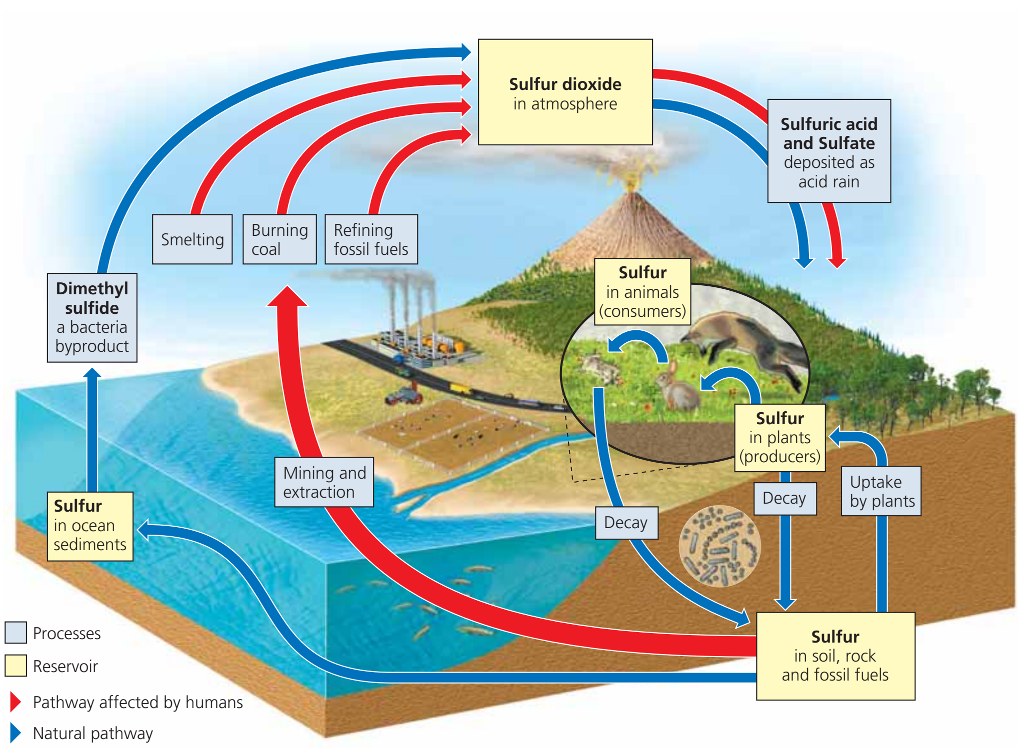
Certain marine algae produce large amounts of volatile dimethyl sulfide, or DMS (CH_3SCH_3). Tiny droplets of DMS serve as nuclei for the condensation of water into droplets found in clouds. In this way, changes in DMS emissions can affect cloud cover and climate.

In the atmosphere, DMS is converted to sulfur dioxide, some of which in turn is converted to sulfur trioxide gas (SO_3) and to tiny droplets of sulfuric acid (H_2SO_4). DMS also reacts with other atmospheric chemicals such as ammonia to produce tiny particles of sulfate salts. These droplets and particles fall to the earth as components of *acid deposition* (Figure 15-4, p. 351), which along with other air pollutants can harm trees and aquatic life.

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

Effects of Human Activities on the Sulfur Cycle

Human activities have affected the sulfur cycle primarily by releasing large amounts of sulfur dioxide (SO_2) into the atmosphere (Figure 1, red arrows). These emissions result from burning



ThomsonNOW™ **Active Figure 1** 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* ThomsonNOW. **Question:** What are three ways in which your lifestyle directly or indirectly affects the sulfur cycle?

coal that contains sulfur impurities, burning and refining (Figure 13-4, p. 283) oil that also contains sulfur impurities, and the roasting of sulfur-containing metallic mineral ores into free metals such as copper, lead, and zinc (Figure 12-7, p. 268). Once in the atmosphere, SO_2 is converted to droplets of sulfuric acid (H_2SO_4) and particles of sulfate (SO_4^{2-}) salts that return to the earth as acid deposition (Figure 15-4, p 351).

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—an activity that releases large amounts of sulfur dioxide into the environment.

RESEARCH FRONTIER

How human activities affect the major nutrient cycles and how we can reduce these effects

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

Classifying and Naming Species (Chapters 3, 4, 6)

SUPPLEMENT 9

Biologists classify species into different *kingdoms,* on the basis of similarities and differences in their nutrition, cell structure, appearance, and developmental features.

On the basis of their cell structure, organisms can be classified as either eukaryotic or prokaryotic. Each cell of a *eukaryotic* organism is surrounded by a membrane and has a distinct *nucleus* with a membrane containing genetic material in the form of DNA (Figure 11 on p. S36 in Supplement 7) and several other internal parts called organelles. Most organisms consist of eukaryotic cells.

Each cell of a *prokaryotic* organism is also surrounded by a membrane but the cell contains no nucleus or organelles surrounded by membranes. All bacteria are single-celled prokaryotic organisms.

In this book, the earth's organisms are classified into six kingdoms: *eubacteria, archaebacteria, protists, fungi, plants,* and *animals* (Figure 1).

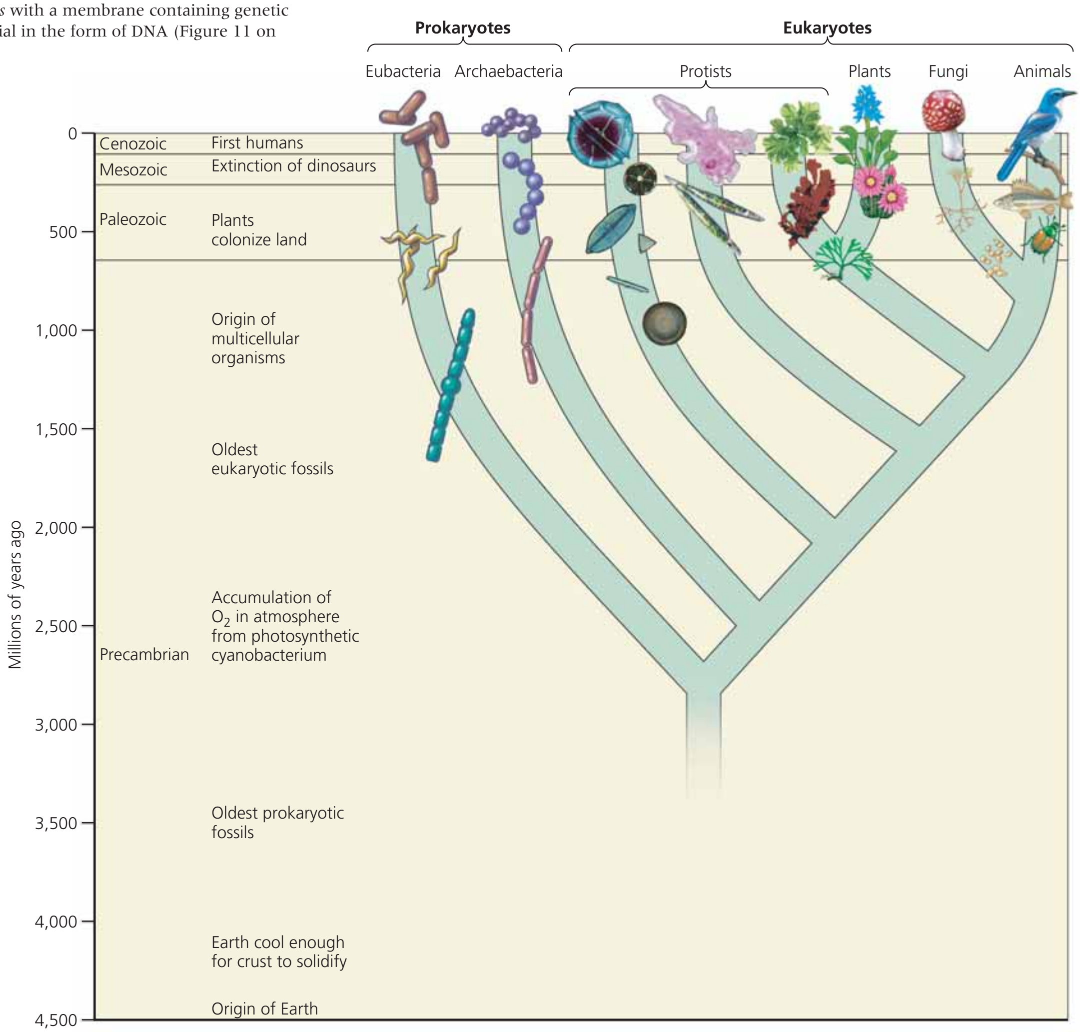


Figure 1 Overview of the evolution of life on the earth into six major kingdoms of species as a result of natural selection.

Eubacteria consist of single-celled prokaryotic bacteria not including archaebacteria. 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.

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 and sleeping sickness.

Fungi are mostly many-celled, sometimes microscopic, eukaryotic organisms such as mushrooms, molds, mildews, and yeasts. Many fungi are decomposers. Other fungi kill various plants 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,* which can live for more than 2 years, such as roses, grapes, elms, and magnolias.

Animals are also many-celled, eukaryotic organisms. Most have no backbones and hence are called *invertebrates.* Invertebrates include sponges, jellyfish, worms, arthropods (insects, shrimp, and spiders), mollusks (snails, clams, and octopuses), and echinoderms (sea urchins and sea stars). *Vertebrates* (animals with backbones and a brain protected by skull bones) include fishes (e.g., sharks and tuna), amphibians (e.g., frogs and salamanders), reptiles (e.g., crocodiles and snakes), birds (e.g., eagles and robins), and mammals (e.g., bats, elephants, whales, and humans).

Within each kingdom, biologists have created subcategories based on anatomical, physiological, and behavioral characteristics. Kingdoms are divided into *phyla,* which are divided into subgroups called *classes.* Classes are subdivided into *orders,* which are further divided into *families.* Families consist of *genera* (singular, *genus*), and each genus contains one or more *species.* Note that the word *species* is both singular and plural. Figure 2 shows this detailed taxonomic classification for the current human species.

Most people call a species by its common name, such as robin or grizzly bear. Biologists use scientific names (derived from Latin) consisting of two parts (printed in italics, or underlined) to describe a species. The first word is the capitalized name (or abbreviation) for the genus to which the organism belongs. It is followed by a lowercase name that distinguishes the species from other members of the same genus. For example, the scientific name of the robin is *Turdus migratorius* (Latin for "migratory thrush") and the grizzly bear goes by the scientific name *Ursus horribilis* (Latin for "horrible bear").

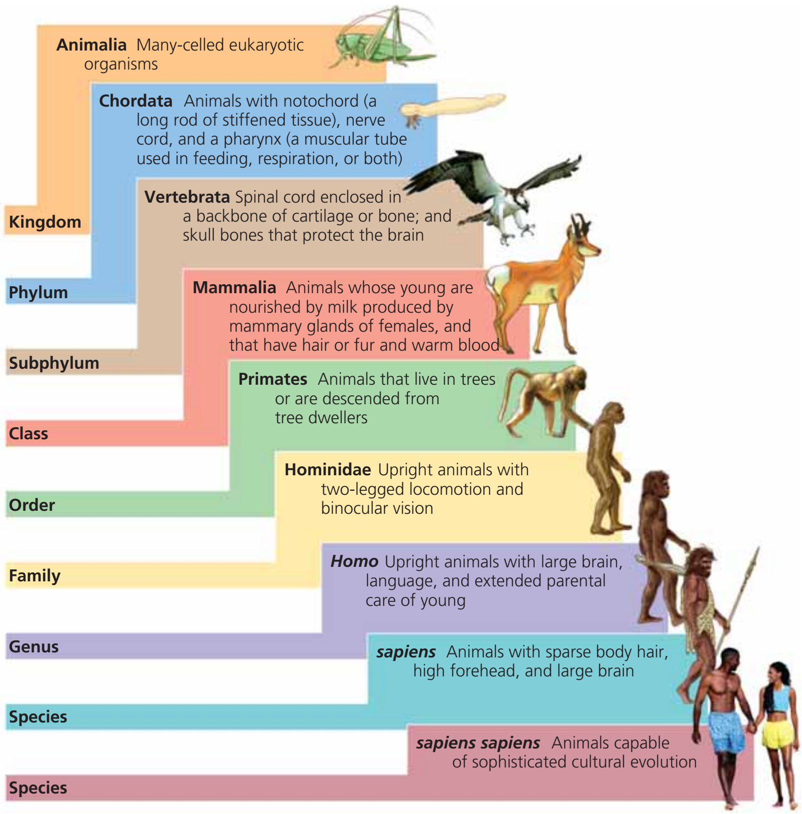


Figure 2 Taxonomic classification of the latest human species, *Homo sapiens sapiens.*

Weather Basics, El Niño, Tornadoes, and Tropical Cyclones (Chapters 5, 11, 15)

SUPPLEMENT 10

Weather Is Affected by Moving Masses of Warm and Cold Air

Weather is an area's short-term atmospheric conditions—typically those occurring over hours or days. Examples of atmospheric conditions include temperature, pressure, moisture content, precipitation, sunshine, cloud cover, and wind direction and speed.

Meteorologists use equipment 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 the next several days by calculating the probabilities that air masses, winds, and other factors will move and change in certain ways.

Much of the weather we experience results from interactions between the leading edges of moving masses of warm and cold air. Weather changes as one air mass replaces or meets another. The most dramatic changes in weather occur along a **front,** the boundary between two air masses with different temperatures and densities.

A **warm front** is the boundary between an advancing warm air mass and the cooler one it is replacing (Figure 1, left). Because warm air is less dense (weighs less per unit of volume) than cool air, an advancing warm front rises up over a mass of cool air. As the warm front rises, its moisture begins condensing into droplets, forming layers of clouds at different altitudes. Gradually the clouds thicken, descend to a lower altitude, and often release their moisture as rainfall. A moist warm front can bring days of cloudy skies and drizzle.

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).

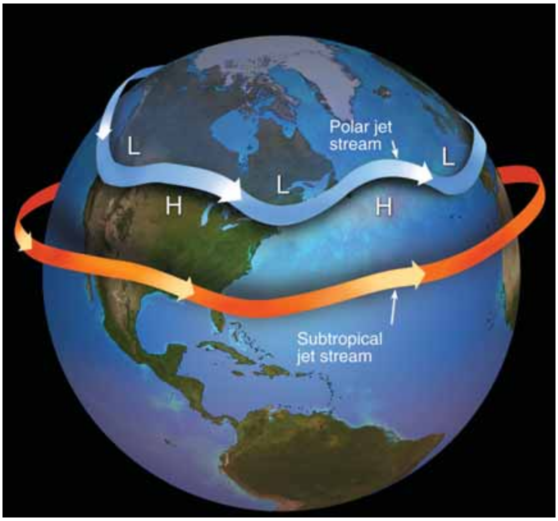


Figure 2 A *jet stream* is a rapidly flowing air current that moves west-to-east in a wavy pattern. This figure shows a polar jet stream and a subtropical jet stream in winter in the northern hemisphere. In reality, jet streams are discontinuous and their positions vary from day to day. (Used by permission from C. Donald Ahrens, *Meteorology Today,* 8th ed. Belmont, Calif.: Brooks/Cole, 2006)

Weather Is Affected by Changes in Atmospheric Pressure

Changes in atmospheric pressure also affect weather. *Air pressure* results from molecules of gases (mostly nitrogen and oxygen) in the atmosphere zipping around at very high speeds and hitting and bouncing off anything they encounter.

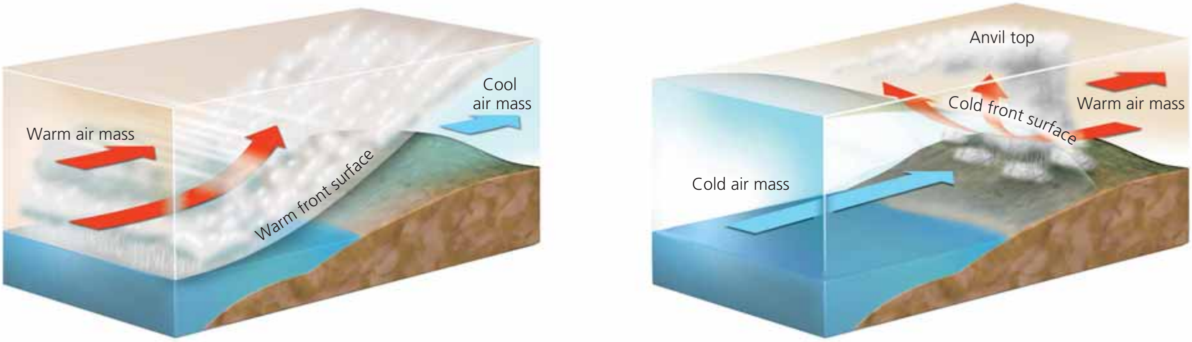


Figure 1 *Weather fronts:* a *warm front* (left) arises when an advancing mass of warm air meets and rises up over a retreating mass of denser cool air. A *cold front* (right) forms when a mass of cold air wedges beneath a retreating mass of less dense warm air.

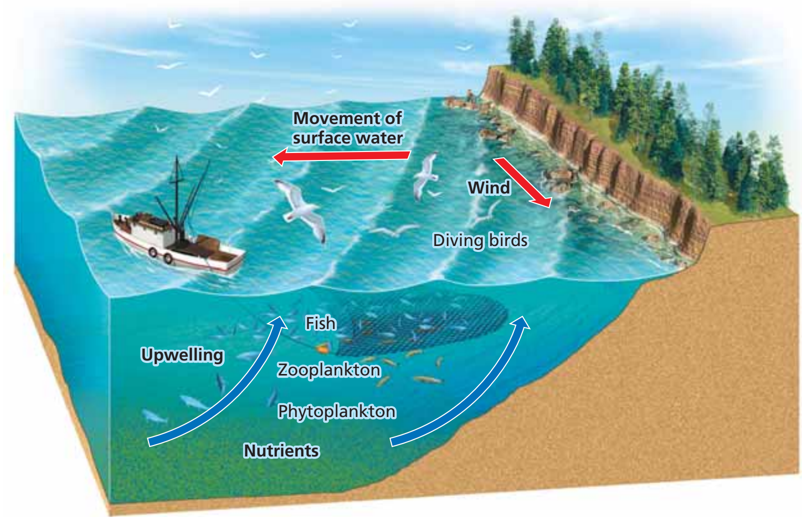


Figure 3 A *shore upwelling* occurs when deep, cool, nutrient-rich waters are drawn up to replace surface water moved away from a steep coast by wind flowing along the coast toward the equator.

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 toward the earth's surface and becomes warmer. Fair weather 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 large and heavy drops, 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 Affect Global Weather Patterns

An **upwelling,** or upward movement of ocean water, can mix ocean water. It brings 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 5-2 (p. 77) shows the ocean's major upwelling zones. Upwellings far from shore occur when surface currents move apart and draw water up from deeper layers. Strong upwellings are also found along the steep western coasts of some continents when winds blowing along the coasts push surface water away from the land and draw water up from the ocean bottom (Figure 3).

Every few years in the Pacific Ocean, normal shore upwellings (Figure 4, left) are affected by changes in climate 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 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.

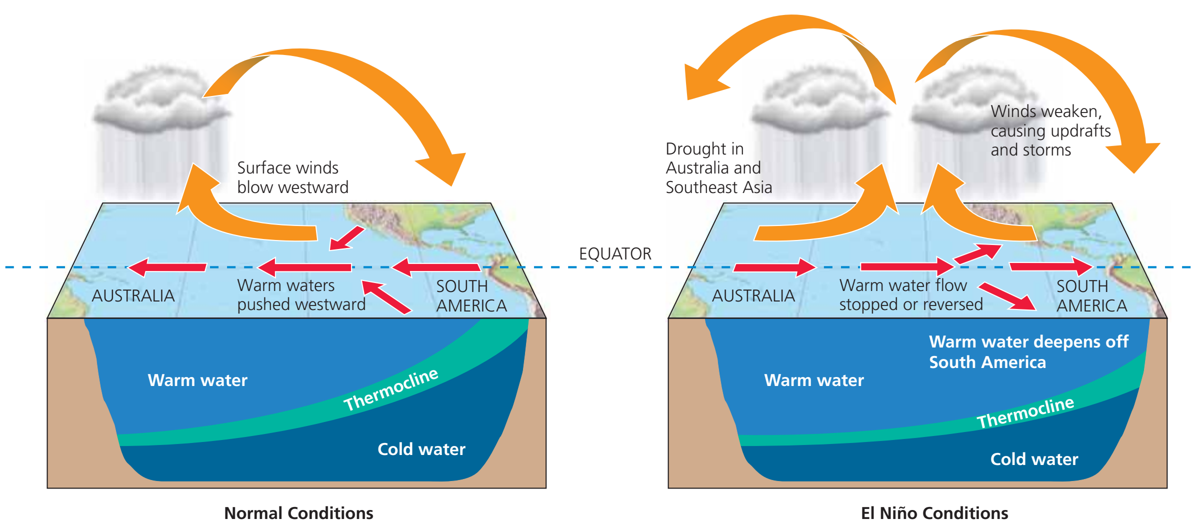


Figure 4 Normal trade winds blowing east to west cause shore upwellings of cold, nutrient-rich bottom water in the tropical Pacific Ocean near the coast of Peru (left). A zone of gradual temperature change called the *thermocline* separates the warm and cold water. Every few years a shift in trade winds 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).

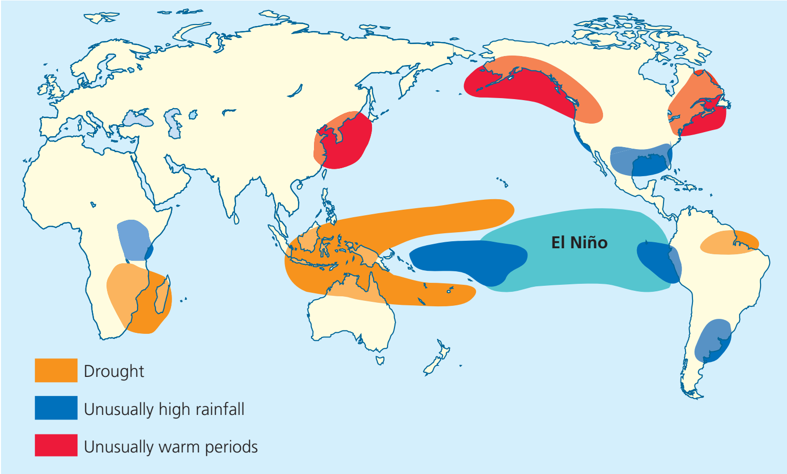


Figure 5 Typical global weather effects of an El Niño–Southern Oscillation (ENSO). During the 1996–98 ENSO, huge waves battered the coast in the U.S. state of California, and torrential rains caused widespread flooding and mudslides. In Peru, floods and mudslides killed hundreds of people, left about 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)

A strong ENSO can alter the weather of at least two-thirds of the globe—especially in lands along the Pacific and Indian Oceans (Figure 5). Scientists do not completely understand the causes of an ENSO but they 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 (Figure 6). 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. Figure 7 (p. S46) shows the areas of greatest risk from tornadoes in the continental United States.

As the large warm-air mass moves rapidly over the more dense cold-air mass, it rises swiftly and forms strong vertical convection currents that suck air upward, as shown in Figure 6. Scientists hypothesize that the rising vortex of air starts spinning because the air near the ground in the funnel is moving more slowly than the air above. This difference causes the air ahead of the advancing front to roll or spin in a vertically rising air mass or vortex.

Tropical cyclones are spawned by the formation of low-pressure cells of air over warm tropical seas. Figure 8 (p. S46) shows the formation and structure of a tropical cyclone. *Hurricanes* are tropical cyclones that form in the Atlantic Ocean; those forming in the Pacific Ocean usually are called *typhoons.* Tropical cyclones take a long time to form and gain strength. As a result,

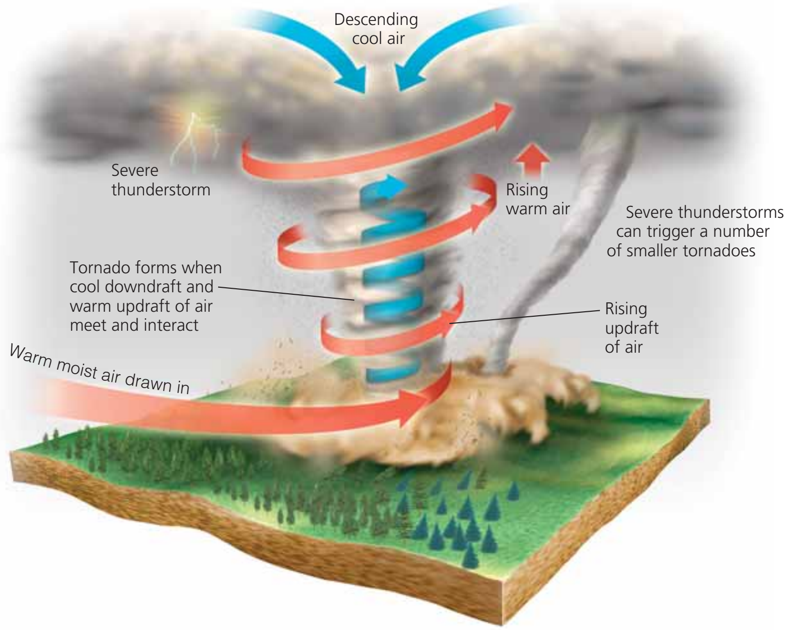
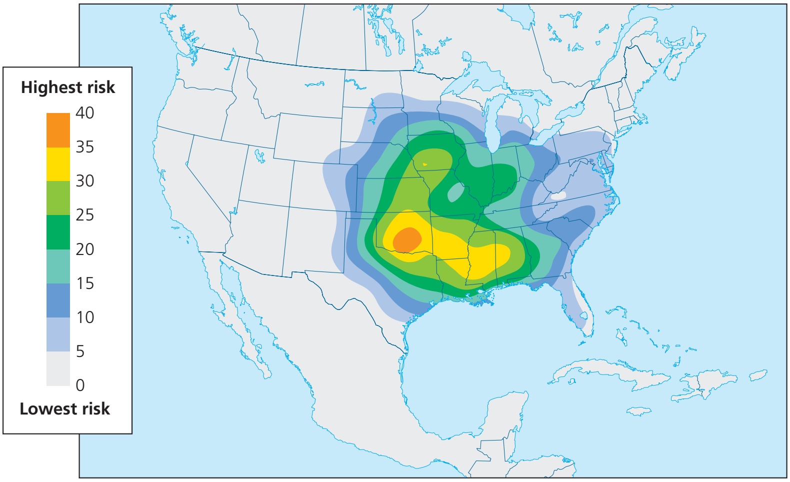


Figure 6 Formation of a *tornado* or *twister.* Although twisters can form at any time of the year, the most active tornado season in the United States is usually March through August. Meteorologists cannot tell us with great accuracy when or where most tornadoes will form.

Figure 7 States with very high and high tornado risk in the continental United States. (Data from NOAA)



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. 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).

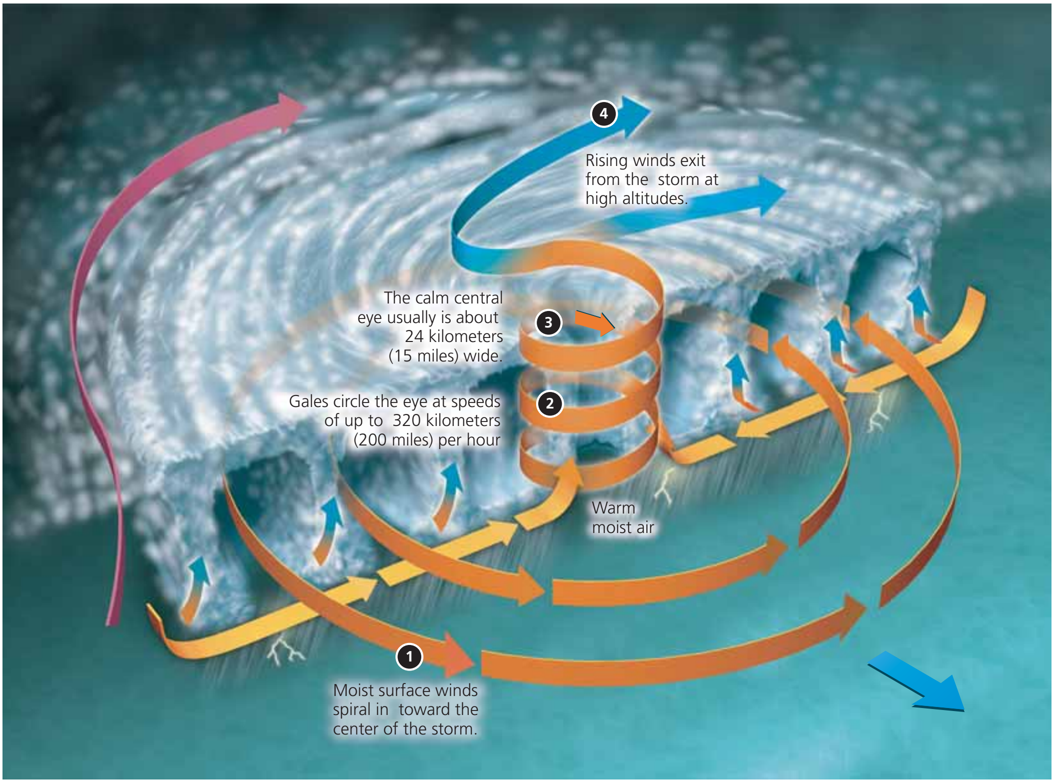


Figure 8 Formation of a *tropical cyclone.* Those forming in the Atlantic Ocean usually are called *hurricanes;* those forming in the Pacific Ocean usually are called *typhoons.*

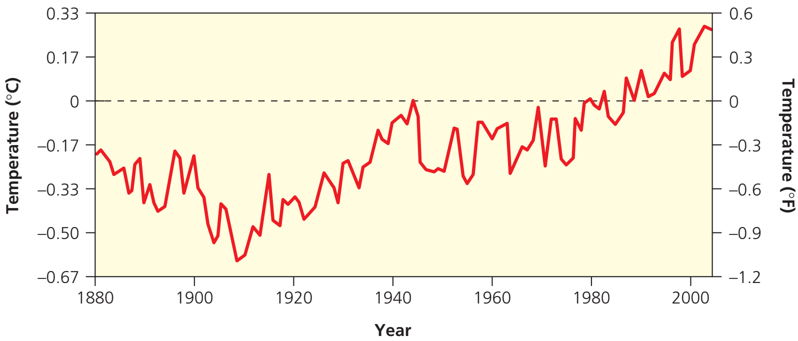


Figure 9 Change in global ocean temperature from its average baseline temperature from 1971 to 2000. (Data from National Oceanic and Atmospheric Administration)

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.

Figure 9 shows the change in the average surface temperature of the global ocean between 1880 and 2004. Note the rise in this temperature since 1980. These higher temperatures, especially in tropical waters, may help explain why average intensity of tropical cyclones has increased since 1990. For example, between 1990 and 2006, there were 250 Category 4 and 5 tropical cyclones (120 of them in the West Pacific) compared to 161 between 1975 and 1989. With the number of people living along the world's coasts increasing, the danger to lives and property has risen dramatically.

Scientists have not been able to correlate the number of tropical cyclones with global warming of the atmosphere and the world's oceans. However, they have found a statistical correlation between global warming of the atmosphere and the global ocean (Figure 9) and the size and intensity of tropical cyclones. If this is correct, the size and intensity of tropical cyclones are expected to increase as the atmosphere warms during this century. However, other natural climate factors and cycles may play an important role in the frequency and intensity of tropical cyclones. The greatest risk from hurricanes in the continental United States is along the gulf and eastern coasts, as shown in Figure 10.

Hurricanes and typhoons can kill and injure people and damage property and agricultural production. Sometimes, however, the long-term ecological and economic benefits of a tropical cyclone can 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 out of the bays and marshes reduced brown tides consisting of explosive growths of algae feeding on excess nutrients. It also increased growth of sea grasses, which serve as nurseries for shrimp, crabs, and fish and provide food for millions of ducks wintering in Texas bays. Production of commercially important species of shellfish and fish also increased.

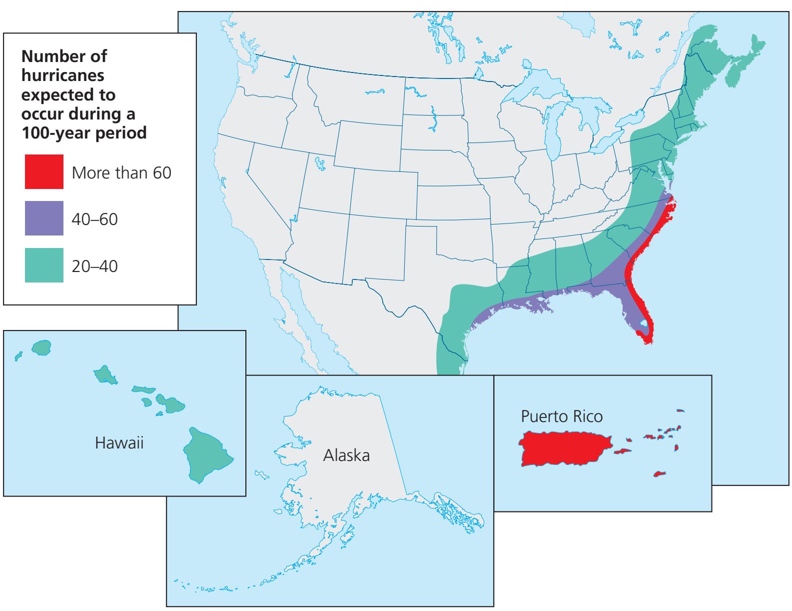


Figure 10 The number of hurricanes expected to occur during a 100-year period in the continental United States (based on historical data). **Question:** What is the degree of risk where you live or go to school? (Data from U.S. Geological Survey)

SUPPLEMENT

11 Components and Interactions in Major Biomes

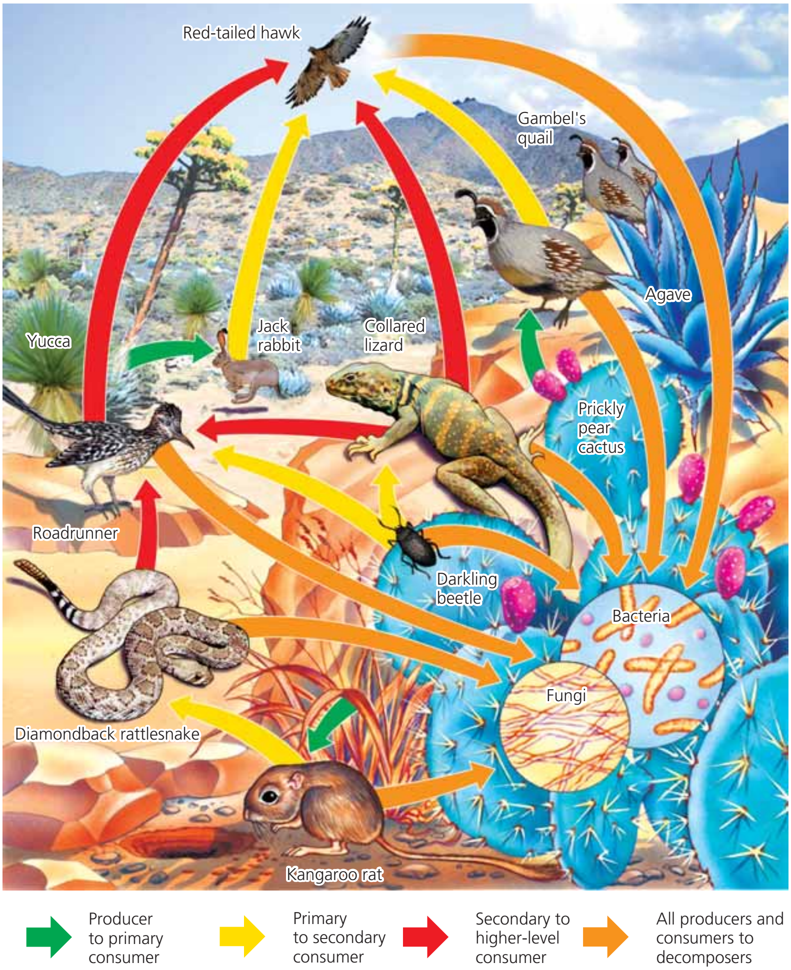
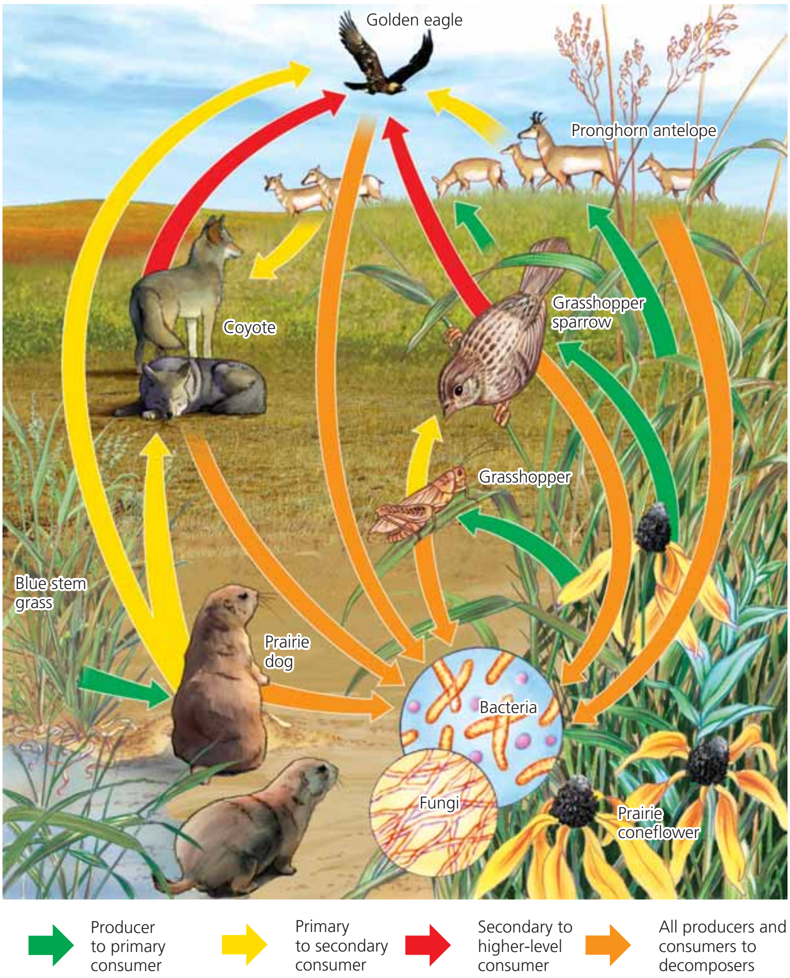


Figure 1 Some components and interactions in a *temperate desert ecosystem.* When these organisms die, decomposers break down their organic matter into minerals that plants use. Colored arrows indicate transfers of matter and energy between producers; primary consumers (herbivores); secondary, or higher-level, consumers (carnivores); and decomposers. Organisms are not drawn to scale. **Question:** What species might undergo population growth and what species might suffer a population decline if the diamondback rattlesnake was eliminated from this ecosystem?



ThomsonNOW™ Active Figure 2 Some components and interactions in a *temperate tall-grass prairie ecosystem* in North America. When these organisms die, decomposers break down their organic matter into minerals that plants can use. Colored arrows indicate transfers of matter and energy between producers, primary consumers (herbivores), secondary consumers (carnivores), and decomposers. Organisms are not drawn to scale. *See an animation based on this figure at* ThomsonNOW. **Question:** What species might increase and what species might decrease in population if the threatened prairie dog was eliminated from this ecosystem?

Figure 3 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 between 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 their population size if the Artic fox was eliminated from this ecosystem?

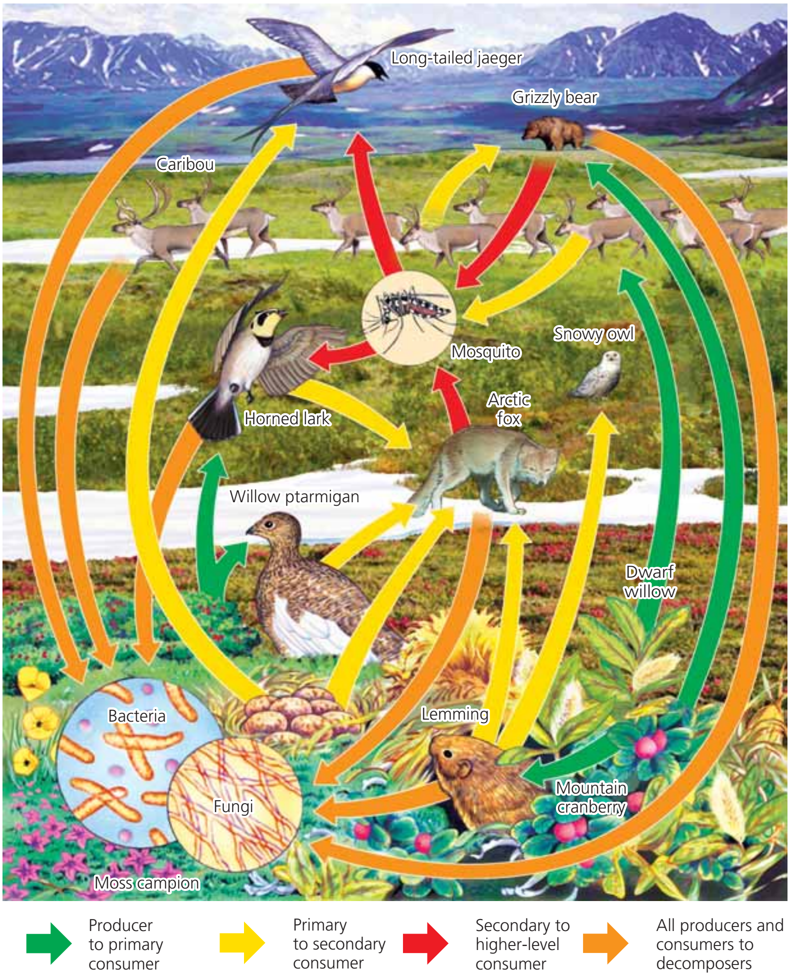
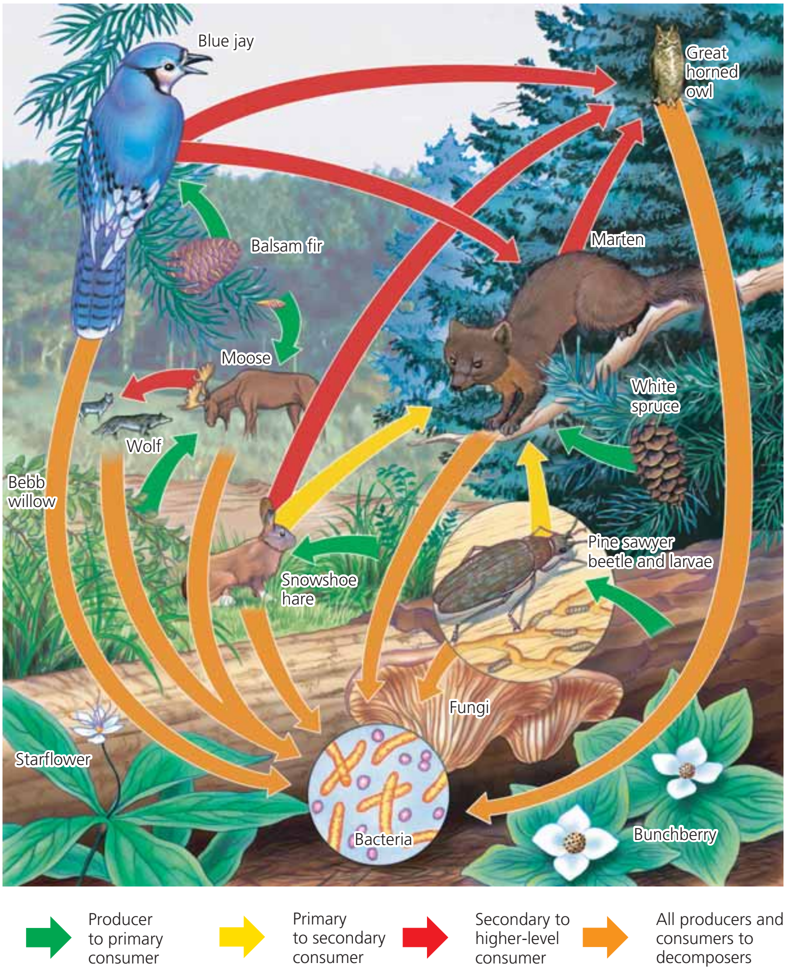


Figure 4 Some components and interactions in a *temperate deciduous forest ecosystem.* When these organisms die, decomposers break down their organic matter into minerals that plants use. Colored arrows indicate transfers of matter and energy between producers; primary consumers (herbivores); secondary, or higher-level, consumers (carnivores); and decomposers. Organisms are not drawn to scale. **Question:** What populations might increase if the broad-winged hawk is eliminated from this ecosystem?

Figure 5 Some components and interactions in an *evergreen coniferous* (*boreal* or *taiga*) *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. **Question:** What populations might increase in size if the great horned owl is eliminated from this ecosystem?



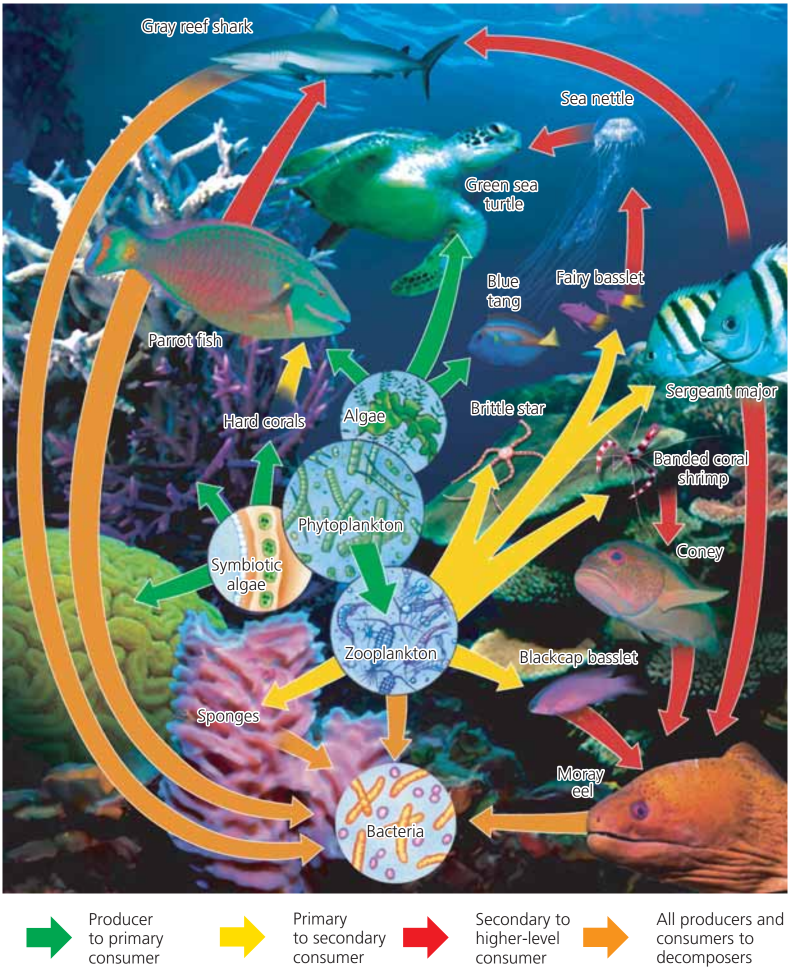


Figure 6 Components and interactions in a *coral reef ecosystem.* When these organisms die, decomposers break down their organic matter into minerals used by plants. Colored arrows indicate transfers of matter and energy between producers; primary consumers (herbivores); secondary, or higher-level, consumers (carnivores); and decomposers. Organisms are not drawn to scale. See the photo of a coral reef in Figure 5-20 (left, p. 93). **Question:** How would the species in this ecosystem be affected if phytoplankton populations suffered a sharp decline?

SUPPLEMENT

12 Earthquakes, Tsunamis, and Volcanic Eruptions (Chapters 5, 12, 14, 15)

Earthquakes Are Geological Rock-and-Roll Events

Stress in the earth's crust can cause solid rock to deform until it suddenly fractures and shifts along the fracture, producing a fault (Figure 12-5, p. 265). The faulting or a later abrupt movement on an existing fault causes an **earthquake** (Figure 1).

Relief of the earth's internal stress releases energy as shock 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 shock waves. The magnitude is a measure of the amount of energy released in the earthquake, as indicated by the amplitude (size) of the vibrations when they reach a recording instrument (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 is 10 times greater than a magnitude 4.0 earthquake, and a magnitude 6.0 quake is 100 times greater than a magnitude 4.0 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).

Earthquakes often have *aftershocks* that gradually decrease in frequency over a period of as long as several months. Some also are preceded by *foreshocks* that occur from seconds to weeks before the main shock.

The *primary effects of earthquakes* include shaking and sometimes a permanent vertical or horizontal displacement of the ground. These effects may have serious consequences for people and for buildings, bridges, freeway overpasses, dams, and pipelines. A major earthquake is a very large rock-and-roll event.

Secondary effects of earthquakes include rockslides, urban fires, and flooding caused by *subsidence* (sinking) of land. 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 also map high-risk areas, establish building codes that regulate the placement and design of buildings in such areas, and increase research geared toward predicting when and where earthquakes will occur. Then people can decide how high the risk might be and whether they want to accept that risk and live in areas subject to earthquakes. Figure 2 shows the areas of greatest earthquake risk in the continental United States and Figure 3 shows such risks throughout the world.

Engineers know how to make homes, large buildings, bridges, and freeways more earthquake resistant. But this can be expensive, especially the reinforcement of existing structures.

Earthquakes on the Ocean Floor Can Cause Huge Waves Called Tsunamis

A **tsunami,** from a Japanese word meaning "harbor wave"), is a series of large waves generated when part of the ocean floor suddenly rises or drops (Figure 4). Most large tsunamis are caused when thrust faults in the ocean floor move up or down as a result of a large underwater earthquake or a landslide caused by such an earthquake. Such earthquakes often

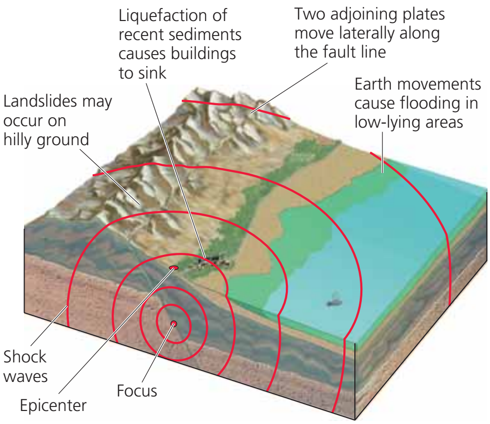


Figure 1 Major features and effects of an *earthquake.*

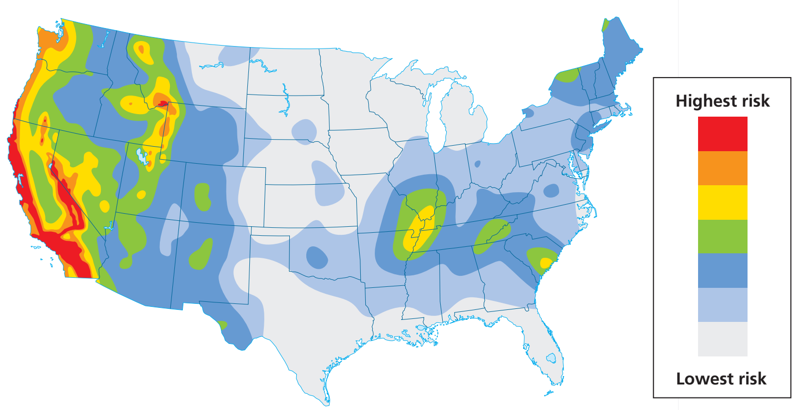


Figure 2 Areas of greatest earthquake (seismic) risk in the continental United States. **Question:** What is the degree of risk where you live or go to school? (Data from U.S. Geological Survey)

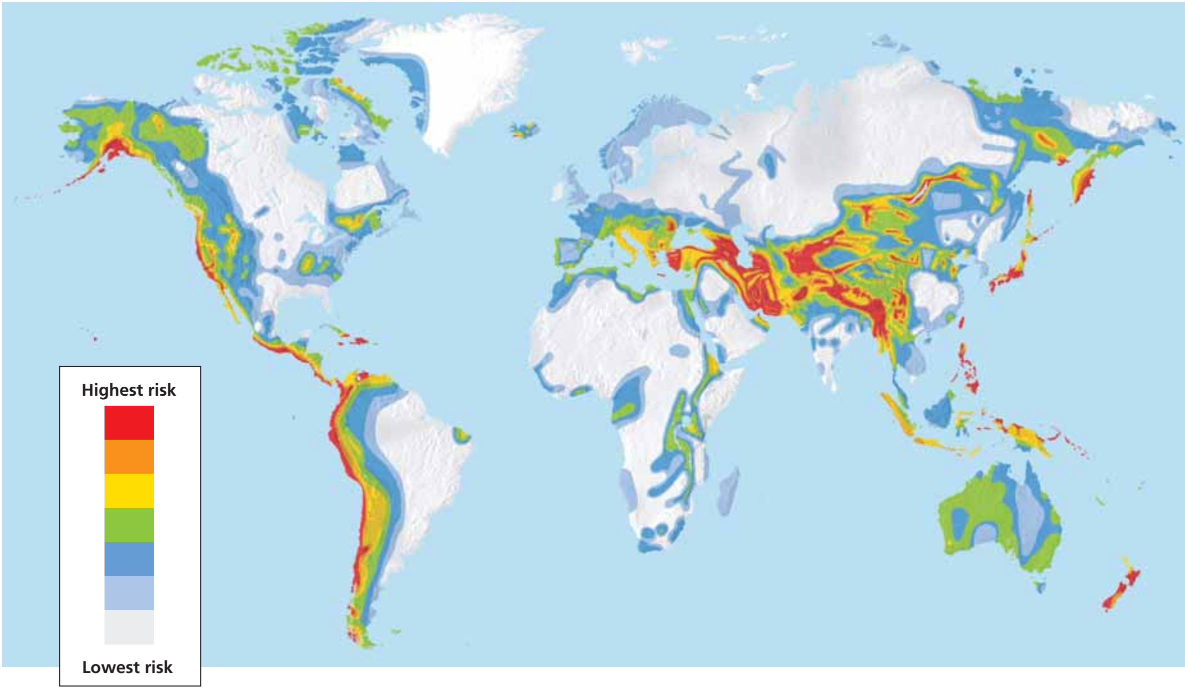


Figure 3 Areas of greatest earthquake (seismic) risk in the world **Question:** What is the degree of risk where you live or go to school? (Data from U.S. Geological Survey)

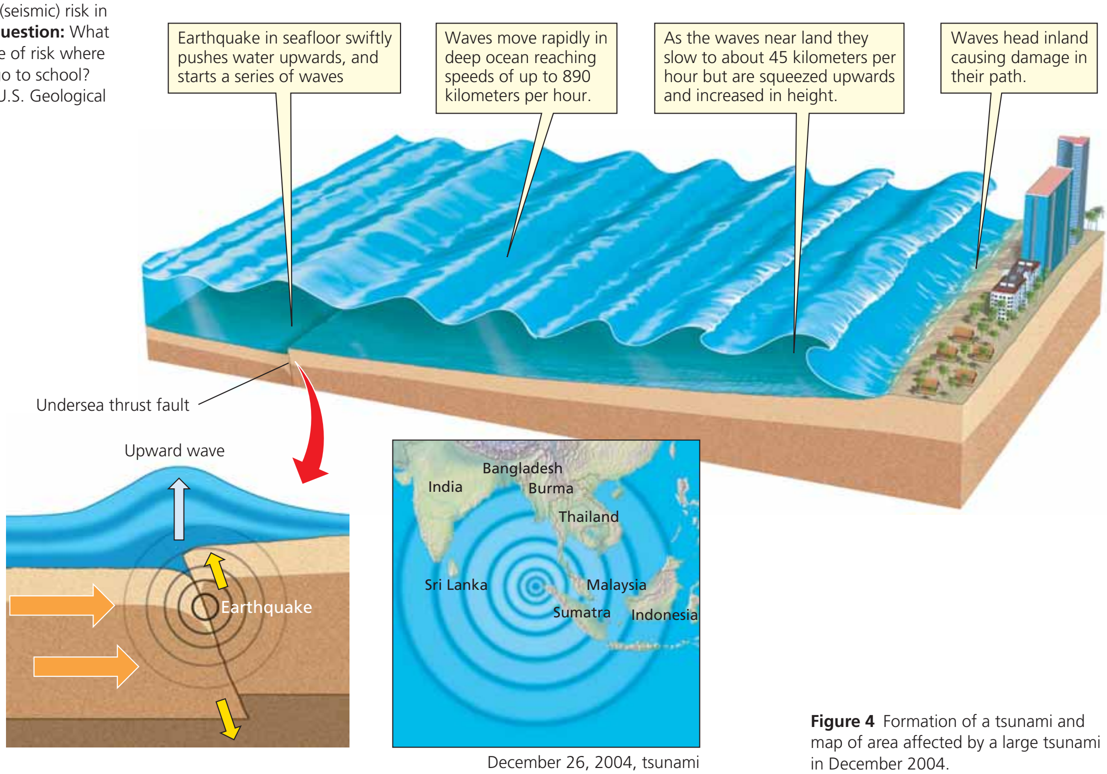


Figure 4 Formation of a tsunami and map of area affected by a large tsunami in December 2004.

Figure 5 In December 2004, a major earthquake on the seafloor of the Pacific Ocean created a large tsunami that killed 168,000 people in Indonesia. These photos show the Banda Aceh Shore Gleebruk in Indonesia on June 23, 2004, before (top) the tsunami and on December 28, 2004, after it was stuck by the tsunami (bottom).

DigitalGlobe

DigitalGlobe

occur offshore at subduction zones where a tectonic plate slips under a continental plate (Figure 12-3, p. 264).

Tsunamis are often called tidal waves, although they have nothing to do with tides. They travel very far and as fast as 890 kilometers (550 miles) per hour—the speed of a jet plane. At this speed, a tsunami could travel across the Pacific Ocean in less than a day.

In deep water the waves are very far apart—sometimes hundreds of kilometers—and their crests are not very high. When the tsunami reaches shallow water and approaches a coast it slows down and 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 to provide some degree of early warning by using a network of ocean buoys. A pressure recorder on the ocean floor measures changes in water pressure as the waves of a tsunami pass over it. These data are relayed to a weather buoy, which then transmits the data via satellite to tsunami emergency warning centers.

Between 1900 and late 2004, an estimated 278,000 people in the Pacific Ocean regions were killed by tsunamis. The largest loss of life occurred in December 2004 when a large tsunami killed 228,000 people (168,000 of them in Indonesia) and devastated many coastal areas of Asia (Figure 5 and map in Figure 4).

Satellite observations and ground studies in February 2005 by the U.N. Environment Programme pointed to the role that healthy coral reefs and mangrove forests (Figure 5-20, p. 93), played in reducing the death toll and destruction from the 2004 tsunami. For example, intact mangrove forests in parts of Thailand helped protect buildings and people from the force of the huge waves. In contrast, the extensive damage and high death toll from the 2004 tsunami in India's Tamus state has been attributed in part to the widespread clearing of a third of the coastal area's mangrove forest in recent decades. In Sri Lanka, some of the greatest damage occurred where illegal coral mining and reef damage had caused severe beach erosion.

Volcanoes Release Molten Rock from the Earth's Interior

An active **volcano** occurs where magma (molten rock) reaches the earth's surface through a central vent or a long crack (*fissure;* Figure 6). Volcanic activity can release *ejecta* (debris ranging from large chunks of lava rock to glowing hot ash), liquid lava, and gases (such as water vapor, carbon dioxide, and sulfur dioxide) into the environment.

Volcanic activity is concentrated for the most part in the same areas as seismic activity. Some volcanoes erupt explosively and eject large

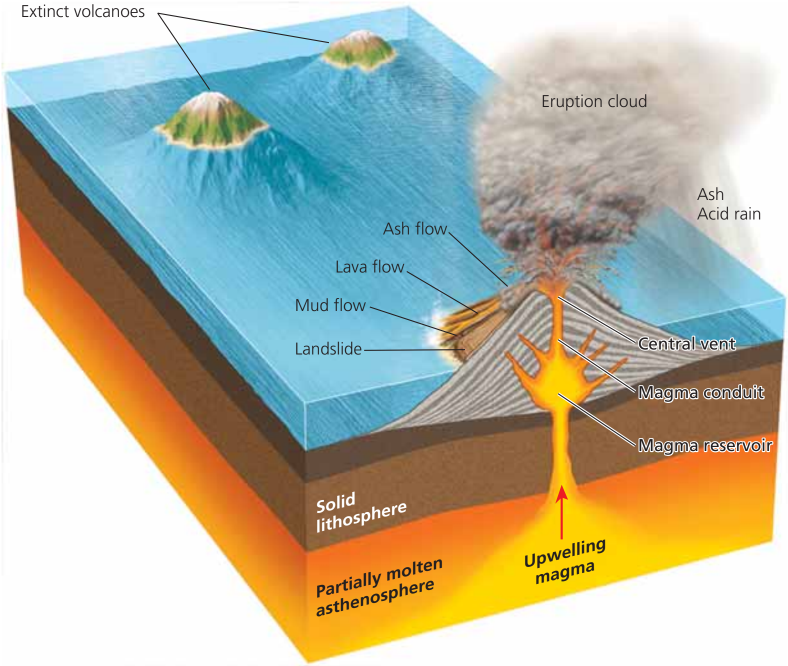


Figure 6 A *volcano* erupts when molten magma in the partially molten asthenosphere rises in a plume through the lithosphere to erupt on the surface as lava that can spill over or be ejected into the atmosphere. Chains of islands can be created by eruptions of volcanoes that then become inactive.

quantities of gases and particulate matter (soot and mineral ash) high into the atmosphere (Figure 15-1, p. 344). Most of this soot and ash soon falls back to the earth's surface. Gases such as sulfur dioxide remain in the atmosphere, however, where they are converted to tiny droplets of sulfuric acid. This acid may remain above the clouds where it may not be washed out by rain for as long as 3 years. The tiny droplets reflect some of the sun's energy and can cool the atmosphere for 1–4 years.

Other volcanoes erupt more quietly. They involve primarily lava flows, which can cover roads and villages and ignite brush, trees, and homes.

We tend to think of volcanic activity as an undesirable event, but it does provide some benefits. For example, it creates outstanding scenery in the form of majestic mountains, some lakes (such as Crater Lake in Oregon; Figure 5-30, left, p. 101), and other landforms. Perhaps the most important benefit of volcanism is the highly fertile soils produced by the weathering of lava.

We can reduce the loss of human life and sometimes property damage caused by volcanic eruptions in several ways. For example, we can use historical records and geologic measurements to identify high-risk areas so that people can avoid living in them. We can also develop effective evacuation plans and measurements that warn us when volcanoes are likely to erupt.

Scientists continue to study the phenomena that precede an eruption. Examples include tilting or swelling of the cone, changes in magnetic and thermal properties of the volcano, changes in gas composition, and increased seismic activity.

SUPPLEMENT

13

CASE STUDY

Whales and Whaling (Chapter 9)

There Are Two Major Types of Whales

Cetaceans are an order of mostly marine mammals ranging in size from the 0.9-meter (3-foot) porpoise to the giant 15- to 30-meter (50- to 100-foot) blue whale. They are divided into two major groups: *toothed whales* and *baleen whales* (Figure 1).

Toothed whales, such as the porpoise, sperm whale, and killer whale (orca), bite and chew their food and feed mostly on squid, octopus, and other marine animals. *Baleen whales,* such as the blue, gray, humpback, and finback, are filter feeders. They use plates made of baleen, or whalebone, that hang down from their upper jaw. to filter plankton from the seawater, especially tiny shrimplike krill (Figure 3-15, p. 51).

THINKING ABOUT
Whales

Why are baleen whales more abundant than toothed whales? (*Hint:* Think food webs.)

Whales Are Easy To Kill

Whales are fairly easy to kill because of their large size and their need to come to the surface to breathe. Mass slaughter became efficient with the use of radar and airplanes to locate them, fast ships, harpoon guns, and inflation lances that pump dead whales full of air and make them float.

Whale harvesting, mostly in international waters, has followed the classic pattern of a tragedy of the commons, with whalers killing an estimated 1.5 million whales between 1925 and 1975. This overharvesting reduced the populations of 8 of the 11 major species to the point at which it no longer paid to hunt and kill them (*commercial extinction*). It also drove some commercially prized species such as the giant blue whale to the brink of biological extinction (Science Focus, below) and has threatened other species.

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.

This did not work well for two reasons. *First,* IWC quotas often were based on inadequate data or ignored by whaling countries. *Second,* 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 in the IWC, the IWC has imposed a moratorium on commercial whaling since 1986. It worked. The estimated number of whales killed commercially worldwide dropped from 42,480 in 1970 to about 1,300 in 2006.

Despite the ban, Japan, Norway, and Iceland kill about 1,300 whales of certain species each year (Figure 2) for scientific purposes. Critics see these whale hunts as poorly disguised commercial whaling because the whale meat is sold to restaurants with each whale worth up to $30,000 wholesale. In 2005, Japan more than doubled its whaling catch, allegedly for scientific purposes, from 440 minke whales to 850 minke whales and 10 fin whales, and began harvesting humpback whales in 2006. Another 370 whales are harvested legally each year, mostly for food, by indigenous people in Russia, Denmark, South Korea, and the United States.

Should We Resume Commercial Whaling?

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.

SCIENCE FOCUS

Code Blue: Near Extinction of the Blue Whale

The endangered blue whale (Figure 1) is the world's largest animal. Fully grown, it is longer than three train boxcars and weighs more than 25 elephants. The adult has a heart the size of a Volkswagen Beetle car, and some of its arteries are so big that a child could swim through them.

Blue whales spend about 8 months a year in Antarctic waters. There they find an abundant supply of krill (Figure 3-15, p. 51), which they filter from seawater by the trillions daily. During the winter, they migrate to warmer waters where their young are born.

Before commercial whaling began an estimated 200,000 blue whales roamed the Antarctic Ocean. Today the species has been hunted to near biological extinction for its oil, meat, and bone. There are probably fewer than 10,000 of these whales left.

A combination of prolonged overharvesting and certain natural characteristics of blue whales caused its decline. Their huge size made them easy to spot. They were caught in large numbers because they grouped together in their Antarctic feeding grounds. They also 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 once its population falls beneath a certain threshold.

Blue whales have not been hunted commercially since 1964 and have been classified as an endangered species since 1975. Despite this protection, some marine biologists fear that too few blue whales remain for the species to recover and avoid extinction. Others believe that with continued protection they will make a slow comeback.

Critical Thinking

What difference does it make if the blue whale becomes prematurely extinct mostly because of human activities? Explain.

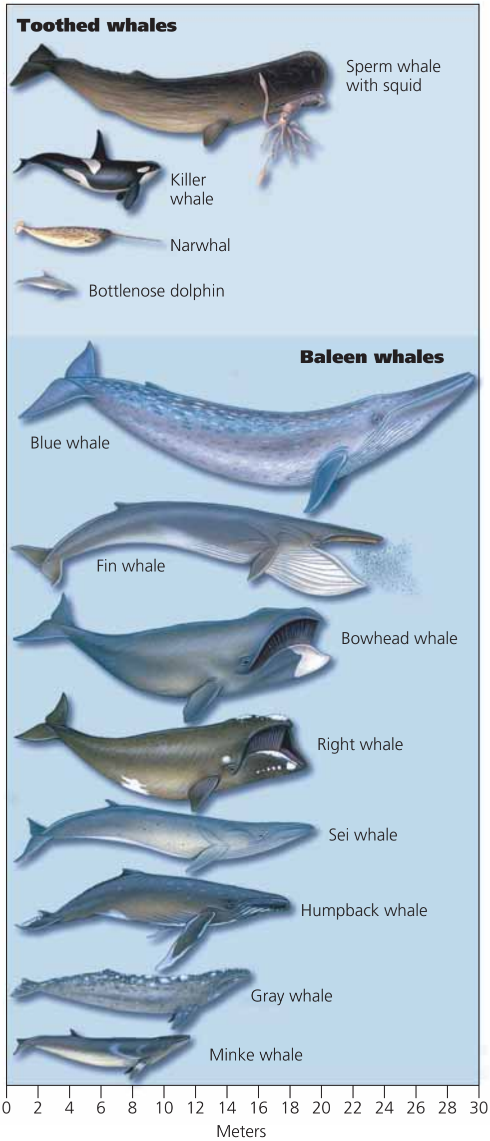


Figure 1 **Natural capital:** examples of cetaceans, which can be classified as either toothed whales or baleen whales.

Figure 2 Norwegian whalers harpooning a sperm whale. Norway, Japan, and Iceland kill about 1,300 whales a year, allegedly for scientific purposes. They also believe that increased but sustainable commercial whaling should be allowed for sperm, minke, and pilot whales whose stocks have built back to large numbers.

They argue that commercial whaling should be allowed because it has been a traditional part of the economies and cultures of their countries. They also contend that the ban is based on emotion, not on updated scientific estimates of whale populations.

The moratorium on commercial whaling has led to a sharp rebound in the estimated populations of sperm, pilot, and minke whales. Proponents of whaling see no scientific reason for not resuming controlled and sustainable hunting of these and other whale species with populations of at least 1 million.

They argue that proposed hunting levels are too low to deplete stocks again. Japan and other pro-whaling nations have also agreed to a plan to allow independent observers on whaling vessels. They may agree to a system that uses DNA tests of whale meat in markets to determine whether or not it came from whales killed according to IWC rules.

Most conservationists disagree. Some argue that whales are peaceful, intelligent, sensitive, and highly social mammals that pose no threat to humans and that they should be protected for ethical reasons. Others question IWC estimates of the allegedly recovered whale species, noting the inaccuracy of past estimates of whale populations. Also, many conservationists fear that opening the door to any commercial whaling may eventually lead to widespread harvests of most whale species by weakening current international disapproval and legal sanctions against commercial whaling.

People in the whale watching business also argue that whales are worth more alive than dead. Each year about 10 million people go on whale watching boats in the world's $1 billion a year whale watching business.

Proponents of resuming whaling say that people in other countries have no right to tell Japanese, Norwegians, and people in other whaling countries not to eat whales just because others disapprove. They argue it is the same as people in India who consider cows sacred telling Americans and Europeans not to eat beef.

HOW WOULD YOU VOTE?

Should carefully controlled commercial whaling be resumed for species with populations of 1 million or more? Cast your vote online at **www.thomsonedu.com/biology/miller**.

SUPPLEMENT

14

CASE STUDY

Mining Law of 1872 (Chapters 12, 16, 17)

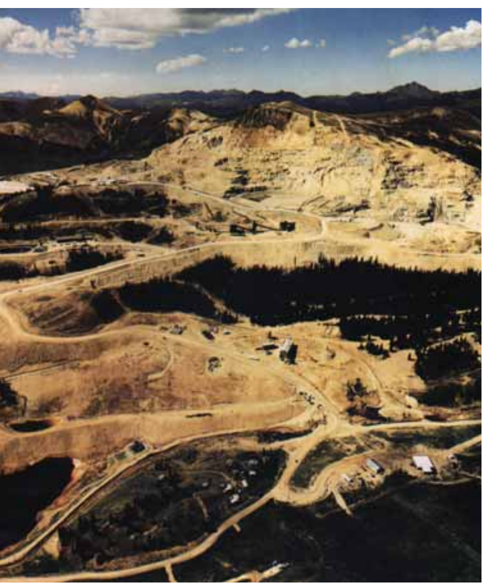
Some people have gotten rich by using the little-known U.S. General Mining Law of 1872. It was designed to encourage mineral exploration and the mining of *hardrock minerals* (such as gold, silver, copper, zinc, nickel, and uranium) on U.S. public lands and to help develop the then sparsely populated West. But hardrock mining devastates the landscape and generates more toxic waste than any other U.S. industry.

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 hardrock minerals and 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 a moratorium was declared in 1995, you could pay the U.S. federal government $6–12 per hectare ($2.50–5.00 an acre) to buy the land and then use it for essentially any purpose, or to lease it, build on it, or sell it. People have constructed golf courses, hunting lodges, hotels, and housing subdivisions on public land that they bought from taxpayers at 1872 prices.

In 2004, Phelps Dodge bought a plot of U.S. Forest Service land atop Colorado's Mt. Emmons near the ski resort town of Crested Butte for $875. The land could be worth as much as $155 million. The company was able to buy the land because it had the option to buy before the 1995 moratorium. According to a 2004 study by the Environmental Working Group, public lands containing an estimated $285 billion of publicly owned mineral resources have been transferred to private companies—one-fifth of them foreign companies—at 1872 giveaway prices.

According to the Bureau of Land Management, mining companies with claims remove hardrock minerals worth at least $4 billion per year from U.S. public land. These companies pay taxpayers royalties amounting to only 2.3% of the value of the minerals, compared to 13.2% royalties paid for oil, natural gas, and coal resources on public lands, and 14% for grazing rights.



U.S. Geological Survey

Figure 1 Summitville gold mining site near Alamosa, Colorado, became a Superfund site after the Canadian company that owned it declared bankruptcy and abandoned the site, rather than clean up the acids and toxic metals that leaked from the site into the nearby Alamosa River. Clean-up expenses by the EPA will cost U.S. taxpayers about $120 million.

After removing valuable minerals and disrupting the land, some mining companies have declared bankruptcy and walked away from their mining operations, leaving behind large amounts of cyanide-laden water in leaking holding ponds. A glaring example is the Summitville gold mine site near Alamosa, Colorado (USA) (Figure 1). A Canadian company used the 1872 mining law to buy the land from the federal government at a pittance, spent $1 million developing the site, and removed $98 million worth of gold.

Shoddy construction allowed acids and toxic metals to leak from the site and poison a 27-kilometer (17-mile) stretch of the Alamosa River, the source of irrigation water for farms and ranches in Colorado's San Luis Valley. Instead of dealing with the pollution problems, the company declared bankruptcy and abandoned the property, but only after being allowed to retrieve $2.5 million of the $7.5 million reclamation bond it had posted with the state. Summitville is now a Superfund site, with the EPA spending $40,000 a day to contain the site's toxic wastes. Ultimately, the EPA expects to spend about $120 million of taxpayers' money to finish the cleanup.

In 1992, the 1872 law was modified to require mining companies to post bonds to cover 100% of the estimated clean-up 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, if the government decides to clean up land and streams damaged by more than 550,000 abandoned hardrock mines, the bill for U.S. taxpayers will be $33–72 billion. According to former Arkansas Senator Dale Bumpers, the 1872 mining law is a "license to steal" from U.S. citizens who jointly own all public lands.

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 hardrock minerals. In addition, their mining operations provide high-paying jobs to miners, supply vital resources for industry, stimulate the national and local economies, and reduce trade deficits. They also save U.S. consumers money on products produced from minerals. But the money taxpayers give as subsidies to mining companies offsets the lower mineral prices.

Critics of this ancient law call for a permanent ban on such sales of public lands but support 20-year leases of designated public land for hardrock mining. They would also require mining companies to pay a *gross* royalty of 8–12% on the wholesale value of all minerals removed from public land—similar to the rates that oil, natural gas, and coal companies pay. Mining companies have been pressuring Congress to lift the ban on sales of public lands.

Canada, Australia, South Africa, and several other countries have laws that require royalty payments and full responsibility for environmental damage.

THINKING ABOUT
The 1872 Mining Law

Explain why you support or oppose each of the following proposals concerning extraction of hardrock minerals on public land in the United States: **(a)** not granting title to public land for actual or claimed hardrock mining, **(b)** requiring mining companies to pay a royalty of 8–12% on the *gross* revenues they earn from hardrock minerals they extract from public lands, and **(c)** making hardrock mining companies legally responsible for restoring the land and cleaning up environmental damage caused by their activities.

Brief History and Possible Future of the Age of Oil (Chapter 13)

SUPPLEMENT 15

Some milestones in the Age of Oil (based on a survey of economic reports and projections):

- **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 to 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 a 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 launch a second Persian Gulf War to oust Saddam Hussein from power in Iraq and to protect Western access to oil supplies in Saudi Arabia, Kuwait, and Iraq.
- **2007:** OPEC has 67% of world oil reserves and produces 40% of the world's oil. The United States has only 2.9% of oil reserves, uses 26% of the world's oil production, and imports 60% of its oil at an average cost of $868,000 per minute.
- **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.

SUPPLEMENT

16

Maps of Energy Resources and Carbon Dioxide Emissions (Chapters 13, 15, 17)

This supplement provides maps showing the actual or potential availability of the world's major nonrenewable and renewable energy resources. As oil supplies dwindle in this century and concerns increase about carbon dioxide emissions from burning of coal and other fossil fuels, some energy analysts believe that we will have to depend on an array of renewable resources, such as solar, wind, geothermal, biomass, and hydroelectricity, based on local and regional availability. Maps in this supplement show per capita energy use, the availability of energy resources, and per capita CO_2 emissions.

THINKING ABOUT
Renewable Energy

Which renewable energy resources are potentially available in the local area or the region where you live? Which, if any, of these resources are currently being used? How would you increase the use of such resources in your local community and in your lifestyle? Relate this to the four principles of sustainability (see back cover).

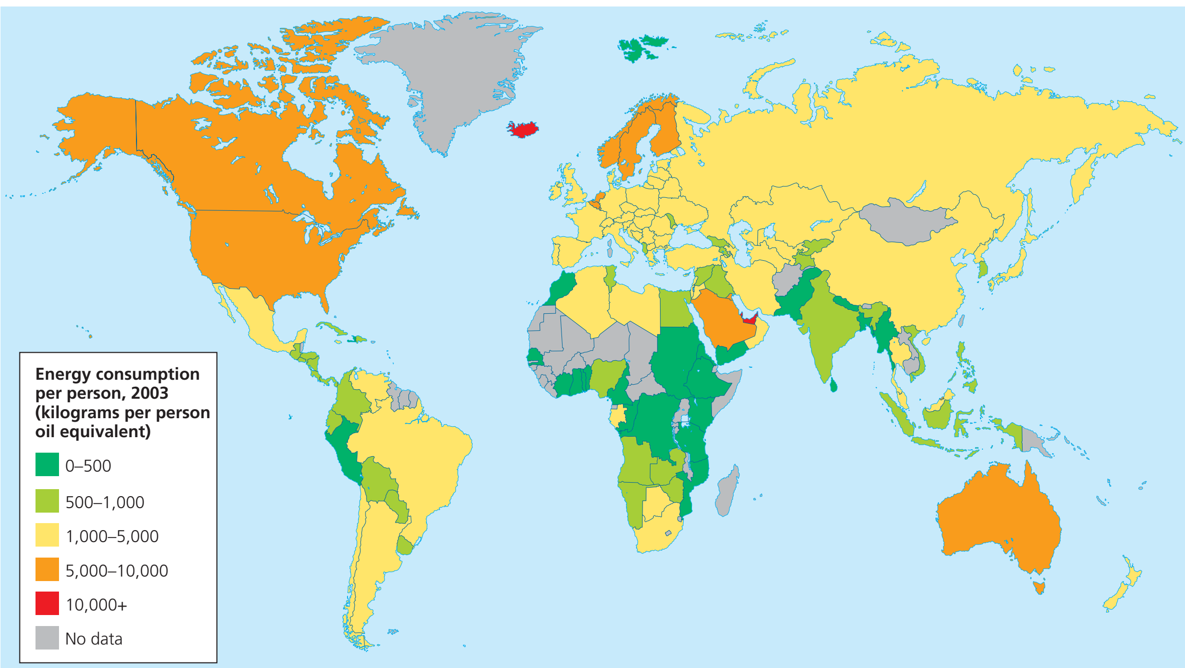
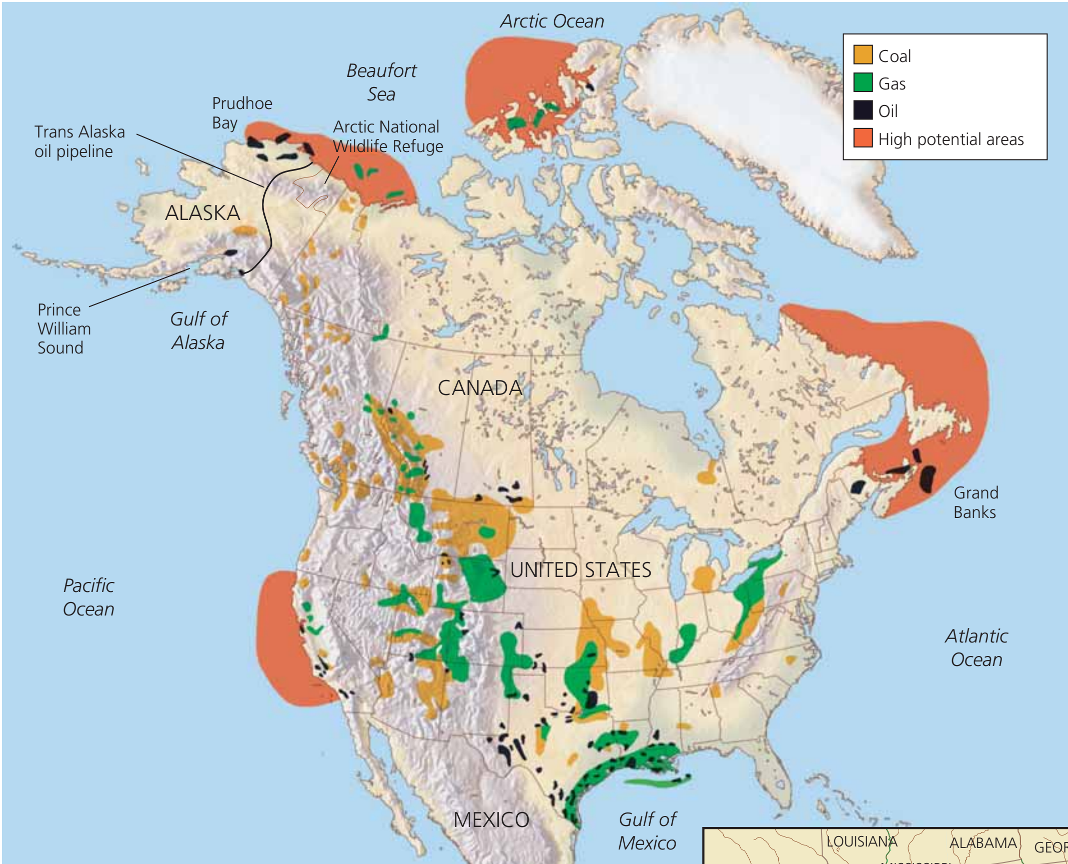


Figure 1 Energy use per person in 2003 (latest data available) in kilograms per person oil equivalent. **Question:** What are two conclusions you can draw from these data? (Data from International Energy Agency)



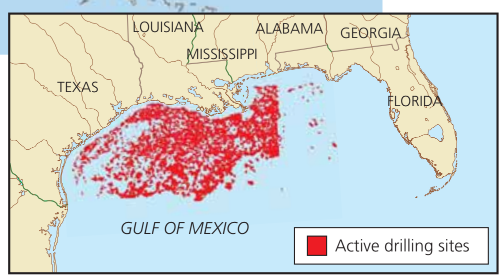


Figure 2 Locations of the major known deposits of oil, natural gas, and coal in North America and offshore areas where more crude oil and natural gas might be found. Geologists do not expect to find very much new oil and natural gas in North America. Offshore drilling (Figure 13-1, p. 279) for oil accounts for about one-fourth of U.S. oil production. Nine of every 10 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). **Question:** What are two conclusions you can draw from this map? (Data from Council on Environmental Quality and U.S. Geological Survey)

Figure 3 Known and suspected deposits of methane hydrates in U.S. coastal waters. Developing the technology to tap into only 1% of these deposits could double the nation's supply of natural gas. **Question:** What might be the harmful environmental consequences of tapping into these deposits? (Data from U.S. Geological Survey)

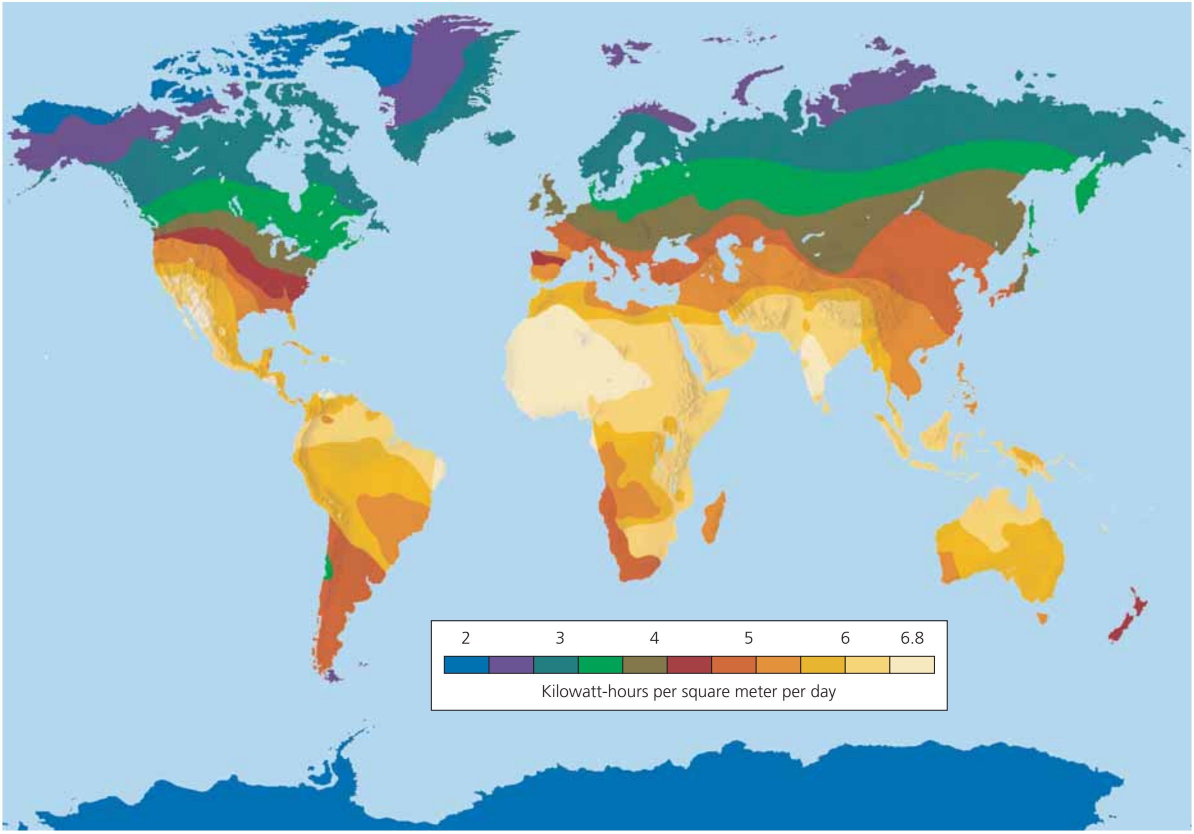
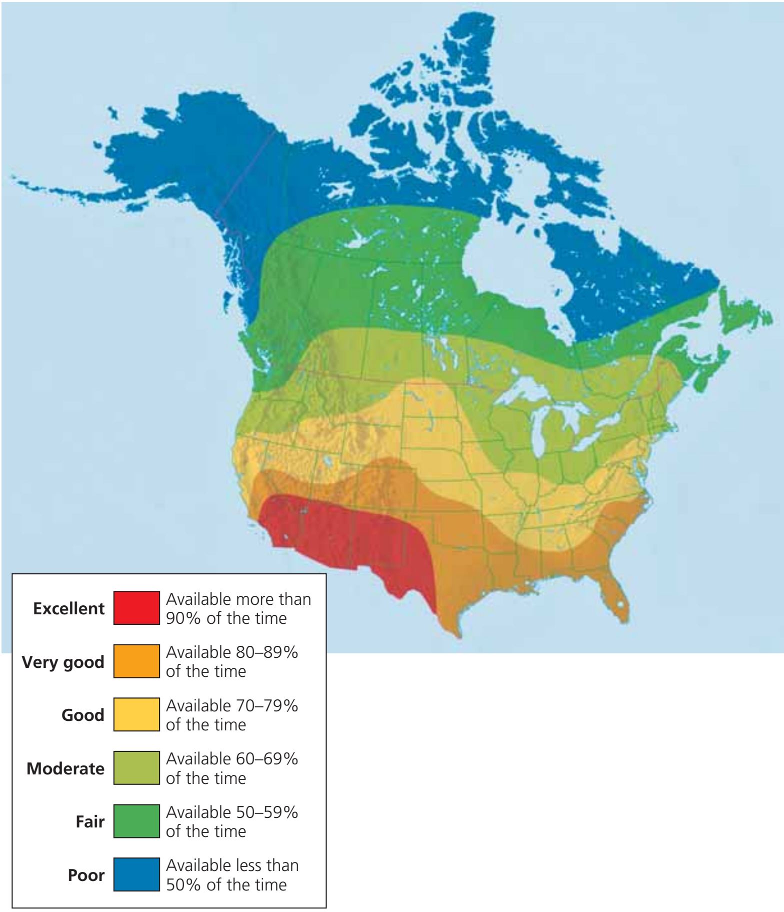


Figure 4 Global availability of direct solar energy. Areas with more than 3.5 kilowatt-hours per square meter per day (see scale) are good candidates for passive and active solar heating systems and use of solar cells to produce electricity. The United Nations is mapping the potential wind and solar energy resources of 13 developing countries in Africa, Asia, and South and Central America. **Question:** What is the potential for making greater use of solar energy to provide heat and produce electricity where you live or go to school? (Data from U.S. Department of Energy)

Figure 5 Availability of direct solar energy in the continental United States and Canada. If prices come down as expected, large banks of solar cells in desert areas in the southwestern United States could produce enough energy to meet all U.S. electricity needs. Electricity produced by such solar-cell power plants would be distributed through an overdue upgrading of the country's electric power grid. **Question:** If you live in the United States, what is the potential for making increased use of solar energy to provide heat and electricity (with solar cells) where you live or go to school? (Data from the U.S. Department of Energy and the National Wildlife Federation)



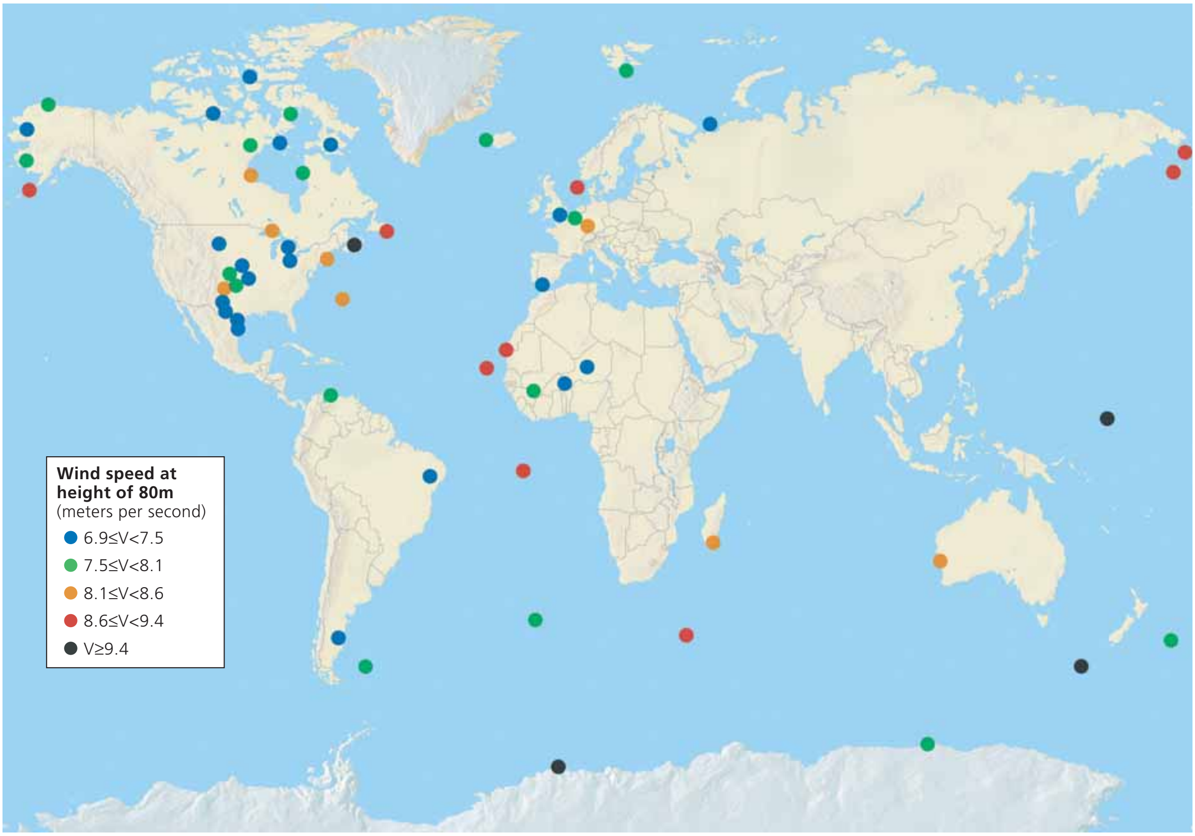


Figure 6 Global potential of winds (an indirect form of solar energy) at a height of 80 meters (260 feet) above the earth's surface based on analysis of over 8,000 wind speed measurements around the world in 2000. This map shows locations of Category 3 through 7 wind speeds, with Category 3 (wind speeds of 6.9–7.5 meters per second or 15–17 miles per hour) being the minimum speed required for economically useful wind generation. The U.S. Department of Energy, National Renewable Energy Laboratory website at **http://rredc.nrel.gov/wind/** shows that areas with great wind potential are found in northern Europe along the North Sea, the southern tip of the South American continent, the island of Tasmania in Australia, the Great Lakes region, and the northeastern and northwestern coasts of North America. The United Nations is mapping the potential wind (and solar) energy resources of 13 developing countries in Africa, Asia, and South and Central America. **Question:** What are the five regions of the world with the least wind energy potential? (Data from Cristina L. Archer and Mark Z. Jacobson, Department of Civil and Environmental Engineering, Stanford University, Stanford, California, USA)

Figure 7 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://rredc.nrel.gov/wind/**. **Questions:** If you live in the United States, what is the general wind energy potential where you live or go to school? Is this potential source of energy for producing electricity being tapped? Why or why not?

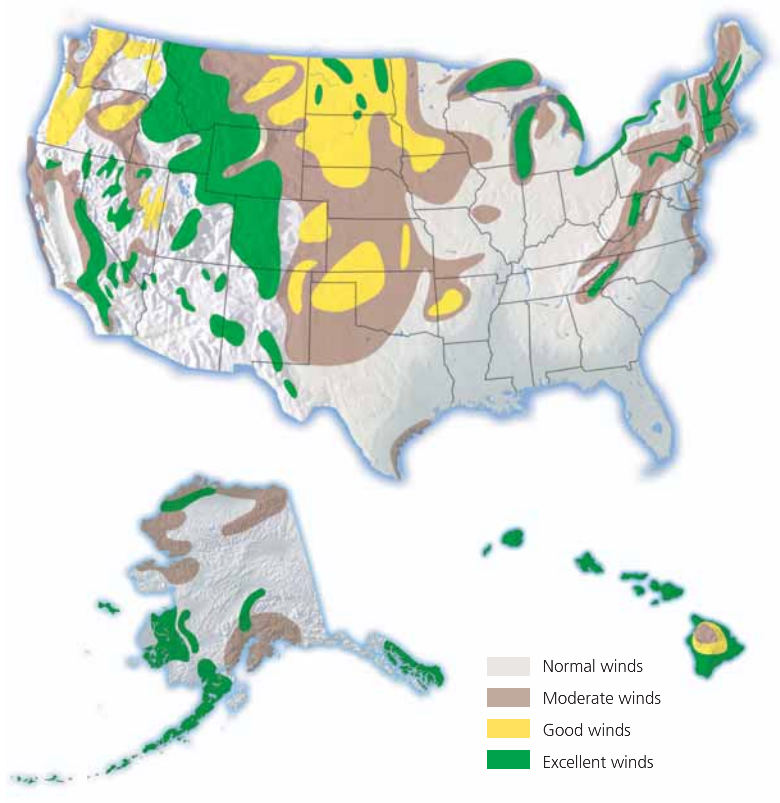
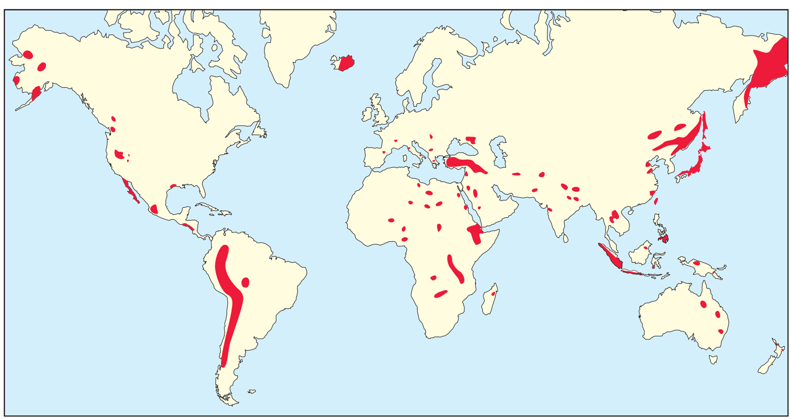


Figure 8 Known global reserves of moderate- to high- temperature geothermal energy. (Data from Canadian Geothermal Resources Council) **Question:** What is the potential for tapping into geothermal energy as a source of heat or electricity where you live or go to school?



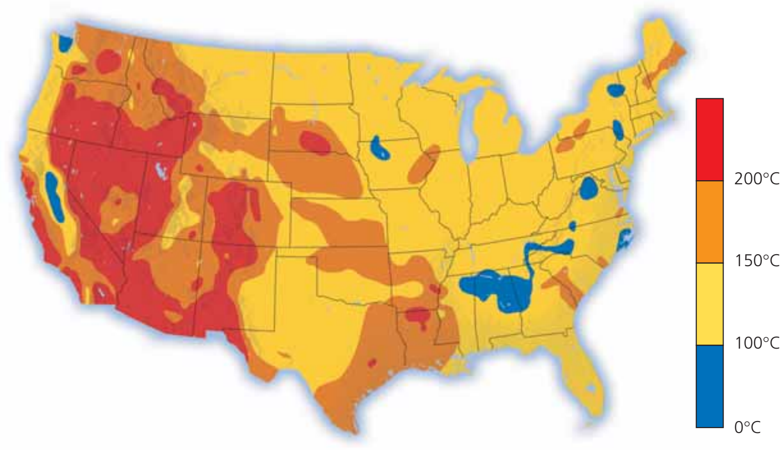


Figure 9 Potential geothermal energy resources in the continental United States. **Question:** If you live in the United States, what is the potential for using solar energy to provide heat or electricity (solar cells) where you live or go to school? (Data from U.S. Department of Energy)

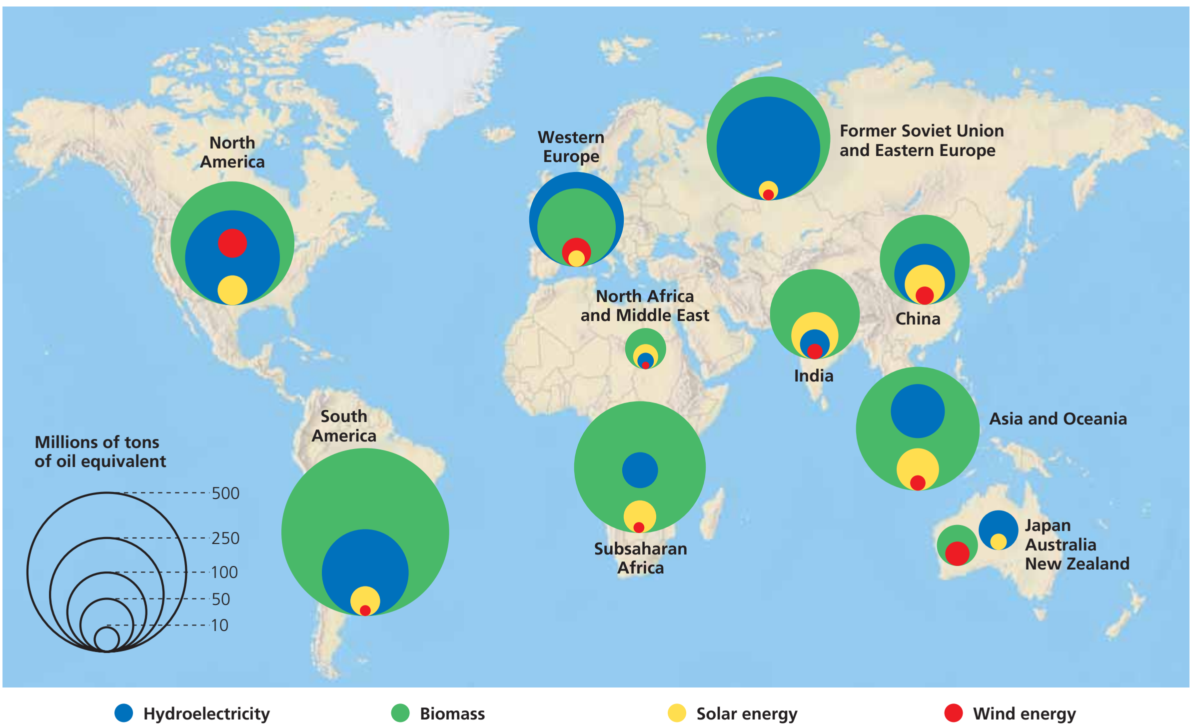


Figure 10 Global potential for renewable solar, wind, hydroelectric, and biomass energy. The circle sizes represent the energy potentially available from these resources in millions of metric tons of oil. **Question:** Which mix of renewable energy resources have the most potential in the country or region where you live? (Data from Worldwatch Institute)

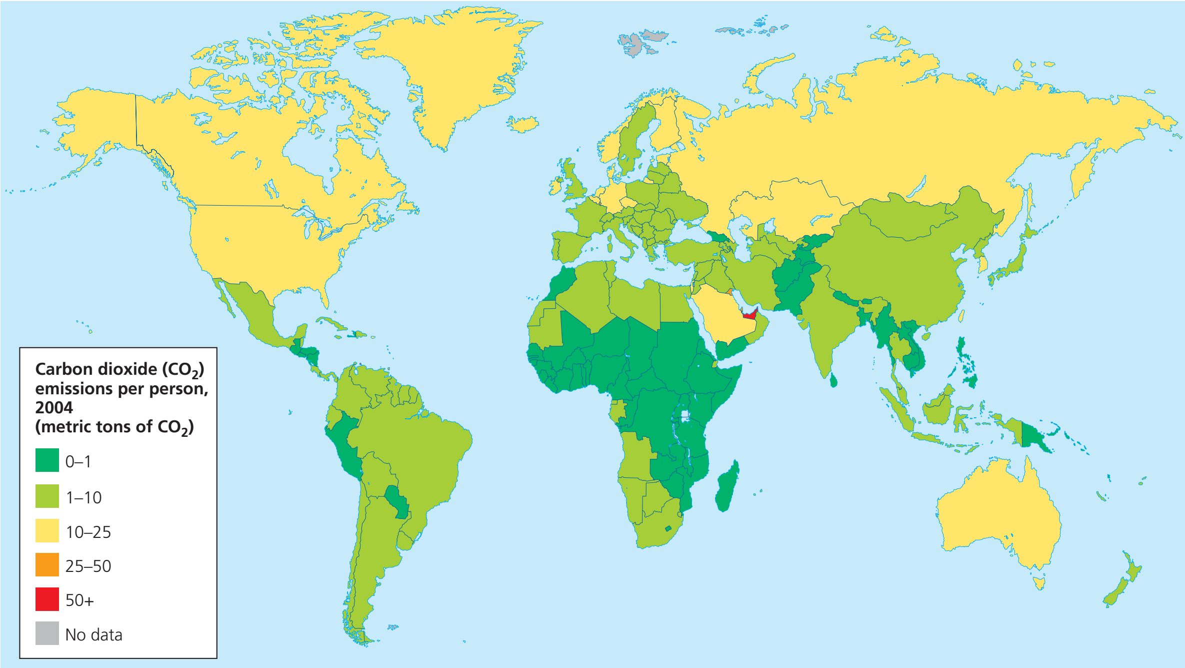


Figure 11 Carbon dioxide (CO_2) emissions per person, 2004. **Question:** What are two conclusions you can draw from these data? (Data from World Resources Institute and International Energy Agency)

Estimating the Toxicity of a Chemical (Chapters 14, 16)

SUPPLEMENT 17

Scientists Use Live Laboratory Animals 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 they are small, they can reproduce rapidly under controlled laboratory conditions, and as mammals, their systems function somewhat like human systems do.

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. The goal is to develop data on the responses of the test animals to various doses of a chemical, but estimating the effects of low doses is difficult.

Animal welfare groups want to limit or ban the use of test animals or ensure that they are treated in the most humane manner possible. More humane methods for carrying out toxicity tests are available, including computer simulations. Substances can also be tested on tissue cultures of cells and bacteria, chicken egg membranes, and individual animal cells.

These alternatives can greatly decrease the use of animals for testing toxicity. But some scientists point out that some animal testing is needed because the alternative methods cannot adequately mimic the complex biochemical interactions taking place in a live animal.

One approach is to determine the lethal dose of a chemical needed to kill an animal. A chemical's *median lethal dose* (LD50) is the dose that kills 50% of the animals (usually rats and mice) in a test population within an 18-day period (Figure 1).

Chemicals vary widely in their toxicity (Table 1). Some poisons can cause serious harm

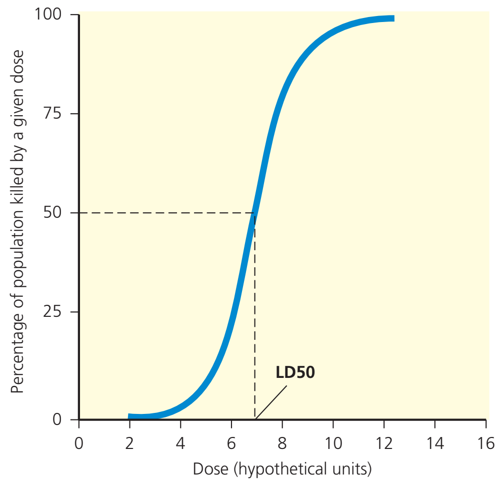


Figure 1 Hypothetical *dose-response curve* showing determination of the LD50, the dosage of a specific chemical that kills 50% of the animals in a test group. Toxicologists widely use this method to compare the toxicities of different chemicals.

Table 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 0.01	Less than 1 drop	Nerve gases, botulism toxin, mushroom toxins, dioxin (TCDD)
Extremely toxic	Less than 5	Less than 7 drops	Potassium cyanide, heroin, atropine, parathion, nicotine
Very toxic	5–50	7 drops to 1 teaspoon	Mercury salts, morphine, codeine
Toxic	50–500	1 teaspoon to 1 ounce	Lead salts, DDT, sodium hydroxide, sodium fluoride, sulfuric acid, caffeine, carbon tetrachloride
Moderately toxic	500–5,000	1 ounce to 1 pint	Methyl (wood) alcohol, ether, phenobarbital, amphetamines (speed), kerosene, aspirin
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 70.4-kilogram (155-pound) human

or death after a single acute exposure at very low dosages. Others cause such harm only at dosages so huge that it is nearly impossible to get enough into the body to cause injury or death. Most chemicals fall between these two extremes. In 2004, the U.S. Environmental Protection Agency listed arsenic, lead, mercury, vinyl chloride (used to make PVC plastics), and polychlorinated biphenyls (PCBs) as the top five toxic substances, in order, in terms of human and environmental health.

Scientists also use acute toxicity tests to develop a **dose-response curve,** which shows the responses of a group of test animals to various dosages of a toxic agent. In *controlled experiments,* the responses of a *test group* are compared with the responses of a *control group* of organisms not exposed to the chemical. Care is taken that organisms in each group are as identical as possible in terms of age, health status, and genetic makeup, and that all are exposed to the same environmental conditions.

There are two general types of dose-response curves (Figure 2). With the *nonthreshold dose-response model* (Figure 2, left), any dosage of a toxic chemical causes harm that increases with the dosage. With the *threshold dose-response model* (Figure 2, right), a threshold dosage must be reached before any detectable harmful effects occur, presumably because the body can repair the damage caused by low dosages of some substances.

Establishing which of these models applies at low dosages is extremely difficult and controversial. To be on the safe side, the nonthreshold dose-response model often is assumed. Fairly high dosages are used to reduce the number of test animals needed, obtain results quickly, and lower costs. Otherwise, tests would have to be run on millions of laboratory animals for many years, and manufacturers could not afford to test most chemicals.

For the same reasons, scientists usually use mathematical models to extrapolate the results from high-dose exposures to low-dose exposures. Then they extrapolate the low-dose results from the test organisms to humans to estimate LD50 values for acute toxicity (Table 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 or harmful to several different test animal species.

RESEARCH FRONTIER

Computer modeling and other alternatives to animal testing

The problems with estimating toxicities using laboratory experiments get worse. 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 individual effects over the short and long term. Toxicologists already have great difficulty in estimating the toxicity of a single substance. But 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 three of the 500 most widely used industrial chemicals would take 20.7 million experiments—a physical and financial impossibility.

THINKING ABOUT
Animal Testing

Should laboratory-bred mice, rats, and other animals be used to determine toxicity and other effects of chemicals? Explain.

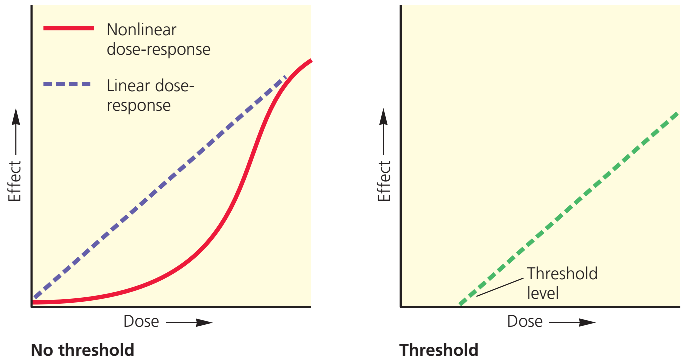


Figure 2 Two types of *dose-response curves.* The linear and nonlinear curves in the left graph apply if even the smallest dosage of a chemical has a harmful effect that increases with the dosage. The curve on the right applies if a harmful effect occurs only when the dosage exceeds a certain *threshold level.* Which model is better for a specific harmful agent is uncertain and controversial because of the difficulty in estimating the response to very low dosages. **Question:** Which model do you think should be used? Why?

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.

Toxicological studies of the effects of various chemicals on wildlife can provide clues about possible harmful effects of such chemicals on humans. Examples include the effects of hormonally active agents, HAAs, on alligators (pp. 332–333) and the effects of atrazine and other pesticides on amphibians (Case Study, p. 108).

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,* they usually take a long time. *Third,* conclusively linking an observed effect with exposure to a particular chemical is difficult because people are exposed to many different toxic agents throughout their lives and can vary in their sensitivity to such chemicals. *Fourth,* we cannot use epidemiological studies to evaluate hazards from new technologies or chemicals to which people have not yet been exposed.

Can a Little Bit of Arsenic Be Good for You?

There is a hypothesis that some toxic substances that can harm or kill us at high doses may have beneficial health effects at very low doses. This phenomenon is called *hormesis.* A possible explanation for this effect is that very small doses of some substances may stimulate cellular repair or other beneficial responses.

Edward Calabrese, a respected toxicologist at the University of Massachusetts, Amherst, has made a thorough examination of the literature on this subject. He has concluded that the idea has merit, and that more research is needed to test its validity and to discover the possible mechanisms involved.

Scientists are waiting for more evidence before accepting the hormesis hypothesis. Stay tuned for more developments about this fascinating idea.

How to Analyze a Scientific Article (Chapter 2)

SUPPLEMENT 18

This journal article reports on the movements of a female wolf during the summer of 2002 in northwestern Canada. It also reports on a scientific process of inquiry, observation and interpretation to learn where, how and why the wolf traveled as she did. In some ways, this article reflects the story of how science is done, told in Chapter 2 of this textbook. These notes are intended to help you read and understand how scientists work and how they report on their work.

1 ARCTIC

2 VOL. 57, NO. 2 (JUNE 2004) P. 196–203

3 Long Foraging Movement of a Denning Tundra Wolf

4 Paul F. Frame,[1,2] David S. Hik,[1] H. Dean Cluff,[3] and Paul C. Paquet[4]

5 (*Received 3 September 2003; accepted in revised form 16 January 2004*)

6 **ABSTRACT** Wolves (*Canis lupus*) on the Canadian barrens are intimately linked to migrating herds of barren-ground caribou (*Rangifer tarandus*). We deployed a Global Positioning System (GPS) radio collar on an adult female wolf to record her movements in response to changing caribou densities near her den during summer. This wolf and two other females were observed nursing a group of 11 pups. She traveled a minimum of 341 km during a 14-day excursion. The straight-line distance from the den to the farthest location was 103 km, and the overall minimum rate of travel was 3.1 km/h. The distance between the wolf and the radio-collared caribou decreased from 242 km one week before the excursion to 8 km four days into the excursion. We discuss several possible explanations for the long foraging bout.

7 *Key words:* wolf, GPS tracking, movements, *Canis lupus*, foraging, caribou, Northwest Territories

8 **RÉSUMÉ** Les loups (*Canis lupus*) dans la toundra canadienne sont étroitement liés aux hardes de caribous des toundras (*Rangifer tarandus*). On a équipé une louve adulte d'un collier émetteur muni d'un système de positionnement mondial (GPS) afin d'enregistrer ses déplacements en réponse au changement de densité du caribou près de sa tanière durant l'été. On a observé cette louve ainsi que deux autres en train d'allaiter un groupe de 11 louveteaux. Elle a parcouru un minimum de 341 km durant une sortie de 14 jours. La distance en ligne droite de la tanière à l'endroit le plus éloigné était de 103 km, et la vitesse minimum durant tout le voyage était de 3,1 km/h. La distance entre la louve et le caribou muni du collier émetteur a diminué de 242 km une semaine avant la sortie à 8 km quatre jours après la sortie. On commente diverses explications possibles pour ce long épisode de recherche de nourriture.

Mots clés: loup, repérage GPS, déplacements, *Canis lupus*, recherche de nourriture, caribou, Territoires du Nord-Ouest

Traduit pour la revue *Arctic* par Nésida Loyer.

9 Introduction

Wolves (*Canis lupus*) that den on the central barrens of mainland Canada follow the seasonal movements of their main prey, migratory barren-ground caribou (*Rangifer tarandus*) (Kuyt, 1962; Kelsall, 1968; Walton et al., 2001). However, most wolves do not den near caribou calving grounds, but select sites farther south, closer to the tree line (Heard and Williams, 1992). Most caribou migrate beyond primary wolf denning areas by mid-June and do not return until mid-to-late July (Heard et al., 1996; Gunn et al., 2001). Consequently, caribou density near dens is low for part of the summer.

During this period of spatial separation from the main caribou herds, wolves must either search near the homesite for scarce caribou or alternative prey (or both), travel to where prey are abundant, or use a combination of these strategies. 10

Walton et al. (2001) postulated that the travel of tundra wolves outside their normal summer ranges is a response to low caribou availability rather than a pre-dispersal exploration like that observed in territorial wolves (Fritts and Mech, 1981; Messier, 1985). The authors postulated this because most such travel was directed toward caribou calving grounds. We report details of such a long-distance excursion by a breeding female tundra wolf wearing a GPS radio collar. We discuss the relationship of the excursion to movements of satellite-collared caribou (Gunn et al., 2001), supporting the hypothesis that tundra wolves make directional, rapid, long-distance movements in response to seasonal prey availability. 11

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196

1 Title of the journal, which reports on science taking place in Arctic regions.

2 Volume number, issue number and date of the journal, and page numbers of the article.

3 Title of the article: a concise but specific description of the subject of study—one episode of long-range travel by a wolf hunting for food on the Arctic tundra.

4 Authors of the article: scientists working at the institutions listed in the footnotes below. Note #2 indicates that P. F. Frame is the *corresponding author*—the person to contact with questions or comments. His email address is provided.

5 Date on which a draft of the article was received by the journal editor, followed by date on which a revised draft was accepted for publication. Between these dates, the article was reviewed and critiqued by other scientists, a process called peer review. The authors revised the article to make it clearer, according to those reviews.

6 ABSTRACT: A brief description of the study containing all basic elements of this report. First sentence summarizes the *background* material. Second sentence encapsulates the *methods* used. The rest of the paragraph sums up the *results.* Authors introduce the main *subject* of the study—a female wolf (#388) with pups in a den—and refer to later *discussion* of possible explanations for her behavior.

7 Key words are listed to help researchers using computer databases. Searching the databases using these key words will yield a list of studies related to this one.

8 RÉSUMÉ: The French translation of the abstract and key words. Many researchers in this field are French Canadian. Some journals provide such translations in French or in other languages.

9 INTRODUCTION: Gives the background for this wolf study. This paragraph tells of known or suspected wolf behavior that is important for this study. Note that (a) major species mentioned are always accompanied by scientific names, and (b) statements of fact or *postulations* (claims or assumptions about what is likely to be true) are followed by references to studies that established those facts or supported the postulations.

10 This paragraph focuses directly on the wolf behaviors that were studied here.

11 This paragraph starts with a statement of the *hypothesis* being tested, one that originated in other studies and is supported by this one. The hypothesis is restated more succinctly in the last sentence of this paragraph. This is the *inquiry* part of the scientific process—asking questions and suggesting possible answers.

12 This map shows the study area and depicts wolf and caribou locations and movements during one summer. Some of this information is explained below.

13 STUDY AREA: This section sets the stage for the study, locating it precisely with latitude and longitude coordinates and describing the area (illustrated by the map in Figure 1).

14 Here begins the story of how prey (caribou) and predators (wolves) interact on the tundra. Authors describe movements of these nomadic animals throughout the year.

15 We focus on the denning season (summer) and learn how wolves locate their dens and travel according to the movements of caribou herds.

12

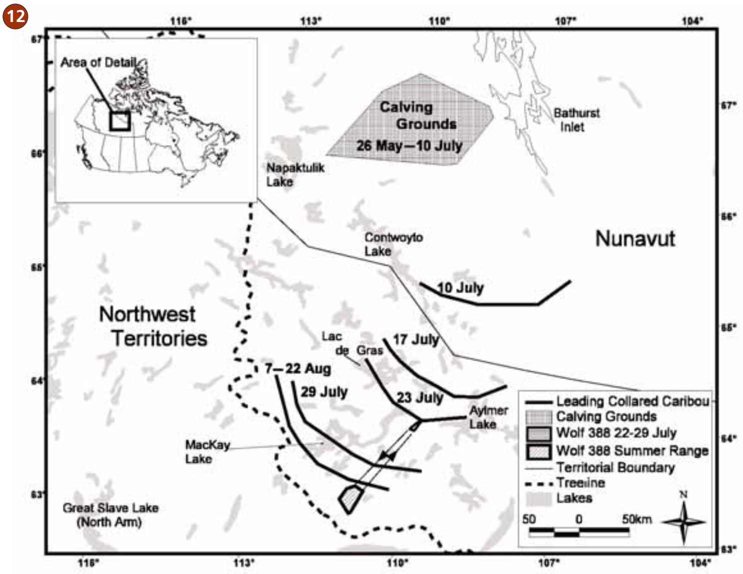

Figure 1. Map showing the movements of satellite radio-collared caribou with respect to female wolf 388's summer range and long foraging movement, in summer 2002.

13 Study Area

Our study took place in the northern boreal forest–low Arctic tundra transition zone (63° 30′ N, 110° 00′ W; Figure 1; Timoney et al., 1992). Permafrost in the area changes from discontinuous to continuous (Harris, 1986). Patches of spruce (*Picea mariana*, *P. glauca*) occur in the southern portion and give way to open tundra to the northeast. Eskers, kames, and other glacial deposits are scattered throughout the study area. Standing water and exposed bedrock are characteristic of the area.

14 *Details of the Caribou-Wolf System*

The Bathurst caribou herd uses this study area. Most caribou cows have begun migrating by late April, reaching calving grounds by June (Gunn et al., 2001; Figure 1). Calving peaks by 15 June (Gunn et al., 2001), and calves begin to travel with the herd by one week of age (Kelsall, 1968). The movement patterns of bulls are less known, but bulls frequent areas near calving grounds by mid-June (Heard et al., 1996; Gunn et al., 2001). In summer, Bathurst caribou cows generally travel south from their calving grounds and then, parallel to the tree line, to the northwest. The rut usually takes place at the tree line in October (Gunn et al., 2001). The winter range of the Bathurst herd varies among years, ranging through the taiga and along the tree line from south of Great Bear Lake to southeast of Great Slave Lake. Some caribou spend the winter on the tundra (Gunn et al., 2001; Thorpe et al., 2001).

In winter, wolves that prey on Bathurst caribou do not behave territorially. Instead, they follow the herd throughout its winter range (Walton et al., 2001; Musiani, 2003). However, during denning (May– 15

Table 1. Daily distances from wolf 388 and the den to the nearest radio-collared caribou during a long excursion in summer 2002.

Date (2002)	Mean distance from caribou to wolf (km)	Daily distance from closest caribou to den
12 July	242	241
13 July	210	209
14 July	200	199
15 July	186	180
16 July	163	162
17 July	151	148
18 July	144	137
19 July[1]	126	124
20 July	103	130
21 July	73	130
22 July	40	110
23 July[2]	9	104
29 July[3]	16	43
30 July	32	43
31 July	28	44
1 August	29	46
2 August[4]	54	52
3 August	53	53
4 August	74	74
5 August	75	75
6 August	74	75
7 August	72	75
8 August	76	75
9 August	79	79

[1] Excursion starts.
[2] Wolf closest to collared caribou.
[3] Previous five days' caribou locations not available.
[4] Excursion ends.

August, parturition late May to mid-June), wolf movements are limited by the need to return food to the den. To maximize access to migrating caribou, many wolves select den sites closer to the tree line than to caribou calving grounds (Heard and Williams, 1992). Because of caribou movement patterns, tundra denning wolves are separated from the main caribou herds by several hundred kilometers at some time during summer (Williams, 1990:19; Figure 1; Table 1).

16 Muskoxen do not occur in the study area (Fournier and Gunn, 1998), and there are few moose there (H.D. Cluff, pers. obs.). Therefore, alternative prey for wolves includes waterfowl, other ground-nesting birds, their eggs, rodents, and hares (Kuyt, 1972; Williams, 1990:16; H.D. Cluff and P.F. Frame, unpubl. data). During 56 hours of den observations, we saw no ground squirrels or hares, only birds. It appears that the abundance of alternative prey was relatively low in 2002.

17 Methods

Wolf Monitoring

18 We captured female wolf 388 near her den on 22 June 2002, using a helicopter net-gun (Walton et al., 2001). She was fitted with a releasable GPS radio collar (Merrill et al., 1998) programmed to acquire locations at 30-minute intervals. The collar was electronically released (e.g., Mech and Gese, 1992) on 20 August 2002. From 27 June to 3 July 2002, we observed 388's den with a 78 mm spotting scope at a distance of 390 m.

Caribou Monitoring

In spring of 2002, ten female caribou were captured by helicopter net-gun and fitted with satellite radio collars, bringing the total number of collared Bathurst cows to 19. Eight of these spent the summer of 2002 south of Queen Maud Gulf, well east of normal Bathurst caribou range. Therefore, we used 11 caribou for this analysis. The collars provided one location per day during our study, except for five days from 24 to 28 July. Locations of satellite collars were obtained from Service Argos, Inc. (Landover, Maryland).

Data Analysis

Location data were analyzed by ArcView GIS software (Environmental Systems Research Institute Inc., Redlands, California). We calculated the average distance from the nearest collared caribou to the wolf and the den for each day of the study. 19

Wolf foraging bouts were calculated from the time 388 exited a buffer zone (500 m radius around the den) until she re-entered it. We considered her to be traveling when two consecutive locations were spatially separated by more than 100 m. Minimum distance traveled was the sum of distances between each location and the next during the excursion.

We compared pre- and post-excursion data using Analysis of Variance (ANOVA; Zar, 1999). We first tested for homogeneity of variances with Levene's test (Brown and Forsythe, 1974). No transformations of these data were required.

Results 20

Wolf Monitoring

Pre-Excursion Period: Wolf 388 was lactating when captured on 22 June. We observed her and two other females nursing a group of 11 pups between 27 June and 3 July. During our observations, the pack consisted of at least four adults (3 females and 1 male) and 11 pups. On 30 June, three pups were moved to a location 310 m from the other eight and cared for by an uncollared female. The male was not seen at the den after the evening of 30 June. 21

Before the excursion, telemetry indicated 18 foraging bouts. The mean distance traveled during these bouts was 25.29 km (± 4.5 SE, range 3.1–82.5 km). Mean greatest distance from the den on foraging

16 Other variables are considered—prey other than caribou and their relative abundance in 2002.

17 METHODS: There is no one scientific method. Procedures for each and every study must be explained carefully.

18 Authors explain when and how they tracked caribou and wolves, including tools used and the exact procedures followed.

19 This important subsection explains what data were calculated (average distance …) and how, including the software used and where it came from. (The calculations are listed in Table 1.) Note that the behavior measured (traveling) is carefully defined.

20 RESULTS: The heart of the report and the *observation* part of the scientific process. This section is organized parallel to the Methods section.

21 This subsection is broken down by periods of observation. Pre-excursion period covers the time between 388's capture and the start of her long-distance travel. The investigators used visual observations as well as telemetry (measurements taken using the global positioning system (GPS)) to gather data. They looked at how 388 cared for her pups, interacted with other adults, and moved about the den area.

22 The key in the lower right-hand corner of the map shows areas (shaded) within which the wolves and caribou moved, and the dotted trail of 388 during her excursion. From the results depicted on this map, the investigators tried to determine when and where 388 might have encountered caribou and how their locations affected her traveling behavior.

23 The wolf's excursion (her long trip away from the den area) is the focus of this study. These paragraphs present detailed measurements of daily movements during her two-week trip—how far she traveled, how far she was from collared caribou, her time spent traveling and resting, and her rate of speed. Authors use the phrase "minimum distance traveled" to acknowledge they couldn't track every step but were measuring samples of her movements. They knew that she went at least as far as they measured. This shows how scientists try to be exact when reporting results. Results of this study are depicted graphically in the map in Figure 2.

22

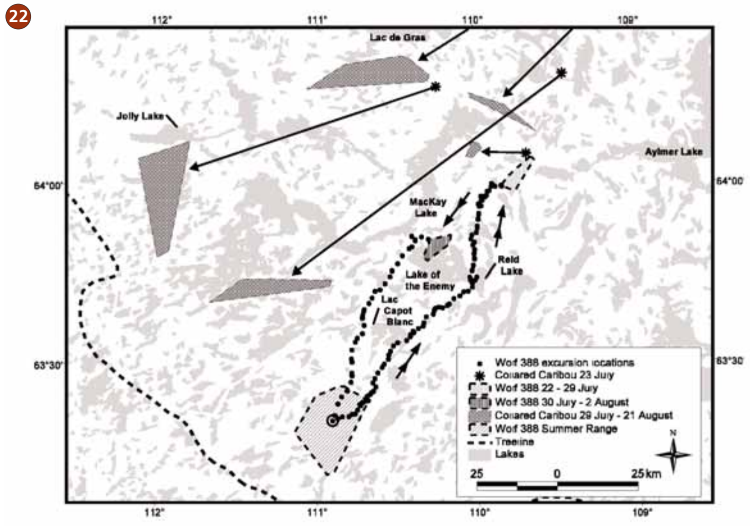

Figure 2. Details of a long foraging movement by female wolf 388 between 19 July and 2 August 2002. Also shown are locations and movements of three satellite radio-collared caribou from 23 July to 21 August 2002. On 23 July, the wolf was 8 km from a collared caribou. The farthest point from the den (103 km distant) was recorded on 27 July. Arrows indicate direction of travel.

bouts was 7.1 km (± 0.9 SE, range 1.7–17.0 km). The average duration of foraging bouts for the period was 20.9 h (± 4.5 SE, range 1–71 h).

The average daily distance between the wolf and the nearest collared caribou decreased from 242 km on 12 July, one week before the excursion period, to 126 km on 19 July, the day the excursion began (Table 1).

23 **Excursion Period:** On 19 July at 2203, after spending 14 h at the den, 388 began moving to the northeast and did not return for 336 h (14 d; Figure 2). Whether she traveled alone or with other wolves is unknown. During the excursion, 476 (71%) of 672 possible locations were recorded. The wolf crossed the southeast end of Lac Capot Blanc on a small land bridge, where she paused for 4.5 h after traveling for 19.5 h (37.5 km). Following this rest, she traveled for 9 h (26.3 km) onto a peninsula in Reid Lake, where she spent 2 h before backtracking and stopping for 8 h just off the peninsula. Her next period of travel lasted 16.5 h (32.7 km), terminating in a pause of 9.5 h just 3.8 km from a concentration of locations at the far end of her excursion, where we presume she encountered caribou. The mean duration of these three movement periods was 15.7 h (± 2.5 SE), and that of the pauses, 7.3 h (± 1.5). The wolf required 72.5 h (3.0 d) to travel a minimum of 95 km from her den to this area near caribou (Figure 2). She remained there (35.5 km2) for 151.5 h (6.3 d) and then moved south to Lake of the Enemy, where she stayed (31.9 km^2) for 74 h (3.1 d) before returning to her den. Her greatest distance from the den, 103 km, was recorded 174.5 h (7.3 d) after the excursion

began, at 0433 on 27 July. She was 8 km from a collared caribou on 23 July, four days after the excursion began (Table 1).

The return trip began at 0403 on 2 August, 318 h (13.2 d) after leaving the den. She followed a relatively direct path for 18 h back to the den, a distance of 75 km.

The minimum distance traveled during the excursionwas 339 km. The estimated overall minimum travel rate was 3.1 km/h, 2.6 km/h away from the den and 4.2 km/h on the return trip.

24 **Post-Excursion Period:** We saw three pups when recovering the collar on 20 August, but others may have been hiding in vegetation.

Telemetry recorded 13 foraging bouts in the post-excursion period. The mean distance traveled during these bouts was 18.3 km (+ 2.7 SE, range 1.2–47.7 km), and mean greatest distance from the den was 7.1 km (+ 0.7 SE, range 1.1–11.0 km). The mean duration of these post-excursion foraging bouts was 10.9 h (+ 2.4 SE, range 1–33 h).

When 388 reached her den on 2 August, the distance to the nearest collared caribou was 54 km. On 9 August, one week after she returned, the distance was 79 km (Table 1).

Pre- and Post-Excursion Comparison

25 We found no differences in the mean distance of foraging bouts before and after the excursion period ($F = 1.5$, $df = 1, 29$, $p = 0.24$). Likewise, the mean greatest distance from the den was similar pre- and post-excursion ($F = 0.004$, $df = 1, 29$, $p = 0.95$). However, the mean duration of 388's foraging bouts decreased by 10.0 h after her long excursion ($F = 3.1$, $df = 1, 29$, $p = 0.09$).

26 *Caribou Monitoring*

Summer Movements: On 10 July, 5 of 11 collared caribou were dispersed over a distance of 10 km, 140 km south of their calving grounds (Figure 1). On the same day, three caribou were still on the calving grounds, two were between the calving grounds and the leaders, and one was missing. One week later (17 July), the leading radio-collared cows were 100 km farther south (Figure 1). Two were within 5 km of each other in front of the rest, who were more dispersed. All radio-collared cows had left the calving grounds by this time. On 23 July, the leading radio-collared caribou had moved 35 km farther south, and all of them were more widely dispersed. The two cows closest to the leader were 26 km and 33 km away, with 37 km between them. On the next location (29 July), the most southerly caribou were 60 km farther south. All of the caribou were now in the areas where they remained for the duration of the study (Figure 2).

A Minimum Convex Polygon (Mohr and Stumpf, 1966) around all caribou locations acquired during the study encompassed 85 119 km^2.

Relative to the Wolf Den: The distance from the nearest collared caribou to the den decreased from 241 km one week before the excursion to 124 km the day it began. The nearest a collared caribou came to the den was 43 km away, on 29 and 30 July. During the study, four collared caribou were located within 100 km of the den. Each of these four was closest to the wolf on at least one day during the period reported. 27

28 Discussion

Prey Abundance

Caribou are the single most important prey of tundra wolves (Clark, 1971; Kuyt, 1972; Stephenson and James, 1982; Williams, 1990). Caribou range over vast areas, and for part of the summer, they are scarce or absent in wolf home ranges (Heard et al., 1996). Both the long distance between radio-collared caribou and the den the week before the excursion and the increased time spent foraging by wolf 388 indicate that caribou availability near the den was low. Observations of the pups' being left alone for up to 18 h, presumably while adults were searching for food, provide additional support for low caribou availability locally. Mean foraging bout duration decreased by 10.0 h after the excursion, when collared caribou were closer to the den, suggesting an increase in caribou availability nearby. 29

Foraging Excursion

One aspect of central place foraging theory (CPFT) deals with the optimality of returning different-sized food loads from varying distances to dependents at a central place (i.e., the den) (Orians and Pearson, 1979). Carlson (1985) tested CPFT and found that the predator usually consumed prey captured far from the central place, while feeding prey captured nearby to dependants. Wolf 388 spent 7.2 days in one area near caribou before moving to a location 23 km back towards the den, where she spent an additional 3.1 days, likely hunting caribou. She began her return trip from this closer location, traveling directly to the den. While away, she may have made one or more successful kills and spent time meeting her own energetic needs before returning to the den. Alternatively, it may have taken several attempts to make a kill, 30

24 Post-excursion measurements of 388's movements were made to compare with those of the pre-excursion period. In order to compare, scientists often use *means*, or averages, of a series of measurements—mean distances, mean duration, etc.

25 In the comparison, authors used statistical calculations (F and df) to determine that the differences between pre- and post-excursion measurements were *statistically insignificant*, or close enough to be considered essentially the same or similar.

26 As with wolf 388, the investigators measured the movements of caribou during the study period. The areas within which the caribou moved are shown in Figure 2 by shaded polygons mentioned in the second paragraph of this subsection.

27 This subsection summarizes how distances separating predators and prey varied during the study period.

28 DISCUSSION: This section is the *interpretation* part of the scientific process.

29 This subsection reviews observations from other studies and suggests that this study fits with patterns of those observations.

30 Authors discuss a prevailing *theory* (CBFT) which might explain why a wolf would travel far to meet her own energy needs while taking food caught closer to the den back to her pups. The results of this study seem to fit that pattern.

31 Here our authors note other possible explanations for wolves' excursions presented by other investigators, but this study does not seem to support those ideas.

32 Authors discuss possible reasons for why 388 traveled directly to where caribou were located. They take what they learned from earlier studies and apply it to this case, suggesting that the lay of the land played a role. Note that their description paints a clear picture of the landscape.

33 Authors suggest that 388 may have learned in traveling during previous summers where the caribou were. The last two sentences suggest ideas for future studies.

34 Or maybe 388 followed the scent of the caribou. Authors acknowledge difficulties of proving this, but they suggest another area where future studies might be done.

35 Authors suggest that results of this study support previous studies about how fast wolves travel to and from the den. In the last sentence, they speculate on how these observed patterns would fit into the theory of evolution.

36 Authors also speculate on the fate of 388's pups while she was traveling. This leads to . . .

which she then fed on before beginning her return trip. We do not know if she returned food to the pups, but such behavior would be supported by CPFT.

31 Other workers have reported wolves' making long round trips and referred to them as "extraterritorial" or "pre-dispersal" forays (Fritts and Mech, 1981; Messier, 1985; Ballard et al., 1997; Merrill and Mech, 2000). These movements are most often made by young wolves (1–3 years old), in areas where annual territories are maintained and prey are relatively sedentary (Fritts and Mech, 1981; Messier, 1985). The long excursion of 388 differs in that tundra wolves do not maintain annual territories (Walton et al., 2001), and the main prey migrate over vast areas (Gunn et al., 2001).

Another difference between 388's excursion and those reported earlier is that she is a mature, breeding female. No study of territorial wolves has reported reproductive adults making extraterritorial movements in summer (Fritts and Mech, 1981; Messier, 1985; Ballard et al., 1997; Merrill and Mech, 2001). However, Walton et al. (2001) also report that breeding female tundra wolves made excursions.

Direction of Movement

32 Possible explanations for the relatively direct route 388 took to the caribou include landscape influence and experience. Considering the timing of 388's trip and the locations of caribou, had the wolf moved northwest, she might have missed the caribou entirely, or the encounter might have been delayed.

A reasonable possibility is that the land directed 388's route. The barrens are crisscrossed with trails worn into the tundra over centuries by hundreds of thousands of caribou and other animals (Kelsall, 1968; Thorpe et al., 2001). At river crossings, lakes, or narrow peninsulas, trails converge and funnel towards and away from caribou calving grounds and summer range. Wolves use trails for travel (Paquet et al., 1996; Mech and Boitani, 2003; P. Frame, pers. observation). Thus, the landscape may direct an animal's movements and lead it to where cues, such as the odor of caribou on the wind or scent marks of other wolves, may lead it to caribou.

33 Another possibility is that 388 knew where to find caribou in summer. Sexually immature tundra wolves sometimes follow caribou to calving grounds (D. Heard, unpubl. data). Possibly, 388 had made such journeys in previous years and killed caribou. If this were the case, then in times of local prey scarcity she might travel to areas where she had hunted successfully before. Continued monitoring of tundra wolves may answer questions about how their food needs are met in times of low caribou abundance near dens.

Caribou often form large groups while moving south to the tree line (Kelsall, 1968). After a large aggregation of caribou moves through an area, its scent can linger for weeks (Thorpe et al., 2001:104). It is conceivable that 388 detected caribou scent on the wind, which was blowing from the northeast on 19–21 July (Environment Canada, 2003), at the same time her excursion began. Many factors, such as odor strength and wind direction and strength, make systematic study of scent detection in wolves difficult under field conditions (Harrington and Asa, 2003). However, humans are able to smell odors such as forest fires or oil refineries more than 100 km away. The olfactory capabilities of dogs, which are similar to wolves, are thought to be 100 to 1 million times that of humans (Harrington and Asa, 2003). Therefore, it is reasonable to think that under the right wind conditions, the scent of many caribou traveling together could be detected by wolves from great distances, thus triggering a long foraging bout. 34

Rate of Travel

Mech (1994) reported the rate of travel of Arctic wolves on barren ground was 8.7 km/h during regular travel and 10.0 km/h when returning to the den, a difference of 1.3 km/h. These rates are based on direct observation and exclude periods when wolves moved slowly or not at all. Our calculated travel rates are assumed to include periods of slow movement or no movement. However, the pattern we report is similar to that reported by Mech (1994), in that homeward travel was faster than regular travel by 1.6 km/h. The faster rate on return may be explained by the need to return food to the den. Pup survival can increase with the number of adults in a pack available to deliver food to pups (Harrington et al., 1983). Therefore, an increased rate of travel on homeward trips could improve a wolf's reproductive fitness by getting food to pups more quickly. 35

Fate of 388's Pups

Wolf 388 was caring for pups during den observations. The pups were estimated to be six weeks old, and were seen ranging as far as 800 m from the den. They received some regurgitated food from two of the females, but were unattended for long periods. The excursion started 16 days after our observations, and it is improbable that the pups could have traveled the distance that 388 moved. If the pups died, this would have removed parental responsibility, allowing the long movement. 36

Our observations and the locations of radio-collared caribou indicate that prey became scarce in the area of the den as summer progressed. Wolf 388 may have abandoned her pups to seek food for herself. However, she returned to the den after the excursion, where she was seen near pups. In fact, she foraged in a similar pattern before and after the excursion, suggesting that she again was providing for pups after her return to the den.

37 A more likely possibility is that one or both of the other lactating females cared for the pups during 388's absence. The three females at this den were not seen with the pups at the same time. However, two weeks earlier, at a different den, we observed three females cooperatively caring for a group of six pups. At that den, the three lactating females were observed providing food for each other and trading places while nursing pups. Such a situation at the den of 388 could have created conditions that allowed one or more of the lactating females to range far from the den for a period, returning to her parental duties afterwards. However, the pups would have been weaned by eight weeks of age (Packard et al., 1992), so nonlactating adults could also have cared for them, as often happens in wolf packs (Packard et al., 1992; Mech et al., 1999).

Cooperative rearing of multiple litters by a pack could create opportunities for long-distance foraging movements by some reproductive wolves during summer periods of local food scarcity. We have recorded multiple lactating females at one or more tundra wolf dens per year since 1997. This reproductive strategy may be an adaptation to temporally and
38 spatially unpredictable food resources. All of these possibilities require further study, but emphasize both the adaptability of wolves living on the barrens and their dependence on caribou.

Long-range wolf movement in response to caribou
39 availability has been suggested by other researchers (Kuyt, 1972; Walton et al., 2001) and traditional ecological knowledge (Thorpe et al., 2001). Our report demonstrates the rapid and extreme response of wolves to caribou distribution and movements in summer. Increased human activity on the tundra (mining, road building, pipelines, ecotourism) may influence caribou movement patterns and change the interactions between wolves and caribou in the region. Continued monitoring of both species will help us to assess whether the association is being affected adversely by anthropogenic change.

40 Acknowledgements

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37 Discussion of cooperative rearing of pups and, in turn, to speculation on how this study and what is known about cooperative rearing might fit into the animal's strategies for survival of the species. Again, the authors approach the broader theory of evolution and how it might explain some of their results.

38 And again, they suggest that this study points to several areas where further study will shed some light.

39 In conclusion, the authors suggest that their study supports the hypothesis being tested here. And they touch on the implications of increased human activity on the tundra predicted by their results.

40 ACKNOWLEDGEMENTS: Authors note the support of institutions, companies, and individuals. They thank their reviewers and list permits under which their research was carried on.

41 REFERENCES: List of all studies cited in the report. This may seem tedious, but is a vitally important part of scientific reporting. It is a record of the sources of information on which this study is based. It provides readers with a wealth of resources for further reading on this topic. Much of it will form the foundation of future scientific studies like this one.

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SUPPLEMENT

19

Key Concepts (by Chapter)

CHAPTER 1 Environmental Problems, Their Causes, and Sustainability

Concept 1-1A Our lives and economies depend on energy from the sun (*solar capital*) 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.

Concept 1-2 Societies can become more environmentally sustainable through economic development dedicated to improving the quality of life for everyone without degrading the earth's life support systems.

Concept 1-3 As our ecological footprints grow, we are depleting and degrading more of the earth's natural capital.

Concept 1-4 Preventing pollution is more effective and less costly than cleaning up pollution.

Concept 1-5A Major causes of environmental problems are population growth, unsustainable resource use, poverty, excluding the environmental costs of resource use from market prices of goods and services, and trying to manage nature with insufficient knowledge.

Concept 1-5B People with different environmental worldviews often disagree about the seriousness of environmental problems and what we should do about them.

Concept 1-6 Nature has sustained itself for billions of years by using solar energy, biodiversity, population regulation, and nutrient cycling—lessons from nature that we can apply to our lifestyles and economies.

CHAPTER 2 Science, Matter, and Energy

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

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

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

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

Concept 2-4B Whenever energy is changed from one form to another, we end up with lower quality or less usable energy than we started with (second law of thermodynamics).

Concept 2-5A The processes of life must conform to the law of conservation of matter and the two laws of thermodynamics.

Concept 2-5B We can live more sustainably by using and wasting less matter and energy, recycling and reusing most matter resources, and controlling human population growth.

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

Concept 3-1 Ecology is a study of how organisms interact with one another and with their physical environment of matter and energy.

Concept 3-2 Life is sustained by the flow of energy from the sun through the biosphere, the cycling of nutrients within the biosphere, and gravity.

Concept 3-3 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.

Concept 3-4A The biodiversity found in the earth's genes, species, ecosystems, and ecosystem processes is vital to sustaining life on the earth.

Concept 3-4B Soil is an important component of biodiversity that supplies most of the nutrients needed for plant growth and helps purify and store water and control levels of carbon dioxide in the atmosphere.

Concept 3-5 As energy flows through ecosystems in food chains and webs, the amount of chemical energy available to organisms at each succeeding feeding level decreases.

Concept 3-6 Matter cycles within and among ecosystems and in the biosphere, and human activities are altering these chemical cycles.

Concept 3-7 Scientists use field research, laboratory research, and mathematical and other models to learn about ecosystems.

CHAPTER 4 Evolution and Biodiversity

Concept 4-1A The scientific theory of evolution explains how life on earth changes over time through changes in the genes of populations.

Concept 4-1B 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).

Concept 4-2 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.

Concept 4-3 As a result of biological evolution, each species plays a specific ecological role called its niche.

Concept 4-4A As environmental conditions change, the balance between formation of new species and extinction of existing ones determines the earth's biodiversity.

Concept 4-4B Human activities decrease the earth's biodiversity by causing the premature extinction of species and by destroying or degrading habitats needed for the development of new species.

Concept 4-5 Genetic engineering enables scientists to transfer genetic traits between different species—a process that holds great promise and raises difficult issues.

CHAPTER 5 Climate and Biodiversity

Concept 5-1 An area's climate is determined mostly by solar radiation, the earth's rotation, global patterns of air and water movement, gases in the atmosphere, and the earth's surface features.

Concept 5-2 Differences in average annual precipitation and temperature lead to the formation of tropical, temperate, and cold deserts, grasslands, and forests, and largely determine their locations.

Concept 5-3 In many areas, human activities are impairing ecological and economic services provided by deserts, grasslands, forests, and mountains.

Concept 5-4A Saltwater and freshwater aquatic life zones cover almost three-fourths of the earth's surface with oceans dominating the planet.

Concept 5-4B Most aquatic organisms live in the surface, middle, or bottom layers of saltwater and freshwater systems.

Concept 5-5 In many areas, human activities are impairing ecological and economic services provided by saltwater systems, especially coastal wetlands, shorelines, mangrove forests, and coral reefs.

Concept 5-6 Human activities are impairing ecological and economic services provided by many rivers and freshwater lakes and wetlands.

CHAPTER 6 Community and Population Ecology

Concept 6-1 Species diversity is a major component of biodiversity and tends to increase the sustainability of communities and ecosystems.

Concept 6-2 Based on certain ecological roles they play in communities, species are described as native, nonnative, indicator, keystone, or foundation species.

Concept 6-3A Five basic species interactions—competition, predation, parasitism, mutualism, and commensalism—affect the resource use and population sizes of species in a community.

Concept 6-3B Some species develop adaptations that allow them to reduce or avoid competition for resources with other species.

Concept 6-4A The structure and species composition of communities change in response to changing environmental conditions through a process called ecological succession.

Concept 6-4B According to the *precautionary principle,* we should take measures to prevent or reduce harm to human health and the natural systems even if some possible cause-and-effect relationships have not been fully established scientifically.

Concept 6-5 No population can continue to grow indefinitely because of limitations on resources and because of competition among species for those resources.

CHAPTER 7 Applying Population Ecology: Human Population and Urbanization

Concept 7-1 We do not know how long we can continue increasing the earth's carrying capacity for humans without seriously degrading the life-support system for us and many other species.

Concept 7-2A Population size increases because of births and immigration and decreases through deaths and emigration.

Concept 7-2B The average number of children born to women in a population (*total fertility rate*) is the key factor that determines the population size.

Concept 7-3 The numbers of males and females in young, middle, and older age groups determine how fast populations grow or decline.

Concept 7-4 Experience indicates that the most effective ways to slow population growth are to invest in family planning, to reduce poverty, and to elevate the status of women.

Concept 7-5 Cities can improve individual lives, but most cities are unsustainable because of high levels of resource use, waste, pollution, and poverty.

Concept 7-6 A combination of plentiful land, inexpensive fuel, and an expanding network of highways results in dispersed cities that depend on motor vehicles for most transportation.

Concept 7-7 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.

CHAPTER 8 Sustaining Biodiversity: The Ecosystem Approach

Concept 8-1A We are degrading and destroying biodiversity in many parts of the world and these threats are increasing.

Concept 8-1B We should protect biodiversity because it exists and because of its usefulness to us and other species.

Concept 8-2 We can sustain forests by recognizing the economic value of their ecological services, protecting old-growth forests, harvesting trees no faster than they are replenished, and making most paper from fast-growing plants and agricultural residues instead of trees.

Concept 8-3 We can reduce tropical deforestation by protecting large forest areas, teaching settlers about sustainable agriculture and forestry, using government subsidies that encourage sustainable forest use, reducing poverty, and slowing population growth.

Concept 8-4 We can sustain the productivity of rangeland by controlling the number and distribution of livestock and by restoring degraded rangeland.

Concept 8-5 Sustaining biodiversity will require protecting much more of the earth's remaining undisturbed land area, starting with the most endangered biodiversity hot spots.

Concept 8-6 Sustaining biodiversity will require a global effort to rehabilitate and restore damaged ecosystems.

Concept 8-7 We can sustain aquatic biodiversity by establishing protected sanctuaries, managing coastal development, reducing water pollution, and preventing overfishing.

Concept 8-8 Sustaining the world's biodiversity requires mapping terrestrial and aquatic biodiversity, protecting terrestrial and aquatic hotspots and old-growth forests, initiating ecological restoration projects worldwide, and making conservation profitable.

CHAPTER 9 Sustaining Biodiversity: The Species Approach

Concept 9-1 The current rate of species extinction is at least 100 times the rate that existed before modern humans arrived on earth, and is expected to increase to between 1,000 and 10,000 times the earlier rate during this century.

Concept 9-2 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.

Concept 9-3 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.

Concept 9-4A We can use existing environmental laws and treaties and work to enact new laws designed to prevent species extinction and to protect overall biodiversity.

Concept 9-4B We can help prevent species extinction by creating and maintaining wildlife refuges, gene banks, botanical gardens, zoos, and aquariums.

Concept 9-5 We can help protect some species from premature extinction by finding ways to share the places we dominate with them.

CHAPTER 10 Food, Soil, and Pest Management

Concept 10-1 Meeting the nutritional needs of the world's people requires reducing poverty and the harmful environmental impacts of agriculture.

Concept 10-2 Producing enough food to feed the rapidly growing human population will require growing food in a mix of monocultures and polycultures and decreasing the enormous environmental impact of industrialized agriculture.

Concept 10-3 We can reduce soil erosion and degradation by using proven agricultural techniques and restoring depleted soil nutrients.

Concept 10-4 Industrialized agriculture has increased global food production dramatically, but its harmful environmental impacts may limit future food production.

Concept 10-5A Rangeland overgrazing and the harmful environmental impacts of industrial livestock production may limit meat production.

Concept 10-5B We can harvest fish more sustainably to prevent overfishing and use improved types of aquaculture.

Concept 10-6 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).

Concept 10-7 Sustainable agriculture involves reducing topsoil erosion, eliminating overgrazing and overfishing, irrigating more efficiently, using integrated pest management, providing government subsidies for sustainable farming and fishing, and promoting agrobiodiversity.

CHAPTER 11 Water and Water Pollution

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 do not have sufficient access to clean water, and this situation will almost certainly get worse.

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 transport systems to transfer water to arid regions has increased water supplies in those 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.

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.

Concept 11-4 We can improve flood control by protecting more wetlands and natural vegetation in watersheds and by not building in areas subject to frequent flooding.

Concept 11-5A Streams can cleanse themselves of many pollutants if we do not overload them.

Concept 11-5B Preventing water pollution usually works better and costs less than trying to clean it up.

Concept 11-5C Reducing water pollution requires preventing it, working with nature in treating sewage, cutting resource use and waste, reducing poverty, and slowing population growth.

CHAPTER 12 Geology and Nonrenewable Mineral Resources

Concept 12-1 Gigantic plates in the earth's crust move very slowly atop the planet's mantle, and wind and water move matter from place to place across the earth's surface.

Concept 12-2A Some naturally occurring substances in the earth's crust can be extracted and processed into useful materials.

Concept 12-2B Igneous, sedimentary, and metamorphic rocks in the earth's crust are recycled very slowly by geologic processes.

Concept 12-3 Extracting and using mineral resources can disturb the land, erode soils, produce large amounts of solid waste, and pollute the air, water, and soil.

Concept 12-4 An increase in the price of a scarce mineral resource can lead to increased supplies and more efficient use of the mineral, but there are limits to this effect.

Concept 12-5 We can try to find substitutes for scarce resources, recycle and reuse minerals, reduce resource waste, and convert the wastes from some businesses into raw materials for other businesses.

CHAPTER 13 Energy

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 usable energy available from a resource after the amount of energy needed to make it available is subtracted.

Concept 13-2 Oil, natural gas, and coal are currently abundant and relatively inexpensive, but using them causes air and water pollution and releases greenhouse gases to the atmosphere.

Concept 13-3 The nuclear power fuel cycle has a low environmental impact and a low accident risk, but high costs, radioactive wastes, vulnerability to sabotage, and the potential for spreading nuclear weapons technology have limited its use.

Concept 13-4 We could save more than 40% of all the energy we use by improving energy efficiency.

Concept 13-5 Using a mix of renewable energy sources—especially wind, solar energy, hydropower, biofuels, geothermal energy, and hydrogen—can drastically reduce pollution, greenhouse gas emissions, and biodiversity losses.

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 environmental costs in the market prices of all energy resources.

CHAPTER 14 Environmental Hazards and Human Health

Concept 14-1 People face health hazards from biological, chemical, physical, and cultural factors and from the choices they make in their lifestyles.

Concept 14-2 In terms of death rates, the most serious infectious diseases are flu, AIDS, diarrhea, and malaria, with most of these deaths occurring in developing countries.

Concept 14-3 There is growing concern about chemicals that can cause cancer and disrupt the human immune, nervous, and endocrine systems.

Concept 14-4A Any synthetic or natural chemical can be harmful if ingested in a large enough quantity.

Concept 14-4B Many health scientists call for much greater emphasis on pollution prevention to reduce our exposure to potentially harmful chemicals.

Concept 14-5 We can reduce the major risks we face by becoming informed, thinking critically about risks, and making careful choices.

CHAPTER 15 Air Pollution, Climate Change, and Ozone Depletion

Concept 15-1A Three major outdoor air pollution problems are *industrial smog* from burning coal, *photochemical smog* from motor vehicle and industrial emissions, and *acid deposition* from coal burning and motor vehicle exhaust.

Concept 15-1B The most threatening indoor air pollutants are smoke and soot from wood and coal fires (in developing countries) and chemicals used in building materials and products (in developed countries).

Concept 15-2 Legal, economic, and technological tools can help clean up air pollution, but scientists call for much greater emphasis on preventing air pollution.

Concept 15-3 Evidence indicates that the earth's atmosphere is warming rapidly, mostly because of human activities, and that this will lead to significant climate change during this century with severe and long-lasting consequences for humans and many other forms of life.

Concept 15-4 Some areas will benefit from a warmer climate and others will suffer from melting ice, rising sea levels, more extreme weather events, increased drought and floods, and shifts in locations of wildlife habitats and agricultural areas.

Concept 15-5A We can slow the rate of warming and climate change by increasing energy efficiency, relying more on renewable energy resources, greatly reducing greenhouse gas emissions and slowing population growth.

Concept 15-5B Governments can subsidize energy efficiency and renewable energy use, tax greenhouse gas emissions, and cooperate internationally, and individuals and institutions can sharply reduce their greenhouse gas emissions.

Concept 15-6A Widespread use of certain chemicals has reduced ozone levels in the stratosphere, which allows more harmful ultraviolet radiation to reach the earth's surface.

Concept 15-6B To reverse ozone depletion, we must stop producing ozone-depleting chemicals, and adhere to the international treaties that ban such chemicals.

CHAPTER 16 Solid and Hazardous Waste

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.

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.

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.

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 eventually contribute to pollution and land degradation.

Concept 16-5 A sustainable approach to hazardous waste is first to produce less of it, then to reuse or recycle it, then to convert it to less hazardous materials, and finally to safely store what is left.

Concept 16-6 Shifting to a low-waste society requires individuals and businesses to reduce resource use and to reuse and recycle wastes at local, national, and global levels.

CHAPTER 17 Environmental Economics, Politics, and Worldviews

Concept 17-1 Ecological economists and most sustainability experts regard human economic systems as subsystems of the biosphere and subject to its limiting factors.

Concept 17-2A Using resources sustainably will require including the harmful environmental and health costs of resource use in the market prices of goods and services (*full-cost pricing*).

Concept 17-2B Governments can help improve and sustain environmental quality by subsidizing environmentally beneficial activities and by taxing pollution and wastes instead of wages and profits.

Concept 17-3 Reducing poverty can help us to reduce population growth, resource use, and environmental degradation.

Concept 17-4 Individuals can work with others, starting at the local level, to influence how environmental policies are made and whether or not they succeed.

Concept 17-5 Major environmental worldviews differ over what is more important—human needs and wants, or the overall health of ecosystems and the biosphere; different worldviews include varying mixes of both priorities.

Concept 17-6 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.

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.

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.*

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 sex) 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.

alpha particle Positively charged matter, consisting of two neutrons and two protons, that is emitted as radioactivity from the nuclei of some radioisotopes. See also *beta particle, gamma rays.*

altitude Height above sea level. Compare *latitude.*

anaerobic respiration Form of cellular respiration in which some decomposers get the energy they need through the breakdown of glucose (or other nutrients) in the absence of oxygen. Compare *aerobic respiration.*

ancient forest See *old-growth forest.*

animal manure Dung and urine of animals used as a form of organic fertilizer. Compare *green manure.*

annual Plant that grows, sets seed, and dies in one growing season. Compare *perennial.*

anthropocentric Human-centered.

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, estuaries, or the open ocean. See *fish farming, fish ranching.*

aquatic Pertaining to water. Compare *terrestrial.*

aquatic life zone Marine and freshwater portions of the biosphere. Examples include freshwater life zones (such as lakes and streams) and ocean or marine life zones (such as estuaries, coastlines, coral reefs, and the 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.*

atmosphere The whole mass of air surrounding the earth. See *stratosphere, troposphere.* Compare *biosphere, geosphere, hydrosphere.*

atom Minute unit made of subatomic particles that is the basic building block of all chemical elements and thus all matter; the smallest unit of an element that can exist and still have the unique characteristics of that element. Compare *ion, molecule.*

atomic number Number of protons in the nucleus of an atom. Compare *mass number.*

atomic theory the 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 also *alpha particle, gamma ray.*

bioaccumulation An increase in the concentration of a chemical in specific organs or tissues at a level higher than would normally be expected. Compare *biomagnification.*

biocentric Life-centered. Compare *anthropocentric.*

biodegradable Capable of being broken down by decomposers.

biodegradable pollutant Material that can be broken down into simpler substances (elements and compounds) by bacteria or other decomposers. Paper and most organic wastes such as animal manure are biodegradable but can take decades to biodegrade in modern landfills. Compare *nondegradable pollutant.*

biodiversity The number and abundance of different species (*species diversity*), genetic variability among individuals within each species or population (*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*).

biofuel Gas 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 amplification See *biomagnification.*

biological community See *community.*

biological diversity See *biodiversity.*

biological evolution Change in the genetic makeup of a population of a species in successive generations. If continued long enough, it can lead to the formation of a new species. Note that populations-not individuals-evolve. See also *adaptation, differential reproduction, natural selection, theory of evolution.*

biological pest control Control of pest populations by natural predators, parasites, or disease-causing bacteria and viruses (pathogens).

biomagnification Increase in concentration of DDT, PCBs, and other slowly degradable, fat-soluble chemicals in organisms at successively higher trophic levels of a food chain or web. Compare *bioaccumulation.*

biomass Organic matter produced by plants and other photosynthetic producers; total dry weight of all living organisms that can be supported at each trophic level in a food chain or web; dry weight of all organic matter in plants and animals in an ecosystem; plant materials and animal wastes used as fuel.

biome Terrestrial regions inhabited by certain types of life, especially vegetation. Examples include various types of deserts, grasslands, and forests.

biosphere Zone of the earth where life is found. It consists of parts of the atmosphere (the troposphere), hydrosphere (mostly surface water and groundwater), and lithosphere (mostly soil and surface rocks and sediments on the bottoms of oceans and other bodies of water) where life is found. Compare *atmosphere, geosphere, hydrosphere.*

biotic Living organisms. Compare *abiotic.*

biotic pollution The effect of invasive species that can reduce or wipe out populations of many native species and trigger ecological disruptions.

biotic potential Maximum rate at which the population of a given species can increase when there are no limits on its rate of growth. See *environmental resistance.*

birth rate See *crude birth rate.*

bitumen Gooey, black, high-sulfur, heavy oil extracted from oil sand and then upgraded to synthetic fuel oil. See *oil sand.*

broadleaf deciduous plants Plants such as oak and maple trees that survive drought and cold by shedding their leaves and becoming dormant. Compare *broadleaf evergreen plants, coniferous evergreen plants.*

broadleaf evergreen plants Plants that keep most of their broad leaves year-round. An example is the trees found in the canopies of tropical rain forests. Compare *broadleaf deciduous plants, coniferous evergreen plants.*

buffer Substance that can react with hydrogen ions in a solution and thus hold the acidity or pH of a solution fairly constant. See *pH.*

calorie Unit of energy; amount of energy needed to raise the temperature of 1 gram of water by 1C° (unit on Celsius temperature scale). See also *kilocalorie.*

cancer Group of more than 120 different diseases, one for each type of cell in the human body. Each type of cancer produces a tumor in which cells multiply uncontrollably and invade surrounding tissue.

carbon cycle Cyclic movement of carbon in different chemical forms from the environment to organisms and then back to the environment.

carcinogen Chemicals, ionizing radiation, and viruses that cause or promote the development of cancer. See *cancer.* Compare *mutagen, teratogen.*

carnivore Animal that feeds on other animals. Compare *herbivore, omnivore.*

carrying capacity (*K*) Maximum population of a particular species that a given habitat can support over a given period.

cell Smallest living unit of an organism. Each cell is encased in an outer membrane or wall and contains genetic material (DNA) and other parts to perform its life function. Organisms such as bacteria consist of only one cell, but most organisms contain many cells.

cell theory The idea that all living things are composed of cells; the most widely accepted scientific theory in biology.

CFCs See *chlorofluorocarbons.*

chain reaction Multiple nuclear fissions, taking place within a certain mass of a fissionable isotope, that 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 arrangement of atoms, ions, or molecules in the elements or compounds involved changes. Compare *nuclear change, physical change.*

chemical formula Shorthand way to show the number of atoms (or ions) in the basic structural unit of a compound. Examples include H_2O, NaCl, and $C_6H_{12}O_6$.

chemical reaction See *chemical change.*

chemosynthesis Process in which certain organisms (mostly specialized bacteria) extract inorganic compounds from their environment and convert them into organic nutrient compounds without the presence of sunlight. Compare *photosynthesis.*

chlorinated hydrocarbon Organic compound made up of atoms of carbon, hydrogen, and chlorine. Examples include DDT and PCBs.

chlorofluorocarbons (CFCs) Organic compounds made up of atoms of carbon, chlorine, and fluorine. An example is Freon-12 (CCl_2F_2), which is used as a refrigerant in refrigerators and air conditioners and in making plastics such as Styrofoam. Gaseous CFCs can deplete the ozone layer when they slowly rise into the stratosphere and their chlorine atoms react with ozone molecules. Their use is being phased out.

chromosome A grouping of genes and associated proteins in plant and animal cells that carry certain types of genetic information. See *genes.*

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, overnutrition.*

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. 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.*

climax community See *mature community.*

coal Solid, combustible mixture of organic compounds with 30-98% carbon by weight, mixed with various amounts of water and small amounts of sulfur and nitrogen compounds. It forms in several stages as the remains of plants are subjected to heat and pressure over millions of years.

coal gasification Conversion of solid coal to synthetic natural gas (SNG).

coal liquefaction Conversion of solid coal to a liquid hydrocarbon fuel such as synthetic gasoline or methanol.

coastal wetland Land along a coastline, extending inland from an estuary that is covered with salt water all or part of the year. Examples include marshes, bays, lagoons, tidal flats, and mangrove swamps. Compare *inland wetland.*

coastal zone Warm, nutrient-rich, shallow part of the ocean that extends from the high-tide mark on land to the edge of a 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 *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 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* and *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.

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 Management of natural resources by humans with the goals of minimizing resource waste and sustaining supplies for current and future generations.

conservation biology Multidisciplinary science created to deal with the crisis of maintaining the genes, species, communities, and ecosystems that make up earth's biological diversity. Its goals are to investigate human impacts on biodiversity and to develop practical approaches to preserving biodiversity.

conservationist Person concerned with using natural areas and wildlife in ways that sustain them for current and future generations of humans and other forms of life.

conservation-tillage farming Crop cultivation in which the soil is disturbed little (minimum-tillage farming) or not at all (no-till farming) in an effort to reduce soil erosion, lower labor costs, and save energy. Compare *conventional-tillage farming.*

constancy Ability of a living system, such as a population, to maintain a certain size. Compare *inertia, resilience.*

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, dredging, mountaintop removal, open-pit mining, subsurface mining.*

controlled burning Deliberately set, carefully controlled surface fires that reduce flammable litter and decrease the chances of damaging crown fires. See *ground fire, surface fire.*

conventional-tillage farming Crop cultivation method in which a planting surface is made by plowing land, breaking up the exposed soil, and then smoothing the surface. Compare *conservation-tillage farming.*

convergent plate boundary Area where the earth's lithospheric plates are pushed together. See *subduction zone.* Compare *divergent plate boundary, transform fault.*

coral reef Formation produced by massive colonies containing billions of tiny coral animals, called polyps, that secrete a stony substance (calcium carbonate) around themselves for protection. When the corals die, their empty outer skeletons form layers and cause the reef to grow. Coral reefs are found in the coastal zones of warm tropical and subtropical oceans.

core Inner zone of the earth. It consists of a solid inner core and a liquid outer core. Compare *crust, geosphere, mantle.*

critical mass Amount of fissionable nuclei needed to sustain a nuclear fission chain reaction.

crop rotation Planting a field, or an area of a field, with different crops from year to year to reduce soil nutrient depletion. A plant such as corn, tobacco, or cotton, which removes large amounts of nitrogen from the soil, is planted one year. The next year a legume such as soybeans, which adds nitrogen to the soil, is planted.

crown fire Extremely hot forest fire that burns ground vegetation and treetops. Compare *controlled burning, ground fire, surface fire.*

crude birth rate Annual number of live births per 1,000 people in the population of a geographic area at the midpoint of a given year. Compare *crude death rate.*

crude death rate Annual number of deaths per 1,000 people in the population of a geographic area at the midpoint of a given year. Compare *crude birth rate.*

crude oil Gooey liquid consisting mostly of hydrocarbon compounds and small amounts of compounds containing oxygen, sulfur, and nitrogen. Extracted from underground accumulations, it is sent to oil refineries, where it is converted to heating oil, diesel fuel, gasoline, tar, and other materials.

crust Solid outer zone of the earth. It consists of oceanic crust and continental crust. Compare *core, geosphere, mantle.*

cultural eutrophication Overnourishment of aquatic ecosystems with plant nutrients (mostly nitrates and phosphates) because of human activities such as agriculture, urbanization, and discharges from industrial plants and sewage treatment plants. See *eutrophication.*

culture The whole of a society's knowledge, beliefs, technology, and practices.

currents Mass movements of surface water produced by prevailing winds blowing over the oceans.

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. Producers return most of these chemicals to the soil and water for reuse. Decomposers consist of various bacteria and fungi. Compare *consumer, detritus feeder, producer.*

deforestation Removal of trees from a forested area without adequate replanting.

democracy Government by the people through their elected officials and appointed representatives. In a *constitutional democracy,* a constitution provides the basis of government authority and puts restraints on government power through free elections and freely expressed public opinion.

demographic transition Hypothesis that countries, as they become industrialized, have declines in death rates followed by declines in birth rates.

density Mass per unit volume.

depletion time The time it takes to use a certain fraction (usually 80%) of the known or estimated supply of a nonrenewable resource at an assumed rate of use. Finding and extracting the remaining 20% usually costs more than it is worth.

desalination Purification of salt water or brackish (slightly salty) water by removal of dissolved salts.

desert Biome in which evaporation exceeds precipitation and the average amount of precipitation is less than 25 centimeters (10 inches) per year. Such areas have little vegetation or have widely spaced, mostly low vegetation. Compare *forest, grassland.*

desertification Conversion of rangeland, rain-fed cropland, or irrigated cropland to desertlike land, with a drop in agricultural productivity of 10% or more. It usually is caused by a combination of overgrazing, soil erosion, prolonged drought, and climate change.

detritivore Consumer organism that feeds on detritus, parts of dead organisms, and cast-off fragments and wastes of living organisms. 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.*

developed country Country that is highly industrialized and has a high per capita GDP-PPP. Compare *developing country.*

developing country Country that has low to moderate industrialization and low to moderate per capita GDP-PPP. 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 The 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.

divergent plate boundary Area where the earth's lithospheric plates move apart in opposite directions. Compare *convergent plate boundary, transform fault.*

DNA (deoxyribonucleic acid) Large molecules in the cells of 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 The 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 The 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 The variety of forests, deserts, grasslands, oceans, streams, lakes, and other biological communities interacting with one another and with their nonliving environment. See *biodiversity.* Compare *functional diversity, genetic diversity, species diversity.*

ecological 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 and recycle 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.*

ecologist Biological scientist who studies relationships between living organisms and their environment.

ecology Biological science that studies the relationships between living organisms and their environment; study of the structure and functions of nature.

economic depletion Exhaustion of 80% of the estimated supply of a nonrenewable resource. Finding, extracting, and processing the remaining 20% usually costs more than it is worth. May also apply to the depletion of a renewable resource, such as a fish or tree species.

economic development Improvement of human living standards by economic growth. Compare *economic growth, environmentally sustainable economic development.*

economic growth Increase in the capacity to provide people with goods and services; an increase in gross domestic product (GDP). Compare *economic development, environmentally sustainable economic development.* See *gross domestic product.*

economic resources Natural resources, capital goods, and labor used in an economy to produce material goods and services. See *natural resources.*

economic system Method that a group of people uses to choose which goods and services to produce, how to produce them, how much to produce, and how to distribute them to people.

economy System of production, distribution, and consumption of economic goods.

ecosphere See *biosphere.*

ecosystem 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. Two or more elements combine to form the compounds that make up most of the world's matter. Compare *compound.*

elevation Distance above sea level.

endangered species A 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 Everything around us; 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 A social movement dedicated to protecting the earth's life support systems for humans and other species.

environmentalist Person who is concerned about the impacts that people have on environmental quality. Most environmentalists believe 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 the development, implementation, and enforcement of environmental laws, regulations, and policies.

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 involving halting population growth and altering lifestyles, political and economic systems, and the way we treat the environment so that we can help sustain ourselves and other species indefinitely. 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) along with those from the social sciences (such as economics, politics, and ethics) to learn how nature works, how we interact with the environment, and how we can deal with environmental problems.

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; it may also *discourage* 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 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 to meet their basic needs.

environmental wisdom worldview We are part of and totally dependent on nature and that nature exists for all species, not just for us and we should encourage environmentally sustainable forms of economic growth and development and discourage environmentally degrading forms. 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 fresh water, carrying fertile silt and runoff from the land, mixes with salty seawater.

eukaryotic A cell that is surrounded by a membrane and has a distinct nucleus. Compare *prokaryotic.*

euphotic zone Upper layer of a body of water through which sunlight can penetrate and support photosynthesis.

eutrophication Physical, chemical, and biological changes that take place after a lake, estuary, or slow-flowing stream receives inputs of plant nutrients, mostly nitrates and phosphates-from natural erosion and runoff from the surrounding land basin. See *cultural eutrophication.*

eutrophic lake Lake with a large or excessive supply of plant nutrients, mostly nitrates and phosphates. Compare *mesotrophic lake, oligotrophic lake.*

evaporation Conversion of a liquid into a gas.

evergreen plants Plants that keep some of their leaves or needles throughout the year. Examples include 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.*

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.*

external benefit Beneficial social effect of producing and using an economic good that is not included in the market price of the good. Compare *external cost, full cost.*

external cost Harmful social effect of producing and using an economic good that is not included in the market price of the good. Compare *external benefit, full cost, internal cost.*

extinction 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 depletion, mass extinction, threatened species.*

extinction rate Expressed as a 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.

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 grow 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. 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.*

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 *throughputs.*

flyway Generally fixed route along which waterfowl migrate from one area to another at certain seasons of the year.

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 Product of partial or complete decomposition of plants and animals exposed to heat and pressure in the earth's crust over millions of years; occurs as crude oil, coal, natural gas, or heavy oil. 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 A 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 fresh water 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. Compare *external cost, internal cost.*

functional diversity Biological and chemical processes or functions such as energy flow and matter cycling needed for the survival of species and biological communities. See *biodiversity, ecological diversity, genetic diversity, species diversity.*

fungicide Chemical that kills fungi.

gamma ray A form of ionizing electromagnetic radiation with a high energy content emitted by some radioisotopes. It readily penetrates body tissues. See also *alpha particle, beta particle.*

GDP See *gross domestic product.*

gene mutation See *mutation.*

gene pool The 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 or population of a 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.*

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.

global climate change Broad term referring to changes in any aspects of the earth's climate, including temperature, precipitation, and storm activity.

global warming Warming of the earth's lower atmosphere (troposphere) because of increases in the concentrations of one or more greenhouse gases primarily as a result of human activities. See *greenhouse effect, greenhouse gases, natural greenhouse effect.*

GMO See *genetically modified organism.*

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 A natural effect that releases heat in the atmosphere near the earth's surface (troposphere). Water vapor, carbon dioxide, ozone, and other gases in the troposphere absorb some of the infrared radiation (heat) radiated by the earth's surface. Their molecules vibrate and transform the absorbed energy into longer-wavelength infrared radiation in the troposphere. If the atmospheric concentrations of these greenhouse gases increase and other natural processes do not remove them, the average temperature of the lower atmosphere will increase 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 (rice, wheat, maize) 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, per capita GDP-PPP.*

gross primary productivity (GPP) The 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. See *aquifer.* 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 sample 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 hot sample of matter to a colder sample of matter. This is one way to state the second law of thermodynamics. Compare *temperature.*

herbicide Chemical that kills a plant or inhibits its growth.

herbivore Plant-eating organism. Examples include deer, sheep, grasshoppers, and zooplankton. Compare *carnivore, omnivore.*

heterotroph See *consumer.*

high An air mass with a high pressure. Compare *low.*

high-grade ore Ore containing a large amount of the desired mineral.

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 Economy found in most advanced industrialized countries, in which ever-increasing economic growth is sustained by maximizing the rate at which matter and energy resources are used, with little emphasis on pollution prevention, recycling, reuse, reduction of unnecessary waste, and other forms of resource conservation. Compare *low-throughput economy, matter-recycling economy.*

high-waste economy See *high-throughput economy.*

HIPPCO Acronym used by conservation biologists for the five 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.

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 The 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.*

igneous rock Rock formed when molten rock material (magma) wells up from the earth's interior, cools, and solidifies into rock masses. Compare *metamorphic rock, sedimentary rock.* See *rock cycle.*

immature community Community at an early stage of ecological succession. It usually has a low number of species and ecological niches and cannot capture and use energy and cycle critical nutrients as efficiently as more complex, mature communities. Compare *mature community.*

immigrant species See *nonnative species.*

immigration Migration of people into a country or area to take up permanent residence.

indicator species Species that serve as early warnings that a community or ecosystem is being degraded. Compare *foundation species, keystone species, native species, nonnative species.*

industrialized agriculture Using large inputs of energy from fossil fuels (especially oil and natural gas), water, fertilizer, and pesticides to produce large quantities of crops and livestock for domestic and foreign sale. 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.

infant mortality rate Number of babies out of every 1,000 born each year who die before their first birthday.

infectious disease See *transmissible 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 fresh water. Compare *coastal wetland.*

inorganic compounds All compounds not classified as organic compounds. See *organic compounds.*

inorganic fertilizer See *commercial inorganic fertilizer.*

input Matter, energy, or information entering a system. Compare *output, throughput.*

input pollution control See *pollution prevention.*

insecticide Chemical that kills insects.

instrumental value Value of an organism, species, ecosystem, or the earth's biodiversity based on its usefulness to humans. Compare *intrinsic value.*

integrated pest management (IPM) Combined use of biological, chemical, and cultivation methods in proper sequence and timing to keep the size of a pest population below the size that causes economically unacceptable losses of crops or livestock animals.

integrated waste management Variety of strategies for both waste reduction and waste management designed to deal with the solid wastes we produce.

intercropping Growing two or more different crops at the same time on a plot. For example, a carbohydrate-rich grain that depletes soil nitrogen and a protein-rich legume that adds nitrogen to the soil may be intercropped. Compare *monoculture, polyculture, polyvarietal cultivation.*

internal cost Direct cost paid by the producer and the buyer of an economic good. Compare *external benefit, external cost, full cost.*

interplanting Simultaneously growing a variety of crops on the same plot. See *agroforestry, intercropping, polyculture, polyvarietal cultivation.*

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.*

isotopes Two or more forms of a chemical element that have the same number of protons but different mass numbers because they have different numbers of neutrons in their nuclei.

J-shaped curve Curve with a shape similar to that of the letter J; can represent prolonged exponential growth. See *exponential growth.*

junk science See *unreliable science.*

kerogen Solid, waxy mixture of hydrocarbons found in oil shale rock. Heating the rock to high temperatures causes the kerogen to vaporize. The vapor is condensed, purified, and then sent to a refinery to produce gasoline, heating oil, and other products. See also *oil shale, shale oil.*

keystone species Species that play roles affecting many other organisms in an ecosystem. Compare *foundation species, indicator species, native species, nonnative species.*

kilocalorie (kcal) Unit of energy equal to 1,000 calories. See *calorie.*

kilowatt (kW) Unit of electrical power equal to 1,000 watts. See *watt.*

kinetic energy Energy that matter has because of its mass and speed or velocity. Compare *potential energy.*

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 fresh water 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 A 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.*

latitude Distance from the equator. Compare *altitude.*

law of conservation of energy See *first law of thermodynamics.*

law of conservation of matter In any physical or chemical change, matter is neither created nor destroyed but merely changed from one form to another; in physical and chemical changes, existing atoms are rearranged into different spatial patterns (physical changes) or different combinations (chemical changes).

law of tolerance The existence, abundance, and distribution of a species in an ecosystem are determined by whether the levels of one or more physical or chemical factors fall within the range tolerated by the species. See *threshold effect.*

LD50 See *median lethal dose.*

LDC See *developing country.*

leaching Process in which various chemicals in upper layers of soil are dissolved and carried to lower layers and, in some cases, to groundwater.

less developed country (LDC) See *developing country.*

life-cycle cost Initial cost plus lifetime operating costs of an economic good. Compare *full cost.*

life expectancy Average number of years a newborn infant can be expected to live.

limiting factor Single factor that limits the growth, abundance, or distribution of the population of a species in an ecosystem. See *limiting factor principle.*

limiting factor principle Too much or too little of any abiotic factor can limit or prevent growth of a population of a species in an ecosystem, even if all other factors are at or near the optimal range of tolerance for the species.

linear growth Growth in which a quantity increases by some fixed amount during each unit of time. An example is growth that increases 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.*

loams Soils containing a mixture of clay, sand, silt, and humus. Good for growing most crops.

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 An air mass with a low pressure. Compare *high.*

low-grade ore Ore containing a small amount of a desired mineral.

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 use and waste, 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 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, chronic undernutrition.*

mangrove swamps Swamps found on the coastlines in warm tropical climates. They are dominated by mangrove trees, any of about 55 species of trees and shrubs that can live partly submerged in the salty environment of coastal swamps.

mantle Zone of the earth's interior between its core and its crust. Compare *core, crust, 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 The amount of material in an object.

mass extinction A catastrophic, widespread, often global event in which major groups of species are wiped out over a short time compared with normal (background) extinctions. Compare *background extinction.*

mass number Sum of the number of neutrons (n) and the number of protons (p) in the nucleus of an atom. It gives the approximate mass of that atom. Compare *atomic number.*

mass transit Buses, trains, trolleys, and other forms of transportation that carry large numbers of people.

material efficiency Total amount of material needed to produce each unit of goods or services. Also called *resource productivity.* Compare *energy efficiency.*

matter Anything that has mass (the amount of material in an object) and takes up space. On the earth, where gravity is present, we weigh an object to determine its mass.

matter quality Measure of how useful a matter resource is, based on its availability and concentration. See *high-quality matter, low-quality matter.*

matter-recycling-and-reuse economy Economy that emphasizes recycling the maximum amount of all resources that can be recycled and reused. The goal is to allow economic growth to continue without depleting matter resources and without producing excessive pollution and environmental degradation. Compare *high-throughput economy, low-throughput economy.*

mature community Fairly stable, self-sustaining community in an advanced stage of ecological succession; usually has a diverse array of species and ecological niches; captures and uses energy and cycles critical chemicals more efficiently than simpler, immature communities. Compare *immature community.*

maximum sustainable yield See *sustainable yield.*

MDC See *developed country.*

median lethal dose (LD50) Amount of a toxic material per unit of body weight of test animals that kills half the test population in a certain time.

megacity City with 10 million or more people.

meltdown The melting of the core of a nuclear reactor.

mesotrophic lake Lake with a moderate supply of plant nutrients. Compare *eutrophic lake, oligotrophic lake.*

metabolism Ability of a living cell or organism to capture and transform matter and energy from its environment to supply its needs for survival, growth, and reproduction.

metamorphic rock Rock produced when a preexisting rock is subjected to high temperatures (which may cause it to melt partially), high pressures, chemically active fluids, or a combination of these agents. Compare *igneous rock, sedimentary rock.* See *rock cycle.*

metastasis Spread of malignant (cancerous) cells from a tumor to other parts of the body.

metropolitan area See *urban area.*

microorganisms Organisms such as bacteria that are so small that it takes a microscope to see them.

micropower systems Systems of small-scale decentralized units that generate 1–10,000 kilowatts of electricity. Examples include microturbines, fuel cells, and household solar panels and solar roofs.

migration The movement of people into and out of specific geographic areas. Compare *emigration* and *immigration.*

mineral Any naturally occurring inorganic substance found in the earth's crust as a crystalline solid. See *mineral resource.*

mineral resource Concentration of naturally occurring solid, liquid, or gaseous material in or on the earth's crust in a form and amount such that extracting and converting it into useful materials or items is currently or potentially profitable. Mineral resources are classified as *metallic* (such as iron and tin ores) or *nonmetallic* (such as fossil fuels, sand, and salt).

minimum-tillage farming See *conservation-tillage farming.*

mixture Combination of one or more elements and compounds.

model An 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.*

more developed country (MDC) See *developed country.*

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 mountain. Compare *area strip mining, contour strip mining.*

MSW See *municipal solid waste.*

multiple use Use of an ecosystem such as a forest for a variety of purposes such as timber harvesting, wildlife habitat, watershed protection, and recreation. Compare *sustainable yield.*

municipal solid waste (MSW) Solid materials discarded by homes and businesses in or near urban areas. See *solid waste.*

mutagen Chemical or form of radiation that causes inheritable changes (mutations) in the DNA molecules in genes. See *carcinogen, mutation, teratogen.*

mutation A 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 The natural resources and natural services that keep us and other species alive and support our economies. See *natural income.* Compare *solar capital.*

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 the earth's natural capital. Compare *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 *nonrenewable resource, renewable resource.*

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. Compare *natural resources.*

nekton Strongly swimming organisms found in aquatic systems. Compare *benthos, plankton.*

net energy Total amount of useful energy available from an energy resource or energy system over its lifetime, minus the amount of energy *used* (the first energy law), *automatically wasted* (the second energy law), and *unnecessarily wasted* in finding, processing, concentrating, and transporting it to users.

net primary productivity (NPP) Rate at which all the plants in an ecosystem produce net useful chemical energy; equal to the difference between the rate at which the plants in an ecosystem produce useful chemical energy (gross primary productivity) and the rate at which they use some of that energy through cellular respiration. Compare *gross primary productivity.*

neurotoxins Chemicals that can harm the human *nervous system* (brain, spinal cord, peripheral nerves).

neutral solution Water solution containing an equal number of hydrogen ions (H^+) and hydroxide ions (OH^-); water solution with a pH of 7. Compare *acid solution, basic solution.*

neutron (n) Elementary particle in the nuclei of all atoms (except hydrogen-1). It has a relative mass of 1 and no electric charge. Compare *electron, proton.*

niche See *ecological niche.*

nitrogen cycle Cyclic movement of nitrogen in different chemical forms from the environment to organisms and then back to the environment.

nitrogen fixation Conversion of atmospheric nitrogen gas by lightning, bacteria, and cyanobacteria into forms useful to plants; it is part of the nitrogen cycle.

noise pollution Any unwanted, disturbing, or harmful sound that impairs or interferes with hearing, causes stress, hampers concentration and work efficiency, or causes accidents.

nondegradable pollutant Material that is not broken down by natural processes. Examples include the toxic elements lead and mercury. Compare *biodegradable pollutant.*

nonionizing radiation Forms of radiant energy such as radio waves, microwaves, infrared light, and ordinary light that do not have enough energy to cause ionization of atoms in living tissue. Compare *ionizing radiation.*

nonnative species Species that migrate into an ecosystem or are deliberately or accidentally introduced into an ecosystem by humans. Compare *native species.*

nonpoint source Large or dispersed land areas such as crop fields, streets, and lawns that discharge pollutants into the environment over a large area. 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 A disease that is not caused by living organisms and does not spread from one person to another. Examples include most cancers, diabetes, cardiovascular disease, and malnutrition. Compare *transmissible disease.*

no-till farming See *conservation-tillage farming.*

NPP See *net primary productivity.*

nuclear change Process in which nuclei of certain isotopes spontaneously change, or are forced to change, into one or more different isotopes. The three principal types of nuclear change are natural radioactivity, nuclear fission, and nuclear fusion. Compare *chemical change, physical change.*

nuclear energy Energy released when atomic nuclei undergo a nuclear reaction such as the spontaneous emission of radioactivity, nuclear fission, or nuclear fusion.

nuclear fission Nuclear change in which the nuclei of certain isotopes with large mass numbers (such as uranium-235 and plutonium-239) are split apart into lighter nuclei when struck by a neutron. This process releases more neutrons and a large amount of energy. Compare *nuclear fusion.*

nuclear fusion Nuclear change in which two nuclei of isotopes of elements with a low mass number (such as hydrogen-2 and hydrogen-3) are forced together at extremely high temperatures until they fuse to form a heavier nucleus (such as helium-4). This process releases a large amount of energy. Compare *nuclear fission.*

nucleus Extremely tiny center of an atom, making up most of the atom's mass. It contains one or more positively charged protons and one or more neutrons with no electrical charge (except for a hydrogen-1 atom, which has one proton and no neutrons in its nucleus).

nutrient Any chemical element or compound an organism must take in to live, grow, or reproduce.

nutrient cycle See *biogeochemical cycle.*

nutrient cycling Circulation of chemicals necessary for life from the environment (soil, water, air) through organisms and back to the environment. Without this natural service, life as we know it could not exist.

oil See *crude oil.*

oil sand Deposit of a mixture of clay, sand, water, and varying amounts of a tarlike heavy oil known as bitumen. Bitumen can be extracted from oil sand by heating. It is then purified and upgraded to synthetic crude oil. See *bitumen.*

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, and the open ocean and its fish. Compare *common property resource, private property resource.*

open dump Field or hole 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 The 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).

organic agriculture Producing crops and livestock naturally by 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); with little or no use of synthetic pesticides, synthetic fertilizers or synthetic growth regulators, and feed additives. See *sustainable agriculture.*

organic compounds Compounds containing carbon atoms combined 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.*

organic fertilizer Organic material such as animal manure, green manure, and compost, applied to cropland as a source of plant nutrients. Compare *commercial inorganic fertilizer.*

organism Any form of life.

output Matter, energy, or information leaving a system. Compare *input, throughput.*

output pollution control See *pollution cleanup.*

overburden Layer of soil and rock overlying a mineral deposit. Surface mining removes this layer.

overfishing Harvesting so many fish of a species, especially immature 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 *chronic undernutrition, malnutrition.*

oxygen-demanding wastes Organic materials that are usually biodegraded by aerobic (oxygen-consuming) bacteria if there is enough dissolved oxygen in the water.

ozone depletion Decrease in concentration of ozone (O_3) in the stratosphere. See *ozone layer.*

ozone layer Layer of gaseous ozone (O_3) in the stratosphere that protects life on earth by filtering out most harmful ultraviolet radiation from the sun.

PANs Peroxyacyl nitrates; group of chemicals found in photochemical smog.

paradigm shift Shift in thinking that occurs when the majority of scientists in a field or related fields agree that a new explanation or theory is better than the old one.

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.*

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 into 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 Organism that produces disease. Examples include bacteria, viruses, and parasites.

PCBs See *polychlorinated biphenyls.*

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 recycle the wastes from such resource use. It measures the average environmental impact of individuals or populations in different countries and areas. Compare *ecological footprint.*

per capita GDP Annual gross domestic product (GDP) of a country divided by its total population at midyear. It gives the average slice of the economic pie per person. Used to be called per capita gross national product (GNP). See *gross domestic product, per capita GDP-PPP.*

per capita GDP-PPP Measure of the amount of goods and services that a country's average citizen could buy in the United States. Compare *per capita GDP.*

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 How long a pollutant stays in the air, water, soil, or body.

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 the arrangement of its atoms, ions, or molecules. Examples include changing the size and shape of a sample of matter (crushing ice and cutting aluminum foil) and changing a sample of matter from one physical state to another (boiling and freezing water). Compare *chemical change, nuclear change.*

phytoplankton Small, drifting plants, mostly algae and bacteria, found in aquatic ecosystems. Compare *plankton, zooplankton.*

pioneer community First integrated set of plants, animals, and decomposers found in an area undergoing primary ecological succession. See *immature community, mature community.*

pioneer species First hardy species-often microbes, mosses, and lichens-that begin colonizing a site as the first stage of ecological succession. See *ecological succession, pioneer community.*

planetary management worldview View holding that we are separate from the nature, that nature exists mainly to meet our needs and increasing wants, and we can use our ingenuity and technology to manage the earth's life-support systems, mostly for our benefit. It assumes that economic growth is unlimited. Compare *environmental wisdom worldview, stewardship worldview.*

plankton Small plant organisms (phytoplankton) and animal organisms (zooplankton) that float in aquatic ecosystems.

plantation agriculture Growing specialized crops such as bananas, coffee, and cacao in tropical developing countries, primarily for sale to developed countries.

plates See *tectonic plates.*

plate tectonics Theory of geophysical processes that explains the movements of lithospheric plates and the processes that occur at their boundaries. See *lithosphere, tectonic plates.*

point source Single identifiable source that discharges pollutants into the environment. Examples include the smokestack of a power plant or an industrial plant, drainpipe of a meatpacking plant, chimney of a house, or exhaust pipe of an automobile. Compare *nonpoint source.*

poison A chemical that adversely affects the health of a living human or animal by causing injury, illness, or death.

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 A particular chemical or form of energy that can adversely affect the health, survival, or activities of humans or other living organisms. See *pollution.*

pollution An 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 An increase or decrease in the size of a population. It is equal to (Births + Immigration) − (Deaths + Emigration).

population density Number of organisms in a particular population found in a specified area or volume.

population dispersion General pattern in which the members of a population are arranged throughout its habitat.

population distribution Variation of population density over a particular geographic area or volume. For example, a country has a high population density in its urban areas and a much lower population density in rural areas.

population dynamics Major abiotic and biotic factors that tend to increase or decrease the population size and affect the age and sex composition of a species.

population size Number of individuals making up a population's gene pool.

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 such 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 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 sewage treatment Mechanical sewage treatment in which large solids are filtered out by screens and suspended solids settle out as sludge in a sedimentation tank. Compare *secondary sewage treatment.*

primary succession Ecological succession in a bare area that has never been occupied by a community of organisms. See *ecological succession.* Compare *secondary succession.*

private property resource Land, mineral, or other resource owned by individuals or a firm. Compare *common property resource, open access renewable resource.*

probability A mathematical statement about how likely it is that something will happen.

producer Organism that uses solar energy (green plants) or chemical energy (some bacteria) to manufacture the organic compounds it needs as nutrients from simple inorganic compounds obtained from its environment. Compare *consumer, decomposer.*

prokaryotic A cell containing no distinct nucleus or organelles. Compare *eukaryotic.*

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.*

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. Compare *pyramid of biomass, pyramid of numbers.*

radiation Fast-moving particles (particulate radiation) or waves of energy (electromagnetic radiation). See *alpha particle, beta particle, gamma ray.*

radioactive decay Change of a radioisotope to a different isotope by the emission of radioactivity.

radioactive isotope See *radioisotope.*

radioactive waste Waste products of nuclear power plants, research, medicine, weapon production, or other processes involving nuclear reactions. See *radioactivity.*

radioactivity Nuclear change in which unstable nuclei of atoms spontaneously shoot out "chunks" of mass, energy, or both at a fixed rate. The three principal types of radioactivity are gamma rays and fast-moving alpha particles and beta particles.

radioisotope Isotope of an atom that spontaneously emits one or more types of radioactivity (alpha particles, beta particles, gamma rays).

rain shadow effect Low precipitation on the far side (leeward side) of a mountain when prevailing winds flow up and over a high mountain or range of high mountains. 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, grasslike plants, and shrubs) for grazing and browsing animals and is not intensively managed. Compare *feedlot, pasture.*

range of tolerance Range of chemical and physical conditions that must be maintained for populations of a particular species to stay alive and grow, develop, and function normally. See *law of tolerance.*

rare species A 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 The 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. Compare *reuse.*

reforestation Renewal of trees and other types of vegetation on land where trees have been removed; can be done naturally by seeds from nearby trees or artificially by planting seeds or seedlings.

reliable runoff Surface runoff of water that generally can be counted on as a stable source of water from year to year. See *runoff.*

reliable science Concepts and ideas that are widely accepted by experts in a particular field of the natural or social sciences. Compare *tentative science, unreliable science.*

renewable resource Resource that can be replenished rapidly (hours to several decades) through natural processes as long as it is not used up faster than it is replaced. Examples include trees in forests, grasses in grasslands, wild animals, fresh surface water in lakes and streams, most groundwater, fresh air, and fertile soil. If such a resource is used faster than it is replenished, it can be depleted and converted into a nonrenewable resource. Compare *nonrenewable resource* and *perpetual resource.* See also *environmental degradation.*

replacement-level fertility Number of children a couple must bear to replace themselves. The average for a country or the world usually is slightly higher than 2 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.

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 The 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 The 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 (*risk assessment*), 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 Using 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 *igneous rock, metamorphic rock, mineral, sedimentary rock.*

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 Fresh water 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 salt 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 Attempts to discover order in nature and use that knowledge to make predictions about what should happen in nature. See *reliable science, scientific data, scientific hypothesis, scientific law, scientific methods, scientific model, scientific theory, tentative science, unreliable science.*

scientific data Facts obtained by making observations and measurements. Compare *scientific hypothesis, scientific law, scientific methods, scientific model, scientific theory.*

scientific hypothesis An educated guess that attempts to explain a scientific law or certain scientific observations. Compare *scientific data, scientific law, scientific methods, scientific model, scientific theory.*

scientific law Description of what scientists find happening in nature repeatedly in the same way, without known exception. See *first law of thermodynamics, law of conservation of matter, second law of thermodynamics.* Compare *scientific data, scientific hypothesis, scientific methods, scientific model, scientific theory.*

scientific methods The ways in which scientists gather data and formulate and test scientific hypotheses, models, theories, and laws. See *scientific data, scientific hypothesis, scientific law, scientific model, scientific theory.*

scientific model A simulation of complex processes and systems. Many are mathematical models that are run and tested using computers.

scientific theory A well-tested and widely accepted scientific hypothesis. Compare *scientific data, scientific hypothesis, scientific law, scientific methods, scientific model.*

secondary consumer Organism that feeds only on primary consumers. Compare *detritivore, omnivore, primary consumer.*

secondary pollutant Harmful chemical formed in the atmosphere when a primary air pollutant reacts with normal air components or other air pollutants. Compare *primary pollutant.*

secondary sewage treatment Second step in most waste treatment systems in which aerobic bacteria decompose as much as 90% of degradable, oxygen-demanding organic wastes in wastewater. It usually involves bringing sewage and bacteria together in trickling filters or in the activated sludge process. Compare *primary sewage treatment.*

secondary 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 succession.*

second-growth forest Stands of trees resulting from secondary ecological succession. Compare *old-growth forest, tree farm.*

second law of energy See *second law of thermodynamics.*

second law of thermodynamics In any conversion of heat energy to useful work, some of the initial energy input is always degraded to lower-quality, more dispersed, less useful energy—usually low-temperature heat that flows into the environment; you cannot break even in terms of energy quality. See *first law of thermodynamics.*

sedimentary rock Rock that forms from the accumulated products of erosion and in some cases from the compacted shells, skeletons, and other remains of dead organisms. Compare *igneous rock, metamorphic rock.* See *rock cycle.*

selective cutting Cutting of intermediate-aged, mature, or diseased trees in an uneven-aged forest stand, either singly or in small groups. This encourages the growth of younger trees and maintains an uneven-aged stand. Compare *clear-cutting, strip cutting.*

septic tank Underground tank for treating wastewater from a home in rural and suburban areas. Bacteria in the tank decompose organic wastes, and the sludge settles to the bottom of the tank. The effluent flows out of the tank into the ground through a field of drainpipes.

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.*

shifting cultivation Clearing a plot of ground in a forest, especially in tropical areas, and planting crops on it for a few years (typically 2-5 years) until the soil is depleted of nutrients or the plot has been invaded by a dense growth of vegetation from the surrounding forest. Then a new plot is cleared and the process is repeated. The abandoned plot cannot successfully grow crops for 10-30 years. See also *slash-and-burn cultivation.*

slash-and-burn cultivation Cutting down trees and other vegetation in a patch of forest, leaving the cut vegetation on the ground to dry, and then burning it. The ashes that are left add nutrients to the nutrient-poor soils found in most tropical forest areas. Crops are planted between tree stumps. Plots must be abandoned after a few years (typically 2-5 years) because of loss of soil fertility or invasion of vegetation from the surrounding forest. See also *shifting cultivation.*

slowly degradable pollutant Material that is slowly broken down into simpler chemicals or reduced to acceptable levels by natural physical, chemical, and biological processes.

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.*

social capital Result of getting people with different views and values to communicate, 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. Compare *soil erosion.*

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 permeability Rate at which water and air move from upper to lower soil layers. Compare *porosity.*

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, functional diversity, genetic diversity.*

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.*

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.

stewardship worldview We can manage the earth for our benefit but that we have an ethical responsibility to be caring and responsible managers, or *stewards,* of the earth. It calls for encouraging environmentally beneficial forms of economic growth and discouraging environmentally harmful forms. Compare *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 reduce depletion of soil nutrients.

strip cutting A 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. See *convergent plate boundary.*

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 a farm family; 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 succession, secondary 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.

superinsulated house House that is heavily insulated and extremely airtight. Typically, active or passive solar collectors are used to heat water, and an air-to-air heat exchanger prevents buildup of excessive moisture and indoor air pollutants.

surface fire Forest fire that burns only undergrowth and leaf litter on the forest floor. Compare *crown fire, ground fire.* See *controlled burning.*

surface mining Removing soil, subsoil, and other strata and then extracting a mineral deposit found fairly close to the earth's surface. See *area strip mining, contour strip mining, mountaintop removal, open-pit mining.* Compare *subsurface mining.*

surface runoff Water flowing off the land into bodies of surface water. See *reliable runoff.*

surface water Precipitation that does not infiltrate the ground or return to the atmosphere by evaporation or transpiration. See *runoff.* Compare *groundwater.*

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 A 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 indefinitely. Such a 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 renewable resource can be used indefinitely without reducing its available supply. See also *environmental degradation.*

synergistic interaction Interaction of two or more factors or processes so that the combined effect is greater than the sum of their separate effects.

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 A set of components that function and interact in some regular and theoretically predictable manner. It usually has an input, throughput, and output of matter, energy, and information.

tailings Rock and other waste materials removed as impurities when waste mineral material is separated from the metal in an ore.

tar sand See *oil sand.*

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 Carnivores that feed on other carnivores. They feed at high trophic levels in food chains and webs. Examples include hawks, lions, bass, and sharks. Compare *detritivore, primary consumer, secondary consumer.*

theory of evolution Widely accepted scientific idea that all life forms developed from earlier life forms. Although this theory conflicts with the creation stories of many religions, it is the way biologists explain how life has changed over the past 3.6–3.8 billion years and why it is so diverse today.

thermal inversion See *temperature inversion.*

third and higher-level consumers See *tertiary consumer.*

threatened species A wild species that is still abundant in its natural range but is likely to become endangered because of a decline in numbers. Compare *endangered species.*

threshold effect The harmful or fatal effect of a small change in environmental conditions that exceeds the limit of tolerance of an organism or population of a species. See *law of tolerance.*

throughput Rate of flow of matter, energy, or information through a system. Compare *input, output.*

throwaway society See *high-throughput economy.*

tolerance limits Minimum and maximum limits for physical conditions (such as temperature) and concentrations of chemical substances beyond which no members of a particular species can survive. See *law of tolerance.*

total fertility rate (TFR) Estimate of the average number of children who will be born alive to a woman during her lifetime if she passes through all her childbearing years (ages 15–44) conforming to age-specific fertility rates of a given year. More simply, it is an estimate of the average number of children a woman will have during her childbearing years.

toxic chemical See *poison, carcinogen, hazardous chemical, mutagen, teratogen.*

toxicity Measure of how harmful a substance is.

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 Producing enough food for a farm family's survival and perhaps a surplus that can be sold. This type of agriculture uses higher inputs of labor, fertilizer, and water than traditional subsistence agriculture. See *traditional subsistence agriculture.* Compare *industrialized agriculture.*

traditional subsistence agriculture Production of enough crops or livestock for a farm family's survival and, in good years, a surplus to sell or put 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.*

transform fault Area where the earth's lithospheric plates move in opposite but parallel directions along a fracture (fault) in the lithosphere. Compare *convergent plate boundary, divergent plate boundary.*

transgenic organisms See *genetically modified organisms.*

transmissible disease A 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, uneven-aged management.*

trophic level All organisms that are the same number of energy transfers away from the original source of energy (such as 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.

undernutrition See *chronic undernutrition.*

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 sprawl Growth of low-density development on the edges of cities and towns. See *smart growth.*

utilitarian value See *instrumental value.*

volcano Vent or fissure in the earth's surface through which magma, liquid lava, and gases are released into the environment.

warm front The 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.*

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 salt water or fresh water, 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.

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 small to medium-sized wind turbines placed in a windy area 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 Regulating how various parcels of land can be used.

zooplankton Animal plankton; small floating herbivores that feed on plant plankton (phytoplankton). Compare *phytoplankton.*

Index

Note: Page numbers in **boldface** type indicate key terms. Page numbers followed by italicized *f, t,* or *b* indicate figures, tables, and boxed material.