International Student Edition

LIVING IN THE ENVIRONMENT

PART-I

G. TYLER MILLER, JR.

THIRTEENTH EDITION

nternational Student Edition

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Living in the Environment

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PREFACE

For Instructors and Students

How Did I Become Involved with Environmental Problems? In 1966, I heard a scientist give a lecture on the problems of population growth and pollution. Afterward I went to him and said, "If even a fraction of what you have said is true, I will feel ethically obligated to give up my research on the corrosion of metals and devote the rest of my life to research and education on environmental problems and solutions. Frankly, I do not want to believe a word you have said, and I am going into the literature to try to show that your statements are either untrue or grossly distorted."

After 6 months of study I was convinced of the seriousness of these and other environmental problems. Since then, I have been studying, teaching, and writing about them. This book summarizes what I have learned in more than three decades of trying to understand environmental principles, problems, connections, and solutions.

What Is My Philosophy of Education? In our lifelong pursuit of knowledge, I believe we should do three things:

- *Question everything and everybody,* as any good scientist does.
- *Develop a list of principles, concepts, and rules to serve as guidelines in making decisions,* and continually evaluate and modify this list on the basis of experience. This is based on my belief that the key goal of education is to learn how to sift through mountains of facts and ideas to find the few that are most useful and worth knowing. We need to be *wisdom seekers,* not information vessels. This takes a firm commitment to learning how to think logically and critically. 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, concepts, principles, and connections.
- *Interact with what you read as a way to sharpen your critical thinking skills.* I do this by marking key sentences and paragraphs with a highlighter or pen. I put an asterisk in the margin next to an idea I think is important and double asterisks next to an idea I think is especially important. I write comments in the margins, such as *Beautiful, Confusing, Misleading,* or *Wrong.* I fold down the top corner of pages with highlighted passages and the top and bottom corners of especially important pages. This way, I can flip through a book and quickly review the key passages. I urge you to interact in such ways with this book.

What Are the Major Trends in Environmental Science Education? This is a *science-based* book designed for introductory courses on environmental science. It is an *interdisciplinary* study of how nature works and how things in nature are interconnected.

This thirteenth edition continues my efforts to emphasize the following major shifts in environmental science education that have taken place over the past 25 years and are expected to accelerate in this century:

- ***Increased emphasis on science-based approaches to understanding and solving environmental problems.*** Since its first edition, this book has led the way in using scientific laws, principles, models, concepts and critical thinking to help us **(1)** understand environmental and resource problems and their possible solutions and **(2)** see how these concepts, problems, and solutions are connected. The first edition had four chapters on basic scientific concepts when other books had a single chapter. In this thirteenth edition, nine chapters (one more than in the last edition) and 303 pages are devoted to the treatment of scientific principles and concepts—far more than in any other introductory environmental science text of this size. This emphasis on basic science will become increasingly important throughout this century. I have introduced only the concepts and principles necessary for understanding the material in the book, and I have tried to present them simply but accurately.
- ***Increased emphasis on solutions.*** The emphasis in this century is on finding and implementing scientific, technological, economic, and political solutions to environmental problems. This text has stressed solutions as a major theme for many years. In this new edition, 245 pages are devoted to presenting and evaluating solutions to environmental problems—far more than in any other introductory environmental science textbook of this size.
- ***Greater emphasis on prevention solutions.*** Since its first edition, this book has categorized solutions to environmental problems that various analysts have proposed as either **(1)** *input* (prevention) solutions

such as pollution prevention and waste reduction or **(2)** *output* (cleanup) solutions such as pollution control and waste management. Both approaches are needed, but so far most emphasis has been on output or management solutions. There is a growing awareness of the need to put more emphasis on input or prevention approaches.

- ***More emphasis on decentralized micropower.*** I highlight the shift from large centralized sources of electricity (mostly coal and nuclear plants) to a dispersed array of smaller micropower plants, including gas turbines, solar-cell arrays, wind turbines, and fuel cells. This shift is under way and will accelerate during this century.

- ***Greater integration of economics and environment.*** I emphasize the increased use of emissions trading, environmental accounting, full-cost pricing, phasing in environmentally friendly government subsidies, and evolving eras of environmental management in businesses. This trend discussed in Chapter 26 (p. 690) is under way and is expected to increase rapidly during this century.

To help ensure that the material is accurate and up to date, I have consulted more than 10,000 research sources in the professional literature and about the same number of Internet sites. I have also benefited from the more than 250 experts and teachers (see list on pp. x–xii) who have provided detailed reviews of this and my other three books in this field.

How Have I Attempted to Achieve Balance? Some environmental issues are controversial. The challenge for an author is to give a fair and balanced presentation of **(1)** opposing viewpoints, **(2)** advantages and disadvantages of various technologies and proposed solutions to environmental problems, and **(3)** good and bad news about environmental problems. This allows you to make up your own mind about important environmental issues. Studying a subject as important as environmental science and ending up with no conclusions, opinions, and beliefs means that both the teacher and student have failed. However, such conclusions should be based on using critical thinking to evaluate opposing ideas and solutions to environmental problems.

A few examples of my efforts to provide a balanced presentation are **(1)** the pros and cons of reducing birth rates (p. 267), **(2)** the Pro/Con box on oil development in the Arctic National Wildlife Refuge (p. 360), **(3)** Section 18-4 (pp. 457–460; Figure 18-15, p. 460, and Figure 18-16, p. 461) on global warming, **(4)** advantages and disadvantages of pesticides (Section 20-2, pp. 515–516 and Section 20-3, pp. 516–518), and **(5)** diagrams summarizing the advantages and disadvantages of various technological solutions to environmental problems (such as Figure 13-17, p. 292; Figure 15-26, p. 361; Figure 16-35, p. 409; Figure 21-13, p. 545); and Figure 25-17, p. 675.

What Are Some Key Features of This Book? This book is *science based, solution oriented,* and *flexible.* About 40% of the book is devoted to providing a *scientific foundation,* 30% to *environmental problems,* and 30% to *solutions* to these problems.

The book is divided into six major parts (see Brief Contents, p. xiii). After the introductory chapters in Part I and the scientific principles and concepts chapters in Part II have been covered, the rest of the book can be used in virtually any order. In addition, most chapters and many sections within these chapters can be moved around or omitted to accommodate courses with different lengths and emphases.

Each chapter begins with a brief *case study* designed to capture interest and set the stage for the material that follows. In addition to these 28 case studies, 65 other case studies are found throughout the book (some in special boxes and others within the text); they provide a more in-depth look at specific environmental problems and their possible solutions. Fourteen *Guest Essays* present the point of view of an individual environmental researcher or activist point of view, which readers can evaluate using the Critical Thinking questions.

Other special boxes found in the text include **(1)** *Pro/Con boxes* that present both sides of a few highly controversial environmental issues, **(2)** *Connections boxes* that show connections in nature and among environmental concepts, problems, and solutions, **(3)** *Solutions boxes* that summarize a variety of solutions to environmental problems proposed by various analysts, **(4)** *Spotlight boxes* that highlight and give insights into key environmental problems and concepts, and **(5)** *Individuals Matter boxes* that describe what people have done to help solve environmental problems. To encourage critical thinking and integrate it throughout the book, all boxes (except Individuals Matter) end with Critical Thinking questions.

This book is an integrated study of environmental problems, connections, and solutions. The five integrated themes are **(1)** *biodiversity and natural resources (ecosystem services),* **(2)** *sustainability,* **(3)** *connections in nature,* **(4)** *pollution prevention,* and **(5)** *the importance of individuals working together to solve problems to environmental advantage.*

I hope you will start by looking at the brief table of contents (p. xiii) to get an overview of this book.

This book has 706 illustrations, 180 of them new to this edition. These illustrations are designed to present complex ideas in understandable ways and to relate learning to the real world.

I have not cited specific sources of information within the text. This is rarely done for an introductory-level text in any field, and it would interrupt the flow of the material. Instead, on the website material for each chapter you will find **(1)** readings, **(2)** Internet site references, and **(3)** references to complete articles that can be accessed online on the *InfoTrac* supplement available free to qualified users of this book. These sources **(1)** back up most of the content of this book and **(2)** serve as springboards to further information and ideas. Placing these references on the website also allows me to update them regularly.

Instructors wanting a shorter book covering this material with a different emphasis and organization can use one of my three other books written for various types of environmental science courses: **(1)** *Environmental Science,* 9th edition (542 pages, Brooks/Cole, 2003), **(2)** *Sustaining the Earth: An Integrated Approach,* 6th edition (349 pages, Brooks/Cole, 2004), and **(3)** *Essentials of Ecology,* 2nd edition (276 pages, Brooks/Cole, 2004).

What Are the Major Changes in the Thirteenth Edition? Detailed changes by chapter are listed in the annotated material in the insert provided with the instructor's version of this book and on this book's website. Major changes include the following:

CONTENT

- Updated and revised material throughout the book.
- 180 new or improved illustrations.
- Expanded coverage of weather and climate in Chapter 6.
- Movement of the chapter on Risk, Toxicology, and Health (Chapter 11) into Part II on Scientific Principles and Concepts to consolidate treatment of scientific principles and allow instructors more flexibility in treatment of chapters and topics.
- Addition of 112 new topics. See the insert provided with the instructor's version of this book and this book's website for a detailed list of these topics listed by chapter. Examples include the following:
  - Good and bad news about economic development (pp. 6–7)
  - Harmful environmental effects of poverty (Spotlight, p. 8)
  - Transfer of energy by convection, conduction, and radiation (Figure 3-11, p. 53)
  - Expanded treatment of weather (pp. 111–114)
  - Life cycle of frogs (figure in box on p. 170)
  - Brief history of oil (Spotlight, p. 359)
  - How Safe Are Radioactive Wastes Stored at Nuclear Power Plants? (Case Study, p. 371)
  - Threat from dirty radioactive bombs (p. 373)
  - Possible beneficial effects of global warming for people in some areas (Figure 18-15, p. 460)
  - Carbon sequestration for reducing carbon dioxide emissions (pp. 467–469 and Figure 18-21, p. 467)
  - Arsenic levels in drinking water (Spotlight, pp. 496–497)
  - Water pollution in the Baltic Sea (Case Study, p. 499)
  - Terrorism and release of toxic chemicals from industrial plants (p. 528)
  - Use of plasma torch to detoxify hazardous chemicals (pp. 542–543)
  - Threat from toxic mercury (pp. 549–551 and Figure 21-19, p. 550)
  - Urban sprawl in Las Vegas, Nevada (Figure 25-7, p. 665)
  - New Guest Essay by Noel Perrin (see pp. 752–753)

LEARNING AIDS

- Greater use of numbered and bulleted lists to make the information as accessible as possible and help students comprehend and review key material.
- New CD-ROM: *Interactive Concepts in Environmental Science* integrates concept summaries and almost 100 engaging animations and interactions based on figures from the text with flashcards and quizzing on the Web.

In-Text Study Aids Each chapter begins with a few general questions 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. A glossary of all key terms is located at the end of the book.

Questions are used as titles for all subsections so readers know the focus of the material that follows. In effect, this is a built-in set of learning objectives.

Each chapter ends with **(1)** a set of Review Questions covering *all* of the material in the chapter as a study guide for students and **(2)** a set of questions to encourage students to think critically and apply what they have learned to their lives. The Critical Thinking questions are followed by several projects that individuals or groups can carry out.

Internet and Online Study Aids Qualified users of this textbook have free access to the *Brooks/Cole Biology and Environmental Science Resource Center.* Access the online resource material for this book by logging on at

[illegible]

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

- Flash Cards, which allow you to test your mastery of the Terms and Concepts to Remember for each chapter.
- Tutorial Quizzes, which provide a multiple-choice practice quiz.
- Student Guide to InfoTrac, which will lead you to Critical Thinking Projects that use InfoTrac College Edition as a research tool.
- References, which lists the major books and articles consulted in writing this chapter.
- A brief What You Can Do list addressing key environmental problems.
- Hypercontents, which takes you to an extensive list of websites with news, research, and images related to individual sections of the chapter.

Qualified adopters of this textbook also have access to *WebTutor Toolbox on WebCT* at

http://e.thomsonlearning.com

It provides access to a full array of study tools, including flashcards (with audio), practice quizzes, online tutorials, and web links.

Students using *new* copies of this textbook also have free and unlimited access to *InfoTrac College Edition.* This fully searchable online library gives users access to complete environmental articles from several hundred periodicals dating back over the past four years. Each chapter ends with two practice exercises to help students learn how to navigate this valuable source of information.

Other student learning tools include:

- A new CD-ROM: *Interactive Concepts in Environmental Science* that integrates concept summaries and almost 100 engaging animations and interactions based on figures from the text with flashcards and quizzing on the Web. The front endpapers list all the animations.
- *Essential Study Skills for Science Students by Daniel D. Chiras.* This books includes chapters on **(1)** developing good study habits, **(2)** sharpening memory, **(3)** getting the most out of lectures, labs, and reading assignments, **(4)** improving test-taking abilities, and **(5)** becoming a critical thinker. Your instructor can have this book bundled FREE with your textbook.
- *Laboratory Manual by C. Lee Rocket and Kenneth J. Van Dellen.* This manual includes a variety of laboratory exercises, workbook exercises, and projects that require a minimum of sophisticated equipment.

Supplementary Materials for Instructors The following supplementary materials are available to instructors adopting this book:

- *Multimedia Manager.* This CD-ROM, free to qualified adopters, allows you to **(1)** create custom lectures using over 2,000 pieces of high-resolution artwork, images, and Quick Time movies from the CD and the web, **(2)** assemble database files, and **(3)** create Microsoft PowerPoint® lectures using text slides and figures from the textbook. This program's editing tools allow **(1)** slides to be moved from one lecture to another, **(2)** modification or removal of figure labels and leaders, **(3)** insertion of your own slides, **(4)** saving slides as JPEGs, and **(5)** preparation of lectures for use on the Web.
- *Transparency Masters and Acetates.* Includes **(1)** 100 color acetates of line art and **(2)** nearly 600 black and white master sheets of key diagrams for making overhead transparencies. Free to qualified adopters.
- *CNN® Today Videos.* These videos, updated annually, contain short clips of news stories about environmental news. Qualified adopters can receive one video free each year for 3 years. These videos are now available to professors electronically for classroom presentation as well as on videotape.
- Two videos, **(1)** *In the Shadow of the Shadow of the Shuttle: Protecting Endangered Species,* and **(2)** *Costa Rica: Science in the Rainforest,* are available to adopters.
- *Instructor's Manual with Test Bank.* Free to qualified adopters.
- *ExamView.* Allows you to **(1)** easily create and customize tests, **(2)** see them on the screen exactly as they will print, and **(3)** print them out.

Help Me Improve This Book Let me know how you think this book can be improved; if you find any errors, bias, or confusing explanations, please e-mail them to me at

mtg89@hotmail.com

Most errors can be corrected in subsequent printings of this edition rather than waiting for a new edition.

Acknowledgments I wish to thank the many students and teachers who **(1)** responded so favorably to the 12 editions of *Living in the Environment,* the 9 editions of *Environmental Science,* and the 5 editions of *Sustaining the Earth* and **(2)** corrected errors and offered many helpful suggestions for improvement. I am also deeply indebted to the more than 250 reviewers, who pointed out errors and suggested many important improvements in the various editions of these three books. Any errors and deficiencies left are mine.

The members of the talented production team, listed on the copyright page, have made vital contributions as well. My thanks also go to production editors Hal Humphrey at Brooks/Cole and Andrea Fincke at Thompson Steele, Thompson Steele's page layout artist Bonnie Van Slyke, Brooks/Cole's hard-working sales staff, and Keli Amann and her talented colleagues who developed the multimedia and the website material associated with this book.

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My deepest thanks go to Jack Carey, biology publisher at Brooks/Cole, for his encouragement, help, 36 years of friendship, and superb reviewing system. It helps immensely to work with the best and most experienced editor in college textbook publishing.

I dedicate this book to the earth that sustains us and to Kathleen Paul Miller, my wife and research assistant.

G. Tyler Miller, Jr.

Guest Essayists and Reviewers

Guest Essayists The following are authors of Guest Essays: **(1) Robert D. Bullard,** professor of sociology and director of the Environmental Justice Resource Center at Clark Atlanta University; **(2) Herman E. Daly,** senior research scholar at the School of Public Affairs, University of Maryland; **(3) Lois Marie Gibbs,** director, Center for Health, Environment, and Justice; **(4) Garrett Hardin,** professor emeritus of human ecology, University of California, Santa Barbara; **(5) Paul G. Hawken,** environmental author and business leader; **(6) Jane Heinze-Fry,** author, teacher, and consultant in environmental education; **(7) Amory B. Lovins,** energy policy consultant and director of research, Rocky Mountain Institute; **(8) Lester W. Milbrath,** director of the research program in environment and society, State University of New York at Buffalo; **(9) Peter Montague,** director, Environmental Research Foundation; **(10) Norman Myers,** tropical ecologist and consultant in environment and development; **(11) David W. Orr,** professor of environmental studies, Oberlin College; **(12) Noel Perrin,** adjunct professor of environmental studies, Dartmouth College; **(13) Andrew C. Revkin,** environmental author and environmental reporter for the *New York Times;* and **(14) Nancy Wicks,** ecopioneer and director of Round Mountain Organics.

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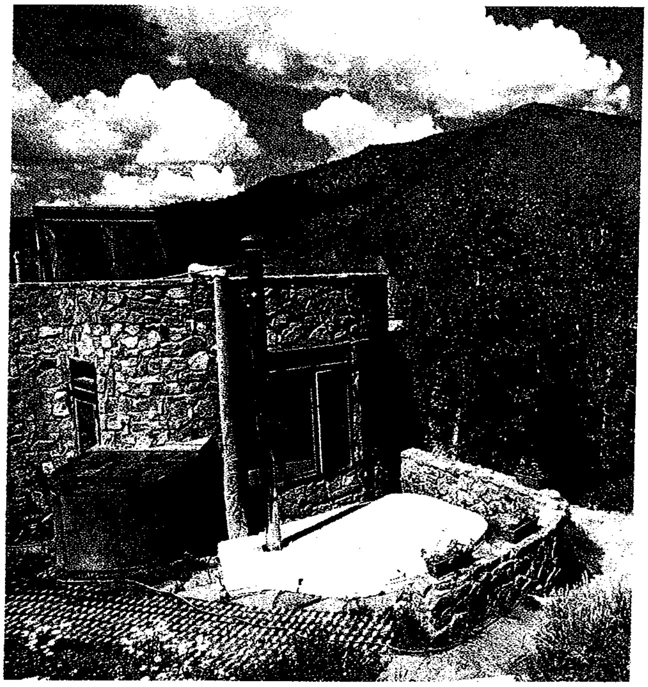

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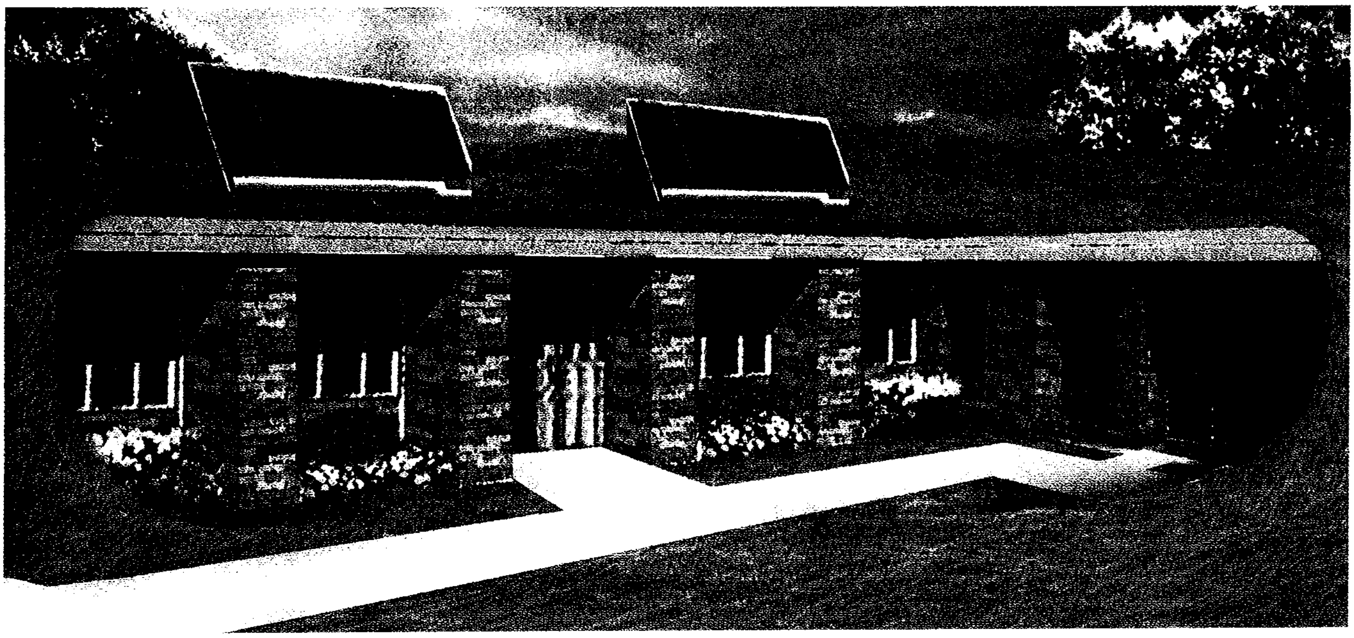

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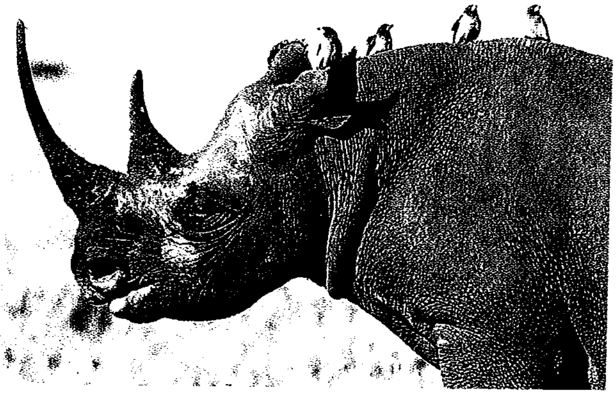

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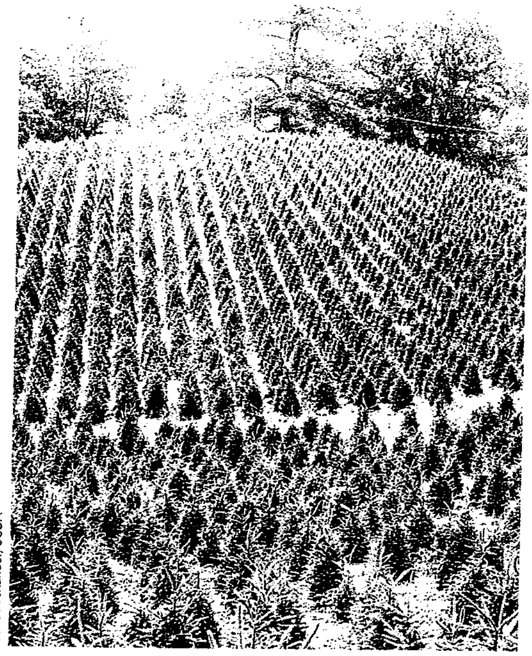

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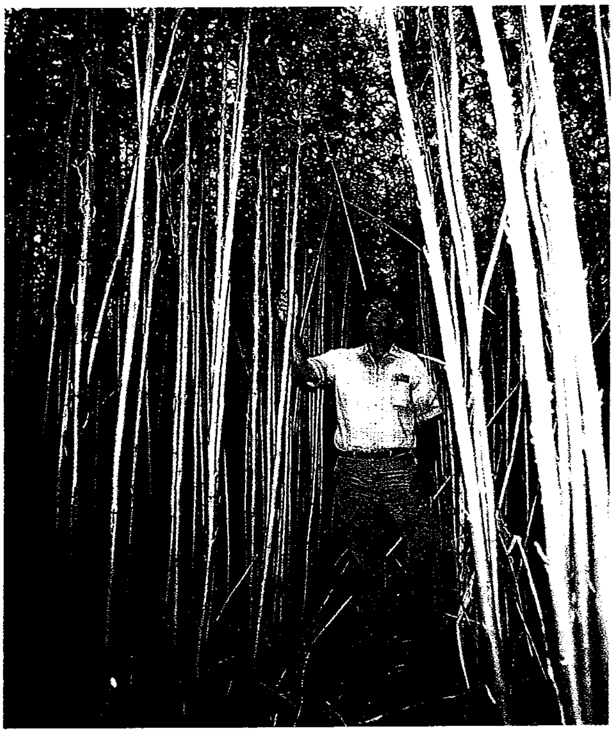

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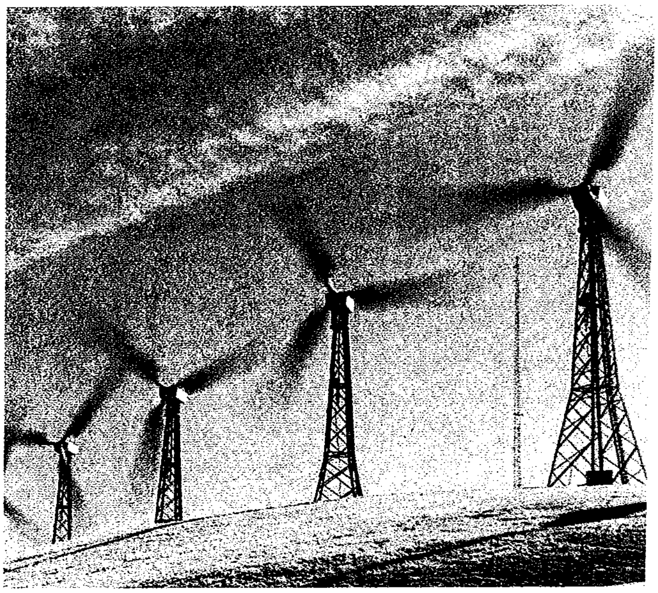

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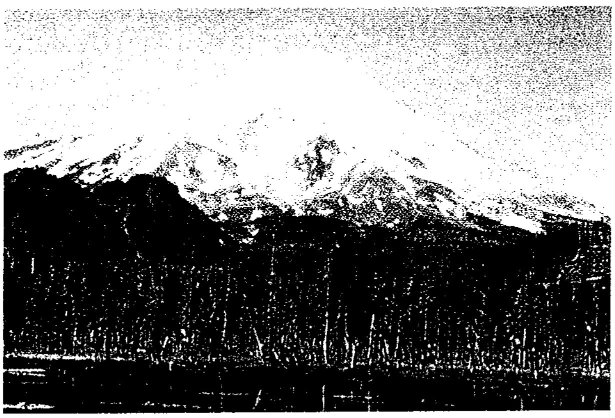

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U.S. Geological Survey

Mt. St. Helens after volcano eruption

NOAA Corps Collection/Photographer: Commander John Bortniak, NOAA Corps. (ret.)

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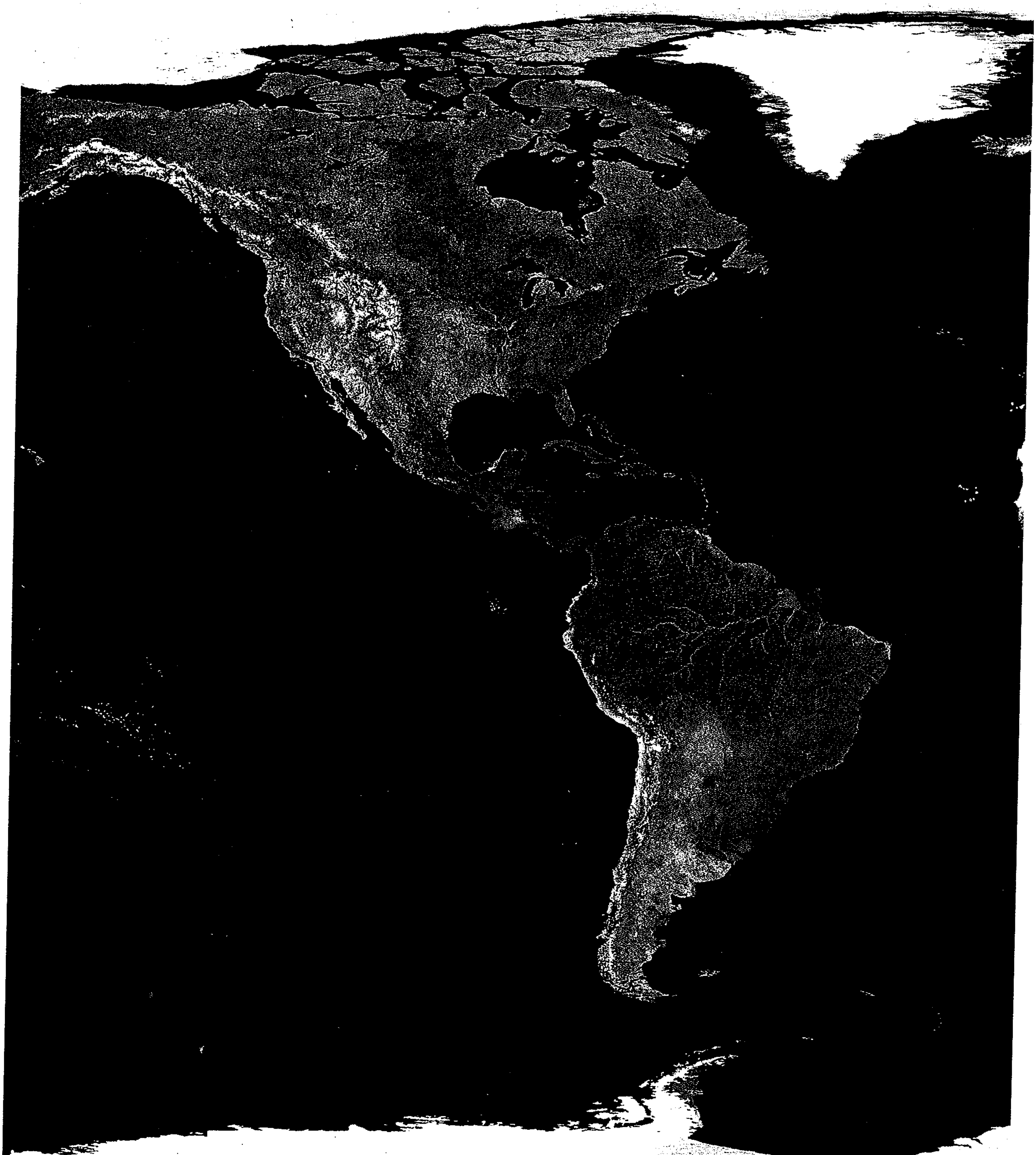
PART I

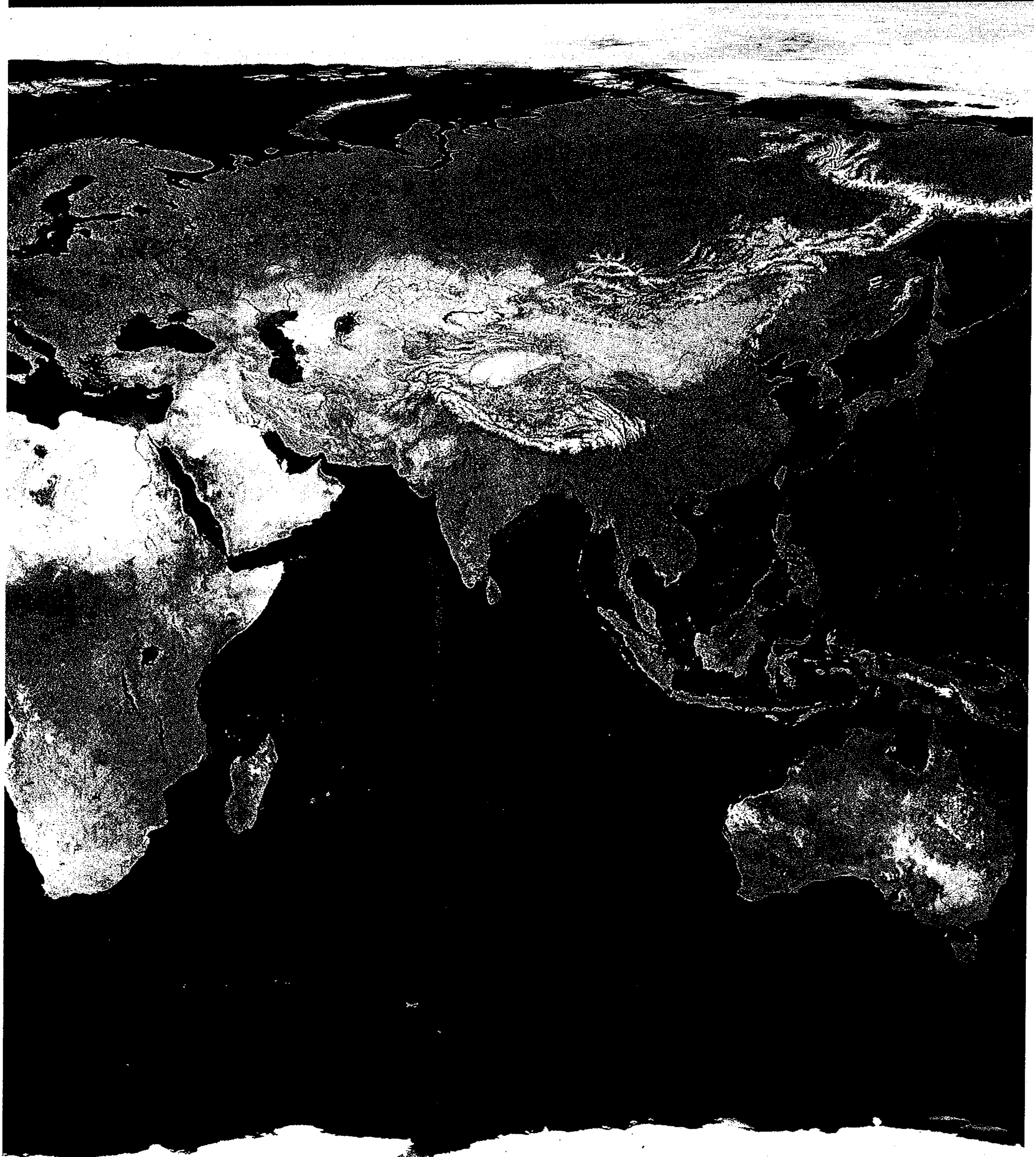
HUMANS AND SUSTAINABILITY: AN OVERVIEW

The environmental crisis is an outward manifestation of a crisis of mind and spirit. There could be no greater misconception of its meaning than to believe it is concerned only with endangered wildlife, human-made ugliness, and pollution. These are part of it, but more



importantly, the crisis is concerned with the kind of creatures we are and what we must become in order to survive.

LYNTON K. CALDWELL



1 ENVIRONMENTAL PROBLEMS, THEIR CAUSES, AND SUSTAINABILITY

Living in an Exponential Age

Once there were two kings who enjoyed playing chess, with the winner claiming 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 on the second, four on the third, and so on. The number of grains was to double each time 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 and still could not produce the incredibly large number of grains of wheat he had promised. In fact, it is probably more than all the wheat that has ever been harvested!

This fictional story illustrates **exponential growth,** in which a quantity increases by a fixed percentage of the whole in a given time. As the losing king learned, 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. If plotted on a graph, continuing exponential growth eventually yields a graph shaped like the letter *J* (Figure 1-1).

Here is another example. Fold a piece of paper in half to double its thickness. If you could do this 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!

Six important environmental issues are **(1)** *population growth,* **(2)** *increasing resource use,* **(3)** *global climate change,* **(4)** *premature extinction of plants and animals,* **(5)** *pollution,* and **(6)** *poverty.* All these issues are interconnected and are growing exponentially.

For example, between 1950 and 2002, the world's population increased from 2.5 billion to 6.2 billion. Unless death rates rise sharply, it may reach 8 billion by 2028, 9 billion by 2050, and 10–14 billion by 2100 (Figure 1-1). Global economic output, much of it environmentally damaging, is a rough measure of resource use. It has increased sevenfold since 1950.

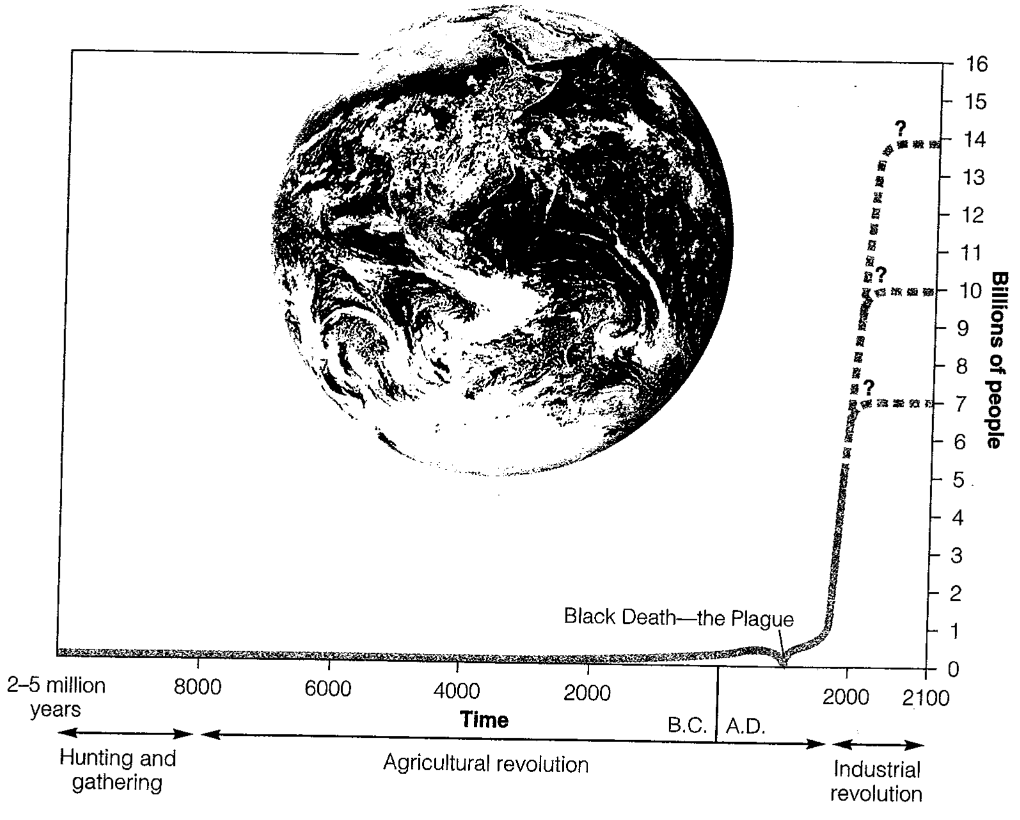


Figure 1-1 The *J*-shaped curve of past exponential world population growth, with projections to 2100. Notice that exponential growth starts off slowly, but as time passes the curve becomes increasingly steep. The current world population of 6.2 billion people is projected to reach 7–14 billion people sometime during this century. (This figure is not to scale.) (Data from World Bank and United Nations; photo courtesy of NASA)

[illegible] through the most delicate adjustments [illegible] but [illegible] degree [illegible] worth our love?

Barbara Ward and René Dubos

This chapter presents an overview of **(1)** environmental problems, **(2)** their causes, **(3)** controversy over their seriousness, and **(4)** ways we can live more sustainably. It discusses these questions:

- What are natural resources, and why are they important? What is an environmentally sustainable society?
- How fast is the human population increasing?
- What is the difference between economic growth and economic development? What are some harmful environmental effects of poverty?
- What are the earth's main types of resources? How can they be depleted or degraded?
- What are the principal types of pollution? How can pollution be reduced and prevented?
- What are the basic causes of today's environmental problems? How are these causes connected?
- Is our current course sustainable? What is environmentally sustainable development? How can we live more sustainably?

1-1 LIVING MORE SUSTAINABLY

What Is the Difference Between Environment, Ecology, and Environmental Science? **Environment** is everything that affects a living organism (any unique form of life). **Ecology** is a biological science that studies the relationships between living organisms and their environment.

This textbook is an introduction to **environmental science.** It is an interdisciplinary science that uses concepts and information from *natural sciences* such as ecology, biology, chemistry, and geology and *social sciences* such as economics, politics, and ethics to help us understand **(1)** how the earth works, **(2)** how we are affecting the earth's life-support systems (environment), and **(3)** how to deal with the environmental problems we face. Many different groups of people are concerned about environmental issues (Spotlight, right).

SPOTLIGHT

Cast of Players in the Environmental Drama

The cast of major characters you will encounter in this book include the following:

- **Ecologists,** who are biological scientists studying relationships between living organisms and their environment.
- **Environmental scientists,** who use information from the physical sciences and social sciences to **(1)** understand how the earth works, **(2)** learn how humans interact with the earth, and **(3)** develop solutions to environmental problems.
- **Conservation biologists,** who in the 1970s created a multidisciplinary science to **(1)** investigate human impacts on the diversity of life found on the earth (biodiversity) and **(2)** develop practical plans for preserving such biodiversity.
- **Environmentalists,** who **(1)** are concerned about the impact of people on environmental quality and **(2)** believe some human actions are degrading parts of the earth's life-support systems for humans and many other forms of life. Some of their beliefs and proposals for dealing with environmental problems are based on scientific information and concepts and some are based on their social and ethical environmental beliefs (environmental worldviews). Environmentalists are a broad group of people from different economic groups (rich, middle-class, poor) and with different political persuasions (ranging from conservative to liberal).
- **Preservationists,** concerned primarily with setting aside or protecting undisturbed natural areas from harmful human activities.
- **Conservationists,** concerned with using natural areas and wildlife in ways that sustain them for current and future generations of humans and other forms of life.
- **Restorationists,** devoted to the partial or complete restoration of natural areas that have been degraded by human activities.

Many people consider themselves members of several of these groups.

Critical Thinking

Which, if any, of these groups do you most identify with? Why?

What Keeps Us Alive? Our existence, lifestyles, and economies depend completely on the sun and the earth, a blue and white island in the black void of space (Figure 1-1). To economists *capital* is wealth used to sustain a business and to generate more wealth. By analogy, we can think of **(1)** energy from the sun as **solar capital** and **(2)** the planet's air, water, soil, wildlife, forests, rangelands, fisheries, minerals, and natural purification, recycling, and pest control processes as **natural resources** or **natural capital** (Guest Essay, p. 16). **Solar energy** is defined broadly to include direct sunlight and indirect forms of solar energy such as **(1)** wind power, **(2)** hydropower (energy from flowing water), and **(3)** biomass (direct solar energy converted to chemical energy stored in biological sources of energy such as wood).

World Population Reached	
1 billion in 1804	
2 billion in 1927	(123 years later)
3 billion in 1960	(33 years later)
4 billion in 1974	(14 years later)
5 billion in 1987	(13 years later)
6 billion in 1999	(12 years later)
World Population May Reach	
7 billion in 2013	(14 years later)
8 billion in 2028	(15 years later)
9 billion in 2050	(22 years later)

Figure 1-2 World population milestones. (Data from United Nations Population Division, *World Population Prospects, 1998*)

What Is an Environmentally Sustainable Society? An **environmentally sustainable society** satisfies the basic needs of its people for food, clean water, clean air, and shelter into the indefinite future without **(1)** depleting or degrading the earth's natural resources and **(2)** thereby preventing current and future generations of humans and other species from meeting their basic needs. *Living sustainably* means **(1)** living off the natural income replenished by soils, plants, air, and water and **(2)** not depleting the earth's endowment of natural capital that supplies this income (Guest Essay, p. 16).

For example, imagine you inherit $1 million. Invest this capital at 10% interest per year, and you will have a sustainable annual income of $100,000 without depleting your capital. If you spend $200,000 a year, your $1 million will be gone early in the 7th year; even if you spend only $110,000 a year, you will be bankrupt early in the 18th year.

The lesson here is a very old one: *Protect your capital.* Deplete your capital, and you move from a sustainable to an unsustainable lifestyle.

The same lesson applies to the earth's natural capital. Environmentalists and many leading scientists believe we are living unsustainably by depleting and degrading the earth's endowment of natural capital at an accelerating rate as our population (Figure 1-1) and demands on the earth's resources and life-sustaining processes increase exponentially.

Other analysts do not believe we are living unsustainably. They contend that **(1)** environmentalists have exaggerated the seriousness of population and environmental problems, and **(2)** any population, resource, and environmental problems we face can be overcome by human ingenuity and technological advances.

1-2 POPULATION GROWTH, ECONOMIC GROWTH, DEVELOPMENT, AND GLOBALIZATION

How Rapidly Is the Human Population Growing? The increasing size of the human population is an example of exponential growth (Figures 1-1 and 1-2 and Spotlight, p. 5). The main reason for the rapid growth of the earth's human population over the past 100 years has been a much greater drop in death rates (mostly because of increases in food supplies and better health and sanitation) than in birth rates.

One measure of population growth is **doubling time:** the number of years it takes for a population growing at a specified rate to double its size. A quick way to calculate doubling time is to use the **rule of 70:** 70/percentage growth rate = doubling time in years (a formula derived from the basic mathematics of exponential growth). For example, in 2002 the world's population grew by 1.28%. If that rate continues, the earth's population will double in about 55 years (70/1.28 = 54.7 or about 55 years).

Some *good news* is that the exponential rate of annual population growth slowed from 2.1% in 1963 to 1.28% in 2002. The *bad news* is that the world's population is still growing exponentially at a rapid rate and is projected to increase from 6.2 billion to 8–14 billion people sometime during this century (Figure 1-1).

What Is Economic Growth? Almost all countries seek **economic growth:** an increase in their capacity to provide people with goods and services. This increase is accomplished by population growth (more consumers and producers), more consumption per person, or both.

Economic growth usually is measured by an increase in several indicators:

- **Gross national income (GNI)**—formerly called **gross national product (GNP):** the market value in current dollars of all goods and services produced *within* and *outside* a country during a year plus net income earned abroad by a country's citizens.
- **Gross national income in purchasing power parity (GNI PPP):** The market value of a country's GNI in terms of the goods and services it would buy in the United States. This is a better way to compare the standards among countries.
- **Gross domestic product (GDP):** the market value in current dollars of all goods and services produced *within* a country during a year.
- **Gross world product (GWP):** the market value in current dollars of all goods and services produced in the world during a year.
- **Per capita GNI**—formerly called **per capita GNP:** the GNI divided by the total population at mid-year. It gives the average slice of the economic pie per person.
- **Per capita GNI in purchasing power parity (per capita GNI PPP):** the GNI PPP divided by the total

Current Exponential Growth of the Human Population

SPOTLIGHT

The world's population is growing exponentially at a rate of about 1.28% per year. The relentless ticking of this population clock means that in 2002 the world's population of 6.2 billion grew by 79 million people (6.2 billion × 0.0128 = 79 million), an average increase of 216,000 people a day, or 9,000 an hour.

At this 1.28% annual rate of exponential growth, it takes only about

- 4 days to add the number of Americans killed in all U.S. wars.
- 2 months to add as many people as live in the Los Angeles basin.
- 1.6 years to add the 129 million people killed in all wars fought in the past 200 years.
- 3.6 years to add 288 million people (the population of the United States in 2002).
- 16 years to add 1.28 billion people (the population of China, the world's most populous country, in 2002).

How much is 79 million? Spending 1 second saying hello to each of 79 million new people added to the earth this past year for 24 hours a day would take you 2.5 years. By then there would be about 198 million more people to shake hands with.

Critical Thinking

Some economists argue that population growth is good because it provides more workers, consumers, and problem solvers to keep the global economy growing. Environmentalists argue that population growth threatens economies and the earth's life-support systems through increased pollution and environmental degradation. What is your position? Why?

population at mid-year. This is a better way to make comparisons of people's economic welfare among countries.

What Is Economic Development? **Economic development** is the improvement of living standards by economic growth. The United Nations classifies the world's countries as economically developed or developing based primarily on their degree of industrialization and their per capita GNI (Figure 1-3).

The **developed countries** (with a total population of 1.2 billion people) include the United States, Canada, Japan, Australia, New Zealand, and all the countries of Europe. Most are highly industrialized

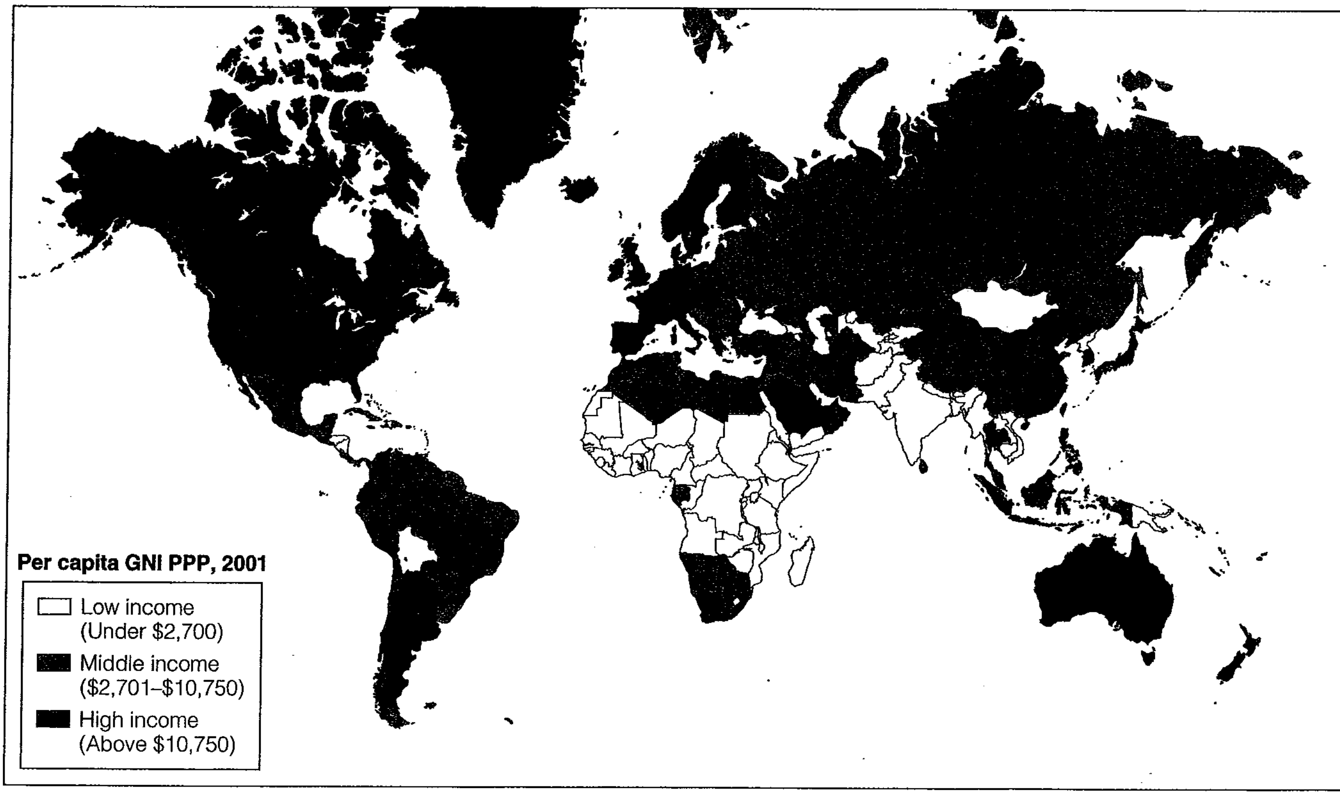


Figure 1-3 Degree of economic development as measured by per capita gross national income in purchasing power parity (per capita GNI PPP) in 2001. (Data from United Nations and the World Bank)

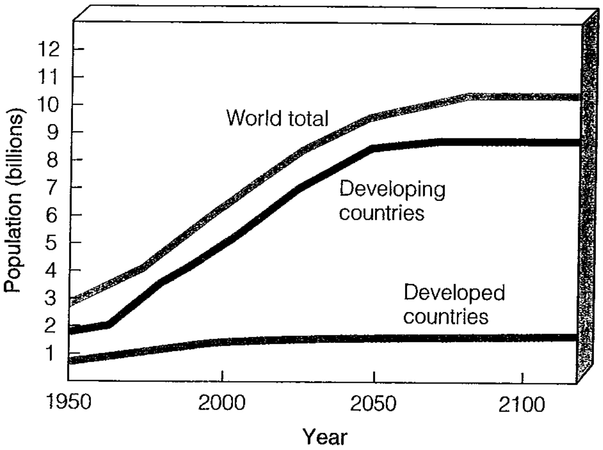


Figure 1-4 Past and projected population size for developed countries, developing countries, and the world, 1950–2120. More than 95% of the addition of 3.6 billion people between 1990 and 2030 is projected to occur in developing countries. (Data from United Nations)

and have high average per capita GNI PPPs (above $10,750 per year, except for industrialized countries in eastern Europe and some in northern and southern Europe). These countries, with 19% of the world's population, **(1)** have about 85% of the world's wealth and income, **(2)** use about 88% of its natural resources, and **(3)** generate about 75% of its pollution and waste.

All other nations (with a total population of 5 billion people) are classified as **developing countries,** most of them in Africa, Asia, and Latin America. Some are *middle-income, moderately developed countries* with average per capita GNI PPPs of $2,701 to $10,750 per year and others are *low-income countries* with per capita GNI PPPs less than $2,701 per year (Figure 1-3). The developing countries with 81% of the world's population **(1)** have about 15% of the world's wealth and income, **(2)** use about 12% of the world's natural resources, and **(3)** produce about 25% of the world's pollution and waste.

More than 95% of the projected increase in the world's population is expected to take place in developing countries (Figure 1-4), *where 1 million people are added every 5 days.* The primary reason for such rapid population growth in developing countries (1.6% compared to 0.1% in developed countries) is the *large percentage of people who are under age 15* (33% compared to 18% in developed countries in 2002).

What Is Some Good News About Economic Development? Here is some *good news* for many of the world's people. Because of a combination of technological innovations, scientific breakthroughs, and economic development

- Between 1900 and 2002, global life expectancy at birth more than doubled from 33 to 67 years (76 in developed countries and 65 in developing countries).
- Between 1955 and 2002, the world's average infant mortality during the first year of life dropped by **(1)** 60% in developed countries and **(2)** 40% in developing countries.
- Global food production has outpaced population growth since 1978.
- Since 1950 the percentage of rural families in developing countries with access to safe drinking water has increased from 10% to almost 75%.
- We have learned how to produce more goods with less raw materials.
- Since 1970 levels of most major air and water pollutants have been reduced in most of the world's developed countries.

What Is Some Bad but Challenging News About Economic Development? Here is some *bad environmental news* that challenges us to do better:

- Average life expectancy in developing countries is 11 years less than in developed countries.
- Infant mortality in developing countries is more than eight times higher than in developed countries.
- The harmful environmental effects of industrialized food production may eventually limit future food production unless there is a shift to more sustainable ways to produce food.
- Air and water pollution levels in most developing countries are much too high according to the World Health Organization.
- Because of increased population growth and per capita resource use, some of the natural resources that support all life are being used unsustainably. This includes **(1)** premature extinction of a growing number of the world's plant and animal species at a rate 100–1,000 times faster than before humans arrived on the scene, **(2)** destruction or degradation of wetlands, coral reefs, and forests in some parts of the world, and **(3)** gradual depletion of underground water supplies in some areas.
- Studies by researchers at Conservation International suggest that roughly 73% of the earth's habitable land surface (that which is not bare rock, ice, or drifting sand) has been partially or heavily disturbed by human activities (Figure 1-5). What will happen to the earth's remaining wildlife habitats and species if the human population increases from 6.2 billion to 8 billion between 2002 and 2028 and perhaps to 9 billion by 2050?
- Gases emitted into the atmosphere from burning fossil fuels and clearing forests could cause the world's climate to become warmer during this cen-

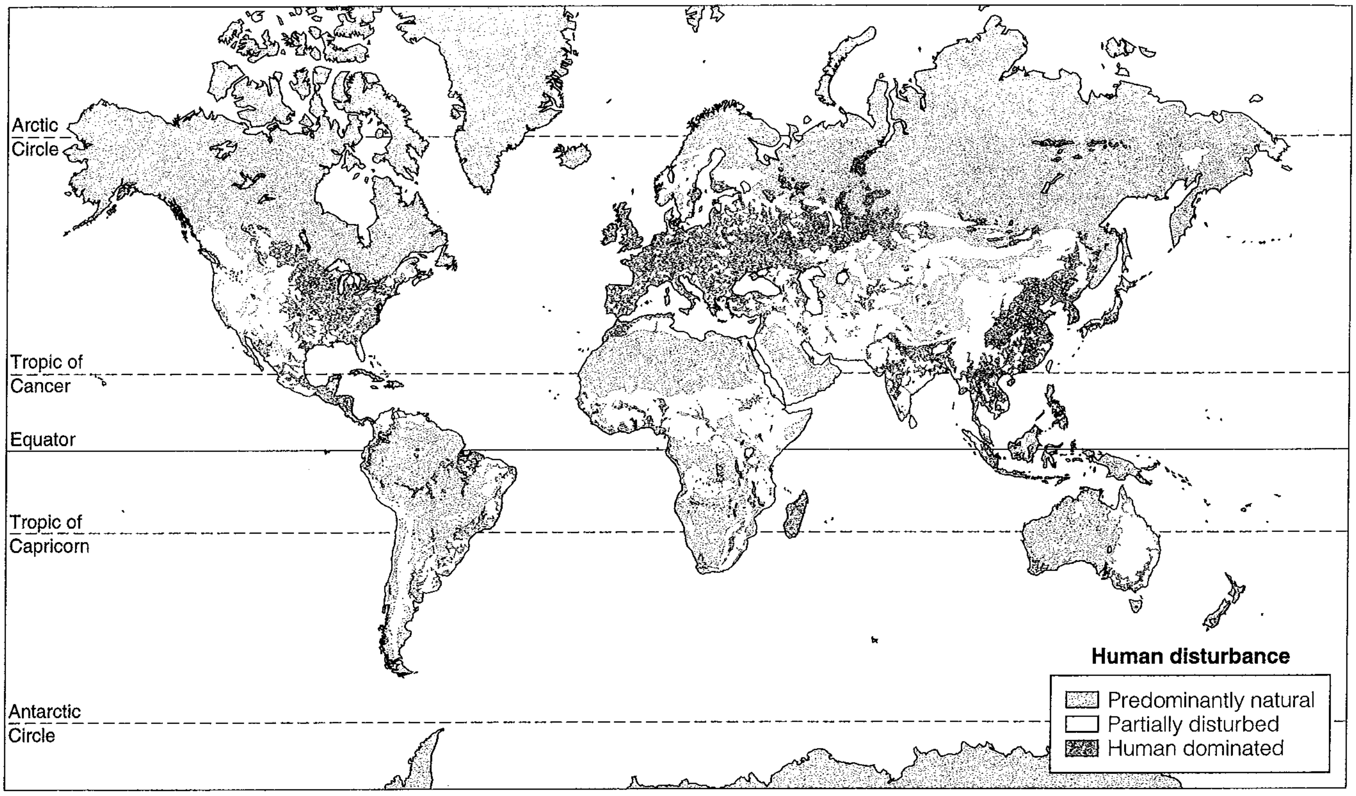


Figure 1-5 Human disturbance of the earth's land area. (Data from Lee Hannah and David Lohse, *1993 Annual Report*, Washington, D.C.: Conservation International)

tury. Such *global warming* can cause environmental and economic disruption by **(1)** shifting areas where crops can be grown, **(2)** altering water supplies by shifting patterns of precipitation, **(3)** shifting where various plants and animals can survive, and **(4)** raising average sea levels, which can flood low-lying cities, islands, coral reefs, and coastal wetlands. Some countries will be winners and some (mostly poorer countries) will be losers in these projected climate shifts.

- An estimated 1.4 billion people in developing countries—roughly one of every four people on the planet—have an annual income of less than $370 (U.S.) per year. This income of roughly $1 (U.S.) per day is the World Bank's definition of **acute poverty** where people cannot meet their basic economic needs. According to a 2000 World Bank study, nearly half of humanity suffer from poverty and are trying to survive on less than $1–3 (U.S.) a day. About 70% of these people are women and children. Such *poverty* has a number of harmful health and environmental effects (Connections, p. 8).

- Despite enormous global economic growth since 1970, the gulf between the world's richest countries and poorest countries has widened dramatically. For example, today the average per capita GNI for the world's ten richest countries is more than 100 times that for the world's ten poorest countries. At the individual level, the total wealth of the world's 200 richest people is greater than the combined wealth of about half or 3.1 billion of the world's people.

What Is Globalization? One of the major trends since 1950, and especially since 1970, is **globalization,** the process of global social, economic, and environmental change that leads to an increasingly integrated world.

Here are a few indicators of globalization:

Economic

- Between 1950 and 2002, the global economy grew from $6.6 trillion to $47 trillion.
- Between 1950 and 2002, international trade of goods and services increased from 5% to 16% of the gross world product.
- Between 1970 and 2002, the number of transnational corporations operating in three or more countries grew from 7,000 to about 60,000.

Information and Communication

- By 2002, roughly 550 million people (1 in every 11 people in the world) had Internet access on a global basis, a figure that is growing rapidly.

Some Harmful Environmental Effects of Poverty

CONNECTIONS

Daily life is a harsh struggle for the estimated one of every two people on the earth who try to survive on an income of $1–3 (U.S.) per day. According to the United Nations, **(1)** about 1.2 billion people do not have access to clean drinking water, adequate sanitation, decent housing, and adequate health care, **(2)** 790 million people do not have enough food for good health (see figure), **(3)** 2 billion people do not have enough fuel to keep warm and to cook food and do not have access to electricity, and **(4)** 854 billion adults cannot read or write (64% of them women).

Poverty is related to environmental quality and people's quality of life because poor people often

- Deplete and degrade local forests, soil, grasslands, wildlife, and water supplies for short-term survival. They do not have the luxury of worrying about long-term supplies of natural resources when their daily life is focused on getting enough food and water to survive.
- Live in areas with high levels of air and water pollution and with the greatest risk of natural disasters such as floods, earthquakes, hurricanes, and volcanic eruptions.
- Spend an average of 4–6 hours **(1)** *per day* searching for and carrying fuelwood and **(2)** *per week* drawing and carrying water.
- Must take jobs (if they can find them) that subject them to unhealthy and unsafe working conditions at very low pay.
- Have many children as a form of economic security. Their children **(1)** help them grow food, **(2)** gather fuel (mostly wood and dung), **(3)** haul drinking water, **(4)** tend livestock, **(5)** work, **(6)** beg in the streets, and **(7)** help them survive in their old age (typically their 50s or 60s).
- Die prematurely from preventable health problems. According to the World Health Organization (WHO), each year at least 10 million of the world's desperately poor die prematurely from **(1)** malnutrition (lack of protein and other nutrients needed for good health), **(2)** infectious diseases caused by drinking contaminated water and **(3)** increased susceptibility to infectious diseases because of their weakened condition from malnutrition. *This premature death of at least 27,400 human beings per day is equivalent to 69 jumbo jet planes, each carrying 400 passengers, accidentally crashing every day with no survivors.* Half of those dying are children under age 5.

Critical Thinking

You are in charge of the world. What are the three most important things you would do to reduce or eliminate acute poverty?

John Bryson/Photo Researchers, Inc.

One in every three children under age 5, such as this Brazilian child, suffers from malnutrition. 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 a weakened condition from malnutrition—an average of 10 preventable deaths each minute.

- According to Forecasting International, by 2010 some 95% of the people in developed countries and 50% of those in developing countries will be online.

Environmental Effects

- Since 1950, the number of species and infectious disease organisms (microbes) transported across international borders by trade and travel has increased significantly.
- Since 1950, many long-lived pollutants have been transferred across the globe by wind, rainfall patterns, ocean currents, and rivers. On an even larger scale, nations now face the global threats of **(1)** widespread ocean pollution, **(2)** depletion of ozone in the upper atmosphere (stratosphere) that keeps much of the sun's harmful ultraviolet radiation from reaching the earth's surface, and **(3)** global and regional climate change caused by chemicals released into the environment by human activities.

1-3 RESOURCES

What Is a Resource? From a human standpoint, a **resource** is anything obtained from the environment to meet human needs and wants. Examples include food, water, shelter, manufactured goods, transportation, communication, and recreation.

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 (oil), iron, groundwater (water found underground), and modern 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 we could sell at affordable prices.

On our short human time scale, we classify the material resources we get from the environment as **(1)** *perpetual,* **(2)** *renewable,* or **(3)** *nonrenewable* (Figure 1-6).

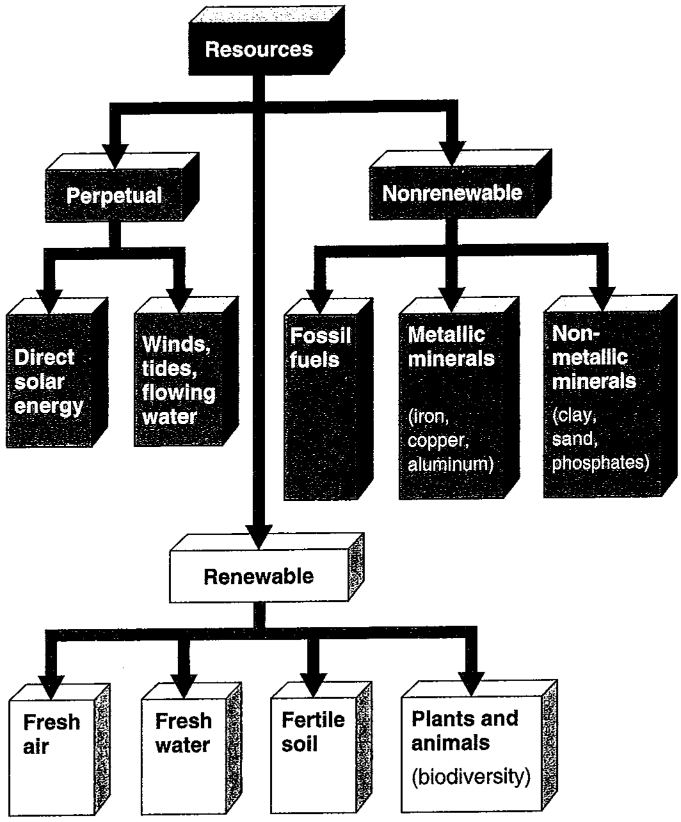


Figure 1-6 Major types of material resources. This scheme is not fixed; renewable resources can become nonrenewable if used for a prolonged period at a faster rate than they are renewed by natural processes.

What Are Perpetual and Renewable Resources? Solar energy is called a **perpetual resource** because on a human time scale it is renewed continuously. It 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 (hours to several decades) through natural processes as long as it is not used up faster than it is replaced. Examples are **(1)** forests, **(2)** grasslands, **(3)** wild animals, **(4)** fresh water, **(5)** fresh air, and **(6)** fertile soil.

However, renewable resources can be depleted or degraded. The highest rate at which a renewable resource can be used *indefinitely* without reducing its available supply is called its **sustainable yield.**

If we exceed a resource's natural replacement rate, the available supply begins to shrink, a process known as **environmental degradation.** Examples of such degradation include **(1)** urbanization of productive land, **(2)** waterlogging and salt buildup in soil, **(3)** excessive topsoil erosion, **(4)** deforestation, **(5)** groundwater depletion, **(6)** overgrazing of grasslands by livestock, **(7)** reduction in the earth's forms of wildlife (biodiversity) by elimination of habitats and species, and **(8)** pollution. A major cause of environmental degradation of renewable resources is a phenomenon known as the *tragedy of the commons* (Connections, p. 11).

What Are Nonrenewable Resources? Resources that exist in a fixed quantity or stock in the earth's crust are called **nonrenewable resources.** On a time scale of millions to billions of years, geological processes can renew such resources. However, on the much shorter human time scale of hundreds to thousands of years, these resources can be depleted much faster than they are formed.

These exhaustible resources include **(1)** *energy resources* (such as coal, oil, and natural gas, which cannot be recycled), **(2)** *metallic mineral resources* (such as iron, copper, and aluminum, which can be recycled), and **(3)** *nonmetallic mineral resources* (such as salt, clay, sand, and phosphates, which usually are difficult or too costly to recycle) (Figure 1-6).

Figure 1-7 (p. 10) shows the production and depletion cycle of a nonrenewable energy or mineral resource. We never completely exhaust a nonrenewable mineral resource. However, such a resource becomes *economically depleted* when the costs of extracting and using what is left exceed its economic value. At that point, we have six choices: **(1)** try to find more, **(2)** recycle or reuse existing supplies (except for nonrenewable energy resources, which cannot be recycled or reused), **(3)** waste less, **(4)** use less, **(5)** try to develop a substitute, or **(6)** wait millions of years for more to be produced.

Some nonrenewable material resources, such as copper and aluminum, can be recycled or reused to extend supplies. **Recycling** involves collecting and reprocessing a resource into new products. For example, glass bottles can be crushed and melted to make new bottles or other glass items. **Reuse** involves using a resource over and over in the same form. For example, glass bottles can be collected, washed, and refilled many times.

Recycling nonrenewable metallic resources takes much less energy, water, and other resources and produces much less pollution and environmental degradation than exploiting virgin metallic resources. Reusing such resources takes even less energy and other resources and produces less pollution and environmental degradation than recycling.

Nonrenewable energy resources, such as coal, oil, and natural gas, cannot be recycled or reused. Once burned, the useful energy in these fossil fuels is gone, leaving behind waste heat and polluting exhaust gases.

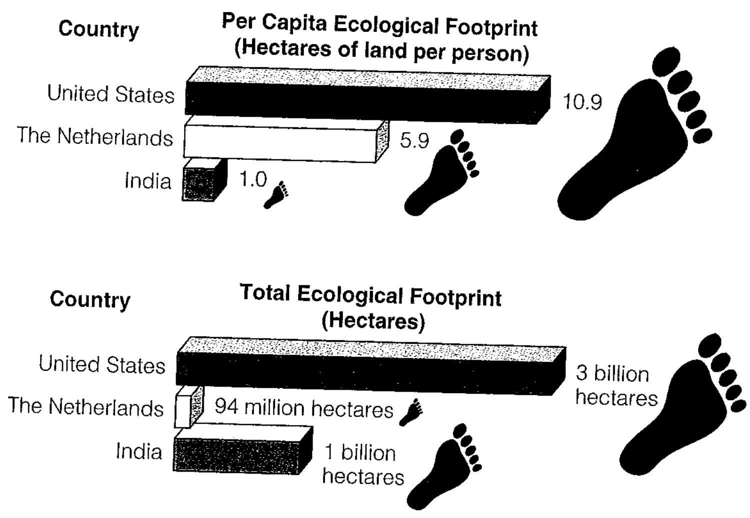


Figure 1-8 Relative ecological footprints of the United States, the Netherlands, and India. (Data from William Rees and Mathis Wackernagel)

What Is Our Ecological Footprint? An **ecological footprint** is the amount of land needed to produce the resources needed by an average person in a country. Largely as a result of increased human land use (Figure 1-5), and resource use per person, the environmental impact or *ecological footprint* of each person in developed countries is large compared to that in developing countries (Figure 1-8).

China and other developing countries hope to increase their total and per capita economic growth, which will increase the ecological footprints of their people (Connections, p. 15). According to William Rees and Mathis Wackernal, developers of the ecological footprint concept, it would take the land area of about three planet earths if all the world's 6.2 billion people consumed the same amount of resources as each person in the United States.

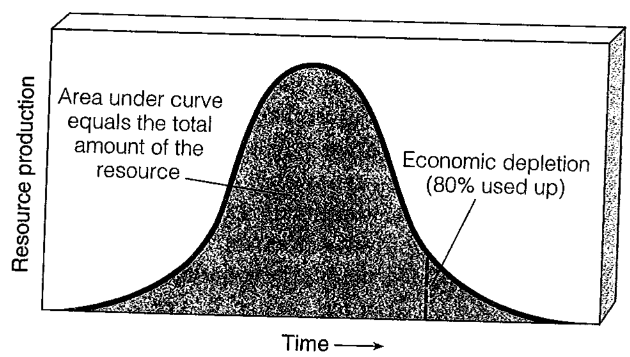


Figure 1-7 Full production and exhaustion cycle of a nonrenewable resource such as copper, iron, oil, or coal. Usually, a nonrenewable resource is considered *economically depleted* when 80% of its total supply has been extracted and used. Normally, it costs too much to extract and process the remaining 20%.

1-4 POLLUTION

What Is Pollution, and Where Do Pollutants Come From? Any addition to air, water, soil, or food that threatens the health, survival, or activities of humans or other living organisms is called **pollution.** Pollutants can enter the environment **(1)** naturally (for example, from volcanic eruptions) or **(2)** through human (anthropogenic) activities (for example, from burning coal). Most pollution from human activities occurs in or near urban and industrial areas, where pollutants are concentrated. Industrialized agriculture also is a major source of pollution.

Some pollutants contaminate the areas where they are produced; others are carried by wind or flowing water to other areas. Pollution does not respect local, state, or national boundaries.

There are two types of pollutant sources:

- **Point sources,** where pollutants come from single, identifiable sources. Examples are the **(1)** smokestack of a coal-burning power plant, **(2)** drainpipe of a factory, or **(3)** exhaust pipe of an automobile.
- **Nonpoint sources,** where pollutants come from dispersed (and often difficult to identify) sources. Examples are **(1)** runoff of fertilizers and pesticides (from farmlands, golf courses, and suburban lawns and gardens) into streams and lakes and **(2)** pesticides sprayed into the air or blown by the wind into the atmosphere.

Free-Access Resources and the Tragedy of the Commons

CONNECTIONS

One cause of environmental degradation is the overuse of **common-property** or **free-access resources.** Such resources are owned by no one (or jointly by everyone in a country or area) but are available to all users at little or no charge.

Examples include **(1)** clean air, **(2)** the open ocean and its fish, **(3)** migratory birds, **(4)** wildlife species, **(5)** publicly owned lands (such as national forests, national parks, and wildlife refuges), **(6)** gases of the lower atmosphere, and **(7)** space.

In 1968, biologist Garrett Hardin called the degradation of renewable free-access resources the **tragedy of the commons.** It happens because each user reasons, "If I do not use this resource, someone else will. The little bit I use or pollute is not enough to matter, and such resources are renewable."

With only a few users, this logic works. However, the cumulative effect of many people trying to exploit a free-access resource eventually exhausts or ruins it. Then no one can benefit from it, and therein lies the tragedy.

Two solutions to this problem are to

- *Use free-access resources at rates well below their estimated sustainable yields or overload limits by reducing population, regulating access, or both.* This prevention approach is rarely used because **(1)** it entails establishing and enforcing regulations that restrict resource use or population growth, and **(2)** it is difficult and expensive to determine the sustainable yield of a forest, grassland, or animal population because such yields vary with weather, climate, and unpredictable biological factors.
- *Convert free-access resources to private ownership.* The reasoning is that owners of land or some other resource have a strong incentive to protect their investment. However, this approach is not practical for global common resources (such as the atmosphere, the open ocean, most wildlife species, and migratory birds) that cannot be divided up and converted to private property.

Experience shows another possibility. Just because a resource is easily available to a community does not always mean people have free and unregulated access to that resource. Many communities have established a set of rules and traditions to regulate and share their access to a common-property resource such as ocean fisheries, grazing lands, and forests.

Critical Thinking

Give three examples of how you cause environmental degradation as a result of the tragedy of the commons. How should we deal with this problem? Explain.

It is much easier and cheaper to identify and control pollution from point sources than from widely dispersed nonpoint sources.

What Types of Harm Do Pollutants Cause? Unwanted effects of pollutants include the following:

- Disruption of life-support systems for humans and other species
- Damage to wildlife, human health, and property
- Nuisances such as noise and unpleasant smells, tastes, and sights

Solutions: What Can We Do About Pollution? We use two basic approaches to deal with pollution: **(1)** prevent it from reaching the environment or **(2)** clean it up if it does. **Pollution prevention** or **input pollution control** reduces or eliminates the production of pollutants. We can prevent (or at least reduce) pollution by following the five *R*s of resource use: *refuse (do not use), replace (find a less harmful sustitute), reduce (use less), reuse,* and *recycle.*

Pollution cleanup or **output pollution control** involves cleaning up pollutants after they have been produced. Environmentalists have identified three problems with relying primarily on pollution cleanup:

- *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 air pollution. But increases in the number of cars and in the total distance each travels have reduced the effectiveness of this cleanup approach.
- *It 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 **(1)** burned (perhaps causing air pollution and leaving a toxic ash that must be put somewhere), **(2)** dumped into streams, lakes, and oceans (perhaps causing water pollution), or **(3)** buried (perhaps causing soil and groundwater pollution).
- *Once pollutants have entered and become dispersed into the environment at harmful levels, it usually costs too much to reduce them to acceptable levels.*

Both pollution prevention and pollution cleanup are needed. Environmentalists and some economists urge us to emphasize prevention because it works better and is cheaper than cleanup. As Benjamin Franklin observed long ago, "An ounce of prevention is worth a pound of cure." An increasing number of businesses have found that *pollution prevention pays.*

Governments can encourage both pollution prevention and pollution cleanup by

- Using incentives such as various subsidies and tax write-offs.
- Using regulations and taxes.

Most analysts believe a combination of both approaches is best because excessive regulation and too much taxation can cause a political backlash. Achieving the right balance is difficult.

1-5 ENVIRONMENTAL PROBLEMS: CAUSES AND CONNECTIONS

What Are Key Environmental Problems and Their Basic Causes? We face a number of interconnected environmental and resource problems (Figure 1-9). The first step in dealing with these problems is to identify their underlying causes (Figure 1-10).

How Are Environmental Problems and Their Causes Connected? Once we have identified environmental problems and their root causes, the next step is to understand how they are connected to one another. The three-factor model in Figure 1-11 is a starting point.

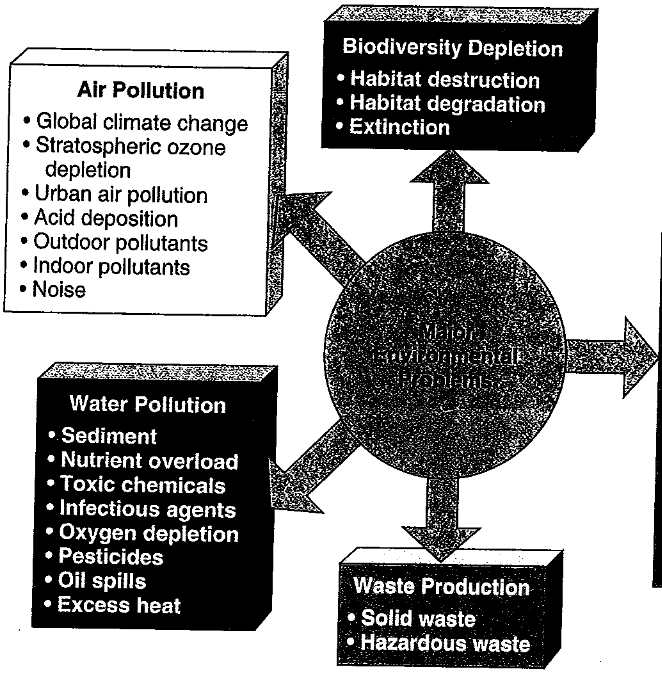


Figure 1-9 Major environmental and resource problems.

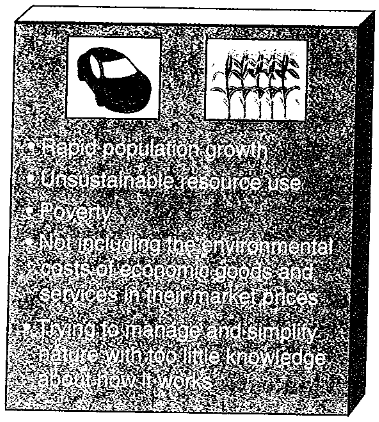


Figure 1-10 Environmentalists have identified five basic causes of the environmental problems we face.

According to this simple model, the environmental impact (**I**) of population on a given area depends on three key factors: **(1)** number of people (**P**), **(2)** average resource use per person (affluence, **A**), and **(3)** the beneficial and harmful environmental effects of the technologies (**T**) used to provide and consume each unit of resource.

In developing countries, population size and the resulting degradation of potentially renewable resources (as the poor struggle to stay alive, Connections, p. 8) tend to be the key factors in total environmental impact (Figure 1-11, top). In such countries per capita resource use is low.

In developed countries, high rates of per capita resource use and the resulting high levels of pollution and environmental degradation per person usually are the key factors determining **(1)** overall environmental impact (Figure 1-11, bottom) and **(2)** a country's ecological footprint per person (Figure 1-8). For example, the average U.S. citizen consumes about 35 times as much as the average citizen of India and 100 times as much as the average person in the world's poorest countries. *Thus poor parents in a developing country would need 70–200 children to have the same lifetime resource consumption as 2 children in a typical U.S. family.*

Some forms of technology, such as polluting factories and motor vehicles and energy-wasting devices, increase environmental impact by raising the T factor in the equation. Other technologies, such as pollution control and prevention, solar cells, and energy-saving devices, lower environmental impact by decreasing the T factor in the equation. In other words, some forms of technology are *environmentally harmful* and some are *environmentally beneficial.* Figure 1-11 shows that ways to reduce our environmental impact are to **(1)** slow population growth, **(2)** decrease resource use and waste (especially by using resources more efficiently), **(3)** increase use of environmentally beneficial technologies, and **(4)** phase out environmentally harmful technologies.

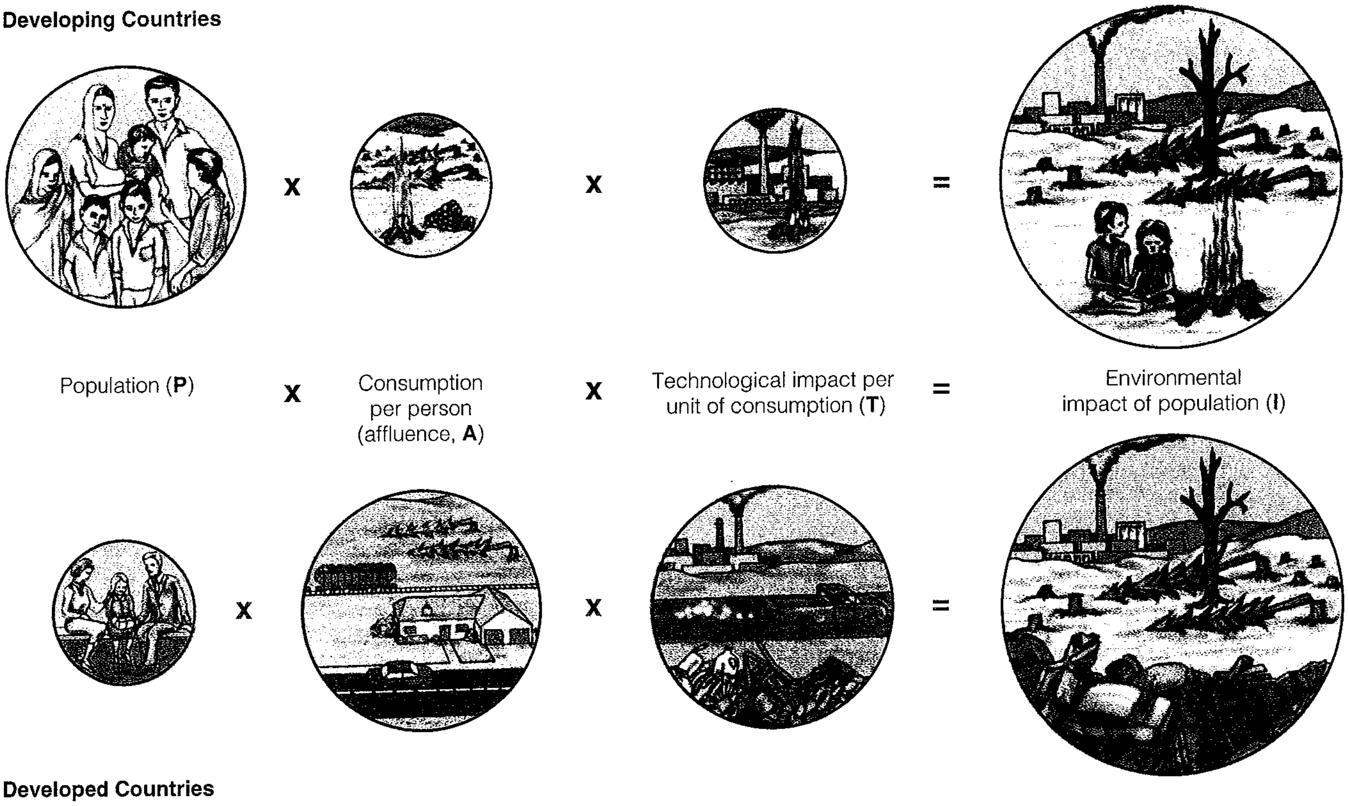


Figure 1-11 Simplified model of how three factors—population, affluence, and technology—affect the environmental impact of population in developing countries (top) and developed countries (bottom).

The three-factor model in Figure 1-11 can **(1)** help us understand how key environmental problems and some of their causes are connected and **(2)** guide us in seeking solutions to these problems. However, these problems involve a number of poorly understood interactions among many more factors than those in this simplified model, as outlined in Figure 1-12 (p. 14). For a more detailed model, see the inside back cover.

1-6 IS OUR PRESENT COURSE SUSTAINABLE?

Are Things Getting Better or Worse? Experts disagree about **(1)** how serious our population and environmental problems are and **(2)** what we should do about them. Some analysts believe human ingenuity and technological advances will allow us to **(1)** clean up pollution to acceptable levels, **(2)** find substitutes for any resources that become scarce, and **(3)** keep expanding the earth's ability to support more humans, as we have done in the past. They accuse most scientists and environmentalists of **(1)** exaggerating the seriousness of the problems we face and **(2)** failing to appreciate the progress we have made in improving quality of life and protecting the environment.

In contrast, environmentalists and many leading scientists contend we are disrupting the earth's life-support system for us and other forms of life at an accelerating rate, which if kept up could lead to serious environmental and economic harm. They are greatly encouraged by the progress we have made in increasing average life expectancy, reducing infant mortality, increasing food supplies, and reducing many forms of pollution. But they point out how much more we need to do to help make the earth more sustainable for present and future human generations and for other species that support us and other forms of life.

On November 18, 1992, some 1,680 of the world's senior scientists from 70 countries, including 102 of the 196 living scientists who are Nobel laureates, signed and sent an urgent warning to government leaders of all nations. According to this warning,

> *Our massive tampering with the world's interdependent web of life—coupled with the environmental damage inflicted by deforestation, species loss, and climate change—could trigger widespread adverse effects, including unpredictable collapses of critical biological systems whose interactions and dynamics we only imperfectly understand. . . . No more than one or a few decades remain before the chance to avert the threats we now confront will be lost and the prospects for humanity immeasurably diminished.*

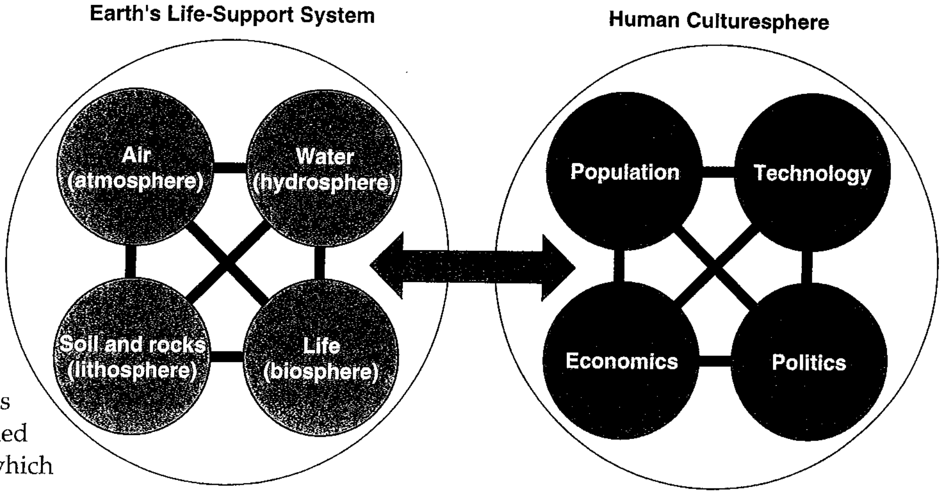


Figure 1-12 Major components and interactions within and between the earth's life-support system and the human sociocultural system (culturesphere). The goal of environmental science is to learn as much as possible about these complex interactions.

Also in 1992, the U.S. National Academy of Sciences and the Royal Society of London, two of the world's leading scientific organizations, issued a joint report, their first ever, which began,

> *If current predictions of population growth prove accurate and patterns of human activity on the planet remain unchanged, science and technology may not be able to prevent either irreversible degradation of the environment or continued poverty for much of the world. . . . Sustainable development can be achieved, but only if irreversible degradation of the environment can be halted in time.*

These warnings are not the views of a small number of scientists but the consensus of the mainstream scientific community, consisting of most of the world's key researchers on environmental problems.

The most useful answer to the question of whether things are getting better or worse is *both.* Some things are getting better and some are getting worse. We need to encourage environmentally beneficial trends and discourage environmentally harmful trends.

Our challenge is not to get trapped into confusion and inaction by listening primarily to

- *Technological optimists* who overstate the situation by telling us to be happy and not to worry because technological innovations and conventional economic growth and development will lead to a wonderworld for everyone.
- *Environmental pessimists* who overstate the problems to the point where our environmental situation seems hopeless. According to the noted conservationist Aldo Leopold (p. 36), "I have no hope for a conservation based on fear."

Whom Should We Believe? A Clash of Environmental Worldviews Conflicts over how serious our environmental problems are and what we should do about them arise mostly out of differing **environmental worldviews: (1)** how people think the world works, **(2)** what they think their role in the world should be, and **(3)** what they believe is right and wrong environmental behavior (**environmental ethics**).

People with widely differing environmental beliefs or worldviews can take the same data, be logically consistent, and arrive at quite different conclusions because they start with different assumptions and values.

Many different environmental worldviews exist, but most are variations of two major opposing ones.

Most people in today's industrial consumer societies have a **planetary management worldview,** which has become increasingly common in the past 50 years. According to this view, human beings, as the planet's most important and dominant species, can and should manage the planet mostly for their own benefit.

The basic environmental beliefs of this worldview include the following:

- ***We are in charge of nature.***
- ***There is always more.*** The earth has an unlimited supply of resources for use by us through science and technology. If we deplete a resource, we will find substitutes. To deal with pollutants, we can invent technology to clean them up, dump them into space, or move into space ourselves. If we extinguish other species, we can use genetic engineering to create new and better ones.
- ***All economic growth is good, and the potential for global economic growth is essentially limitless.***
- ***Our success depends on how well we can understand, control, and manage the earth's life-support systems for our benefit.***

All or most aspects of this worldview are widely supported because it is said to be the primary driving force behind the major improvements in the human condition since the beginning of the industrial revolution about 275 years ago.

Another environmental worldview, known as the **environmental wisdom worldview,** is based on the following major beliefs, which are the opposite of those making up the planetary management worldview:

- ***Nature does not exist just for us and we only think we are in charge.*** We need the earth, but the earth does not need us.
- ***There is not always more.*** The earth's resources are **(1)** limited, **(2)** should not be wasted, and **(3)** should be used efficiently and sustainably for us and other species.
- ***Some forms of technology and economic growth are environmentally beneficial and should be encouraged, but some are environmentally harmful and should be discouraged.***
- ***Our success depends on (1) learning how the earth sustains itself and adapts to ever-changing environmental conditions and (2) integrating such scientific lessons from nature (environmental wisdom) into the ways we think and act.***

What Is Environmentally Sustainable Economic Development? A growing number of analysts have called for a shift during this century from an emphasis on traditional economic development fueled by economic growth of essentially any type to an emphasis on **environmentally sustainable economic development.** This type of development uses **(1)** economic rewards (government subsidies, tax breaks, and emissions trading) to *encourage* environmentally beneficial and sustainable forms of economic development and **(2)** economic penalties (government taxes and regulations) to *discourage* environmentally harmful and unsustainable forms of economic growth.

According to Lester R. Brown, an environmental leader:

> *Some* good news *is that there is a growing worldwide recognition outside the environmental community that the economy we now have cannot take us where we want to go. Three decades ago, only environmental activists were speaking out on the need for a change to a more environmentally sustainable economy. Now the ranks of activists have broadened to include CEOs of major corporations, government ministers, prominent scientists, and intelligence agencies.*
>
> *The goal is to develop a new type of economy to replace our eventually unsustainable fossil fuel–based, automobile-centered, throwaway economy. This new eco-economy is a solar-powered, bicycle- and rail-centered, reuse and recycle economy that uses energy, water, land, and materials much more efficiently and wisely than we do today. In addition to helping sustain the earth's life-support systems, such an economy can lead to greater economic security, healthier lifestyles, and a worldwide improvement in the human condition.*

Implementing an *environmental or sustainability revolution* over the next 50 years involves shifting our efforts from

- Pollution cleanup to pollution prevention (cleaner production).

Connections: Lessons from China

CONNECTIONS

China is the world's most populous country, with almost 1.3 billion people. Since 1980, it has also been the world's fastest growing economy—expanding more than fourfold between 1980 and 2002.

As incomes in China have risen, so has consumption of resources. Suppose that China could shift to the meat-based, fossil fuel–based, automobile-centered, high resource use and waste economy found in the United States. Environmental leader Lester R. Brown has estimated the following impacts on global resource consumption if per capita Chinese consumption of key resources reached U.S. per capita levels:

- If China switched to an automobile economy and consumed oil at the U.S. rate, its annual oil consumption would be greater than what the entire world now produces each year.
- If China's per capita consumption of fossil fuels reached U.S. levels, global emissions of carbon dioxide would double and accelerate projected global warming.
- If annual per capita paper consumption in China reached the U.S. level, China would need more paper each year than the world currently produces.

According to Lester R. Brown, China is showing us why **(1)** it and other industrializing countries cannot follow the industrialized model of today's industrialized countries, **(2)** the economies of the world's industrialized countries cannot be sustained in the long run, and **(3)** there is an urgent need for developed and developing countries alike to shift to more environmentally sustainable economies or eco-economies.

Critical Thinking

What do you believe would be the three most important effects on your lifestyle if **(a)** we shifted to an environmentally sustainable economy over the next 50 years and **(b)** we do not shift to such an economy? Explain.

Natural Capital

GUEST ESSAY

Paul G. Hawken

Paul G. Hawken understands both business and ecology. In addition to founding Smith & Hawken, a retail company known for its environmental initiatives, he has written seven widely acclaimed books, including Growing a Business *(1987),* The Ecology of Commerce *(1993),* Factor 10, The Next Industrial Revolution *(1998, with Amory and Hunter Lovins), and* Natural Capitalism *(1999, with Amory and Hunter Lovins). He produced and hosted* Growing a Business, *a series for public television shown nationwide on 210 stations and now shown in 115 countries.* The Ecology of Commerce *was hailed as the best business book of 1993 and one of the most important books of the 20th century. In 1987,* Inc. *magazine named Hawken one of the 12 best entrepreneurs of the 1980s, and in 1995 he was named by the* Utne Reader *as one of the 100 visionaries who could change our lives.*

Great ideas, in hindsight, seem obvious. The concept of natural capital is such an idea. *Natural capital* is the myriad necessary and valuable resources and ecological processes that we rely on to produce our food, products, and services.

The concept of natural capital is not a new one. Economists have long noted that natural capital is a factor in industrial production, but a marginal factor.

A new view is emerging: Our economic systems cannot long endure without taking the flow of renewable and nonrenewable resources [Figure 1-6] through economies into account. This revision of neoclassical economics, yet to be accepted by most mainstream academicians, provides business and public policy with a powerful new tool for the continued prosperity of business and the preservation and restoration of the earth's living natural systems.

Most Americans are filled with cornucopian fantasies of technological prowess, where human ingenuity bypasses natural limits and creates unimagined abundance. Optimism easily intertwines with the belief that nanotechnology, biotechnology, computers, and technologies yet to be developed will eliminate hunger, disease, and want.

Dreams of alleviating human suffering are worthy. However, they usually overlook the absolute necessity of fertile soil, ocean fisheries, a stable climate, biological diversity, and pure water, all of which we are degrading and none of which can be created by any human-made technology known or imagined.

In our pursuit of dominance over the natural world, we have not taken into account the basic principle that industrialism, for all its sophistication, is enormously inefficient with respect to resource use, energy use, and waste production. The hypotheses and theories of neoclassical economists originated in a time of resource abundance. Today it is difficult for many of these economists to understand that the success of linear industrial systems based on increasing economic growth by increasing the rate of flow of materials and energy through economic systems has laid the groundwork for the next stage in economic evolution.

This shift is profoundly biological. It involves incorporating the cycling of material resources that supports natural systems into our ways of making things and our ways of dealing with the waste matter produced by our current linear industrial systems. This shift is going to happen because cyclical industrial systems work better than linear ones. They close the loop and reincorporate wastes as part of the production cycle. There are no landfills in a cyclical society.

If there is so much inefficiency in our current system, why is it not more apparent? The inefficiencies are

- Waste disposal (mostly burial and burning) to waste prevention and reduction.
- Protecting species to protecting the places (habitats) where they live.
- Environmental degradation to environmental restoration.
- Increased resource use to more efficient (less wasteful) resource use.
- Population growth to population stabilization by decreasing birth rates.

The Solutions box (p. 18) gives some guidelines that various analysts have suggested for living more sustainably by working with the earth.

This chapter has presented an overview of the problems most environmentalists and many of the world's most prominent scientists believe we face and their root causes. It has also summarized the controversy over how serious environmental problems are and described two opposing environmental worldviews. The rest of this book presents a more detailed analysis of these problems, the controversies they have created, and solutions proposed by analysts.

Try not to be overwhelmed or immobilized by the *bad environmental news* because there is also some *great environmental news.* We **(1)** have made immense progress in improving the human condition and dealing with many environmental problems, **(2)** are learning a great deal about how nature works and sustains itself, and **(3)** have numerous scientific, technological, and economic solutions available to deal with the environmental problems we face, as you will learn in this book.

The challenge is to make creative use of our economic and political systems to implement such masked by a financial system in which money, prices, and markets give us inaccurate information. Markets are not giving us correct information about how much our suburbs, cars, and plastic drinking water bottles truly cost based on the environmental harm they cause.

Instead, we are getting warning signals from the beleaguered airsheds and watersheds, the overworked and eroded soils, the life-degrading inner cities and rural counties, the breakdown of stability worldwide, and the conflicts based on shortages of water and some other resources in parts of the world. These feedbacks from nature are providing the information that our prices should give us but do not.

Prices do not give us good information for a simple reason: *improper accounting.* Natural capital has never been placed on the balance sheets of companies or the countries of the world. To paraphrase G. K. Chesterton, it could fairly be said that capitalism might be a good idea, but we have not tried it yet. Capitalism cannot be fully attained or practiced until we have an accurate balance sheet, as any accounting student will tell us.

As it stands, our economic system is based on accounting principles that would bankrupt a company. When natural capital is placed on the balance sheet, not as a free resource of infinite supply but as an integral and valuable part of the production process, everything changes. The nearly obsessive pursuit of improvement in *human productivity* becomes balanced by the need for improved *resource productivity.* Using more and more resources to make fewer people more productive flies in the face of what we need to improve our society and the environment. After all, it is people we have plenty of, so it is people we must use to reduce the flow of matter and energy resources through economies and the resulting pollution and loss of natural capital. Moving from linear industrial systems to cyclical ones that mimic nature accomplishes this.

Many people sincerely believe an economic system based on the integrity of natural systems is unworkable. To answer that concern, we may want to reverse the question and ask, "How have we created an economic system that tells us it is cheaper to destroy natural capital than to maintain it?" We know this is not the way to take care of our cars, houses, and bridges, but somehow we have managed to overlook a pricing system that discounts the future and sells off the past. Or to put it another way, "How did we create an economic system that confuses capital with income?"

Can we devise and implement a more rational economic system? I think so. It is right before us. It requires no new theories, only common sense. It is based on the simple but powerful proposition that *all capital must be valued.*

There may be no *right* way to value a forest or a river, but there is a *wrong* way, which is to give it little or no value. If we have doubts about how to value a 500-year-old tree, we need only ask how much it would cost to make a new one from scratch. Or a new river. Or a new atmosphere.

Our goal should be to estimate and integrate the worth of living systems into every aspect of our culture and commerce so that human systems mimic natural systems. Only if we do this can our cultures reflect growth and harmony rather than damage and discord.

Critical Thinking

If you were in charge of the world's economy, what are the three most important things you would do? Compare your answers with those of other members of your class.

solutions. This requires governments, businesses, and individuals to integrate social, economic, and environmental goals and policies in their decision making (Figure 1-13).

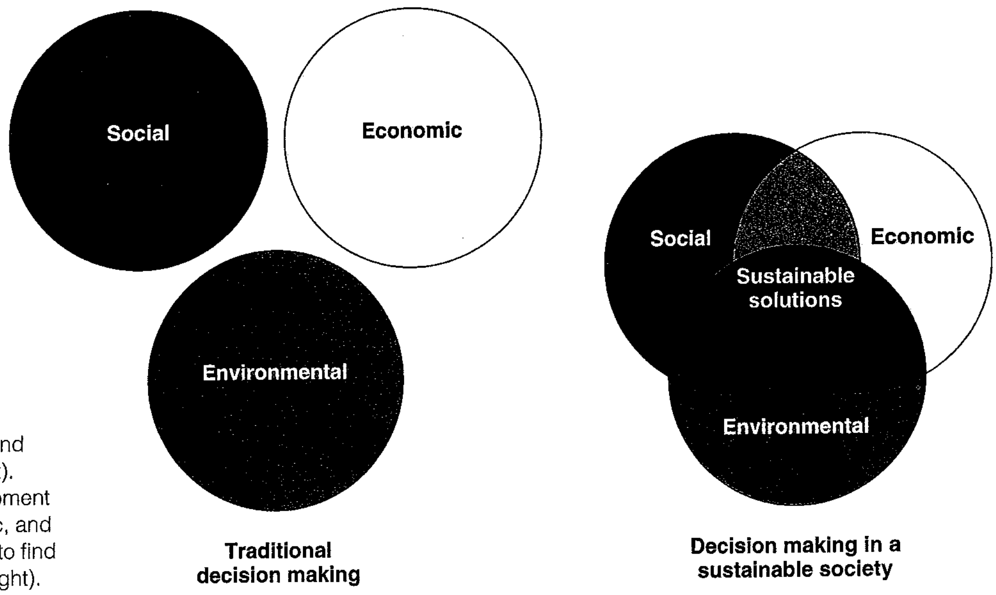


Figure 1-13 Types of decision making in traditional and sustainable societies. The traditional decision making in most societies involves treating social, economic, and environmental issues separately (left). Environmentally sustainable development calls for integrating social, economic, and environmental issues and concepts to find *sustainable solutions* to problems (right).

Some Guidelines for Working with the Earth

SOLUTIONS

- Leave the earth in as good as or better shape than we found it.
- Take no more than we need.
- Try not to harm life, air, water, or soil.
- Sustain the variety of the earth's life-forms and the places (habitats) where they live (biodiversity).
- Help maintain the earth's capacity for self-repair and adaptation.
- Do not use renewable resources (soil, water, forests, grasslands, and wildlife) faster than they are replenished.
- Do not waste resources.
- Do not release pollutants into the environment faster than the earth's natural processes can dilute or recycle them.
- Emphasize pollution prevention and waste reduction.
- Slow the rate of population growth by decreasing birth rates.
- Have the market prices of all goods and services include all of their harmful environmental costs and thus tell the ecological truth.
- Reduce poverty.

See various chapters on the website for this book for specific ways you can work with the earth by trying to implement such guidelines.

Critical Thinking

Which of these guidelines do you agree with and which do you disagree with? Why? Can you add any other guidelines?

One key is to recognize that most economic and political change comes about as a result of individual actions and individuals acting together to bring about change. Social scientists suggest it only takes about 5–10% of the population of a country or of the world to bring about major social change. Anthropologist Margaret Mead summarized our potential for change: "Never doubt that a small group of thoughtful, committed citizens can change the world. Indeed, it is the only thing that ever has."

We live in exciting times during what might be called a *hinge of cultural history.* Indeed, if I had to pick a time to live, it would be the next 50 years as we face the challenge of developing more environmentally sustainable societies.

REVIEW QUESTIONS

1. Define the boldfaced terms in this chapter.

2. What is *exponential growth?* Give two examples of exponential growth.

3. Distinguish among *environment, ecology,* and *environmental science.* Distinguish among *ecologists, environmental scientists, conservation biologists, environmentalists, preservationists, conservationists,* and *restorationists.*

4. Distinguish between *solar capital* and *natural capital* (*natural resources*).

5. What is an *environmentally sustainable society?* Distinguish between living on principal and living on interest, and relate this to the sustainability of **(a)** the earth's life-support system and **(b)** your lifestyle.

6. What is the main reason for the rapid growth of the world's population during the past 100 years? What are *doubling time* and the *rule of 70?* Use the rule of 70 to calculate how many years it would take for the population of a country to double if it was growing at 2% per year.

7. Define *economic growth, gross national income, gross national income purchasing power parity, gross domestic product, gross world product, per capita GNI, per capita GNI PPP,* and *economic development.* Distinguish between *developed countries* and *developing countries.*

8. List six pieces of *good news* about economic development. List nine pieces of *bad but challenging news* about economic development.

9. Why does it make sense for a poor family to have a large number of children? List six ways in which poverty is related to environmental quality, people's quality of life, and premature deaths of poor people.

10. Define *globalization* and list seven indicators of this phenomenon.

11. Distinguish among a *perpetual resource, renewable resource,* and *nonrenewable resource,* and give an example of each.

12. What are *sustainable yield* and *environmental degradation?* Give eight examples of environmental degradation.

13. Define and give three examples of *common-property resources.* What is the *tragedy of the commons?* Give three examples of this tragedy on a global scale, and explain how your lifestyle contributes to these examples. List three ways to deal with the tragedy of the commons.

14. Distinguish between a *physically depleted nonrenewable resource* and an *economically depleted nonrenewable resource.* Distinguish between *reuse* and *recycling.* Draw a depletion curve for a nonrenewable resource, and explain how recycling and reuse affect depletion time.

15. What is the *ecological footprint per person* and what useful information does it give us?

16. What is *pollution?* Distinguish between *point sources* and *nonpoint sources* of pollution. List three types of harm caused by pollution.

17. Distinguish between *pollution prevention (input pollution control)* and *pollution cleanup (output pollution control).* What are three problems with relying primarily on pollution cleanup? Why is pollution prevention better than pollution control? List two ways that governments can encourage both pollution prevention and pollution cleanup.

18. According to environmentalists, what are five basic causes of the environmental problems we face?

19. Describe a simple model of relationships between population, resource use per person, resource use technology, and overall environmental impact. How do these factors differ in developed and developing countries?

20. What is an *environmental worldview?* Distinguish between the *planetary management* and *environmental wisdom environmental worldviews.*

21. What is *environmentally sustainable economic development?* How does it differ from traditional economic growth and economic development?

22. List six major changes that environmentalists believe should take place over the next 50 years as part of an *environmental* or *sustainability revolution.* What are two important keys to bringing about such changes?

23. List 12 guidelines that environmentalists have suggested for working with the earth.

CRITICAL THINKING

1. Do you believe the society you live in is on an unsustainable path? Explain. Do you believe it is possible for the society you live in to become a mostly sustainable society within the next 50 years? Explain.

2. Do you favor instituting policies designed to reduce population growth and stabilize **(a)** the size of the world's population as soon as possible and **(b)** the size of the population of the country where you live as soon as possible? Explain. If you agree that population stabilization is desirable, what three major policies would you implement to accomplish this goal?

3. Explain why you agree or disagree with the following propositions:
   - **a.** The economic growth from high levels of resource use in developed countries provides money for more financial aid to developing countries for reducing pollution, environmental degradation, and poverty.
   - **b.** Stabilizing population is not desirable because without more consumers, economic growth would stop.
   - **c.** The world will never run out of renewable resources and most currently used nonrenewable resources because technological innovations will produce substitutes, reduce resource waste, or allow use of lower grades of scarce nonrenewable resources.

4. List **(a)** three forms of economic growth you believe are environmentally unsustainable and **(b)** three forms you believe are environmentally sustainable.

5. When you read that at least 27,400 human beings die prematurely each day (19 per minute) from preventable malnutrition and infectious disease, do you **(a)** doubt whether 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. How do you feel when you read that **(1)** the average American consumes about 50 times more resources than the average Chinese citizen, **(2)** human activities lead to the premature extinction of at least 10 species per day, **(3)** humans have disturbed about 73% of the earth's habitable land (Figure 1-5, p. 7), and **(4)** human activities are projected to make the earth's climate warmer: **(a)** skeptical about their accuracy, **(b)** indifferent, **(c)** sad, **(d)** helpless, **(e)** guilty, **(f)** concerned, or **(g)** outraged? Which of these feelings help perpetuate such problems, and which can help alleviate these problems?

7. Do you agree or disagree with the five basic causes of environmental problems listed in Figure 1-10, p. 12? Explain. List any other root causes you believe should be added.

8. One of the tragic characters in Greek mythology is Cassandra. The god Apollo gave her the gift of being able to foretell the future but then added the curse that no one would believe her. Have the environmental problems we face been **(a)** overblown by prophets of doom (Cassandras) or **(b)** reduced in severity because enough people have listened to their warnings and acted to prevent the prophecies from coming true? Explain.

9. 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 species depends only on whether they are useful to us, **(e)** because all species eventually become extinct we should not worry about whether our activities cause the premature extinction of a species, **(f)** all species 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 species.

10. Explain why you agree or disagree with each of the beliefs of **(a)** the planetary management worldview on p. 14 and **(b)** the environmental wisdom worldview on p. 15.

11. What are the basic beliefs of your environmental worldview? Are the beliefs of your environmental worldview consistent with your answers to question 9? Are your environmental actions consistent with your environmental worldview?

12. Do you believe your current lifestyle is sustainable? If your answer is no, explain why and list five things you could do now to make your lifestyle more sustainable. Which of these things do you actually plan to do?

PROJECTS

1. What are the major resource and environmental problems in the city, town, or rural area where you live? Which of these problems affect you directly? Have these problems gotten better or worse during the last 10 years?

2. Roughly what percentages of key resources such as water, food, and energy used by your local community come from the following places: nearby, another state, or another country?

3. Make a list of the resources you truly need. Then make another list of the resources you use each day only because you want them. Finally, make a third list of resources you want and hope to use in the future. Compare your lists with those compiled by other members of your class, and relate the overall result to the tragedy of the commons (Connections, p. 11).

4. When the "World Scientists' Warning to Humanity" (p. 15) was released to the press, the television networks and major papers in the United States and Canada almost ignored it, with the *Washington Post* and the *New York Times* in the United States rejecting the story as not newsworthy. Use the library or Internet to see what the major news stories were in the *Washington Post* and the *New York Times* on November 18, 1992, and evaluate their importance relative to the "World Scientists' Warning to Humanity."

5. Use the library or the Internet to find out bibliographic information about *Lynton B. Caldwell, Barbara Ward, René Dubos,* and *Henry David Thoreau,* whose quotes appear at the beginning and end of this chapter.

6. Write two-page scenarios describing what your life and that of any children you choose to have might be like 50 years from now if **(a)** we continue on our present path or **(b)** we shift to more environmentally sustainable societies throughout most of the world.

7. Make a concept map of this chapter's major ideas using the section heads and subheads and the key terms (in boldface type). Look on the website for this book for information about making concept maps.

INTERNET STUDY RESOURCES AND RESOURCES FOR FURTHER READING AND RESEARCH

The website for this book contains helpful study aids and many ideas for further reading and research. Log on to

www.info.brookscole.com/miller13

and click on the Chapter-by-Chapter area. Choose Chapter 1 and select a resource:

- Flash Cards allows you to test your mastery of the Terms and Concepts to Remember for this chapter.
- Tutorial Quizzes provides a multiple-choice practice quiz.
- Student Guide to InfoTrac will lead you to Critical Thinking Projects that use InfoTrac College Edition as a research tool.
- References lists the major books and articles consulted in writing this chapter.
- Hypercontents takes you to an extensive list of sites with news, research, and images related to individual sections of the chapter.

INFOTRAC COLLEGE EDITION

Improve your skills with InfoTrac College Edition, a searchable online database of articles from more than 700 periodicals. Log on to

http://www.infotrac-college.com

or access InfoTrac through the website for this book. Try to find the following articles:

1. Clark, W. C. 2001. A transition toward sustainability. *Ecology Law Quarterly* 27: 1021. *Keywords:* "Clark" and "sustainability." This is a very comprehensive article that details how human society and its interaction with the environment must adjust to assure future sustainability.

2. Jones, K., A. Scholtz, and A. G. Lehmer. 2002. Rio+10': Let the people be heard. *Earth Island Journal* 17: 12. *Keywords:* "Rio" and "sustainability" Ten years after the Rio Earth Summit, there appears to have been little action on the part of participating countries to realize the recommendation of the summit. In fact, we may actually be going in the other direction.

2 ENVIRONMENTAL HISTORY: AN OVERVIEW

Near Extinction of the American Bison

In 1500, before Europeans settled North America, 30–60 million North American bison—commonly known as the buffalo—grazed the plains, prairies, and woodlands over much of the continent.

These animals were once so numerous that in 1832 a traveler wrote, "As far as my eye could reach the country seemed absolutely blackened by innumerable herds." A single herd on the move might thunder past for hours.

For centuries, several Native American tribes depended heavily on bison, and they typically killed only the animals needed for food, clothing, and shelter. The dried feces of these animals, known as "buffalo chips," were used as fuel. These Native Americans did not deplete the bison because they hunted only with lances and bows and arrows, and occasionally drove some bison over cliffs.

By 1906, however, the once vast range of the bison had shrunk to a tiny area, and the species had been driven nearly to extinction (Figure 2-1). How did this happen? First, settlers moving west after the Civil War upset the sustainable balance between Native Americans and bison. Several plains tribes traded bison skins to settlers for steel knives and firearms, which allowed them to kill more bison.

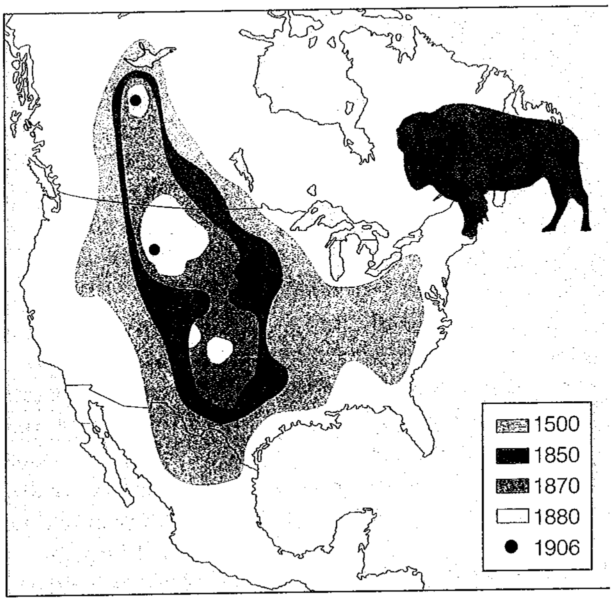


Figure 2-1 The historical range of the bison shrank severely between 1500 and 1906, mostly because of unregulated and deliberate overhunting.

But it was the new settlers who caused the most relentless slaughter. As railroads spread westward in the late 1860s, railroad companies hired professional bison hunters—including Buffalo Bill Cody—to supply construction crews with meat. Passengers also gunned down bison from train windows for sport, leaving the carcasses to rot.

Commercial hunters shot millions of bison for their hides and tongues (considered a delicacy), leaving most of the meat to rot. "Bone pickers" collected the bleached bones that whitened the prairies and shipped them east to be ground up as fertilizer.

Farmers shot bison because they damaged crops, fences, telegraph poles, and sod houses. Ranchers killed them because they competed with cattle and sheep for pasture. The U.S. Army killed at least 12 million bison as part of its campaign to subdue the plains tribes by killing off their primary source of food.

Between 1870 and 1875, at least 2.5 million bison were slaughtered each year. Only 85 bison were left by 1892. They were given refuge in Yellowstone National Park and protected by an 1893 law that forbids the killing of wild animals in national parks.

In 1905, 16 people formed the American Bison Society to protect and rebuild the captive population. Soon thereafter, the federal government established the National Bison Range near Missoula, Montana. Today an estimated 200,000 bison survive, about 97% of them on privately owned ranches.

Some wildlife conservationists have suggested restoring large herds of bison on public lands in the North American plains. This idea has been strongly opposed by ranchers with permits to graze cattle and sheep on federally managed lands.

The history of humanity's relationships to the environment provides many important lessons that can help us deal with today's environmental problems and not repeat past mistakes.

A continent ages quickly once we come.
Ernest Hemingway

This chapter addresses the following questions:

- What major effects have hunter–gatherer societies, agricultural societies, and industrialized societies had on the environment? What might be the environmental impact of the current information and globalization revolution?
- What are the major phases in the history of land and wildlife conservation, public health, and environmental protection in the United States?
- What is Aldo Leopold's land ethic?

2-1 CULTURAL CHANGES AND THE ENVIRONMENT

What Major Human Cultural Changes Have Taken Place? Evidence from fossils and studies of ancient cultures suggests that the current form of our species, *Homo sapiens sapiens*, has walked the earth for only about 60,000 years (some recent evidence suggests 90,000–176,000 years), an instant in the planet's estimated 4.6-billion-year existence.

Until about 12,000 years ago, we were mostly hunter–gatherers who typically moved as needed to find enough food for survival. Since then, three major cultural changes have occurred: **(1)** the *agricultural revolution* (which began 10,000–12,000 years ago), **(2)** the *industrial revolution* (which began about 275 years ago), and **(3)** the *information and globalization revolution* (which began about 50 years ago).

These major cultural changes have

- Given us much more energy and new technologies with which to alter and control more of the planet to meet our basic needs and increasing wants.
- Allowed expansion of the human population, mostly because of increased food supplies and longer life spans.
- Increased our environmental impact because of increased resource use, pollution, and environmental degradation.

How Did Ancient Hunting-and-Gathering Societies Affect the Environment During most of our 60,000-year existence, we were **hunter–gatherers** who survived by collecting edible wild plant parts, hunting, fishing, and scavenging meat from animals killed by other predators. Our hunter–gatherer ancestors typically lived in small bands (of fewer than 50 people) who worked together to get enough food to survive. Many groups were nomadic, picking up their few possessions and moving seasonally from place to place to find enough food.

The earliest hunter–gatherers (and those still living this way today) survived through expert knowledge and understanding of their natural surroundings. They discovered **(1)** which plants and animals could be eaten and used as medicines, **(2)** where to find water, **(3)** how plant availability changed throughout the year, and **(4)** how some game animals migrated to get enough food. Because of a high infant mortality and an estimated average life span of 30–40 years, hunter–gatherer populations grew very slowly.

Advanced hunter–gatherers had a greater impact on their environment than did early hunter–gatherers. They **(1)** used more advanced tools and fire to convert forests into grasslands, **(2)** contributed to the extinction of some large animals (including the mastodon, saber-toothed tiger, giant sloth, cave bear, mammoth, and giant bison), and **(3)** altered the distribution of plants (and animals feeding on such plants) as they carried seeds and plants to new areas.

Early and advanced hunter–gatherers exploited their environment to survive. But their environmental impact usually was limited and local because of **(1)** their small population sizes, **(2)** low resource use per person, **(3)** migration, which allowed natural processes to repair most of the damage they caused, and **(4)** lack of technology that could have expanded their impact.

How Has the Agricultural Revolution Affected the Environment? Some 10,000–12,000 years ago, a cultural shift known as the **agricultural revolution** began in several regions of the world. It involved a gradual move from usually nomadic hunting-and-gathering groups to settled agricultural communities in which people domesticated wild animals and cultivated wild plants.

Plant cultivation probably developed in many areas, especially in the tropical forests of Southeast Asia, northeast Africa, and Mexico. People discovered how to grow various wild food plants from roots or tubers (fleshy underground stems). To prepare the land for planting, they cleared small patches of tropical forests by cutting down trees and other vegetation and then burning the underbrush (Figure 2-2). The ashes fertilized the often nutrient-poor soils in this **slash-and-burn cultivation.**

Early growers also used various forms of **shifting cultivation** (Figure 2-2), primarily in tropical regions. After a plot had been used for several years, the soil became depleted of nutrients or reinvaded by the forest. Then the growers cleared a new plot. They learned that each abandoned patch normally had to be left fallow (unplanted) for 10–30 years before the soil became fertile enough to grow crops again. While patches were regenerating, growers used them for tree crops, medicines, fuelwood, and other purposes. In this manner, most early growers practiced *sustainable cultivation.*

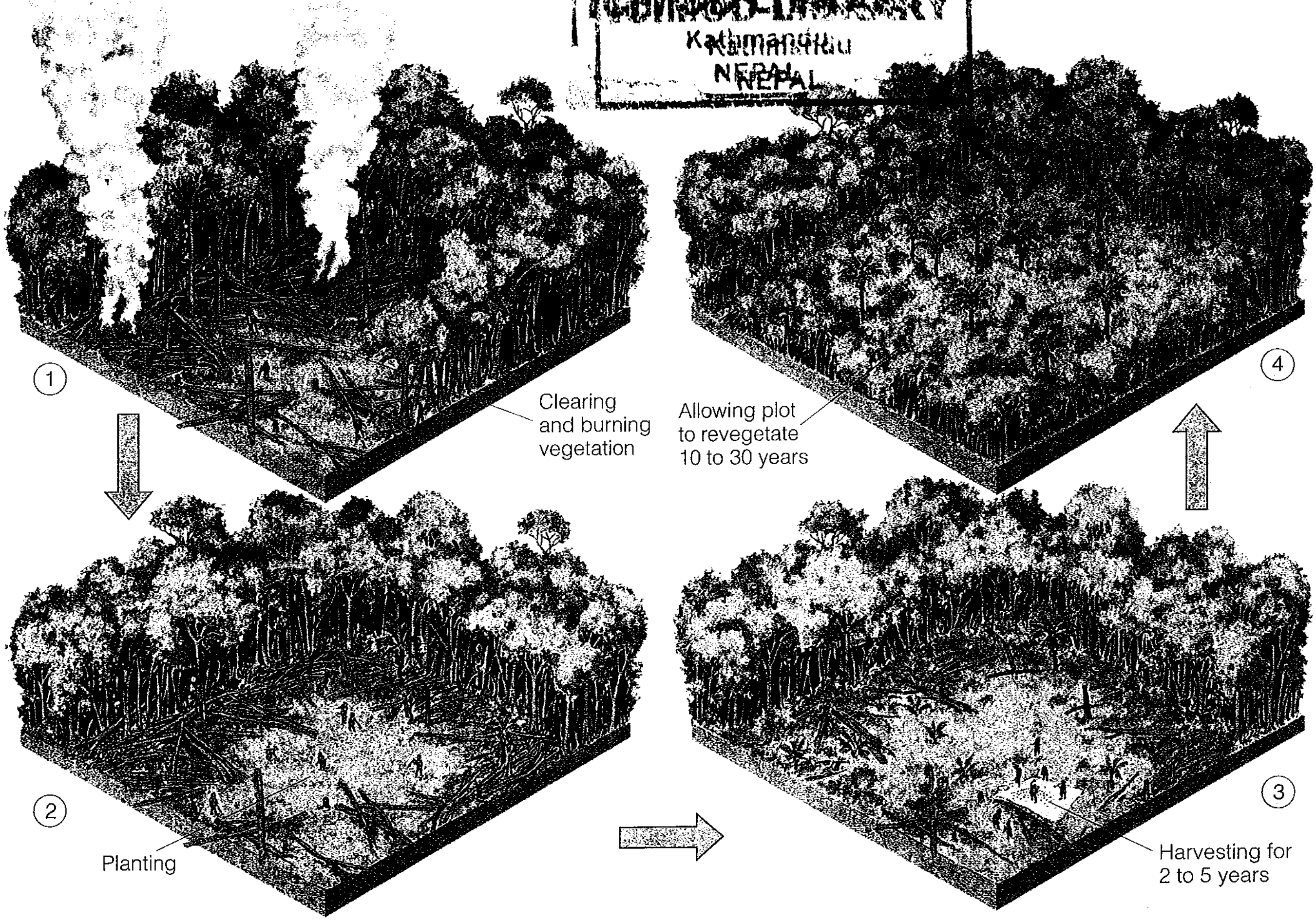


Figure 2-2 The first crop-growing technique may have been a combination of slash-and-burn and shifting cultivation in tropical forests. This method is sustainable only if small plots of the forest are cleared, cultivated for no more than 5 years, and then allowed to regenerate for 10–30 years to renew soil fertility. Indigenous cultures have developed many variations of this technique and have found ways to use some former plots nondestructively while they are being regenerated.

These early farmers had fairly little impact on the environment because **(1)** their dependence mostly on human muscle power and crude stone or stick tools meant they could cultivate only small plots, **(2)** their population size and density were low, and **(3)** normally enough land was available so they could move to other areas and leave abandoned plots unplanted for the several decades needed to restore soil fertility. The gradual shift from hunting and gathering to farming had several significant effects (Connections, p. 24).

How Has the Industrial Revolution Affected the Environment? The next cultural shift, the **industrial revolution,** began in England in the mid-1700s and spread to the United States in the 1800s. It led to a rapid expansion in the production, trade, and distribution of material goods.

The industrial revolution represented a shift from dependence on **(1)** *renewable* wood (with supplies dwindling in some areas because of unsustainable cutting) and flowing water to **(2)** dependence on machines running on *nonrenewable* fossil fuels (first coal and later oil and natural gas). This led to a switch from small-scale, localized production of handmade goods to large-scale production of machine-made goods in centralized factories in rapidly growing industrial cities.

Factory towns grew into cities as rural people came to the factories for work. There they worked long hours under noisy, dirty, and hazardous conditions. Other workers toiled in dangerous coal mines. In these early industrial cities, coal smoke belching out of chimneys was so heavy that many people died prematurely of lung ailments. Ash and soot covered everything, and on some days the smoke was so thick that it blotted out the sun.

Fossil fuel–powered farm machinery, commercial fertilizers, and new plant-breeding techniques increased per acre crop yields. This helped protect biodiversity by reducing the need to expand the area of cropland to grow food. Because fewer farmers were needed, more people migrated to cities. With a larger

Consequences of the Agricultural Revolution

CONNECTIONS

Here are some of the beneficial and harmful effects of the agricultural revolution:

- *Using domesticated animals to plow fields, haul loads, and perform other tasks increased the ability to expand agriculture and support more people.*
- *People* **(1)** *cut down vast forests to supply wood for fuel and building materials,* **(2)** *plowed up large expanses of grassland to grow crops, and* **(3)** *built irrigation systems to transfer water from one place to another.* Such extensive land clearing degraded or destroyed the habitats of many wild plants and animals, causing or hastening their extinction.
- *Soil erosion, salt buildup in irrigated soils, and overgrazing of grasslands by huge herds of livestock helped turn fertile land into desert; topsoil washed into streams, lakes, and irrigation canals.* This environmental degradation was a factor in the downfall of many great civilizations in the Middle East, North Africa, and the Mediterranean.
- *People began accumulating material goods.* Nomadic hunter–gatherers could not carry many possessions in their travels, but farmers living in one place could acquire as much as they could afford.
- *Farmers could grow more than enough food for their families.* They could store the excess for emergencies or use it to barter for other goods and services.
- *Urbanization—the formation of villages, towns, and cities—became practical.* Some villages grew into towns and cities, which served as centers for trade, government, and religion. Towns and cities concentrated sewage and other wastes, polluted the air and water, and greatly increased the spread of diseases.
- *Increased production and use of material goods created growing volumes of waste and pollution.*
- *Conflict between societies became more common as ownership of land and water rights became a crucial economic issue.* Armies and their leaders rose to power and conquered large areas of land and water supplies. These rulers forced powerless people (slaves and landless peasants) to do the hard, disagreeable work of producing food and constructing irrigation systems, temples, and walled fortresses.
- *The survival of wild plants and animals, once vital to humanity, became less important.* Wild animals, which competed with livestock for grass and fed on crops, became enemies to be killed or driven from their habitats. Wild plants invading cropfields became weeds to be eliminated.

Critical Thinking

Would we be better off if agricultural practices had never been developed and we were still hunter–gatherers? Explain.

and more reliable food supply and longer life spans, the size of the human population began the sharp increase that continues today (Figure 1-1, p. 2, and Figure 1-2, p. 4).

After World War I (1914–18), more efficient machines and mass production techniques were developed. These technologies became the basis of today's advanced industrial societies in places such as the United States, Canada, Japan, Australia, and western Europe. Advanced industrial societies have provided numerous benefits along with environmental problems (Connections, p. 25).

How Might the Information and Globalization Revolution Affect the Environment? We are in the midst of a new cultural shift, the **information and globalization revolution,** in which new technologies such as the telephone, radio, television, computers, the Internet, automated databases, and remote sensing satellites mean we have increasingly rapid access to much more information on a global scale. Scientific information now doubles about every 12 years, and general information doubles about every 2.5 years. The World Wide Web contains at least 1 billion electronic pages and grows by roughly a million electronic pages per day.

This new cultural revolution can have beneficial and harmful environmental effects. On the *positive side,* today's information technologies

- Help us understand more about how the earth, economies, and other complex systems work and how such systems might be affected by our actions.
- Allow us to respond to environmental problems more effectively and rapidly.
- Allow us to use remote sensing satellites to survey resources and monitor changes in the world's forests, grasslands, oceans, rivers, polar regions, cities, and other systems.
- Enable us to develop sophisticated computer models and computer-generated maps of the earth's environmental systems.
- Can reduce pollution and environmental degradation by substituting data for materials and energy and communication for transportation.

On the *negative side,* information technologies

- Provide an overload of information.
- Cause confusion, distraction, and a sense of hopelessness as we try to identify useful environmental

information and ideas in a rapidly growing sea of information.

- Increase environmental degradation and decrease cultural diversity as a globalized economy spreads over most of the earth and homogenizes the world's cultures.

2-2 ENVIRONMENTAL HISTORY OF THE UNITED STATES: THE TRIBAL AND FRONTIER ERAS

What Happened During the Tribal Era? The environmental history of the United States can be divided into four eras: **(1)** tribal, **(2)** frontier, **(3)** conservation, and **(4)** environmental.

During the *tribal era,* North America was occupied by 5–10 million tribal people for at least 10,000 years before European settlers began arriving in the early 1600s. These indigenous people, called Indians by the Europeans and now often called Native Americans, practiced hunting and gathering, burned and cleared fields, and planted crops. Because of their small populations and simple technology, they had a fairly low environmental impact.

With some exceptions, most Native American cultures had a deep respect for the land and its animals and did not believe in land ownership, as indicated by these quotes:

> *My people, the Blackfeet Indians, have always had a sense of reverence for nature that made us want to move through the world carefully, leaving as little mark behind as possible. (Jamake Highwater, Blackfoot)*

> *From our childhood we are taught that the animals and even the trees and other plants that we share a place with are our brothers and sisters. So when we speak of land, we are not speaking of property, territory, or even a piece of property upon which our houses sit and our crops are grown. We are speaking of something truly sacred. (Jimmie Durham, Cherokee)*

What Happened During the Frontier Era (1607–1890)? The frontier era began in the early 1600s when European colonists began settling North America. Faced with a continent containing seemingly inexhaustible forest and wildlife resources and rich soils, the early colonists developed a **frontier environmental worldview.** They viewed most of the continent as a wilderness to be conquered by clearing and planting and with vast resources. Forests were cleared not only for timber and cropland but also because they were seen as a hostile wilderness full of dangerous savages and wild beasts.

CONNECTIONS: Consequences of Advanced Industrial Societies

The *good news* is that advanced industrial societies provide a variety of benefits to most people living in them, including

- Mass production of many useful and affordable products
- A sharp increase in agricultural productivity
- Lower infant mortality and longer life expectancy because of better sanitation, hygiene, nutrition, and medical care
- A decrease in the rate of population growth
- Better health, birth control methods, and education
- Methods for controlling pollution
- Greater average income and old-age security

However, the *bad news* is the resource and environmental problems we face today (Figure 1-9, p. 12), mostly because of the rise of advanced industrial societies.

Critical Thinking

1. On balance, do you believe the advantages of the industrial revolution have outweighed its disadvantages? Explain.
2. What three major things would you do to reduce the harmful environmental impacts of advanced industrial societies?

This frontier environmental worldview contrasted sharply with that of some Native American cultures. According to Luther Standing Bear, a Sioux, "Only to the white man was nature a 'wilderness' and only to him was the land infested with 'wild animals' and 'savage' people. To us it was tame and bountiful."

Another factor accelerating settling of the continent and use of its resources was the transfer of vast areas of public land to private interests between 1850 and 1900. In 1850, the U.S. government owned about 80% of the total land area of the territorial United States. Tribal cultures occupied about 4% of the land, mostly in reservations designated by the government.

By 1900, more than half of the country's public land had been given away or sold cheaply to railroad, timber, and mining companies, land developers, states, schools, universities, and homesteaders to encourage settlement across the country. Under the Homestead Act of 1862, each qualified settler in the Great Plains was given 65 hectares (160 acres) of land free of charge.

This frontier environmental view prevailed for more than 280 years, until the government declared the frontier officially closed in 1890. However, this frontier environmental worldview remains part of American culture.

2-3 ENVIRONMENTAL HISTORY OF THE UNITED STATES: THE EARLY CONSERVATION ERA (1832–1960)

Who Were Some 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 that part of the unspoiled wilderness on public lands owned jointly by all people (but managed by the government) be protected as a legacy to future generations.

Two of these early conservationists were *Henry David Thoreau* (1817–62) and *George Perkins Marsh* (1812–1939). Thoreau (Figure 2-3) 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 2-3 Henry David Thoreau (1817–62) was an American writer and naturalist who kept journals about his excursions into wild 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 influential citizens see the need for resource conservation. Marsh **(1)** questioned the idea that the country's resources were inexhaustible, **(2)** 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 resource base, and **(3)** formulated basic resource conservation principles we still use today.

What Happened Between 1870 and 1930? Between 1870 and 1930, a number of actions increased the role of the federal government and private citizens in resource conservation and public health (Figure 2-4). The *Forest Reserve Act of 1891* was a turning point in establishing the responsibility of the federal government for protecting public lands from resource exploitation.

In 1892, nature preservationist and activist *John Muir* (Figure 2-5) founded the Sierra Club. He became the leader of the *preservationist movement,* advocating the protection of 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. He also proposed and lobbied for creation of a national park system on public lands, an idea that became law in 1916 (two years after his death).

Mostly because of political opposition, effective protection of forests and wildlife did not begin until *Theodore Roosevelt* (Figure 2-6, p. 28), an ardent conservationist, became president. His term of office, 1901–9, has been called the country's *Golden Age of Conservation.* Some of his major contributions to conservation include the following:

- Persuading Congress to give the president power to designate public land as federal wildlife refuges
- Establishing the first federal refuge at Pelican Island off the east coast of Florida for preservation of the endangered brown pelican in 1903 and adding 35 more reserves by 1904
- Designating the Grand Canyon as one of the first 16 national parks
- More than tripling 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, using the principles of **(1)** *sustainable yield* (cutting trees no faster than they could regenerate) and **(2)** *multiple use* (using the lands for a variety of purposes, including resource extraction, recreation, and wildlife protection).

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 then used this act to protect the Grand Canyon and other areas that would later become national parks.

In 1907, Congress, upset because Roosevelt had added vast tracts to the forest reserves, banned further executive withdrawals of public forests. On the day before the bill became law, Roosevelt defiantly reserved another 6.5 million hectares (16 million acres).

Early in the 20th century, the U.S. conservation movement split over how to use the beautiful Hetch

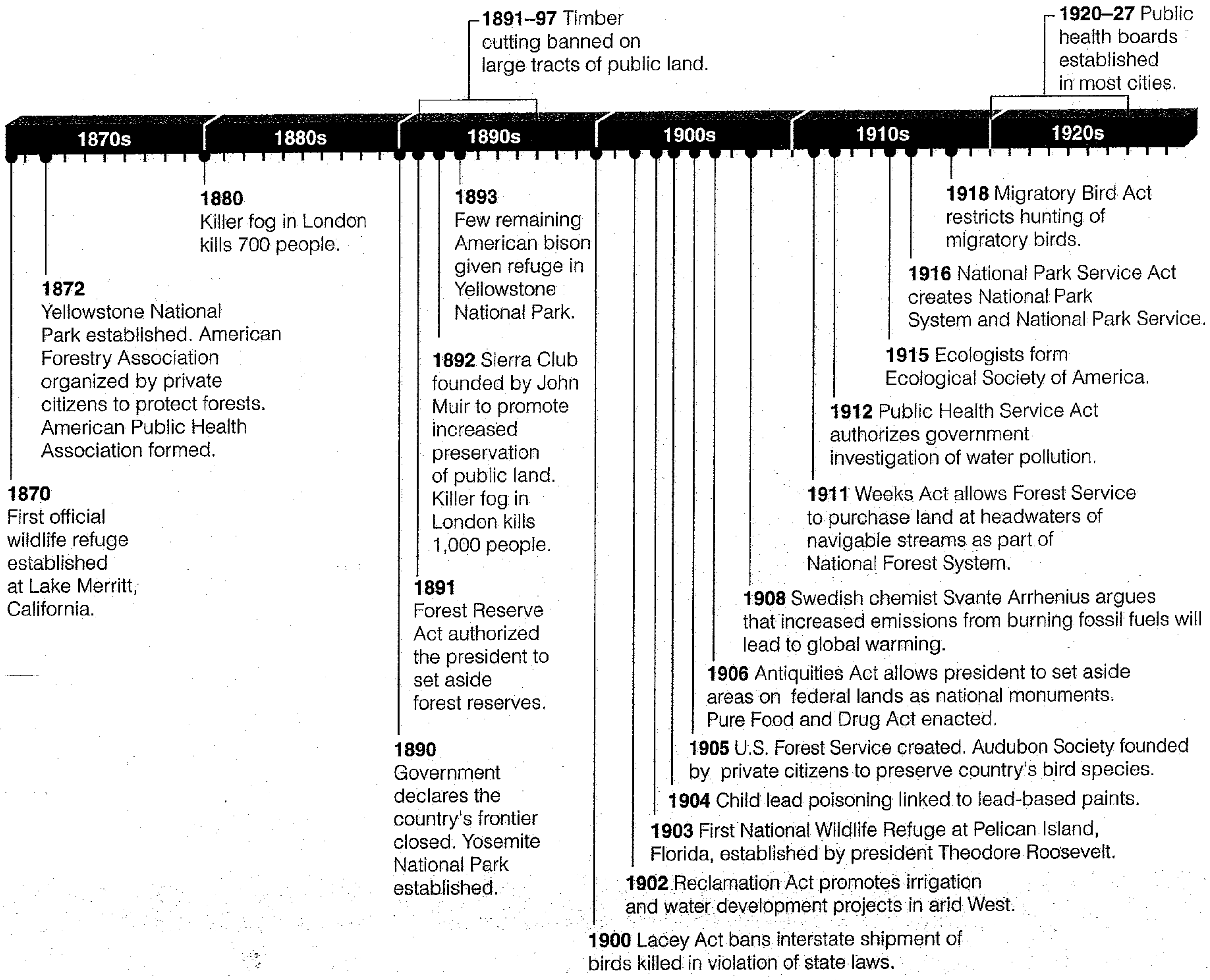


Figure 2-4 Examples of the increased role of the federal government in resource conservation and public health and establishment of key private environmental groups, 1870–1930.

Hetchy Valley (in what is now Yosemite National Park) (Spotlight, p. 32).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 (Figure 2-5), wanted wilderness areas on public lands to be left untouched. This controversy over use of public lands continues today.

In 1916, Congress passed the *National Park Service Act*, which **(1)** declared the parks were to be maintained in a manner that leaves them unimpaired for future generations and **(2)** 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

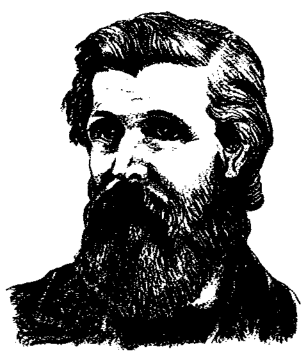


Figure 2-5 John Muir (1838–1914) was a geologist, explorer, and naturalist. He spent 6 years studying, writing journals, and making sketches in the wilderness of California's Yosemite Valley and then went on to explore wilderness areas in Utah, Nevada, the Northwest, and Alaska. He was largely responsible for establishing Yosemite National Park in 1890. He also founded the Sierra Club and spent 22 years lobbying actively for conservation laws.

Figure 2-6 Theodore ("Teddy") Roosevelt (1858–1919) was a writer, explorer, naturalist, avid birdwatcher, and 26th 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.

encourage tourist visits by allowing private concessionaires to operate facilities within the parks.

During the early 1900s, women such as *Jane Addams* (1860–1935) and *Alice Hamilton* (Individuals Matter, below) led efforts to improve public health (Figure 2-4).

After World War I (1914–18), the country entered a new era of economic growth and expansion. During the Harding, Coolidge, and Hoover administrations, the federal government promoted increased resource removal from public lands at low prices to stimulate economic growth.

President Hoover went even further and proposed that the federal government return all remaining federal lands to the states or sell them to private interests for economic development. But the Great Depression (1929–41) made owning such lands unattractive to state governments and private investors.

What Happened Between 1930 and 1960? A second wave of national resource conservation and improvements in public health began in the early 1930s (Figure 2-7) as President *Franklin D. Roosevelt* (1882–1945) strove to bring the country out of the Great Depression. Massive federal government programs designed to provide jobs and restore the environment included

- Low-cost purchase of large tracts of public land from cash-poor landowners.
- The *Civilian Conservation Corps* (CCC), established in 1933 to put 2 million unemployed people to work **(1)** planting trees, **(2)** developing and maintaining parks and recreation areas, **(3)** restoring silted waterways, **(4)** building levees and dams for flood control, **(5)** controlling soil erosion, and **(6)** protecting wildlife.
- Establishing the *Tennessee Valley Authority* (TVA) to provide jobs, replant forests, and build dams for flood control and hydroelectric power in the economically depressed Tennessee Valley.

INDIVIDUALS MATTER

Alice Hamilton

Alice Hamilton (1869–1970) was the country's first influential expert in industrial medicine. After graduating from medical school, she became professor of pathology at the Woman's Medical School of Northwestern University in Chicago, Illinois. She became interested in the neglected and poorly understood field of industrial medicine after hearing numerous stories about health hazards in stockyards and factories.

Hamilton began investigating various hazardous industries. Despite little information, company resistance, and workers' failure to report health problems for fear of losing their jobs, Hamilton's persistence and resourcefulness as a researcher paid off. During the next several decades she became the country's leading investigator of occupational hazards.

In 1919, Hamilton was appointed assistant professor of industrial medicine at Harvard University, the first teaching appointment of a woman at this institution. In the 1920s, she published her classic text *Industrial Poisons in the United States* and became the country's most effective advocate for investigating and dealing with the environmental consequences of industrial activity.

Four decades before the widespread concern about pesticides and other industrial chemicals in the 1960s and 1970s, Hamilton was warning workers of their exposure to a variety of new chemicals whose effects on human health were unknown.

She unsuccessfully opposed the use of tetraethyl lead in gasoline in the 1920s, arguing that no exposure to lead is safe. Her position was vindicated in the late 1980s, when tetraethyl lead was phased out of gasoline in the United States. Her efforts were also instrumental in the introduction of workers' compensation laws.

Alice Hamilton was a strong advocate of *pollution prevention*. In a 1925 article she expressed the hope "that the day is not far off when we shall take the next step and investigate a new danger in industry before it is put to use, before any fatal harm has been done."

Alice Hamilton (1869–1970) was the first and foremost expert on industrial disease in the United States.

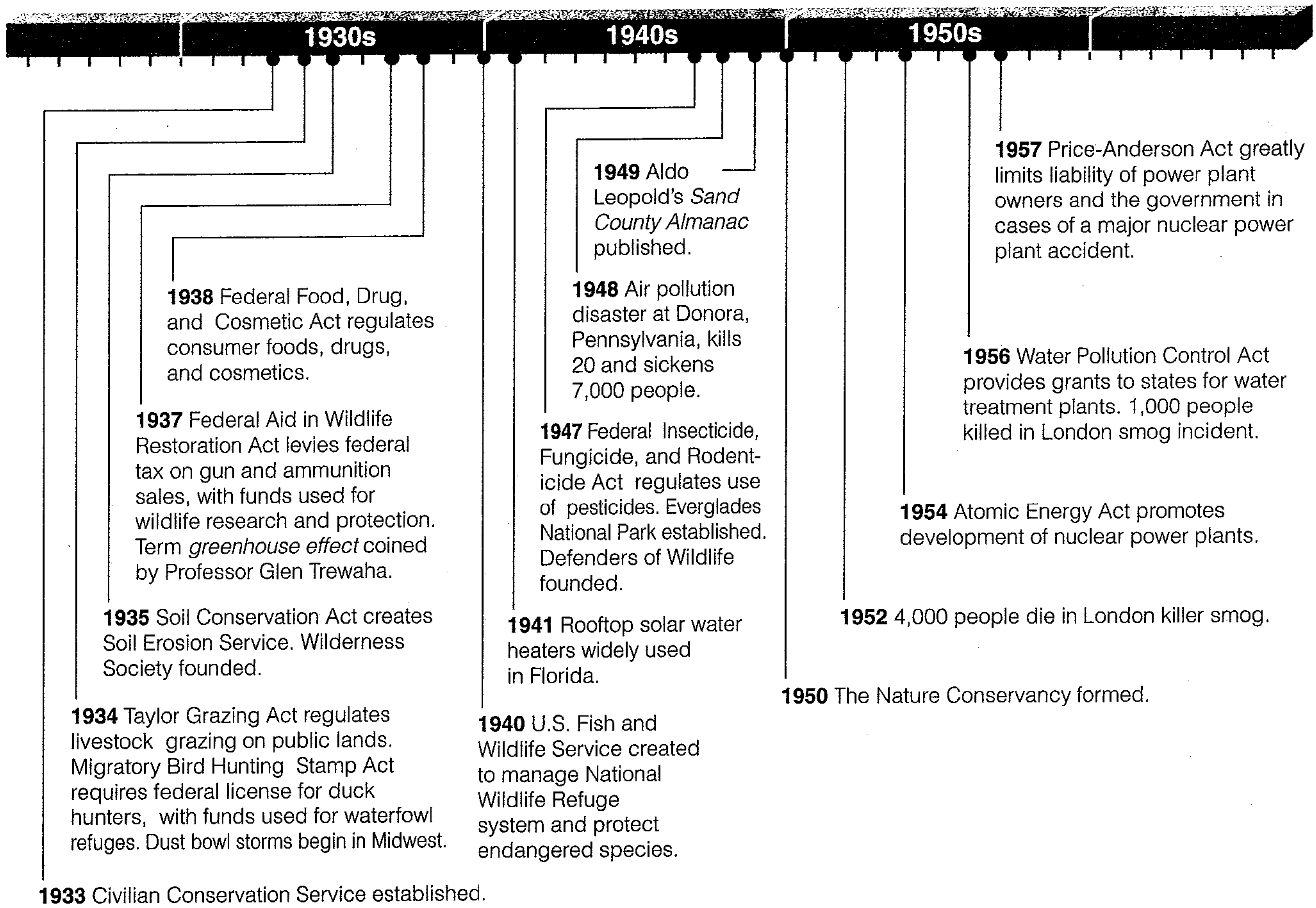


Figure 2-7 Some important conservation and environmental events between 1930 and 1960.

- Building and operating many large dams in the arid western states, including Hoover Dam on the Colorado River, to provide jobs, flood control, cheap irrigation water, and cheap electricity for industry.
- Enacting the Soil Conservation Act of 1935, which 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. Its name was later changed to the *Soil Conservation Service,* and it is now called the *Natural Resources Conservation Service.*

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 1933 and 1960, improvements in public health included **(1)** establishment of public health boards and agencies at the municipal, state, and federal levels, **(2)** increased public education about health issues, **(3)** introduction of vaccination programs, and **(4)** a sharp reduction in waterborne infectious disease, mostly because of improved sanitation and garbage collection.

2-4 ENVIRONMENTAL HISTORY OF THE UNITED STATES: THE ENVIRONMENTAL ERA (1960–2002)

What Happened During the 1960s? A number of important milestones in American environmental history occurred during the 1960s (Figure 2-8, p. 30). In 1962, biologist *Rachel Carson* (1907–64) published *Silent Spring,* which documented the pollution of air, water, and wildlife from pesticides such as DDT (Individuals Matter, p. 33). This influential book helped broaden the concept of resource conservation to include preservation of the *quality* of the air, water, soil, and wildlife.

Many historians mark this wake-up call as the beginning of the modern **environmental movement,** in which a growing number of citizens organized to demand that political leaders enact laws and develop policies to **(1)** curtail pollution, **(2)** clean up polluted environments, and **(3)** protect pristine areas from environmental degradation.

In 1964, Congress passed the *Wilderness Act,* inspired by the vision of John Muir more than 80 years earlier. The act authorized the government to protect

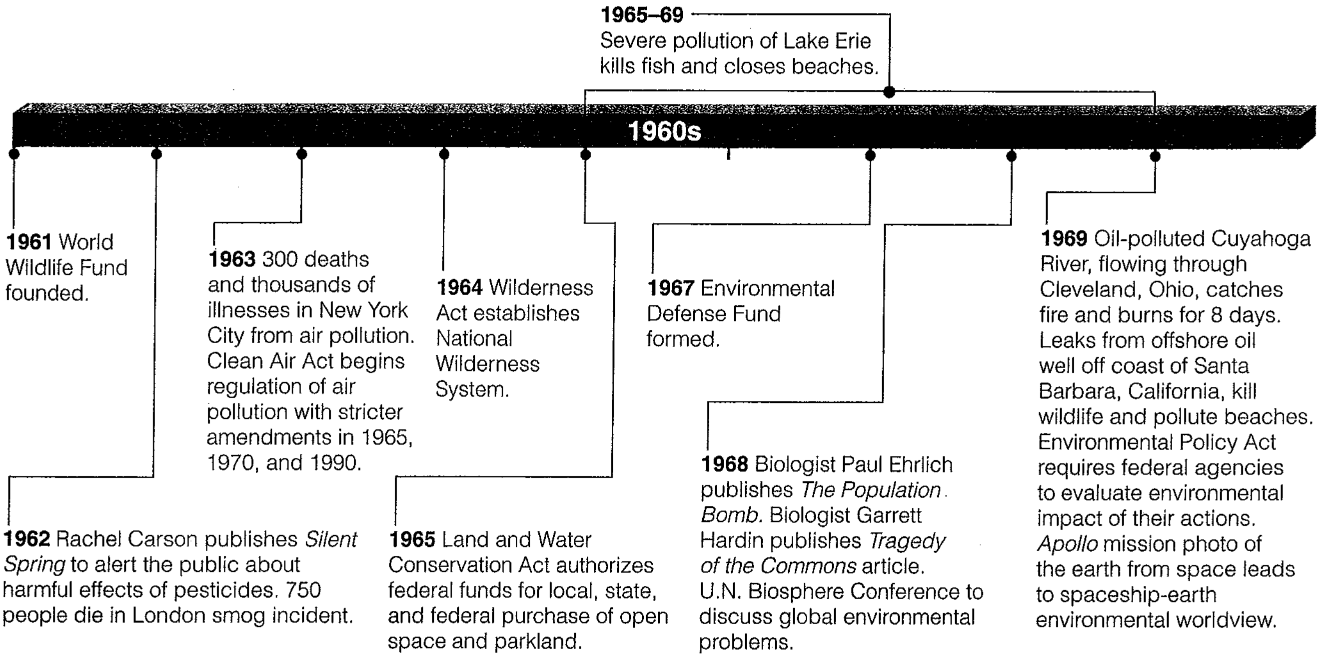


Figure 2-8 Some important environmental events during the 1960s.

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 (Figure 1-11, p. 13).

During that same period, a number of events increased public awareness of pollution (Figure 2-8). 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, the astronauts photographed the earth from space, and we saw our tiny blue and white planet in the black void of space (Figure 1-1, p. 2). This widely publicized photo led to the development of the *spaceship-earth environmental worldview,* reminding us that we had better take care of the earth because it the only home we have.

What Happened During the 1970s? Media attention, public concern about environmental problems, scientific research, and action to address these concerns grew rapidly during the 1970s, sometimes called the *first decade of the environment.* Figure 2-9 summarizes some important events during this decade.

The first annual *Earth Day* was held on April 20, 1970. During this event, proposed by Senator *Gaylord Nelson* (born 1916), some 20 million people in more than 2,000 communities took to the streets to heighten awareness and to demand improvements in environmental quality.

President *Richard Nixon* (1913–94) responded to the rapidly growing environmental movement by **(1)** establishing the *Environmental Protection Agency* (EPA) in 1970 and **(2)** supporting passage of the *Endangered Species Act of 1973,* which greatly strengthened the role of the federal government in protecting endangered species.

An eye-opening event occurred in 1973 when the Arab members of the Organization of Petroleum Exporting Countries (OPEC)* reduced oil exports to the West and banned oil shipments to the United States because of its support for Israel in the 18-day Yom Kippur War with Egypt and Syria. This *OPEC oil embargo,* lasting until March 1974, sharply raised the

*OPEC was formed in 1960 so developing countries with much of the world's known and projected oil supplies could get a higher price for this resource. Today its members are Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela. In 1973, OPEC produced 56% of the world's oil and supplied about 84% of all oil imported by other countries.

price of crude oil. The result was **(1)** double-digit inflation in the United States and many other countries, **(2)** high interest rates, **(3)** soaring international debt, and **(4)** a global economic recession. In 1979, a second reduction in oil supplies and a sharp price increase occurred when Iran's Islamic Revolution shut down most of Iran's oil production.

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 lands was restricted for the first time. In the late 1970s, a coalition of ranchers, miners, loggers, developers, farmers, some elected officials, and others launched a political campaign known as the *sagebrush rebellion* against government regulation of the use of public lands. Its primary goal was to remove most

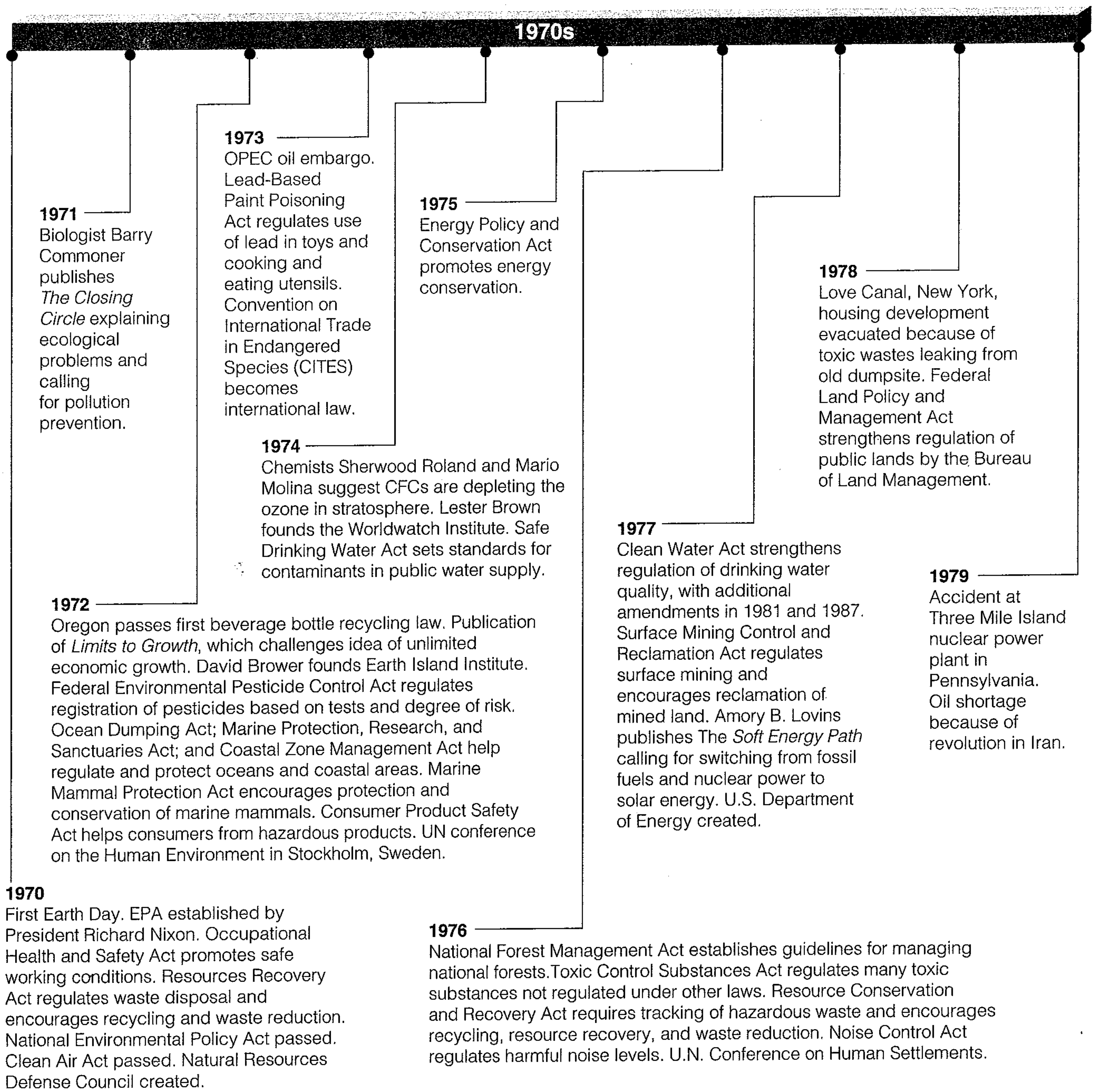


Figure 2-9 Some important environmental events during the 1970s, sometimes called the *environmental decade*.

SPOTLIGHT

How Should Public Land Resources Be Used? Preservationists vs. Conservationists

In 1901, conservationists, led by Gifford Pinchot and San Francisco mayor James D. Phelan, proposed to dam the Tuolumne River running through Hetch Hetchy Valley to supply drinking water for San Francisco. Preservationists, led by John Muir (Figure 2-5), were opposed.

After a bitter 12-year battle, Pinchot's views won, and in 1913 the dam was built and the valley was flooded. Today the controversy continues, with preservationists pressing to have the dam removed.

Preservationists would keep large areas of public lands untouched so they can be enjoyed today and passed on unspoiled to future generations. After Muir's death in 1914, preservationists were led by forester *Aldo Leopold* (Figure 2-12, p. 36), who said the role of the human species should be to protect nature, not conquer it (Section 2-5, p. 36).

Another effective supporter of wilderness preservation was *Robert Marshall* (1901–39) of the U.S. Forest Service. In 1935, he and Leopold founded the Wilderness Society. More recent preservationist leaders include **(1)** *David Brower* (1912–2000), former head of the Sierra Club and founder of both Friends of the Earth and Earth Island Institute, and **(2)** *Howard Zahniser* (1906–64), who as head of the Wilderness Society helped draft the Wilderness Act of 1964 and lobby Congress for its passage.

In contrast, *conservationists* see wilderness and other public lands as resources to be used to enhance the nation's economic growth and to provide the greatest benefit to the greatest number of people. In their view the government should protect these lands from harm by managing them efficiently and scientifically, using the principles of sustainable yield and multiple use.

Roosevelt and Pinchot thought conservation experts should form an elite corps of resource managers within the federal bureaucracy. Shielded from political pressure, they could develop scientific management strategies. Pinchot angered Muir and other preservationists when he stated his "wise-use" principle:

> *The first great fact about conservation is that it stands for development. There has been a fundamental misconception that conservation means nothing but the husbanding of resources for future generations. There could be no more serious mistake. . . . The first principle of conservation is the use of the natural resources now existing on this continent for the benefit of the people who live here now.*

Despite their basic differences, both groups opposed delivering public resources into the hands of a few for private profit. Both groups have been disappointed. Since 1910 rights to extract water and minerals, graze livestock, and harvest trees from public lands routinely have been given away or sold by Congress at below-market prices to large corporate farms, ranches, mining companies, and timber companies.

Critical Thinking

1. Why do the conservationist and preservationist philosophies lead to different management practices for public lands?

2. Which philosophy do you favor? Explain.

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.

When *Jimmy Carter* (born 1924) was president between 1977 and 1981, 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.
- Appointed a number of competent and experienced administrators, drawn heavily from environmental and conservation organizations, to key posts in the EPA, the Department of the Interior, and the Department of Energy.
- Consulted with environmental leaders on environmental and resource policy matters.
- Helped create a *Superfund* as part of the *Comprehensive Environment Response, Compensation, and Liability Act of 1980* to clean up abandoned hazardous waste sites, including the Love Canal near Niagara Falls, New York.
- 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 from development than any other president.

What Happened During the 1980s? Figure 2-10 (p. 34) summarizes some key environmental events during the 1980s. During this decade, farmers and ranchers and leaders of the oil, automobile, mining, and timber industries, who opposed many of the environmental laws and regulations developed in the

INDIVIDUALS MATTER

Rachel Carson

Rachel Carson began her professional career as a biologist for the Bureau of U.S. Fisheries (later to become the U.S. Fish and Wildlife Service). In that capacity, she **(1)** carried out research on oceanography and marine biology, **(2)** wrote articles about the oceans and topics related to the environment, and **(3)** became editor-in-chief of the bureau's publications in 1949.

In 1951, she wrote *The Sea Around Us*, which described in easily understandable terms the natural history of oceans and how humans were harming them. Her book was on the best-seller list for 86 weeks, sold more than 2 million copies, was translated into 32 languages, and won a National Book Award.

During the late 1940s and throughout the 1950s, DDT and related compounds were used increasingly 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 Olga Huckins, a good friend of Carson. After the spraying, Huckins witnessed the agonizing deaths of several of her birds. In distress she asked Carson whether she could find someone to investigate the effects of pesticides on birds and other wildlife.

Carson decided to look into the issue herself and quickly found that almost no independent research on the environmental effects of pesticides existed. As a well-trained scientist, Carson **(1)** surveyed the scientific literature, **(2)** became convinced that pesticides could harm wildlife and humans, and **(3)** methodically built a case against the widespread use of pesticides.

In 1962, she published her findings in popular form in *Silent Spring*, an allusion to the silencing of "robins, catbirds, doves, jays, wrens, and scores of other bird voices" because of their exposure to pesticides. She pointed out that "for the first time in the history of the world, every human being is now subjected to dangerous chemicals, from the moment of conception until death."

Carson's book was read by many scientists, politicians, and policy makers and was embraced by the public. However, the chemical industry viewed the book as a serious threat to booming pesticide sales and mounted a $250,000 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, she was incapable of understanding the highly scientific and technical subject of pesticides. Others charged that she was a hysterical woman and a radical nature lover trying to scare the American public in order to sell books.

During this period of intense controversy Carson was suffering from terminal cancer, but she was able to defend her research and strongly counter 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 emerging modern environmental movement in the United States.

Biologist Rachel Carson (1907–64) was a pioneer in increasing public awareness of the importance of nature and the threat of pollution. She died without knowing that her efforts were important in beginning the modern era of environmentalism in the United States.

1960s and 1970s, organized and funded a strong *anti-environmental movement.*

In 1981, *Ronald Reagan* (born 1911), a self-declared *sagebrush rebel* and advocate of less federal control, became president. During his 8 years in office he

- Appointed to key federal positions people who opposed most existing environmental and public and land use laws and policies.
- Greatly increased private energy and mineral development and timber cutting on public lands.
- 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.
- Lowered automobile gas mileage standards and relaxed federal air and water quality pollution standards.

Although Reagan was an immensely popular president, many people strongly opposed his environmental and resource policies, which prompted **(1)** strong opposition in Congress, **(2)** public outrage, and **(3)** 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 with

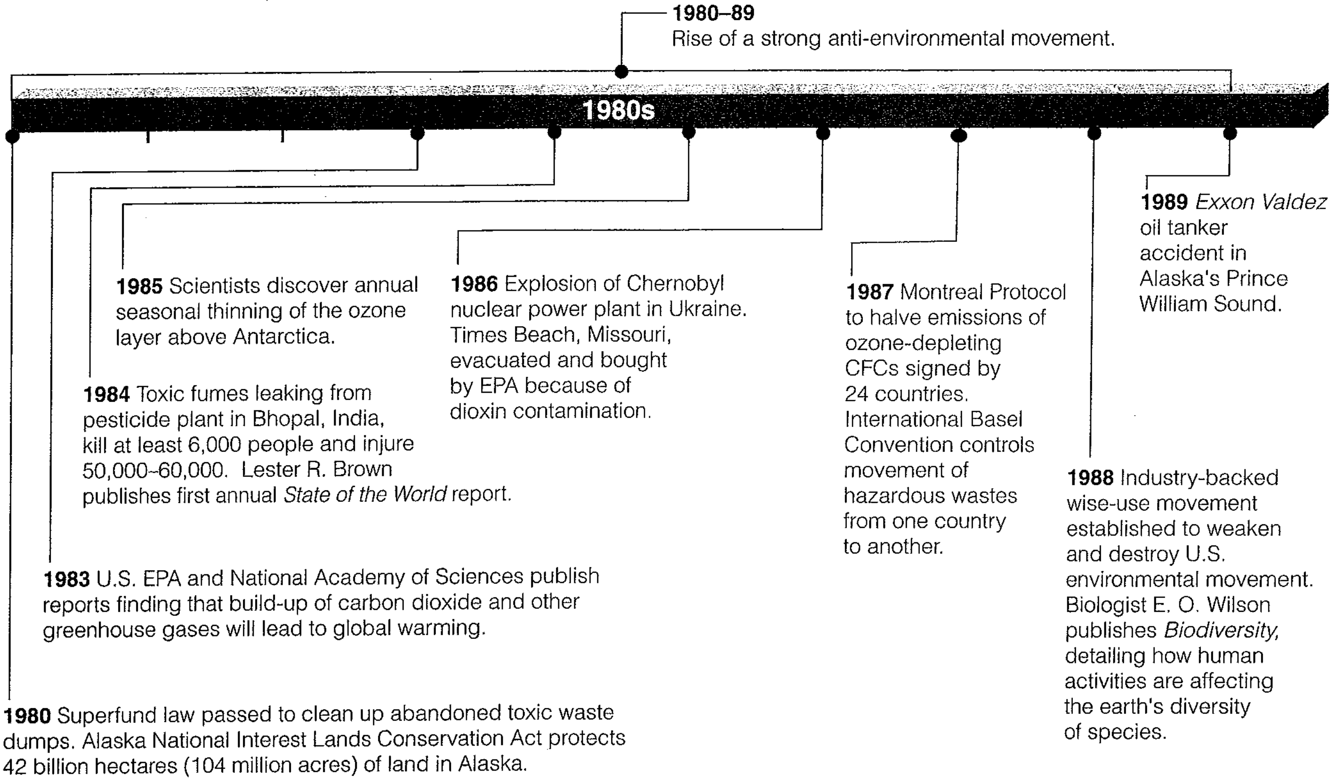


Figure 2-10 Some important environmental events during the 1980s.

the major goals of **(1)** weakening or repealing most of the country's environmental laws and **(2)** destroying the effectiveness of the environmental movement in the United States. Major tactics of the U.S. anti-environmental movement are summarized on the website for this book.

Upon his election in 1989, *George Bush* (born 1924) promised to be "the environmental president." However, he received criticism from environmentalists for

- Not providing leadership on such key environmental issues as population growth, global warming, and loss of biodiversity.
- Continuing support of exploitation of valuable resources on public lands at giveaway prices.
- Allowing some environmental laws to be undercut by the powerful influence of industry, mining, ranching, and real estate development officials.

What Happened from 1990 to 2002? Figure 2-11 lists some other significant environmental events between 1990 and 2002. In 1993, *Bill Clinton* (born 1946) became president and promised to provide national and global environmental leadership. During his 8 years in office he

- Appointed respected environmentalists to key positions in environmental and resource agencies.
- Consulted with environmentalists about environmental policy.
- Vetoed most of the anti-environmental bills (or other bills passed with anti-environmental riders attached) passed by a Republican-dominated Congress between 1995 and 2000.
- Announced regulations requiring sport utility vehicles (SUVs) to meet the same air pollution emission standards as cars.
- Used an executive order to make forest health the primary priority in managing national forests.
- Used an executive order to declare many roadless areas in national forests off limits to roads and logging.
- Used the Antiquities Act of 1906 to protect various parcels of public land in the West from development and resource exploitation as national monuments. He protected more public land as national monuments in the lower 48 states than any other president, including Teddy Roosevelt and Jimmy Carter.

Environmentalists criticized Clinton, however, for failing to push hard enough on key environmental issues such as global warming and global biodiversity protection.

During the 1990s, the anti-environmental movement strengthened because of **(1)** continuing support from its backers and **(2)** the 1994 federal election, which gave Republicans (many of whom were generally unsympathetic to environmental concerns) a majority in Congress.

For the most part, the 1990s were disappointing to environmentalists. They had to spend much of their time and funds **(1)** fighting efforts to discredit the environmental movement and to weaken or eliminate most environmental laws passed during the 1960s and 1970s and **(2)** countering claims by anti-environmental groups that major environmental problems such as global warming and ozone depletion are hoaxes or not very serious.

But during the 1990s,

- Many newer, smaller, and mostly local grassroots environmental organizations sprang up, mostly to deal with environmental threats in their local communities.
- Interest in environmental issues increased on many college campuses.
- Environmental studies programs at colleges and universities expanded.
- Awareness of important environmental issues such as sustainability, population growth, biodiversity protection, and threats from global warming increased.

In 2001, George W. Bush (born 1946) became president. Like President Reagan in the 1980s, he

- Appointed to key federal positions people who opposed or wanted to weaken many existing environmental and public and land use laws and policies.
- Did not consult seriously with environmental groups and leaders in developing his policies.
- Greatly increased private energy and mineral development and timber cutting on public lands.
- Cut federal funding for research on energy conservation and renewable energy resources and

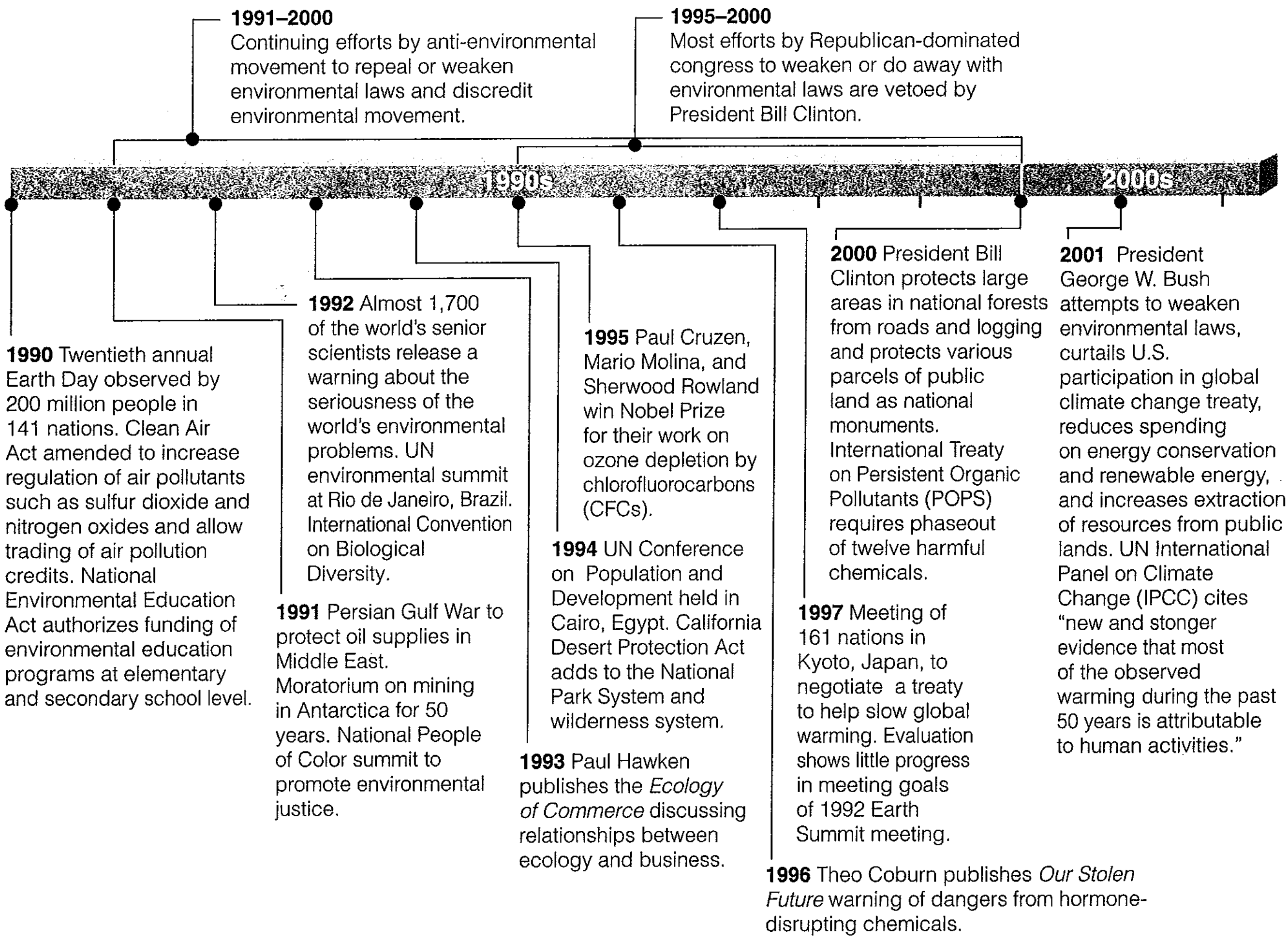


Figure 2-11 Some important environmental events, 1990–2002.

increased federal research spending for fossil fuels and nuclear power.

- Cut funding for the Environmental Protection Agency.
- Opposed increasing automobile gas mileage standards as a way to save energy and reduce dependence on oil imports.
- Supported the relaxing of various federal air and water quality pollution standards.
- Opposed U.S. participation in the international Kyoto treaty designed to reduce carbon dioxide emissions that can promote global warming.
- Repealed or tried to weaken most of the pro-environmental measures established by President Clinton.

Environmentalists and many citizens strongly opposed these measures.

What Are the Major Components of the Environmental Agenda for the 21st Century? Environmental leaders believe the five most important environmental issues to be faced in the 21st century are as follows:

- The threat of climate change and ecosystem and economic disruption from enhanced global warming
- Growing water shortages and political conflicts over water supplies in many local and regional areas
- Continuing population growth
- Continuing biodiversity loss
- Continuing poverty

Major goals of U.S. environmental organizations for the early part of the 21st century are to

- Focus on the five major problems just listed.
- Protect an additional 40 million hectares (100 million acres) of land in the United States.
- End commercial logging in U.S. national forests and use these forests primarily for recreation and conservation.
- Slow urban sprawl and build more livable and sustainable cities.
- Build enough public support for these and other environmental issues to counter opposition by the anti-environmental movement.
- Build a pro-environmental coalition in Congress by electing pro-environmental Democrats and Republicans to the U.S. Congress.
- Use the political and economic system to improve environmental quality by **(1)** phasing out environmentally harmful government subsidies, **(2)** replacing taxes on wealth and income with taxes on environmental pollution, and **(3)** having the market prices of all goods and services include their harmful environmental costs.

2-5 CASE STUDY: ALDO LEOPOLD AND HIS LAND ETHIC

Who Was Aldo Leopold? *Aldo Leopold* (Figure 2-12) is best known as a strong proponent of *land ethics,* a philosophy in which humans as part of nature have an ethical responsibility to preserve wild nature.

After earning a master's degree in forestry from Yale University, he joined the U.S. Forest Service. He became alarmed by overgrazing and land deterioration on public lands where he worked and convinced the United States was losing too much of its mostly untouched wilderness lands.

In 1933, Leopold became a professor at the University of Wisconsin and founded the profession of game management. In 1935, he was one of the founders of the Wilderness Society.

As years passed, he developed a deep understanding and appreciation for wildlife and urged us to include nature in our ethical concerns. Through his writings and teachings he became one of the founders of the *conservation* and *environmental movements* of the 20th century.

Leopold died in 1948 while fighting a brush fire at a neighbor's farm in central Wisconsin. His weekends of planting, hiking, and observing nature at his farm in Wisconsin provided material he used to write his most famous book, *A Sand County Almanac,* published posthumously in 1949. Since then more than 2 million copies of this important book have been sold.

What Is Leopold's Concept of Land Ethics? The following quotes from his writings reflect Leopold's land ethic and form the basis of many of the beliefs of the modern *environmental wisdom worldview* (p. 15)

> *All ethics so far evolved rest upon a single premise: that the individual is a member of a community of interdependent parts.*

> *That land is a community is the basic concept of ecology, but that land is to be loved and respected is an extension of ethics.*

Figure 2-12 Aldo Leopold (1887–1948) was a forester, writer, and conservationist. His book, *A Sand County Almanac* (published after his death), is considered an environmental classic that inspired the modern environmental movement. His *land ethic* expanded the role of humans as protectors of nature

The land ethic changes the role of Homo sapiens *from conqueror of the land-community to plain member and citizen of it.*

We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect.

Anything is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise.

Thank God, they cannot cut down the clouds!
HENRY DAVID THOREAU

REVIEW QUESTIONS

1. What were the key factors in the near extinction of the American bison from the Great Plains of the United States?

2. What are *hunter–gatherers,* and what were their major environmental impacts?

3. What is the *agricultural revolution?* What are its major benefits and environmental drawbacks?

4. What are *slash-and-burn cultivation* and *shifting cultivation?* Under what conditions can these practices be a sustainable form of agriculture?

5. What is the *industrial revolution?* What are its major benefits and environmental drawbacks?

6. What is the *information and globalization revolution?* What are its potential major benefits and environmental drawbacks?

7. What are the four major eras of environmental history in the United States?

8. What major events happened during the *tribal era* of environmental history in North America?

9. What major events happened during the *frontier era* of environmental history in the United States? What is the *frontier environmental worldview?* How did it contrast with the environmental worldview of some Native American cultures?

10. Summarize the contributions of *early conservationists* **(a)** Henry David Thoreau and **(b)** George Perkins Marsh.

11. What major environmental events happened during the *conservation era* of the environmental history of the United States between **(a)** 1870 and 1930 and **(b)** 1930 and 1960?

12. Summarize the major contributions of the following people during the *conservation era* of the environmental history of the United States: **(a)** John Muir, **(b)** Theodore Roosevelt, **(c)** Gifford Pinchot, **(d)** Alice Hamilton, and **(e)** Franklin D. Roosevelt.

13. Distinguish between *preservationists* and *conservationists.* Describe the ongoing controversy between these two groups in the environmental community.

14. What is the *environmental movement* in the United States? What major environmental events happened during the *environmental era* of the environmental history of the United States during the **(a)** 1960s, **(b)** 1970s, **(c)** 1980s, and **(d)** 1990s through 2002?

15. Summarize the major contributions of the following people during the *environmental era* of the environmental history of the United States: **(a)** Rachel Carson, **(b)** Jimmy Carter, and **(c)** Bill Clinton.

16. What is the *spaceship-earth environmental worldview?* What is the *sagebrush rebellion?* Describe what Ronald Reagan did during his presidency to further this movement and weaken environmental laws.

17. Describe why the 1990s through 2002 were largely disappointing for the environmental movement and encouraging for the anti-environmental movement in the United States.

18. What do environmental leaders believe are the five most important environmental issues we face during the 21st century?

19. What are seven major goals of the U.S. environmental movement during the early 21st century?

20. What major contributions did *Aldo Leopold* make to the environmental history of the United States? What is his *land ethic?*

CRITICAL THINKING

1. List the benefits and drawbacks of the *frontier environmental worldview.* List three major ways in which U.S. history might have been different without this worldview. Is this environmental worldview still useful today? Explain.

2. On balance do you believe the potential environmental benefits of the current *information and globalization revolution* will outweigh its potentially harmful environmental effects? Explain.

3. Summarize the major contributions of the following people to the conservation and environmental movements in the United States: **(a)** John Muir, **(b)** Theodore Roosevelt, **(c)** Franklin D. Roosevelt, **(d)** Rachel Carson, **(e)** Aldo Leopold, and **(f)** Jimmy Carter.

4. What one person do you believe has made the greatest and longest lasting contribution to the conservation and environmental movements in the United States? Explain.

5. Public forests, grasslands, wildlife reserves, parks, and wilderness areas are owned by all citizens and managed for them by federal and state governments in the United States. In terms of the management policies for most of these lands, would you classify yourself as a **(a)** preservationist, **(b)** conservationist, or **(c)** advocate of transferring most public lands to private enterprise? Explain.

6. Do you favor or oppose efforts to greatly weaken or repeal most U.S. environmental laws? Explain.

7. Explain why you agree or disagree with the seven major goals of U.S. environmental organizations during the early 21st century listed on p. 36.

8. Some analysts believe the world's remaining hunter–gatherer societies should be given title to the land on which they and their ancestors have lived for centuries and should be left alone by modern civilization. They contend that we have created protected reserves for endangered wild species, so why not create reserves for these endangered human cultures? What do you think? Explain.

PROJECTS

1. Use the library or Internet to analyze speeches and writings that indicate continuation of the frontier environmental worldview in American culture.

2. What major changes (such as a change from agricultural to industrial, from rural to urban, or changes in population size, pollution, and environmental degradation) have taken place in your locale during the past 50 years? On balance, have these changes improved or decreased **(a)** the quality of your life and **(b)** the quality of life for members of your community as a whole?

3. Use the library or Internet to summarize the major goals and accomplishments of the anti-environmental movement in the United States between 1980 and 2003.

4. Use the library or Internet to find bibliographic information about *Ernest Hemingway* and *Henry David Thoreau*, whose quotes appear at the beginning and end of this chapter.

5. Make a concept map of this chapter's major ideas using the section heads and subheads and the key terms (in boldface type). Look on the website for this book for information about making concept maps.

INTERNET STUDY RESOURCES AND RESOURCES FOR FURTHER READING AND RESEARCH

The website for this book contains helpful study aids and many ideas for further reading and research. Log on to

www.info.brookscole.com/miller13

and click on the Chapter-by-Chapter area. Choose Chapter 2 and select a resource:

- Flash Cards allows you to test your mastery of the Terms and Concepts to Remember for this chapter.
- Tutorial Quizzes provides a multiple-choice practice quiz.
- Student Guide to InfoTrac will lead you to Critical Thinking Projects that use InfoTrac College Edition as a research tool.
- References lists the major books and articles consulted in writing this chapter.
- Hypercontents takes you to an extensive list of sites with news, research, and images related to individual sections of the chapter.

INFOTRAC COLLEGE EDITION

Improve your skills with InfoTrac College Edition, a searchable online database of articles from more than 700 periodicals. Log on to

http://www.infotrac-college.com

or access InfoTrac through the website for this book. Try to find the following articles:

1. Grove, R. 2002. Climatic fears: Colonialism and the history of environmentalism. *Harvard International Review* 23: 50. *Keywords:* "history" and "environmentalism." Human-caused environmental problems are not new. The history of human exploration shows us that we have not learned the lessons of the past. However, today's problems are becoming more threatening.

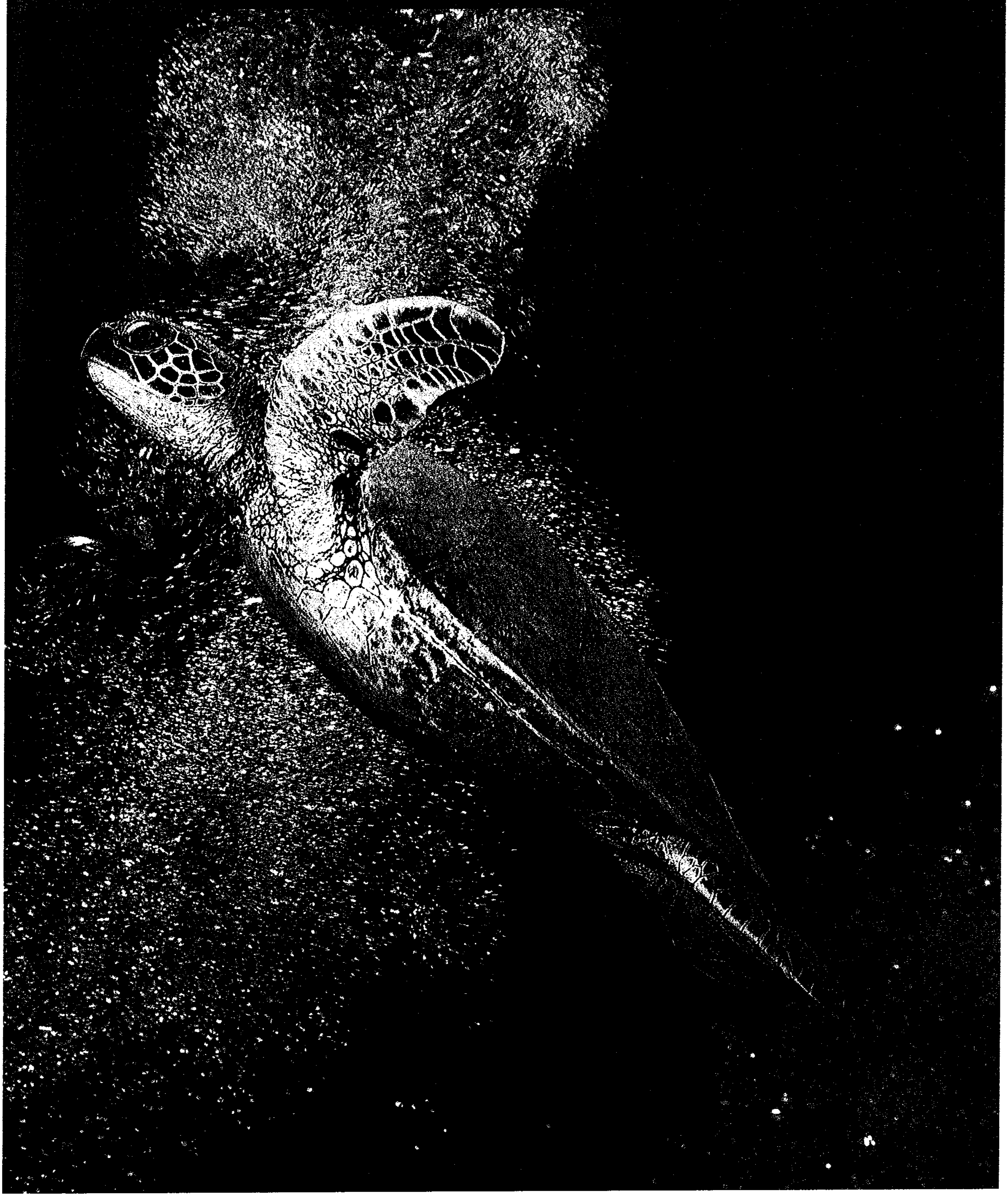
2. Bond, M. 2001. A new environment for Greenpeace. *Foreign Policy* (November–December): 66. *Keywords:* "history" and "Greenpeace." The group Greenpeace is synonymous with environmental activism. This article gives a brief history of the organization, from its founding in 1971 as a nonviolent grassroots protest group to a leading international NGO (nongovernment organization) with millions of members.

PART II

SCIENTIFIC PRINCIPLES AND CONCEPTS

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



3 SCIENCE, SYSTEMS, MATTER, AND ENERGY

Two Islands: Can We Treat This One Better?

Easter Island (Rapa Nui) is a small, isolated island in the great expanse of the South Pacific. It was first colonized by Polynesians about 2,500 years ago.

The civilization they developed was based on the island's towering palm trees, which were used for shelter, tools, fishing boats, fuel, food, rope, and clothing. Using these resources, they developed an impressive civilization and a technology capable of making and moving large stone structures, including their famous statues (Figure 3-1).

The people flourished, with the population peaking at about 10,000 (with estimates ranging from 7,000 to 20,000) by 1400. However, they used up the island's precious trees faster than they were regenerated—an example of the tragedy of the commons (p. 11). Each person who cut a tree reaped immediate personal benefits while helping doom the civilization in the long run.

Once the trees were gone, the islanders could not build canoes for hunting porpoises and catching fish. Without the forest to absorb and slowly release water, springs and streams dried up, exposed soils eroded, crop yields plummeted, and famine struck.

The starving people turned to warfare and possibly cannibalism. Both the population and the civilization collapsed. When Dutch explorers first reached the island on Easter Day, 1722, they found only about 2,000 inhabitants, struggling under primitive conditions on a mostly barren island.

Like Easter Island at its peak, the earth is an isolated island (in the vastness of space) with no other suitable planet to migrate to. As on Easter Island, our population and resource consumption are growing.

Will the humans on Earth Island recreate the tragedy of Easter Island on a grander scale, or will we learn how to live sustainably on this planet that is our only home? Some analysts believe that we **(1)** will not run out of resources and **(2)** are not living unsustainably. Other analysts disagree and warn that we **(1)** are already depleting or degrading some of the earth's natural resources in parts of the world and **(2)** need to learn how to live more sustainably over the next few decades.

Scientific knowledge is a key in evaluating these conflicting claims and learning how to live more sustainably. Thus we need to **(1)** know what science is, **(2)** understand the behavior of complex systems studied by scientists, and **(3)** have a basic knowledge of the nature of the matter and energy that make up the earth's living and nonliving resources.

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Figure 3-1 These massive stone figures on Easter Island are the remains of the technology created by an ancient civilization of Polynesians. This civilization collapsed because the people used up the trees (especially large palm trees) that were the basis of their livelihood. More than 200 of these stone statues once stood on huge stone platforms lining the coast. At least 700 additional statues were abandoned in rock quarries or on ancient roads between the quarries and the coast. No one knows how the early islanders (with no wheels, no draft animals, and no sources of energy except their own muscles) transported these gigantic structures for miles before erecting them. We presume they accomplished it by felling large trees and using them to roll and erect the statues.

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

This chapter addresses the following questions:

- What is science, and what do scientists do? What is critical thinking?
- What are major components and behaviors of complex systems?
- What are the basic forms of matter? What is matter made of? What makes matter useful to us as a resource?
- What are the major forms of energy? What makes energy useful to us as a resource?
- What are physical and chemical changes? What scientific law governs changes of matter from one physical or chemical form to another?
- What three main types of nuclear changes can matter undergo?
- What are two scientific laws governing changes of energy from one form to another?
- How are the scientific laws governing changes of matter and energy from one form to another related to resource use and environmental disruption?

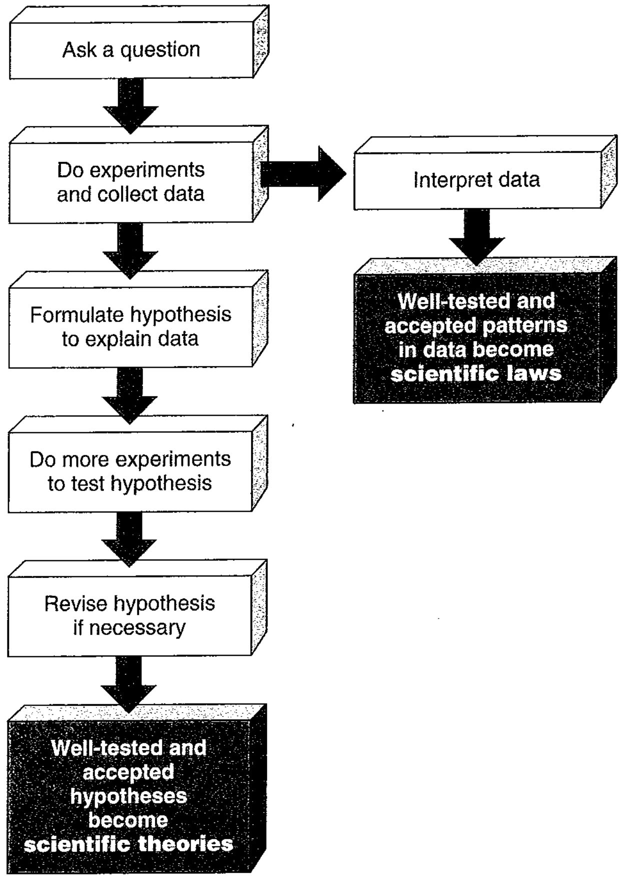


Figure 3-2 What scientists do.

3-1 SCIENCE AND CRITICAL THINKING

What Is Science and What Do Scientists Do? **Science** is an attempt to discover order in nature and use that knowledge to make predictions about what is likely to happen in nature. Figure 3-2 and the Guest Essay on p. 42 summarize the systematic version of the critical thinking process that scientists use.

The first thing scientists do is ask a question or identify a problem to be investigated. Then scientists working on this problem collect **scientific data,** or facts, by making observations and measurements. Repeated observations and measurements must confirm the resulting scientific data or facts, ideally by several different investigators.

The primary goal of science is not facts themselves but a new idea, principle, or model that **(1)** connects and explains certain scientific data and **(2)** leads to useful predictions about what is likely to happen in nature. Scientists working on a particular problem try to come up with a variety of possible or tentative explanations, or **scientific hypotheses,** of what they (or other scientists) observe in nature.

To be accepted, a scientific hypothesis must **(1)** explain scientific data and phenomena and **(2)** make predictions that can be tested by further experiments. One method scientists use to test a hypothesis is to develop a **model,** an approximate representation or simulation of a system being studied.

If repeated experiments or tests using models support a particular hypothesis or a group of related hypotheses, it becomes a **scientific theory.** In other words, a *scientific theory* is a verified, highly reliable, and widely accepted scientific hypothesis or a related group of scientific hypotheses.

To scientists, scientific theories are not to be taken lightly. They are not guesses, speculations, or suggestions. Instead, scientific theories are useful explanations of processes or natural phenomena that have a high degree of certainty because they are supported by extensive evidence.

A scientific theory is the closest thing to the "truth" or "absolute" proof that science can provide. New evidence or a better explanation may modify, or in rare cases overturn, a particular scientific theory. But unless or until this happens a scientific theory is the best and most reliable knowledge we have about how nature works.

Nonscientists often use the word *theory* incorrectly when they mean to refer to a *scientific hypothesis,*

GUEST ESSAY

Critical Thinking and Environmental Studies

Jane Heinze-Fry

Jane Heinze-Fry has a Ph.D. in environmental education and teaches environmental science and biology at Emerson College in Boston, Massachusetts. She is author of Critical Thinking and Environmental Studies: A Beginner's Guide *(with G. Tyler Miller as coauthor). Previously, she taught and directed environmental studies at Sweet Briar College in Virginia. She also taught biology to students at the junior high, high school, and college levels. Her interdisciplinary orientation is reflected in her concept maps, including the one inside the back cover and those on the website for this textbook.*

Learning how to think critically is essential in helping you evaluate the validity and usefulness of what you **(1)** read in newspapers, magazines, and books (such as this textbook), **(2)** hear in lectures and speeches, and **(3)** see and hear on the news and in advertisements.

Learners engaged in critical thinking try to

- Connect new knowledge to prior knowledge and experience.
- Evaluate the validity of claims made by people.
- Relate what they have learned to their own life experiences.
- Understand and evaluate their environmental worldviews.
- Take and defend positions on issues.
- Develop and implement strategies for dealing with problems.

Whenever we are faced with new information, we need to evaluate it by using critical thinking. Do we believe the information or not, and why? Do the claims seem reasonable or exaggerated? Here are some rules for evaluating scientific evidence and claims:

1. Gather all the information you can.
2. Understand the definitions of all key terms and concepts.
3. Question how the information (data) was obtained.
   - Were the studies well designed and carried out?
   - Was there an experimental group and a control group? Were the control and experimental groups treated identically except for the variable changed in the experimental group?
   - Did the investigators repeat their experiments several times and get essentially the same results?
   - Did one or more other investigators verify the results?
4. Question the conclusions derived from the data.
   - Do the data support the claims, conclusions, and predictions?

a tentative explanation that needs further evaluation. The statement, "Oh, that's just a theory," made in everyday conversation, implies a lack of knowledge and careful testing—the opposite of the scientific meaning of the word.

Another important result of science is a **scientific,** or **natural, law:** a description of what we find happening in nature over and over in the same way. For example, after making thousands of observations and measurements over many decades, scientists discovered the *second law of thermodynamics.* Simply stated, this law says that heat always flows spontaneously from hot to cold—something you learned the first time you touched a hot object. *Scientific laws* describe what we find happening in nature in the same way, whereas *scientific theories* are widely accepted explanations of data and laws.

A scientific law is no better than the accuracy of the observations or measurements upon which it is based. New or more accurate data may result in a scientific law being modified, or in rare cases overturned. However, scientific laws are highly reliable and well-tested descriptions of what we find occurring in nature.

How Do Scientists Learn About Nature? We often hear about *the* scientific method. In reality, many **scientific methods** exist: they are ways scientists gather data and formulate and test scientific hypotheses, models, theories, and laws (Figure 3-2, p. 41).

Here is an example of applying the scientific method to an everyday situation.

Observation: You walk into your bedroom at night and flick on the light switch. The light does not come on.

Question: Why did the light not come on?

Hypothesis: Maybe the power for the house is out.

Test the hypothesis: If the power is out, the lights in other rooms should also be out.

Experiment: To check this prediction, go to other rooms and click light switches.

Results: Lights in other rooms come on when their switches are clicked.

Conclusion: Power to whole house is not out.

- Are there other more reasonable interpretations?
- Do experts in the field involved base the conclusions on the results of original research, or are they drawn by reporters or scientists in other fields?
- Are the conclusions based on stories or reports of isolated events (*anecdotal information*) or on careful analysis of a large number of related observations?

5. Try to determine the assumptions and biases of the investigators and then question them.

- Do the investigators have a monetary or political advantage in the outcome of the investigation or issue involved?
- Would investigators with different basic assumptions or worldviews take the same data and come to different conclusions?

6. Are the data, claims, and conclusions based on the tentative results of *frontier science* or the more reliable and widely accepted results of *consensus science?*

7. Based on these steps, take a position by either rejecting or conditionally accepting the claims.

Other ways to improve your critical thinking skills involve using

- *Thinking strategies* such as constructing models, brainstorming, creating alternative solutions, and visualizing future possibilities.
- *Attitude and value strategies* such as reflecting on the effects of your lifestyle on the environment and understanding and evaluating your environmental worldview.
- *Action strategies* such as evaluating alternative solutions, creating plans of action, and developing strategies for implementing action plans.

In the environmental course you are taking, you will have many opportunities to develop your critical thinking skills. Your textbook offers Critical Thinking questions at the ends of chapters and in most boxes. If your course uses the supplement *Critical Thinking and Environmental Studies: A Beginner's Guide*, you will learn the critical thinking strategies mentioned here.

Critical Thinking

1. Can you come up with an example in which critical thinking has helped you make a major change in one or more of your beliefs or helped you make an important personal decision? Can you think of a decision that may have come out better if you had used critical thinking skills such as those discussed in this essay?

2. Rote learning often involves the "memorize and spit back" strategy. Meaningful learning (including critical thinking) goes far beyond memorization and requires us to evaluate the validity of what we learn. Currently, about what percentage of your learning involves rote learning and what percentage involves critical thinking as discussed in this essay?

New hypothesis: Maybe the light bulb is burned out.

Experiment: Replace bulb with a new bulb.

Results: Light comes on when switch is flicked.

Conclusion: Second hypothesis is verified.

Situations in nature are usually much more complicated than this. A number of *variables* or *factors* influence most processes or parts of nature that scientists seek to understand. Ideally, scientists conduct a *controlled experiment* to isolate and study the effect of a single variable. This *single-variable analysis* is done by setting up two groups: **(1)** an *experimental group,* in which the chosen variable is changed in a known way, and **(2)** a *control group,* in which the chosen variable is not changed. If the experiment is designed properly, any difference between the two groups should result from a variable that was changed in the experimental group (Connections, p. 44).

A basic problem is that many of the problems environmental scientists investigate involve a huge number of interacting variables. This limitation is overcome in some cases by using *multivariable analysis.* This involves using mathematical models run on high-speed computers to analyze the interactions of many variables without having to carry out traditional controlled experiments.

What Types of Reasoning Do Scientists Use? Scientists arrive at certain conclusions with varying degrees of certainty by using inductive and deductive reasoning. **Inductive reasoning** involves using specific observations and measurements to arrive at a general conclusion or hypothesis. In other words, it is a form of *"bottom-up" reasoning* that involves going from the specific to the general. For example, suppose we observe that a variety of different objects fall to the ground when we drop them from various heights. We might then use inductive reasoning to conclude that *all objects fall to the earth's surface when dropped.* Depending on the number of observations made there may be a high degree of certainty in this conclusion. However, what we are really saying is that "All of the objects that we or other observers have dropped from various heights fall to the earth's surface." Although it is extremely

CONNECTIONS

What Is Harming the Robins?

Suppose a scientist observes an abnormality in the growth of robin embryos in a certain area. She knows the area has been sprayed with a pesticide and suspects the chemical may be causing the abnormalities she has observed.

To test this hypothesis, the scientist carries out a *controlled experiment.* She maintains two groups of robin embryos of the same age in the laboratory. Each group is exposed to exactly the same conditions of light, temperature, food supply, and so on, except the embryos in the experimental group are exposed to a known amount of the pesticide in question.

The embryos in both groups are then examined over an identical period of time for the abnormality. If she finds a significantly larger number of the abnormalities in the experimental group than in the control group, the results support the idea that the pesticide is the culprit.

To be sure no errors occur during the procedure, the original researcher should repeat the experiment several times. Ideally one or more other scientists should repeat the experiment on an independent basis.

Critical Thinking

Can you find flaws in this experiment that might lead you to question the scientist's conclusions? (*Hint:* What other factors in nature—not the laboratory—and in the embryos themselves could possibly explain the results?)

unlikely, we cannot be absolutely sure someone will drop an object that does not fall to the earth's surface. When scientists say that something has been proved or established by inductive reasoning, they do not mean it is absolutely true but that a very high probability or degree of certainty exists that it is true.

Deductive reasoning involves using logic to arrive at a specific conclusion based on a generalization or premise. In other words, it is a form of *"top-down"* reasoning that goes from the general to the specific. For example,

Generalization or premise: All birds have feathers.

Example: Eagles are birds.

Deductive conclusion: All eagles have feathers.

This conclusion of this *syllogism* (a series of logically connected statements) is valid as long as **(1)** the premise is correct, and **(2)** we do not use faulty logic to arrive at the conclusion.

Deductive and inductive reasoning are important scientific tools. But scientists also try to come up with new or creative ideas to explain some of the things we observe in nature. Often such ideas defy conventional logic and current scientific knowledge. According to physicist Albert Einstein, "There is no completely logical way to a new scientific idea." Intuition, imagination, and creativity are as important in science as they are in poetry, art, music, and other great adventures of the human spirit.

How Valid Are the Results of Science? Scientists can do two major things: **(1)** disprove things, and **(2)** establish that a particular model, theory, or law has a very high probability or degree of certainty of being true. However, like scholars in any field, scientists cannot prove their theories, models, and laws are *absolutely* true.

When people say something has or has not been "scientifically proven," they can mislead us by falsely implying that science yields absolute proof or certainty. Although it may be extremely low, some degree of uncertainty is always involved in any scientific theory, model, or law.

How Does Frontier Science Differ from Consensus Science? News reports often focus on **(1)** new so-called scientific breakthroughs and **(2)** disputes between scientists over the validity of preliminary (untested) data, hypotheses, and models. These preliminary results, called **frontier science,** are controversial because they have not been widely tested and accepted. At the preliminary frontier stage, it is normal and healthy for reputable scientists in a field to disagree about **(1)** the meaning and accuracy of scientific data and **(2)** the validity of various hypotheses.

By contrast, **consensus science** consists of data, theories, and laws that scientists who are considered experts in the field involved widely accept. This aspect of science is very reliable but is rarely considered newsworthy. One way to find out what scientists generally agree on is to seek out reports by scientific bodies such as the U.S. National Academy of Sciences and the British Royal Society that attempt to summarize consensus among experts in key areas of science.

3-2 MODELS AND BEHAVIOR OF SYSTEMS

What Is a System, and What Are Its Major Components? A **system** is a set of components that **(1)** function and interact in some regular and theoretically predictable manner and **(2)** can be isolated for the purposes of observation and study. The environment consists of a vast number of interacting systems involving living and nonliving things.

Most *systems* have the following key components:

- **Inputs** of things such as matter, energy, or information into the system.
- **Flows,** or **throughputs,** of matter, energy, or information within the system at certain rates.
- **Stores,** or **storage areas,** within a system where energy, matter, or information can accumulate for various lengths of time before being released. For example, your body stores various chemicals with different residence times, and water vapor typically remains in the lower atmosphere for about 10 days before it is replaced.
- **Outputs** of certain forms of matter, energy, or information that flow out of the system into *sinks* in the environment (such as the atmosphere, bodies of water, underground water, soil, and land surfaces).

Why Are Models of Complex Systems Useful? Over time, people have learned the value of using models as approximate representations or simulations of real systems to **(1)** find out how systems work and **(2)** evaluate which ideas or hypotheses work.

Some of the most powerful and useful technologies invented by humans are mathematical models, which are used to supplement our mental models. *Mathematical models* consist of one or more equations used to **(1)** describe the behavior of a system and **(2)** make predictions about the behavior of a system.

Making a mathematical model usually requires going many times through three steps: **(1)** Make a guess and write down some equations, **(2)** compute the predictions implied by the equations, and **(3)** compare the predictions with observations, the predictions of mental models, existing experimental data, and scientific hypotheses, laws, and theories.

Mathematical models are important because they can give us improved perceptions and predictions, especially in situations where our mental models are weak. Research has shown that mental models tend to be especially unreliable when **(1)** there are many interacting variables, **(2)** consequences follow actions only after long delays, **(3)** consequences of actions lead to other consequences, **(4)** responses vary from one time to the next, and **(5)** controlled experiments (Connections, p. 44) are impossible, too slow, or too expensive to conduct.

After building and testing a mathematical model, scientists use it to predict what is *likely* to happen under a variety of conditions. In effect, they use mathematical models to answer *if–then* questions: "*If* we do such and such, *then* what is likely to happen now and in the future?"

Despite its usefulness, a mathematical model is nothing more than a set of hypotheses or assumptions about how we think a certain system works. Such models (like all other models) are no better than **(1)** the assumptions built into them and **(2)** the data fed into them to make projections about the behavior of complex systems.

How Do Feedback Loops Affect Systems? Systems undergo change as a result of feedback loops. A **feedback loop** occurs when an output of matter, energy, or information is fed back into the system as an input that changes the system.

There are two types of feedback loops:

- A **positive feedback loop** in which a change in a certain direction provides information that causes a system to change further in the same direction. An example involves depositing money in a bank at compound interest and leaving it there. In this case, the interest increases the balance, which through a positive feedback loop leads to more interest and an even higher balance.
- A **negative feedback loop** in which one change leads to a lessening of that change. For example, recycling aluminum cans involves melting aluminum and feeding it back into an economic system to make new aluminum products. This negative feedback loop of matter reduces the **(1)** need to find, extract, and process virgin aluminum ore and **(2)** flow of waste matter (discarded aluminum cans) into the environment.

Most systems contain one or a series of *coupled positive and negative feedback loops.* For example, the temperature-regulating system of your body involves coupled negative and positive feedback loops (Figure 3-3, p. 46). Normally a negative feedback regulates your body temperature. However, if your body temperature exceeds 42°C (108°F), your built-in negative feedback temperature control system breaks down as your body produces more heat than your sweat-dampened skin can get rid of. Then a positive feedback loop caused by overloading the system (Figure 3-3, p. 46) overwhelms the negative or corrective feedback loop. These conditions produce a net gain in body heat, which produces even more body heat, and so on, until you die from heatstroke.

The tragedy on Easter Island discussed earlier (p. 40) also involved the coupling of positive and negative feedback loops. As the abundance of trees turned to a shortage of trees, the positive feedback loop (more births than deaths) became weaker as death rates rose, and the negative feedback loop (more deaths than births) eventually dominated and caused a dieback of the human population.

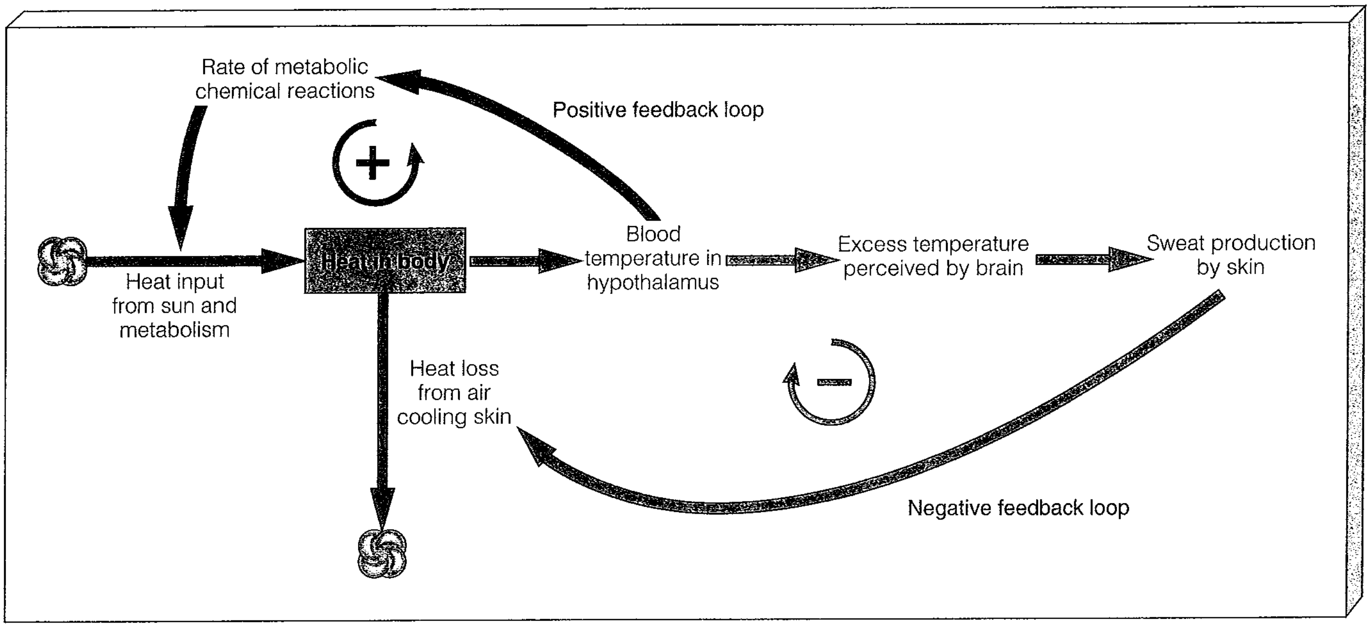


Figure 3-3 Coupled negative and positive feedback loops involved in temperature control of the human body.

How Do Time Delays Affect Complex Systems? Complex systems often show **time delays** between the input of a stimulus and the response to it. A long time delay can mean that corrective action comes too late. For example, a smoker exposed to cancer-causing chemicals in cigarette smoke may not get lung cancer for 20–30 years.

Time delays allow a problem to build up slowly until it reaches a *threshold level* and causes a fundamental shift in the behavior of a system. Examples in which prolonged delays dampen the negative feedback mechanisms that might slow, prevent, or halt environmental problems are **(1)** population growth, **(2)** leaks from toxic waste dumps, and **(3)** degradation of forests from prolonged exposure to air pollutants.

What Is Synergy, and How Can It Affect Complex Systems? In arithmetic, 1 plus 1 always equals 2. However, in some of the complex systems found in nature, 1 plus 1 may add up to more than 2 because of synergistic interactions. A **synergistic interaction** occurs when two or more processes interact so the combined effect is greater than the sum of their separate effects.

Synergy can result when two people work together to accomplish a task. For example, suppose you and I need to move a 140-kilogram (300-pound) tree that has fallen across the road. By ourselves, each of us can lift only, say, 45 kilograms (100 pounds). If we cooperate and use our muscles properly, however, together we can move the tree out of the way. That is using synergy to solve a problem. Research in the social sciences suggests that most political changes or changes in cultural beliefs are brought about by only about 5% (and rarely more than 10%) of a population working together (synergizing) and expanding their efforts to influence other people.

What Is the Law of Conservation of Problems? Biologist Eric Davidson has proposed a law of technodynamics that he calls the *law of conservation of problems.* According to this law, the technological solution of one problem usually creates one or more new unanticipated problems. The reason is that nature's natural systems are connected, so solving a problem by changing one part of a system can affect other parts or other connected systems in unpredictable and sometimes undesirable ways.

For example, modern technology provides cheap chemical fertilizers that can increase crop productivity and replace some of the plant nutrients lost by erosion and poor farming practices. However, the widespread use of such fertilizers creates the new problem of pollution of streams, lakes, and underground water supplies with excess inputs of plant nutrients. In addition, the new water pollution problem is not a local problem confined to a farmer's field. Instead, it becomes a regional problem that affects people who live downstream or who extract and drink polluted groundwater.

The question we face in introducing new technologies and chemicals is: Do the projected or actual *beneficial* effects outweigh the projected or actual *harmful* effects? As we shall see in this book, this is not an easy question to answer because of **(1)** a lack of data, **(2)** imperfect models, and **(3)** different assumptions or beliefs by people about what is considered harmful or beneficial.

How Can We Anticipate Environmental Surprises? One of the basic principles of environmental science is that *we can never do one thing*. Any action in a complex system has multiple and often unpredictable effects.

In recent years, we have experienced unforeseen *environmental surprises*. Two examples are **(1)** sudden dying of large areas of forest after years of exposure to air and soil pollutants and **(2)** a rapid decline in the health of coral reefs.

Environmental surprises are the result of

- *Discontinuities*, or abrupt shifts in a previously stable system when some *environmental threshold* is crossed. By analogy, you may be able to lean back in a chair and balance yourself on two of its legs for a long time with only minor adjustments. But if you pass a certain threshold of movement, your balanced system suffers a discontinuity or sudden shift and you may find yourself on the floor.
- *Synergistic interactions*, in which two or more factors interact to produce effects greater than the sum of their effects acting separately.
- *Unpredictable or chaotic events* such as **(1)** hurricanes, **(2)** earthquakes, **(3)** invasions of ecosystems by nonnative species, or **(4)** slowly building but so far unknown environmental problems (such as gradual buildup of some potentially harmful chemicals in human fatty tissue).

Strategies to help deal with and reduce such surprises include the following:

- Greatly increasing research on environmental thresholds and synergistic interactions
- Developing better models to understand the behavior of complex living systems and our economic and political systems
- Formulating scenarios of possible environmental surprises and developing a range of strategies for dealing with them (as defense departments and emergency management agencies do)
- Acting to prevent or lessen the effects of possible surprises through **(1)** pollution prevention, **(2)** more efficient and environmentally benign use of resources, and **(3)** reduced population growth

3-3 MATTER: FORMS, STRUCTURE, AND QUALITY

What Are Nature's Building Blocks? Matter is anything that has mass (the amount of material in an object) and takes up space. Matter is found in two *chemical forms:*

- **Elements:** the distinctive building blocks of matter that make up every material substance
- **Compounds:** two or more different elements held together in fixed proportions by attractive forces called *chemical bonds*

Various elements, compounds, or both can be found together in **mixtures.**

All matter is built from the 115 known chemical elements (92 of them occur naturally and the other 23 have been synthesized in laboratories). To simplify things, chemists represent each element by a one- or two-letter symbol. Examples used in this book are hydrogen (H), carbon (C), oxygen (O), nitrogen (N), phosphorus (P), sulfur (S), chlorine (Cl), fluorine (F), bromine (Br), sodium (Na), calcium (Ca), lead (Pb), mercury (Hg), arsenic (As), and uranium (U). Chemists have developed a way to classify elements in terms of their chemical behavior by arranging them in a *periodic table of elements*, as discussed in Appendix 2.

If you had a supermicroscope capable of looking at individual elements and compounds, you could see they are made up of three types of building blocks:

- **Atoms:** the smallest units of matter that are unique to a particular element
- **Ions:** electrically charged atoms or combinations of atoms
- **Molecules:** combinations of two or more atoms of the same or different elements held together by chemical bonds

Some elements are found in nature as molecules. Examples are nitrogen and oxygen, which together make up about 99% of the volume of air you breathe. Two atoms of nitrogen (N) combine to form a gaseous molecule, with the shorthand formula N_2 (read as "N-two"). The subscript after the element's symbol indicates the number of atoms of that element in a molecule. Similarly, most of the oxygen gas in the atmosphere exists as O_2 (read as "O-two") molecules. A small amount of oxygen, found mostly in the second layer of the atmosphere (stratosphere), exists as O_3 (read as "O-three") molecules, a gaseous form of oxygen called *ozone*.

What Are Atoms Made Of? If you increased the magnification of your supermicroscope, you would find that each different type of atom contains a certain number of *subatomic particles*. The main building blocks of an atom are **(1)** positively charged **protons** (p), **(2)** uncharged **neutrons** (n), and **(3)** negatively charged **electrons** (e).

Each atom consists of **(1)** an extremely small center, or **nucleus,** containing protons and neutrons, and **(2)** one or more electrons in rapid motion somewhere outside the nucleus. Atoms are incredibly small. For example, more than 3 million hydrogen atoms could sit side by side on the period at the end of this sentence.

Each atom has an equal number of positively charged protons (inside its nucleus) and negatively charged electrons (outside its nucleus). Because these electrical charges cancel one another, *the atom as a whole has no net electrical charge.*

Each element has its own specific **atomic number,** equal to the number of protons in the nucleus of each of its atoms. 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 atoms are electrically neutral, the atomic number of an atom tells us the number of positively charged protons in its nucleus and the equal number of negatively charged electrons outside its nucleus. For example, an atom of uranium with an atomic number of 92 has 92 protons in its nucleus and 92 electrons outside, and thus no net electrical charge.

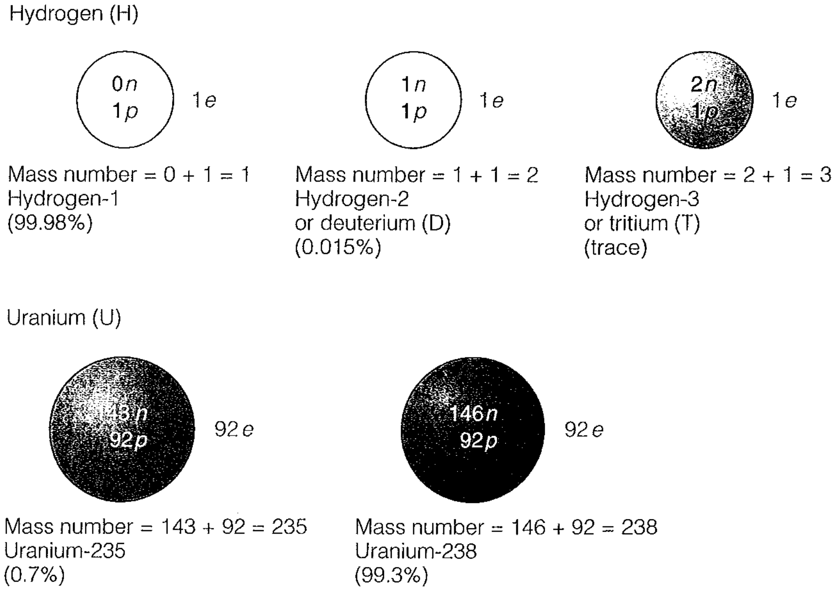


Figure 3-4 Isotopes of hydrogen and uranium. All isotopes of hydrogen have an atomic number of 1 because each has one proton in its nucleus; similarly, all uranium isotopes have an atomic number of 92. However, each isotope of these elements has a different mass number because its nucleus contains a different number of neutrons. Figures in parentheses indicate the percentage abundance by weight of each isotope in a natural sample of the element.

Because electrons have so little mass compared with the mass of a proton or a neutron, *most of an atom's mass is concentrated in its nucleus.* The mass of an atom is described in terms of its **mass number:** the total number of neutrons and protons in its nucleus. For example, **(1)** a hydrogen atom with 1 proton and no neutrons in its nucleus has a mass number of 1, and **(2)** an atom of uranium 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. However, they may have different numbers of uncharged neutrons in their nuclei, and thus may have different mass numbers. Various forms of an element having the same atomic number but a different mass number are called **isotopes** of that element. Isotopes are identified by attaching their mass numbers to the name or symbol of the element. For example, hydrogen has three isotopes: hydrogen-1 (H-1), hydrogen-2 (H-2, common name *deuterium,*) and hydrogen-3 (H-3, common name *tritium.*) A natural sample of an element contains a mixture of its isotopes in a fixed proportion or percentage abundance by weight (Figure 3-4).

What Are Ions? Atoms of some elements can lose or gain one or more electrons to form *ions:* atoms or groups of atoms with one or more net positive (+) or negative (−) electrical charges. For example, an atom of 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). An atom of chlorine (Cl, with an atomic number of 17) can gain an electron and become a chlorine ion with a negative charge of 1 (Cl^-) because it then has 17 positively charged protons and 18 negatively charged electrons.

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 of other ions encountered in this book are **(1)** positive hydrogen ions (H^+), calcium ions (Ca^{2+}), and ammonium ions (NH_4^+), and **(2)** negative nitrate ions (NO_3^-), sulfate ions (SO_4^{2-}), and phosphate ions (PO_4^{3-}).

The amount of a substance in a unit volume of air, water, or other medium is called its **concentration.** The concentration of hydrogen ions (H^+) in a water solution is a measure of its acidity or alkalinity. **pH** is a measure of the concentration of H^+ in a water solution. On a *pH scale* of 0 to 14, *acids* have a pH less than 7, *bases* have a pH greater than 7, and a *neutral solution* has a pH of 7 (Figure 3-5).

What Holds the Atoms and Ions in Compounds Together? Most matter exists as *compounds.* Chemists use a shorthand **chemical formula** to show the number of atoms (or ions) of each type in a compound. The formula **(1)** contains the symbols for each of the elements present and **(2)** uses subscripts to represent the number of atoms or ions of each element in the compound's basic structural unit. Compounds made up of oppositely charged ions are called *ionic compounds.*

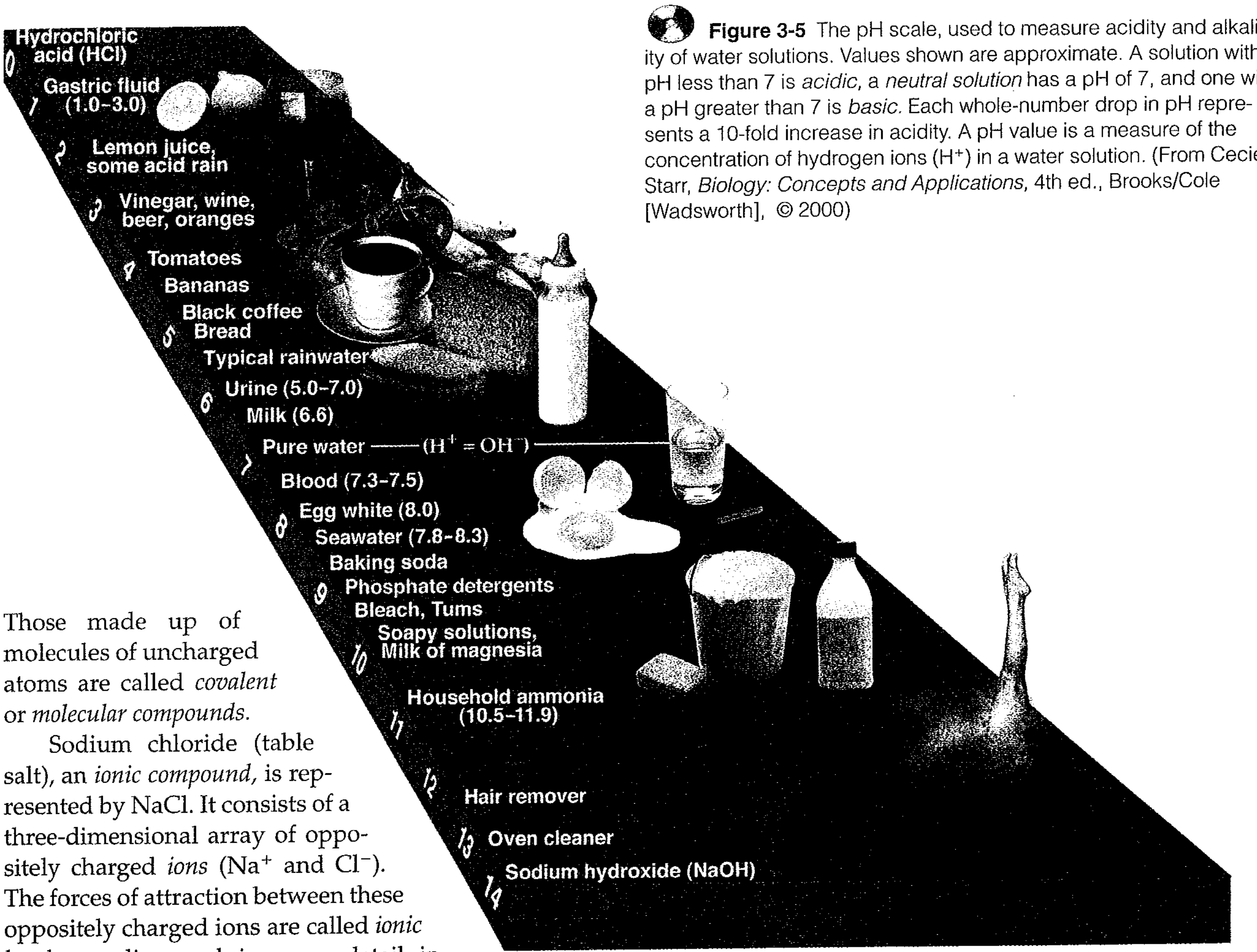


Figure 3-5 The pH scale, used to measure acidity and alkalinity of water solutions. Values shown are approximate. A solution with a pH less than 7 is *acidic*, a *neutral solution* has a pH of 7, and one with a pH greater than 7 is *basic*. Each whole-number drop in pH represents a 10-fold increase in acidity. A pH value is a measure of the concentration of hydrogen ions (H^+) in a water solution. (From Cecie Starr, *Biology: Concepts and Applications*, 4th ed., Brooks/Cole [Wadsworth], © 2000)

Those made up of molecules of uncharged atoms are called *covalent* or *molecular compounds.*

Sodium chloride (table salt), an *ionic compound,* is represented by NaCl. It consists of a three-dimensional array of oppositely charged *ions* (Na^+ and Cl^-). The forces of attraction between these oppositely charged ions are called *ionic bonds,* as discussed in more detail in Appendix 2.

Water, a *covalent* or *molecular 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 (read as "H-two-O") molecules. The bonds between the atoms in such molecules are called *covalent bonds,* as discussed in Appendix 2. There are also weaker forces of attraction, called *hydrogen bonds,* between the molecules of covalent compounds (such as water), as discussed in Appendix 2.

What Are Organic and Inorganic Compounds? Table sugar, vitamins, plastics, aspirin, penicillin, and many other important materials have one thing in common: They are **organic compounds,** containing carbon atoms combined with each other and with atoms of one or more other elements such as hydrogen, oxygen, nitrogen, sulfur, phosphorus, chlorine, and fluorine. Almost all organic compounds are molecular compounds held together by covalent bonds. Organic compounds can be either *natural* or *synthetic* (such as plastics and many drugs made by humans).

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.
- *Chlorinated hydrocarbons:* compounds of carbon, hydrogen, and chlorine atoms. Examples are **(1)** the insecticide DDT ($C_{14}H_9Cl_5$) and **(2)** toxic polychlorinated biphenyls, or PCBs (such as $C_{12}H_5Cl_5$), oily compounds used as insulating materials in electric transformers.
- *Chlorofluorocarbons* (CFCs): compounds of carbon, chlorine, and fluorine atoms. An example is Freon-12 (CCl_2F_2), until recently widely used as **(1)** a coolant in refrigerators and air conditioners, **(2)** an aerosol propellant, and **(3)** a foaming agent for making some plastics.
- *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.

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 cars linked in a freight train. The three major types of organic polymers are **(1)** *complex carbohydrates* consisting of two or more monomers of simple sugars (such as glucose) linked together, **(2)** *proteins* formed by linking together monomers of amino acids, and **(3)** *nucleic acids,* such as DNA and RNA, made by linked sequences of monomers called nucleotides, as discussed in Appendix 2.

Genes consist of specific sequences of nucleotides in a DNA molecule. Each gene carries codes (each consisting of three nucleotides) needed to make various proteins. These coded units of genetic information about specific traits are passed on from parents to offspring during reproduction.

Chromosomes are combinations of genes that make up 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. The relationships of genetic material to cells are depicted in Figure 3-6.

All other compounds are called **inorganic compounds.** Such compounds do not have carbon–carbon or carbon–hydrogen covalent bonds. Some of the inorganic compounds discussed in this book are sodium chloride ($NaCl$), water (H_2O), nitrous oxide (N_2O), nitric oxide (NO), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ammonia (NH_3), hydrogen sulfide (H_2S), sulfuric acid (H_2SO_4), and nitric acid (HNO_3).

What Are Four States of Matter? The atoms, ions, and molecules that make up matter are found in three *physical states:* solid, liquid, and gas. For example, water exists as ice, liquid water, or water vapor depending on its temperature and pressure. The three physical states of matter differ in the spacing and orderliness of its atoms, ions, or molecules, with solids having the most compact and orderly arrangement and gases the least compact and orderly arrangement (Figure 3-7).

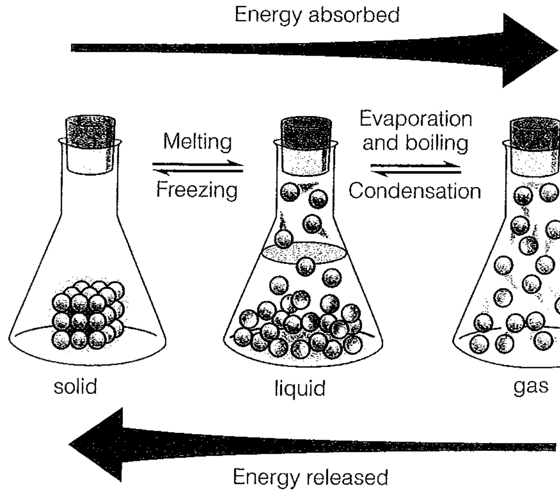


Figure 3-7 Comparison of the solid, liquid, and gaseous physical states of matter.

A fourth state of matter is called **plasma:** a high energy mixture of roughly equal numbers of positively charged ions and negatively charged electrons. A plasma is formed when enough energy is applied to strip electrons away from the nuclei of atoms.

Plasma is the most abundant form of matter in the universe. The sun and all stars consist mostly of plasma. However, there is little natural plasma on the earth, with most of it found in lightning bolts and flames.

However, artificial plasmas are **(1)** produced in fluorescent lights, arc lamps, neon signs, gas discharge lasers, and in TV and computer screens, by running a high voltage electric current through a gas **(2)** used in arc torches to weld, cut, and process many

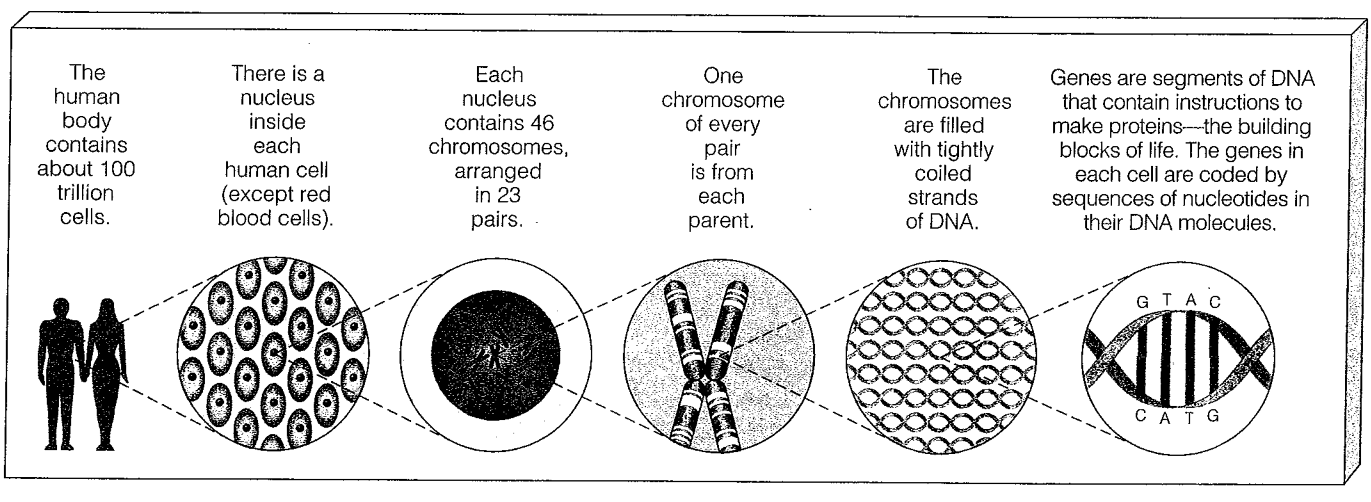


Figure 3-6 Relationships among cells, nuclei, chromosomes, DNA, and genes.

materials, and **(3)** used to make integrated circuits, solar cells, artificial diamonds, and high temperature superconductors.

Scientists hope to be able to develop affordable plasma torches that can **(1)** destroy toxic wastes, **(2)** sterilize and clean water, **(3)** remove soot from exhaust gases, and **(4)** produce clean burning hydrogen gas from diesel fuel, gasoline, or methane for use in fuel cells.

What Are Matter Quality and Material Efficiency? **Matter quality** is a measure of how useful a form of matter is to us as a resource, based on its availability and concentration. **High-quality matter (1)** is concentrated, **(2)** usually is found near the earth's surface, and **(3)** has great potential for use as a matter resource. **Low-quality matter (1)** is dilute, **(2)** often is deep underground or dispersed in the ocean or the atmosphere, and **(3)** usually has little potential for use as a matter resource (Figure 3-8).

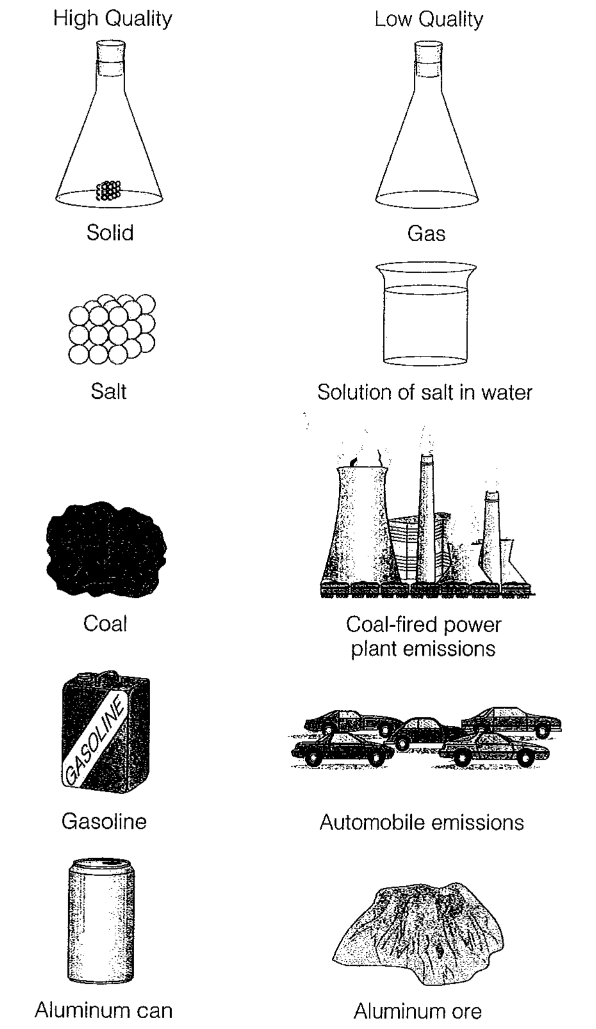


Figure 3-8 Examples of differences in matter quality. High-quality matter (left-hand column) is fairly easy to extract and concentrated; low-quality matter (right-hand column) is more difficult to extract and more dispersed than high-quality matter.

An aluminum can is a more concentrated, higher-quality form of aluminum than aluminum ore containing the same amount of aluminum. That is why it takes less energy, water, and money to recycle an aluminum can than to make a new can from aluminum ore.

Material efficiency, or **resource productivity,** is the total amount of material needed to produce each unit of goods or services. Although resource productivity has been improving, only about 2–6% of the matter resources flowing through the economies of developed countries ends up providing useful goods and services. Because of such waste, business expert Paul Hawken (Guest Essay, p. 16) and physicist Amory Lovins contend that resource productivity in developed countries could be improved by 75–90% within two decades using existing technologies.

3-4 ENERGY: FORMS AND QUALITY

What Is Energy and How Is It Transmitted? **Energy** is the capacity to do work and transfer heat. Work is performed when an object—be it a grain of sand, this book, or a giant boulder—is moved over some distance. Work, or matter movement, also is needed to **(1)** boil water or **(2)** burn natural gas to heat a house or cook food. Energy is also the heat that flows automatically from a hot object to a cold object when they come in contact. **Radiation** is the transmission of energy through space as particles or waves.

What Is the Difference Between Kinetic Energy and Potential Energy? Two major types of energy are

- **Kinetic energy,** which matter has because of its mass and its speed or velocity. Examples of this energy in motion are **(1)** wind (a moving mass of air), **(2)** flowing streams, **(3)** heat flowing from a body at a high temperature to one at a lower temperature, and **(4)** electricity (flowing electrons).

- **Potential energy,** which is stored and potentially available for use. Examples of this stored energy are **(1)** a rock held in your hand, **(2)** an unlit stick of dynamite, **(3)** still water behind a dam, **(4)** the chemical energy stored in gasoline molecules, and **(5)** the nuclear energy stored in the nuclei of atoms.

Potential energy can be changed to kinetic energy. When you drop a rock, its potential energy changes into kinetic energy. When you burn gasoline in a car engine, the potential energy stored in the chemical bonds of its molecules changes into heat, light, and mechanical (kinetic) energy that propels the car.

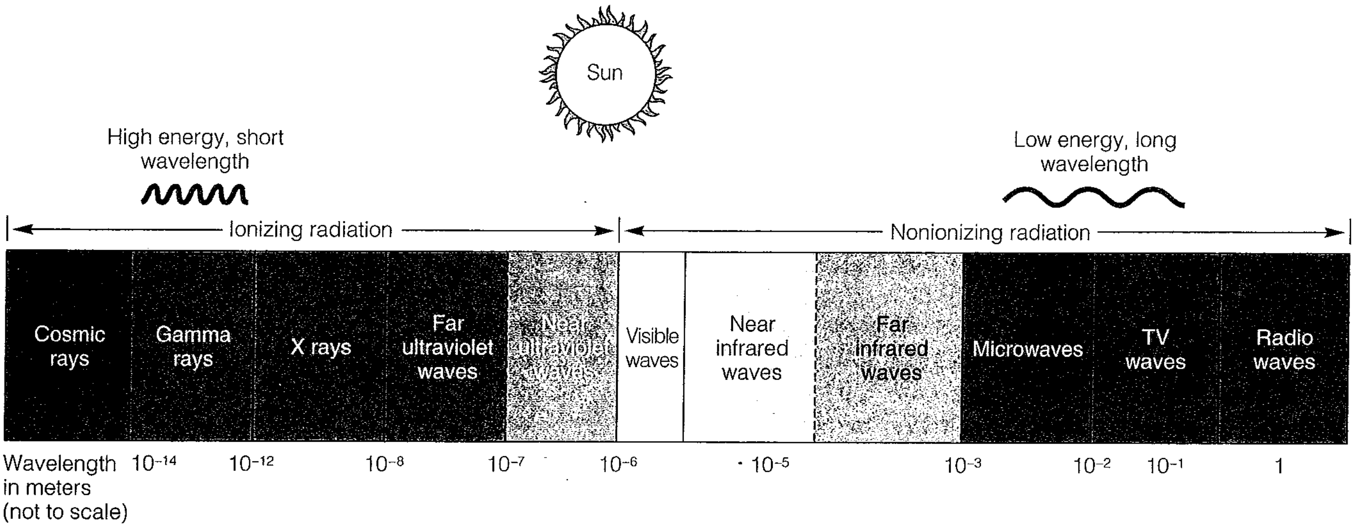


Figure 3-9 The *electromagnetic spectrum:* the range of electromagnetic waves, which differ in wavelength (distance between successive peaks or troughs) and energy content.

What Is Electromagnetic Radiation? Another type of energy is **electromagnetic radiation:** energy radiated in the form of a *wave* as a result of the changing electric and magnetic fields. There are many different forms of electromagnetic radiation, each with a different *wavelength* (distance between successive peaks or troughs in the wave) and *energy content* (Figure 3-9). Such radiation travels through space at the speed of light, which is about 300,000 kilometers per second (186,000 miles per second).

Cosmic rays, gamma rays, X rays, and ultraviolet radiation (Figure 3-9, left side) are called **ionizing radiation** because they have enough energy to knock electrons from atoms and change them to positively charged ions. The resulting highly reactive electrons and ions can **(1)** disrupt living cells, **(2)** interfere with body processes, and **(3)** cause many types of sickness, including various cancers. The other forms of electromagnetic radiation (Figure 3-9, right side) do not contain enough energy to form ions and are called **nonionizing radiation.**

The visible light that we can detect with our eyes is a form of nonionizing radiation that occupies only a small portion of the full range or spectrum of different types of electromagnetic radiation (Figure 3-9). Figure 3-10 shows that visible light makes up most of the spectrum of electromagnetic radiation emitted by the sun (Figure 3-10).

What Is Heat and How Is It Transferred? Heat is the total kinetic energy of all the moving atoms, ions, or molecules within a given substance, excluding the overall motion of the whole object. **Temperature** is the average speed of motion of the atoms, ions, or molecules in a sample of matter at a given moment.

Heat can be transferred from one place to another by three different methods (Figure 3-11):

- **Convection:** the transfer of heat by the movement of heated material. For example, heat can be transferred by convection **(1)** through the atmosphere by the movement of heated air and **(2)** through a pot of boiling water (Figure 3-11, left) or the ocean by movement of heated water.
- **Conduction:** the transfer of heat by collisions of atoms or molecules (Figure 3-11, middle). For example, metals are good conductors of heat and air and most plastics are poor heat conductors.

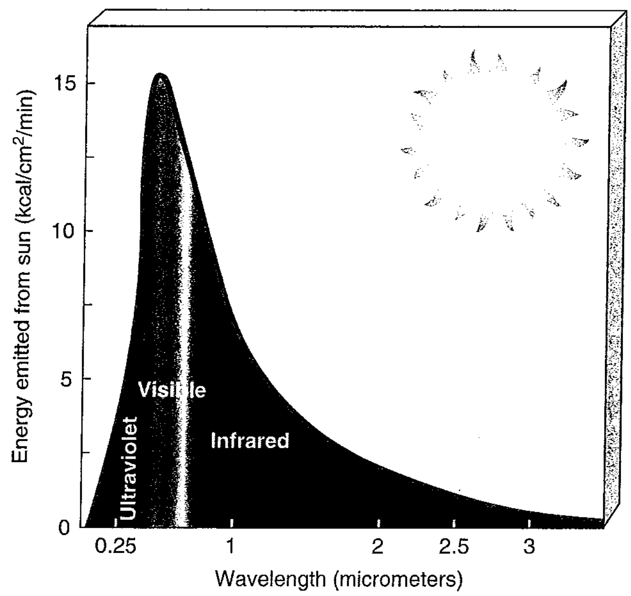
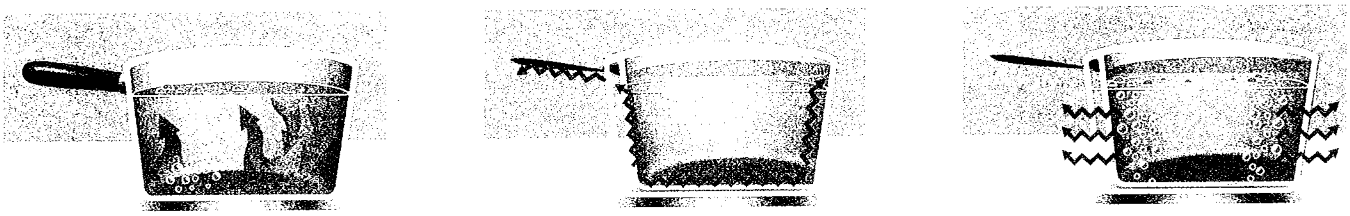


Figure 3-10 The spectrum of electromagnetic radiation released by the sun consists mostly of visible light.



Heating water in the bottom of a pan causes some of the water to vaporize into bubbles. Because they are lighter than the surrounding water, they rise. Water then sinks from the top to replace the rising bubbles.This up and down movement (convection) eventually heats all of the water.

Heat from a stove burner causes atoms or molecules in the pan's bottom to vibrate faster. The vibrating atoms or molecules then collide with nearby atoms or molecules, causing them to vibrate faster. Eventually, molecules or atoms in the pan's handle are vibrating so fast it becomes too hot to touch.

As the water boils, heat from the hot stove burner and pan radiate into the surrounding air, even though air conducts very little heat.

Figure 3-11 Three ways in which heat can be transferred from one place to another.

- **Radiation:** the transfer of heat by wave motion (Figure 3-11, right).

What Is Energy Quality? **Energy quality** is a measure of an energy source's ability to do useful work (Figure 3-12). **High-quality energy** is concentrated and can perform much useful work. Examples are **(1)** electricity, **(2)** the chemical energy stored in coal and gasoline, **(3)** concentrated sunlight, and **(4)** nuclei of uranium-235 used as fuel in nuclear power plants.

By contrast, **low-quality energy** is dispersed and has little ability to do useful work. An example is heat dispersed in the moving molecules of a large amount of matter (such as the atmosphere or a large body of water) so that its temperature is low. For example, 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 the ocean's heat is so widely dispersed, it cannot be used to move things or to heat things to high temperatures. It makes sense to match the quality of an

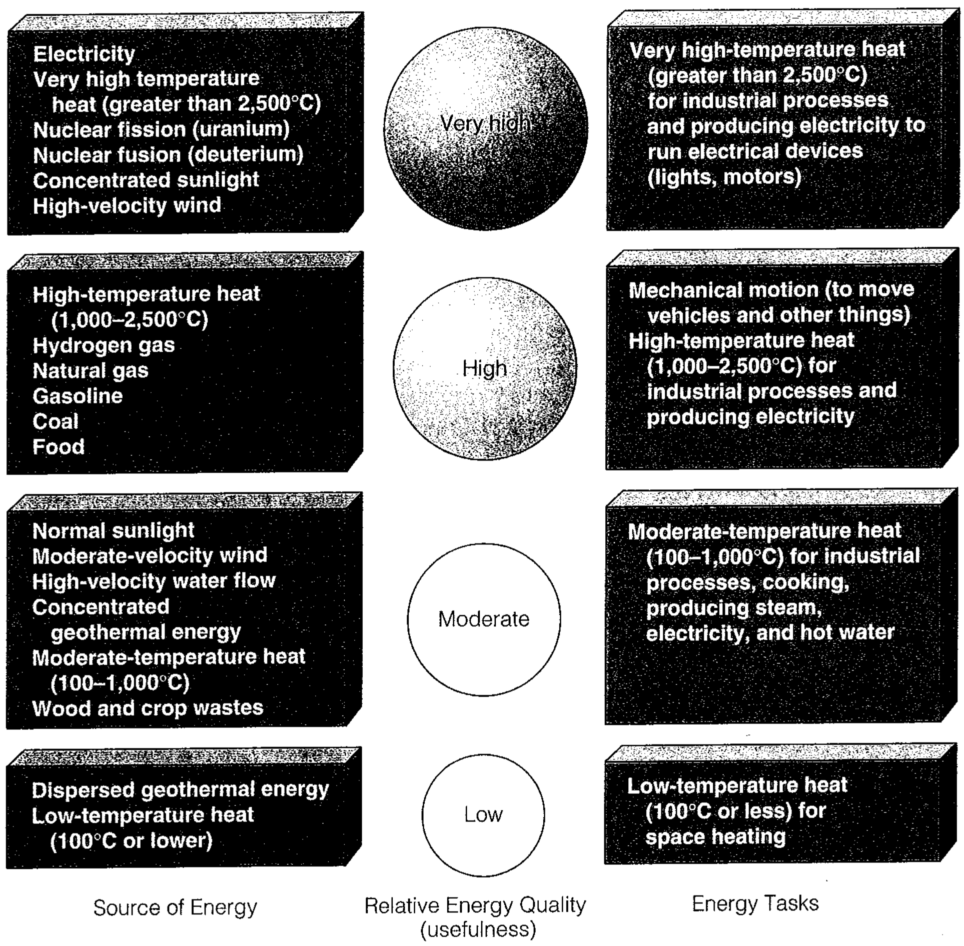
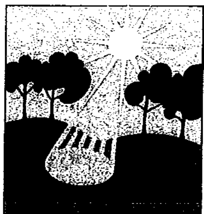


Figure 3-12 Categories of the quality of different sources of energy. *High-quality energy* is concentrated and has great ability to perform useful work. *Low-quality energy* is dispersed and has little ability to do useful work. To avoid unnecessary energy waste, it is best to match the quality of an energy source with the quality of energy needed to perform a task.

Keeping Track of Atoms



SPOTLIGHT

In keeping with the law of conservation of matter, each side of a chemical equation must have the same number of atoms of each element involved. When this is the case, the equation is said to be *balanced.* 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 is passed 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
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 but two atoms are on the right.

We cannot change the subscripts of any of the formulas to balance this equation because then we would be changing the arrangements of the atoms involved. Instead, we could 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
4 H atoms 2 O atoms		2 H atoms		2 O atoms

This equation is still unbalanced because even though the numbers of oxygen atoms on both sides are now equal, the numbers of hydrogen atoms are not.

We can correct this by having the reaction produce two hydrogen molecules:

$2\,H_2O$	$\longrightarrow$	$2\,H_2$	+	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 not been violated. We see that for every two molecules of water through which we pass electricity, two hydrogen molecules and one oxygen molecule are produced.

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).

Critical Thinking

1. Balancing equations is based on the law of conservation of matter. Do you believe this is an ironclad law of nature or one that through new scientific discoveries could be overthrown? Explain.

2. Imagine you have the power to revoke the law of conservation of matter. List the three major ways this would affect your life.

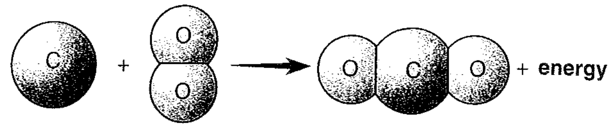
energy source with the quality of energy needed to perform a particular task (Figure 3-12, p. 53) because doing so saves energy and usually money (unless government subsidies or taxes have distorted the energy marketplace).

3-5 PHYSICAL AND CHEMICAL CHANGES AND THE LAW OF CONSERVATION OF MATTER

What Is the Difference Between a Physical and a Chemical Change? A **physical change** involves no change in chemical composition. Cutting a piece of aluminum foil into small pieces is one example. Changing a substance from one physical state to another is a second example. When solid water (ice) is melted or liquid water is boiled, none of the H_2O molecules involved are altered; instead, the molecules are organized in different spatial (physical) patterns (Figure 3-7, p. 50).

In a **chemical change,** or **chemical reaction,** the chemical compositions of the elements or compounds are altered. Chemists use shorthand chemical equations to represent what happens in a chemical reaction. For example, when coal burns completely, the solid carbon (C) it contains combines with oxygen gas (O_2) from the atmosphere to form the gaseous compound carbon dioxide (CO_2):

Reactant(s)			$\longrightarrow$	**Product(s)**		
carbon	+	oxygen	$\longrightarrow$	carbon dioxide	+	**energy**
C	+	O_2	$\longrightarrow$	CO_2	+	**energy**



Energy is given off in this reaction, making coal a useful fuel. The reaction also shows how the complete burning of coal (or any of the carbon-containing compounds in wood, natural gas, oil, and gasoline) gives off carbon dioxide gas, which is a key gas that can lead to warming of the lower atmosphere (troposphere).

The Law of Conservation of Matter: Why Is There No "Away"? *We may change various elements and compounds from one physical or chemical form to another, but in no physical and chemical change can we create or destroy any of the atoms involved.* All we can do is rearrange them into different spatial patterns (physical changes) or different combinations (chemical changes). The italicized statement, based on many thousands of measurements, is known as the **law of conservation of matter.** In describing chemical reactions, chemists use a shorthand system to make sure atoms are neither created nor destroyed, as required by the law of conservation of matter (Spotlight, left).

The law of conservation of matter means there is no "away" in "to throw away." *Everything we think we have thrown away is still here with us in one form or another.* We can collect dust and soot from the smokestacks of industrial plants, but these solid wastes must then be put somewhere. We can remove substances from polluted water at a sewage treatment plant, but we must **(1)** burn them (producing some air pollution), **(2)** bury them (possibly contaminating underground water supplies), or **(3)** clean them up and apply the gooey sludge to the land as fertilizer (dangerous if the sludge contains nondegradable toxic metals such as lead and mercury). Banning use of the pesticide DDT in the United States but still selling it abroad means it can return to the United States as **(1)** DDT residues in imported coffee, fruit, and other foods, or **(2)** fallout from air masses moved long distances by winds.

How Harmful Are Pollutants? We can make the environment cleaner and convert some potentially harmful chemicals into less harmful physical or chemical forms. However, *the law of conservation of matter means we will always face the problem of what to do with some quantity of wastes and pollutants.*

Thus, regardless of what we do, we will always have certain pollutants that can cause harm to humans or other forms of life. Three factors determining the severity of a pollutant's harmful effects are its

- *Chemical nature.*
- *Concentration,* which is sometimes expressed in *parts per million (ppm),* with 1 ppm corresponding to 1 part pollutant per 1 million parts of the gas, liquid, or solid mixture in which the pollutant is found. Smaller concentration units are parts per billion (ppb) and parts per trillion (ppt) (Table 3-1). The concentration of a pollutant can be reduced by dumping it into the air or a large volume of water, but there are limits to the effectiveness of this dilution approach.
- **Persistence,** or how long it stays in the air, water, soil, or body.

Pollutants can be classified into three categories based on their persistence as

- **Degradable,** or **nonpersistent, pollutants** that are broken down completely or reduced to acceptable levels by natural physical, chemical, and biological processes. Complex chemical pollutants that living organisms (usually specialized bacteria) break down (metabolize) into simpler chemicals are called **biodegradable pollutants.** Human sewage in a river, for example, is biodegraded fairly quickly by bacteria if the sewage is not added faster than it can be broken down.
- **Slowly degradable,** or **persistent, pollutants** that take decades or longer to degrade. Examples include the insecticide DDT and most plastics.
- **Nondegradable pollutants** that cannot be broken down by natural processes. Examples include the toxic elements lead, mercury, and arsenic.

3-6 NUCLEAR CHANGES

What Is Natural Radioactivity? In addition to physical and chemical changes, matter can undergo a third type of change known as a **nuclear change.** This occurs when nuclei of certain isotopes

Table 3-1 Equivalents of Some Trace Concentration Units

Unit	1 part per million	1 part per billion	1 part per trillion
Time	1 minute in two years	1 second in 32 years	1 second in 32,000 years
Money	1¢ in $10,000	1¢ in $10,000,000	1¢ in $10,000,000,000
Weight	1 pinch of salt in 10 kilograms (22 lbs.) of potato chips	1 pinch of salt in 10 tons of potato chips	1 pinch of salt in 10,000 tons of potato chips
Volume	1 drop in 1,000 liters (265 gallons) of water	1 drop in 1,000,000 liters (265,000 gallons) of water	1 drop in 1,000,000,000 liters (265,000,000 gallons) of water

spontaneously change or are made to change into one or more different isotopes. Three types of nuclear change are **(1)** natural radioactive decay, **(2)** nuclear fission, and **(3)** nuclear fusion.

Natural radioactive decay is a nuclear change in which unstable isotopes spontaneously emit fast-moving chunks of matter (called particles), high-energy radiation, or both at a fixed rate. The unstable isotopes are called **radioactive isotopes** or **radioisotopes.** Radioactive decay into various isotopes continues until the original isotope is changed into a stable isotope that is not radioactive.

Radiation emitted by radioisotopes is damaging ionizing radiation. The most common form of ionizing energy released from radioisotopes is **gamma rays,** a form of high-energy electromagnetic radiation (Figure 3-9, p. 52). High-speed ionizing particles emitted from the nuclei of radioactive isotopes are most commonly of two types: **(1) alpha particles** (fast-moving, positively charged chunks of matter that consist of two protons and two neutrons) and **(2) beta particles** (high-speed electrons). Figure 3-13 depicts the relative penetrating power of alpha, beta, and gamma ionizing radiation. All of us are exposed to small amounts of harmful ionizing radiation from both natural and human sources.

Each type of radioisotope spontaneously decays at a characteristic rate into a different isotope. This rate of decay can be expressed in terms of **half-life:** the time needed for *one-half* of the nuclei in a radioisotope to decay and emit their radiation to form a different isotope (Figure 3-14). The decay continues, often producing a series of different radioisotopes, until a nonradioactive isotope is formed. Each radioisotope has a characteristic half-life, which may range from a few millionths of a second to several billion years (Table 3-2).

An isotope's half-life cannot be changed by temperature, pressure, chemical reactions, or any other known factor. Half-life can be used to estimate how long a sample of a radioisotope must be stored in a safe container before it decays to what is considered a safe level. A general rule is that such decay takes about

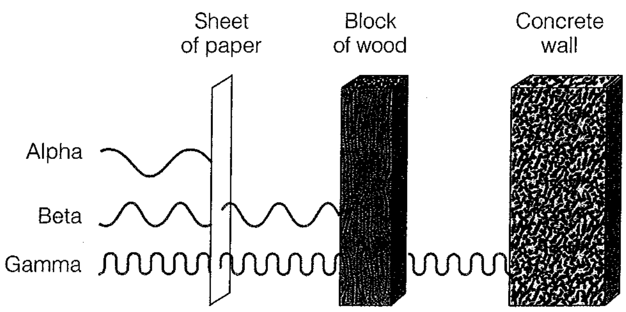


Figure 3-13 The three principal types of ionizing radiation emitted by radioactive isotopes differ greatly in their penetrating power.

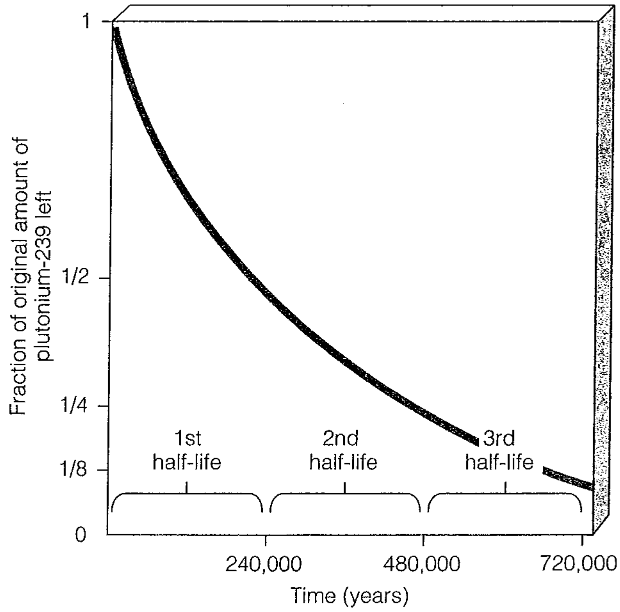


Figure 3-14 The radioactive decay of plutonium-239, which is produced in nuclear reactors and used as the explosive in some nuclear weapons, has a half-life of 240,000 years. The amount of radioactivity emitted by a radioactive isotope decreases by one-half for each half-life that passes. Thus, after three half-lives, amounting to 720,000 years, one-eighth of a sample of plutonium-239 would still be radioactive.

10 half-lives. Thus people must be protected from radioactive waste containing iodine-131 (which concentrates in the thyroid gland and has a half-life of 8 days) for 80 days (10 × 8 days). Plutonium-239, which has a half-life of 24,000 years and is produced in nuclear reactors and used as the explosive in some nuclear weapons, can cause lung cancer when its particles are inhaled in minute amounts. Thus it must be stored safely for 240,000 years (10 × 24,000 years)—

Table 3-2 Half-Lives of Selected Radioisotopes

Isotope	Radiation Half-Life	Emitted
Potassium-42	12.4 hours	Alpha, beta
Iodine-131	8 days	Beta, gamma
Cobalt-60	5.27 years	Beta, gamma
Hydrogen-3 (tritium)	12.5 years	Beta
Strontium-90	28 years	Beta
Carbon-14	5,370 years	Beta
Plutonium-239	24,000 years	Alpha, gamma
Uranium-235	710 million years	Alpha, gamma
Uranium-238	4.5 billion years	Alpha, gamma

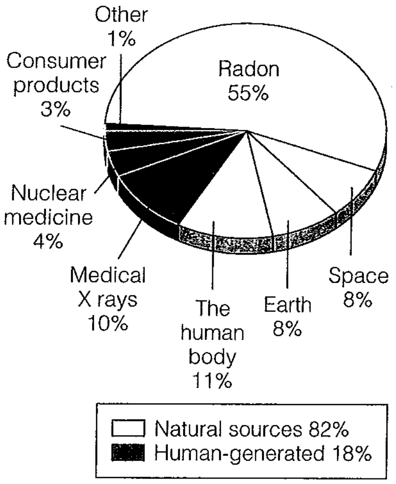


Figure 3-15 Natural and human sources of the average annual dosage of ionizing radiation received by people in the United States. Most studies indicate there is no safe dosage of ionizing radiation. (Data from National Council on Radiation Protection and Measurements)

about four times longer than the latest version of our species has existed.

How Much Ionizing Radiation Are We Exposed To? Each year people are exposed to some ionizing radiation (Figure 3-9, left, p. 52) from natural or background sources and from human activities (Figure 3-15). Sources of natural ionizing radiation include cosmic rays from outer space, soil, rocks, air, water, and food.

Nuclear power plants provide very low exposure to ionizing radiation (in the form of gamma rays, alpha particles, or beta particles) if they are operating properly. However, a serious nuclear accident, such as the one that occurred in 1986 at the Chernobyl nuclear power plant in Ukraine, can release large quantities of radioactive materials that can kill and harm people and make large areas uninhabitable. Most human-caused exposure to ionizing radiation comes from medical X rays and from diagnostic tests and treatments using radioactive isotopes. The federal government estimates that one-third of the X rays taken each year in the United States are unnecessary.

What Are the Effects of Ionizing Radiation? Ionizing radiation can cause harm by **(1)** penetrating a human cell, **(2)** knocking loose (ionizing) one or more electrons from a cellular chemical, and **(3)** thus altering molecules needed for normal cellular functioning. Exposure to ionizing radiation can damage cells in two ways:

- *Genetic damage* from mutations or changes in DNA molecules that alter genes and chromosomes (Figure 3-6, p. 50). If the mutation is harmful, it can lead to genetic defects in the next generation of offspring or several generations later.
- *Somatic damage* to tissues, which causes harm during the victim's lifetime. Examples include burns, miscarriages, eye cataracts, and certain cancers.

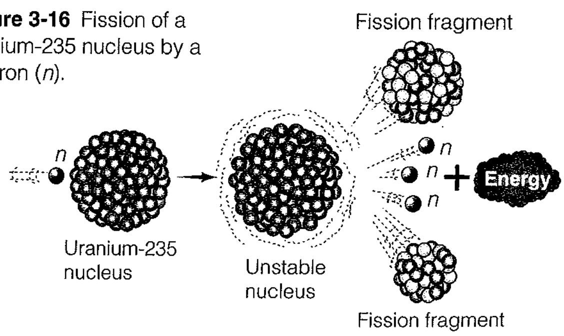
The effects of ionizing radiation vary with **(1)** the type, **(2)** penetrating power (Figure 3-13), **(3)** source (outside or inside the body), and **(4)** half-life of the radioisotope (Figure 3-14 and Table 3-2). Alpha particles lack the penetrating power of beta particles but have more energy; thus, alpha-emitting isotopes are particularly dangerous when breathed in or ingested with food or water. Alpha particles outside the body can cause skin cancer but cannot penetrate the skin and reach vital organs.

Because beta particles can penetrate the skin, a beta emitter outside the body can damage internal organs. In general, radioisotopes with intermediate half-lives pose the greatest threat to human health; they stay around long enough to reach and enter the human body but decay fast enough to cause considerable damage while they are around.

According to the U.S. National Academy of Sciences, exposure over an average lifetime to average levels of ionizing radiation from natural and human sources (Figure 3-15) causes about 1% of all fatal cancers and 5–6% of all normally encountered genetic defects in the U.S. population. No scientific consensus exists on whether nonionizing forms of electromagnetic radiation (Figure 3-9, right, p. 52) given off when an electric current passes through a wire or a motor is harmful to humans.

What Is Nuclear Fission? Splitting Nuclei **Nuclear fission** is a nuclear change in which nuclei of certain isotopes with large mass numbers (such as uranium-235) are split apart into lighter nuclei when struck by neutrons; each fission releases two or three more neutrons and energy (Figure 3-16). Each of these neutrons, in turn, can cause an additional fission. For these multiple fissions to take place, enough fissionable nuclei must be present to provide the **critical mass** needed for efficient capture of these neutrons.

Figure 3-16 Fission of a uranium-235 nucleus by a neutron (*n*).



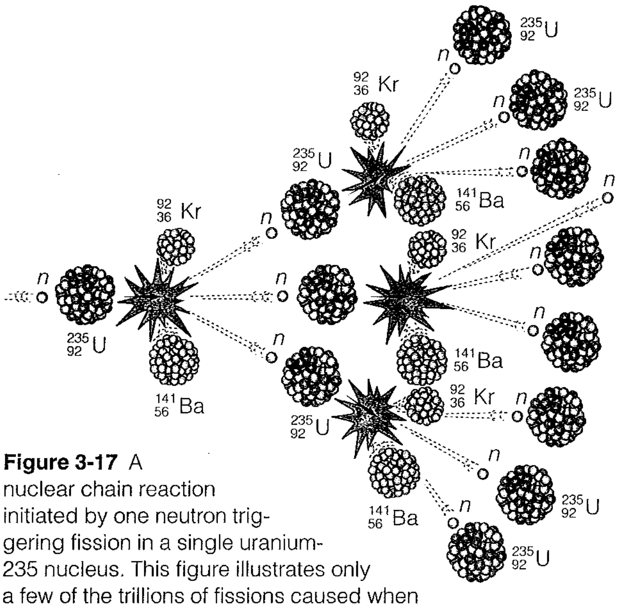


Figure 3-17 A nuclear chain reaction initiated by one neutron triggering fission in a single uranium-235 nucleus. This figure illustrates only a few of the trillions of fissions caused when a single uranium-235 nucleus is split within a critical mass of uranium-235 nuclei. The elements krypton (Kr) and barium (Ba), shown here as fission fragments, are only two of many possibilities.

Multiple fissions within a critical mass form a **chain reaction,** which releases an enormous amount of energy (Figure 3-17). Living cells can be damaged by the ionizing radiation released by the radioactive lighter nuclei and by high-speed neutrons produced by nuclear fission.

In an atomic bomb, an enormous amount of energy is released in a fraction of a second in an uncontrolled nuclear fission chain reaction. This reaction is initiated by an explosive charge, which **(1)** suddenly pushes two masses of fissionable fuel together and **(2)** causes the fuel to reach the critical mass needed for a chain reaction.

In the reactor of a nuclear power plant, the rate at which the nuclear fission chain reaction takes place is controlled so that under normal operation only one of every two or three neutrons released is used to split another nucleus. In conventional nuclear fission reactors, the splitting of uranium-235 nuclei releases heat, which produces high-pressure steam to spin turbines and thus generate electricity.

What Is Nuclear Fusion? Forcing Nuclei to Combine **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. Temperatures of at least 100 million °C are needed to force the positively charged nuclei (which strongly repel one another) to fuse.

Nuclear fusion is much more difficult to initiate than nuclear fission, but once started it releases far more energy per unit of fuel than does fission. Fusion of hydrogen nuclei to form helium nuclei is the source of energy in the sun and other stars.

After World War II, the principle of *uncontrolled nuclear fusion* was used to develop extremely powerful hydrogen, or thermonuclear, weapons. These weapons use the D–T fusion reaction, in which a hydrogen-2, or deuterium (D) nucleus and a hydrogen-3 (tritium, T) nucleus are fused to form a larger, helium-4 nucleus, a neutron, and energy (Figure 3-18).

Scientists have also tried to develop *controlled nuclear fusion,* in which the D–T reaction is used to produce heat that can be converted into electricity. Despite more than 50 years of research, this process is still in the laboratory stage. Even if it becomes technologically and economically feasible, many energy experts do not expect it to be a practical source of energy until 2030, if then.

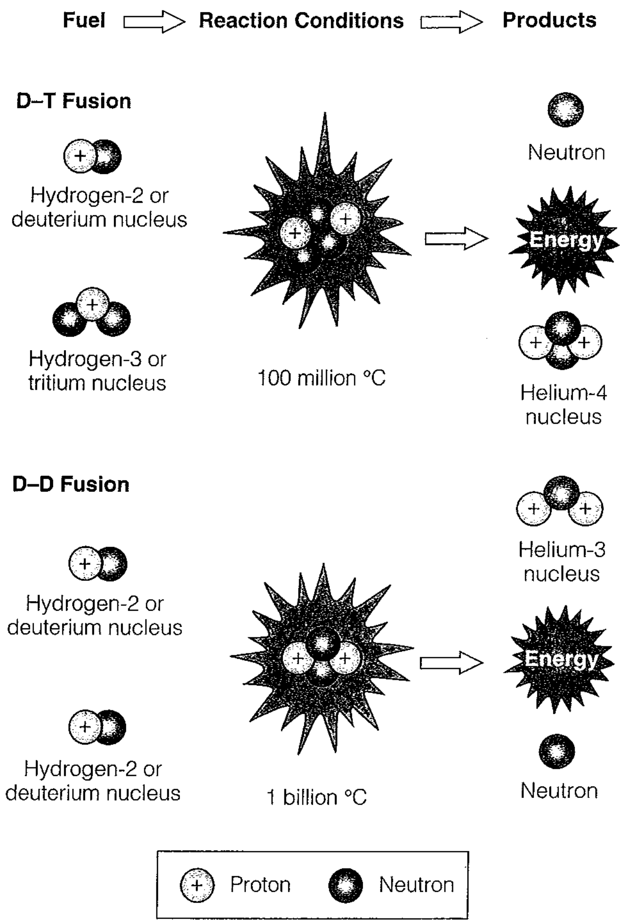


Figure 3-18 The deuterium–tritium (D–T) and deuterium–deuterium (D–D) nuclear fusion reactions, which take place at extremely high temperatures.

3-7 TWO LAWS GOVERNING ENERGY CHANGES

What Is the First Law of Thermodynamics? You Cannot Get Something for Nothing 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 (except in nuclear changes). The results of their experiments have been summarized in the **law of conservation of energy,** also known as the **first law of thermodynamics:** *In all physical and chemical changes, energy is neither created nor destroyed, but it may be converted from one form to another.*

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; in other words, *we cannot get something for nothing in terms of energy quantity.*

What Is the Second Law of Thermodynamics? You Cannot Even Break Even Because the first law of thermodynamics states that energy can be neither created nor destroyed, we may be tempted to think we will always have enough energy. Yet if we fill a car's tank with gasoline and drive around or use a flashlight battery until it is dead, something has been lost. If it is not energy, what is it? The answer is *energy quality* (Figure 3-12, p. 53), the amount of energy available that can perform useful work.

Countless experiments have shown that when energy is changed from one form to another, a decrease in energy quality always occurs. The results of these experiments have been summarized in what is called the **second law of thermodynamics:** *When energy is changed from one form to another, some of the useful energy is always degraded to lower quality, more dispersed, less useful energy.* This degraded energy usually takes the form of heat given off at a low temperature to the surroundings (environment). There it is dispersed by the random motion of air or water molecules and becomes even more disorderly and less useful.

Basically, this law says that in any energy conversion, we always end up with *less* usable energy than we started with. So not only can we not get something for nothing in terms of energy quantity, *we cannot even break even in terms of energy quality because energy always goes from a more useful to a less useful form when energy is changed from one form to another.* No one has ever found a violation of this fundamental scientific law (see quote at the end of this chapter).

Here are three examples of the second law of thermodynamics in action:

- When a car is driven, only about 10% of the high-quality chemical energy available in its gasoline fuel is converted into mechanical energy (to propel the vehicle) and electrical energy (to run its electrical systems). The remaining 90% is degraded to low-quality heat that is released into the environment and eventually lost into space.
- When electrical energy flows through filament wires in an incandescent light bulb, it is changed into about 5% useful light and 95% low-quality heat that flows into the environment. In other words, this so-called *light bulb* is really a *heat bulb.*
- In living systems, solar energy is converted into chemical energy (food molecules) and then into mechanical energy (moving, thinking, and living). During each of these conversions, high-quality energy is degraded and flows into the environment as low-quality heat (Figure 3-19, p. 60).

The second law of thermodynamics also means that *we can never recycle or reuse high-quality energy to perform useful work.* Once the concentrated energy in a serving of food, a liter of gasoline, a lump of coal, or a chunk of uranium is released, it is degraded to low-quality heat that is dispersed into the environment. We can heat air or water at a low temperature and upgrade it to high-quality energy, but the second law of thermodynamics tells us that it will take more high-quality energy to do this than we get in return.

Energy efficiency, or **energy productivity,** is a measure of how much useful work is accomplished by a particular input of energy into a system. As with material efficiency (p. 51), there is plenty of room for improvement. For example, scientists estimate that only about 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%).

Connections: How Does the Second Law of Thermodynamics Affect Life? To form and maintain the highly ordered arrangement of molecules and the organized biochemical processes in your body, you must continually get and use high-quality matter and energy resources from your surroundings. As you use these resources, you add low-quality heat and low-quality waste matter to your surroundings. Your body continuously gives off heat roughly equal to that of a 100-watt incandescent light bulb, which is why a closed room full of people gets warm. You also continuously break down solid large molecules (such as glucose) into smaller molecules of carbon dioxide gas and water vapor, which are dispersed in the atmosphere.

Planting, growing, processing, and cooking food all use high-quality energy and matter resources that

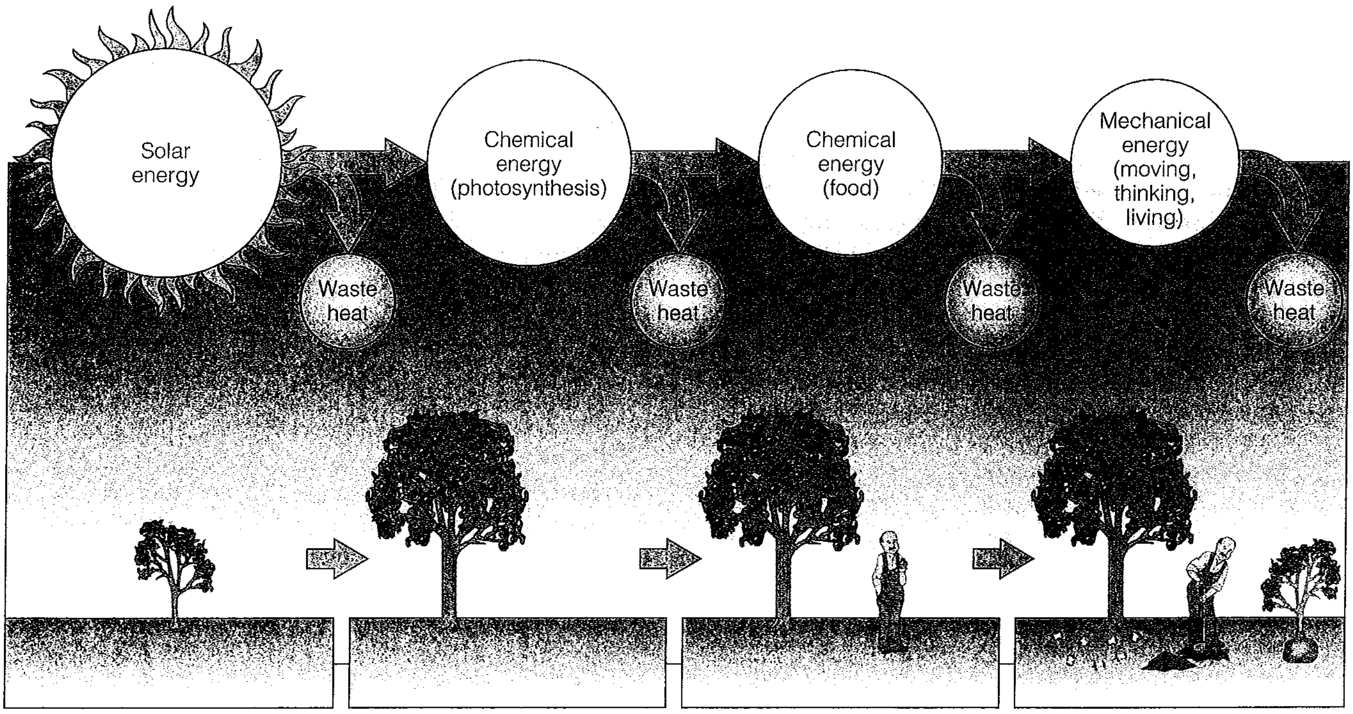


Figure 3-19 The second law of thermodynamics in action in living systems. Each time energy is changed from one form to another, some of the initial input of high-quality energy is degraded, usually to low-quality heat that disperses into the environment.

add low-quality heat and waste materials to the environment. In addition, enormous amounts of low-quality heat and waste matter are added to the environment when concentrated deposits of minerals and fuels are extracted from the earth's crust, processed, and used.

3-8 CONNECTIONS: MATTER AND ENERGY CHANGE LAWS AND ENVIRONMENTAL PROBLEMS

What Is a High-Throughput Economy? As a result of the law of conservation of matter and the second law of thermodynamics, individual resource use 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 sustain ever-increasing economic growth by increasing the flow of matter and energy resources through their economic systems (Figure 3-20). These resources flow through their economies into planetary *sinks* (air, water, soil, organisms), where pollutants and wastes end up and can accumulate to harmful levels.

What happens if more and more people continue to use and waste more and more energy and matter resources at an increasing rate? The law of conservation of matter and the two laws of thermodynamics discussed in this chapter tell us that eventually this will exceed the capacity of the environment to **(1)** dilute and degrade waste matter and **(2)** absorb waste heat. However, they do not tell us how close we are to reaching such limits.

What Is a Matter-Recycling Economy? A stopgap solution to this problem is to convert a high-throughput economy to a **matter-recycling economy.** The goal of such a conversion is to allow economic

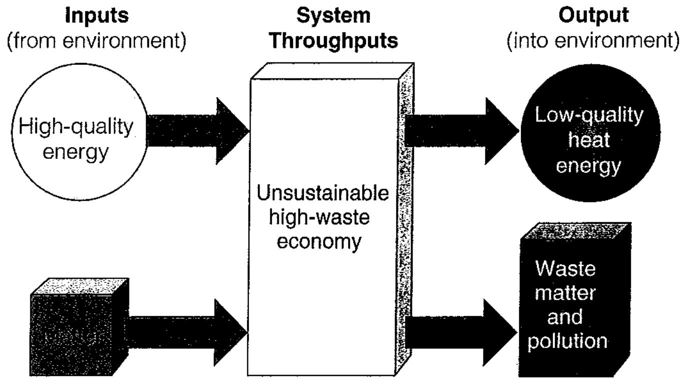


Figure 3-20 The *high-throughput economies* of most developed countries are based on maximizing the rates of energy and matter flow. This process rapidly converts high-quality matter and energy resources into waste, pollution, and low-quality heat.

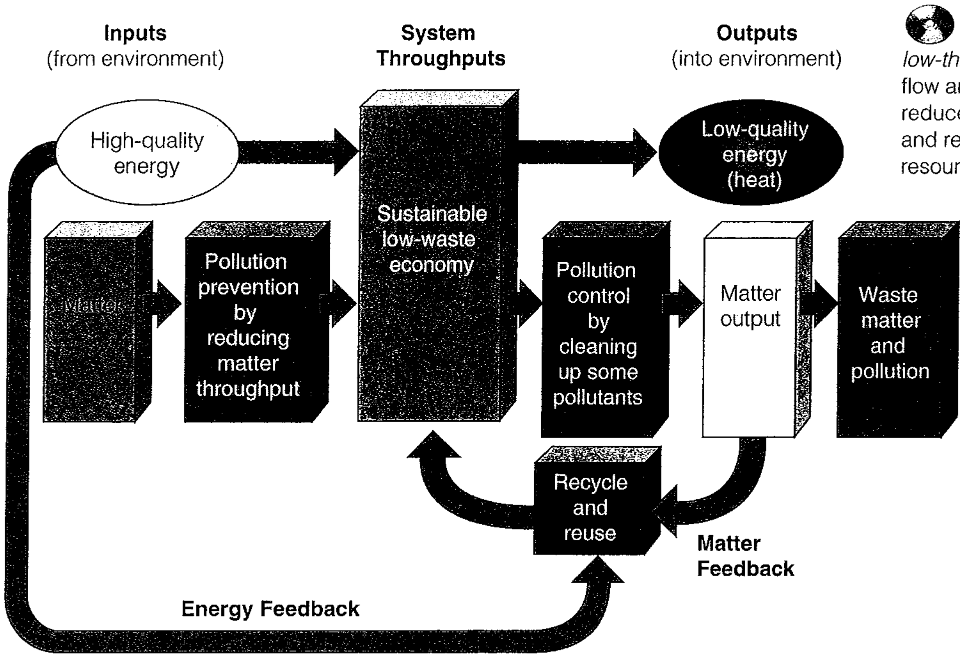


Figure 3-21 Lessons from nature. A *low-throughput economy,* based on energy flow and matter recycling, works with nature to reduce throughput. This is done by **(1)** reusing and recycling most nonrenewable matter resources, **(2)** using renewable resources no faster than they are replenished, **(3)** using matter and energy resources efficiently, **(4)** reducing unnecessary consumption, **(5)** emphasizing pollution prevention and waste reduction, and **(6)** controlling population growth.

growth to continue without depleting matter resources or producing excessive pollution and environmental degradation.

Even though recycling matter saves energy, the two laws of thermodynamics tell us that *recycling matter resources always* **(1)** *requires using high-quality energy (which cannot be recycled) and* **(2)** *adds waste heat to the environment.*

Changing to a matter-recycling economy is an important way to buy some time. However, it does not allow more and more people to use more and more resources indefinitely, even if all of them were somehow perfectly recycled.

What Is a Low-Throughput Economy? Learning from Nature The three scientific laws governing matter and energy changes suggest that the best long-term solution to our environmental and resource problems is to shift from an economy based on maximizing matter and energy flow (throughput) to a more sustainable **low-throughput (low-waste) economy,** as summarized in Figure 3-21.

The next five chapters **(1)** apply the three basic scientific laws of matter and thermodynamics to living systems and **(2)** look at some *biological principles* that can teach us how to live more sustainably by working with 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. Define the boldfaced terms in this chapter.

2. Describe what happened to the people on Easter Island and how it may relate to the current situation on the earth.

3. Define *science* and explain how it works. Distinguish among *scientific data, scientific hypothesis, scientific model, scientific theory,*and *scientific law.* Explain why we should take a scientific theory seriously.

4. What is a *controlled experiment?* What is *multivariable analysis?*

5. Distinguish between *inductive reasoning* and *deductive reasoning,* and give an example of each.

6. What does "scientifically proven" mean? If scientists cannot establish absolute proof, what do they establish?

7. Distinguish between *frontier science* and *consensus science.*

8. What is a *mathematical model,* and how is such a model made? Why are mathematical models important?

9. What is a *system?* Distinguish among the *inputs, flows* or *throughputs, stores,* and *outputs* of a system.

10. What is a *feedback loop?* Distinguish between a *positive feedback loop* and a *negative feedback loop,* and give an example of each.

11. Define and give an example of a *time delay* in a system.

12. Define *synergy,* and give an example of how it can change a system. List two environmental surprises that we have encountered and three causes of environmental surprises.

13. Distinguish among *matter, elements, compounds,* and *mixtures.*

14. Distinguish among *atoms, ions,* and *molecules,* and give an example of each. What are four states of matter?

15. What three major types of subatomic particles are found in atoms? Which two of these particles are found in the nucleus, and which is found outside the nucleus?

16. Distinguish between *atomic number* and *mass number.* What is an *isotope* of an atom?

17. What is the *concentration* of a chemical? What is *pH?*

18. What is a *chemical formula?* Distinguish between *ionic compounds* and *covalent compounds,* and give the names and chemical formulas for an example of each of these types of compounds.

19. Distinguish between *organic compounds* and *inorganic compounds,* and give an example of each type. Distinguish among *hydrocarbons, chlorinated hydrocarbons, chlorofluorocarbons, simple carbohydrates, polymers, complex carbohydrates, proteins, nucleic acids,* and *nucleotides.*

20. Distinguish between *genes* and *chromosomes.*

21. Distinguish between *high-quality matter* and *low-quality matter,* and give an example of each. What is *material efficiency?*

22. What is *energy?* What is *radiation?*

23. Distinguish between *kinetic energy* and *potential energy,* and give an example of each.

24. What is *electromagnetic radiation?* List three types of electromagnetic radiation.

25. Distinguish between *ionizing radiation* and *nonionizing radiation,* and give an example of each.

26. Distinguish between *heat* and *temperature.* Explain how heat can be transmitted by *convection, conduction,* and *radiation.*

27. Distinguish between *high-quality energy* and *low-quality energy,* and give an example of each. What is *energy efficiency?*

28. Distinguish between a *physical change* and a *chemical change,* and give an example of each.

29. What is the *law of conservation of matter?* Explain why there is no "away" as a repository for pollution. What is a *balanced chemical equation,* and how is it related to the law of conservation of matter?

30. What three factors determine the harm that a pollutant causes? Distinguish among concentrations of *parts per million, parts per billion,* and *parts per trillion.* What is the *persistence* of a pollutant? Distinguish among *degradable (nonpersistent), biodegradable, slowly degradable (persistent),* and *nondegradable pollutants,* and give an example of each type.

31. What is a *nuclear change?* Distinguish among *natural radioactive decay, radioisotopes, gamma rays, alpha particles,* and *beta particles.* What is the *half-life* of a radioactive isotope? For how many half-lives should radioactive material be stored safely before it decays to an acceptable level of radioactivity? What are the major sources and effects of human exposure to ionizing radiation?

32. Distinguish between *nuclear fission* and *nuclear fusion.* Distinguish between *critical mass* and a *nuclear chain reaction.*

33. Distinguish between the *first law of thermodynamics* and the *second law of thermodynamics,* and give an example of each law in action. Use the second law of thermodynamics to explain why energy cannot be recycled.

34. Distinguish among a *high-throughput (high-waste) economy,* a *low-throughput (low-waste) economy,* and a *matter-recycling economy.* Use the law of conservation of matter and the first and second laws of thermodynamics to explain the need to shift from a high-throughput economy to a matter-recycling economy and eventually to a low-throughput economy.

CRITICAL THINKING

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

2. See whether you can find an advertisement or an article describing some aspect of science in which **(a)** the concept of scientific proof is misused, **(b)** the term *theory* is used when it should have been *hypothesis,* and **(c)** a consensus scientific finding is dismissed or downplayed because it is "only a theory."

3. How does a scientific law (such as the law of conservation of matter) differ from a societal law (such as one imposing maximum speed limits for vehicles)? Can each be broken?

4. Explain why we do not really consume anything and why we can never really throw matter away.

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

6. If there is no "away," why isn't the world filled with waste matter?

7. Methane (CH_4) gas is the major component of natural gas. Write and balance the chemical equation for the burning of methane when it combines with oxygen gas in the atmosphere to form carbon dioxide and water. Use this equation to explain why burning natural gas can contribute to projected warming of the atmosphere (global warming).

8. Suppose you have 100 grams of radioactive plutonium-239 with a half-life of 24,000 years. How many grams of plutonium-239 will remain after **(a)** 12,000 years, **(b)** 24,000 years, and **(c)** 96,000 years?

9. Someone wants you to invest money in an automobile engine that will produce more energy than the energy in the fuel (such as gasoline or electricity) you use to run the motor. What is your response? Explain.

10. Use the second law of thermodynamics to explain why a barrel of oil can be used only once as a fuel.

11. **(a)** Imagine you have the power to violate the law of conservation of energy (the first law of thermodynamics) for 1 day. What are the three most important things you would do with this power? **(b)** Repeat this process, imagining you have the power to violate the second law of thermodynamics for 1 day.

PROJECTS

1. **(a)** List two examples of negative feedback loops not discussed in this chapter, one that is beneficial and one that is detrimental. Compare your examples with those of other members of your class. **(b)** Give two examples of positive feedback loops not discussed in this chapter. Include one that is beneficial and one that is detrimental. Compare your examples with those of other members of your class.

2. If you have the use of a sensitive balance, try to demonstrate the law of conservation of mass in a physical change. Weigh a container with a lid (a glass jar will do), add an ice cube and weigh it again, and then allow the ice to melt and weigh it again.

3. Use the library or Internet to find examples of various perpetual motion machines and inventions that allegedly violate the two laws of thermodynamics by producing more high-quality energy than the high-quality energy needed to make them run. What has happened to these schemes and machines (many of them developed by scam artists to attract money from investors)?

4. Use the library or the Internet to find bibliographic information about *George Perkins Marsh, Warren Weaver,* and *Arthur S. Eddington,* whose quotes appear at the beginning and end of this chapter.

5. Make a concept map of this chapter's major ideas using the section heads and subheads and the key terms (in boldface). Look on the website for this book for information about making concept maps.

INTERNET STUDY RESOURCES AND RESOURCES FOR FURTHER READING AND RESEARCH

The website for this book contains helpful study aids and many ideas for further reading and research. Log on to

www.info.brookscole.com/miller13

and click on the Chapter-by-Chapter area. Choose Chapter 3 and select a resource:

- Flash Cards allows you to test your mastery of the Terms and Concepts to Remember for this chapter.
- Tutorial Quizzes provides a multiple-choice practice quiz.
- Student Guide to InfoTrac will lead you to Critical Thinking Projects that use InfoTrac College Edition as a research tool.
- References lists the major books and articles consulted in writing this chapter.
- Hypercontents takes you to an extensive list of sites with news, research, and images related to individual sections of the chapter.

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1. Scully, M. 2001. Quantum mechanics boosts engine efficiency. (Brief article) *Inside R&D* (February 1) *Keywords:* "quantum mechanics" and "efficiency." This article explores issues in frontier science by examining the theory of coupling the energy of atomic structure with the energy of atomic motion in the internal combustion engine. This type of system could increase the efficiency of current energy use.

2. Beals, G. 2001. Pining for a breakthrough: Despite years of ostracism, a small and dwindling army of cold-fusion faithful are ever hopeful. (Brief article) *Newsweek International* (October 15): 57. *Keywords:* "cold fusion" and "breakthrough." Twelve years after the first announcement of "cold fusion," and the subsequent lack of repeatability, people are still searching for this elusive "unlimited energy source." However, life on the frontier of cold fusion is starting to get lonelier.

4 ECOSYSTEMS: COMPONENTS, ENERGY FLOW, AND MATTER CYCLING

Have You Thanked the Insects Today?

Insects have a bad reputation. We classify many insect species as *pests* because they **(1)** compete with us for food, **(2)** spread human diseases (such as malaria), and **(3)** invade our lawns, gardens, and houses. Some people have "bugitis," fear all insects, and think the only good bug is a dead bug. However, this view fails to recognize the vital roles insects play in helping sustain life on earth.

A large proportion of the earth's plant species (including many trees) depend on insects to pollinate their flowers (Figure 4-1, left). In turn, we and other land-dwelling animals depend on plants for food, either by eating them or by consuming animals that eat them. Without pollinating insects, very few fruits and vegetables would be available for us and plant-eating animals to eat.

Insects such as the praying mantis (Figure 4-1, right), which eat other insects, 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 nature's services that help sustain us.

Suppose all insects disappeared today. Within a year most of the earth's animals would become extinct because of the disappearance of so much plant life. The earth would be covered with rotting vegetation and animal carcasses being decomposed by unimaginably huge hordes of bacteria and fungi.

Fortunately, this is not a realistic scenario because insects, which have been around for at least 400 million years, are phenomenally successful forms of life. They were the first animals to invade the land and, later, the air. Today they are by far the planet's most diverse, abundant, and successful animals.

Insects can **(1)** rapidly evolve new genetic traits, such as resistance to pesticides, **(2)** have an exceptional ability to evolve into new species when faced with new environmental conditions, and **(3)** are extremely resistant to extinction.

This is another example of the law of conservation of problems (p. 46). Application of chemical pesticides to protect crops from pests can help grow more food. However, the pesticides can also **(1)** contaminate the air and water far from where they are applied, **(2)** harm beneficial insects that help protect crops from other insects, **(3)** threaten the health of wildlife and people, and **(4)** accelerate the natural ability of rapidly reproducing insect pests to develop genetic resistance (immunity) to such pesticides. Thus, in the long run, pesticide technology can backfire and become less effective in solving the problem of crop losses from insect pests.

The environmental lesson is that although insects can thrive without newcomers such as us, we and most other land organisms would perish quickly without them. Learning about the roles insects play in nature requires us to understand how insects and other organisms living in a biological *community* (such as a forest or pond) interact with one another and with the nonliving environment. *Ecology* is the science that studies such relationships and interactions in nature, as I discuss in this chapter and the six chapters that follow.

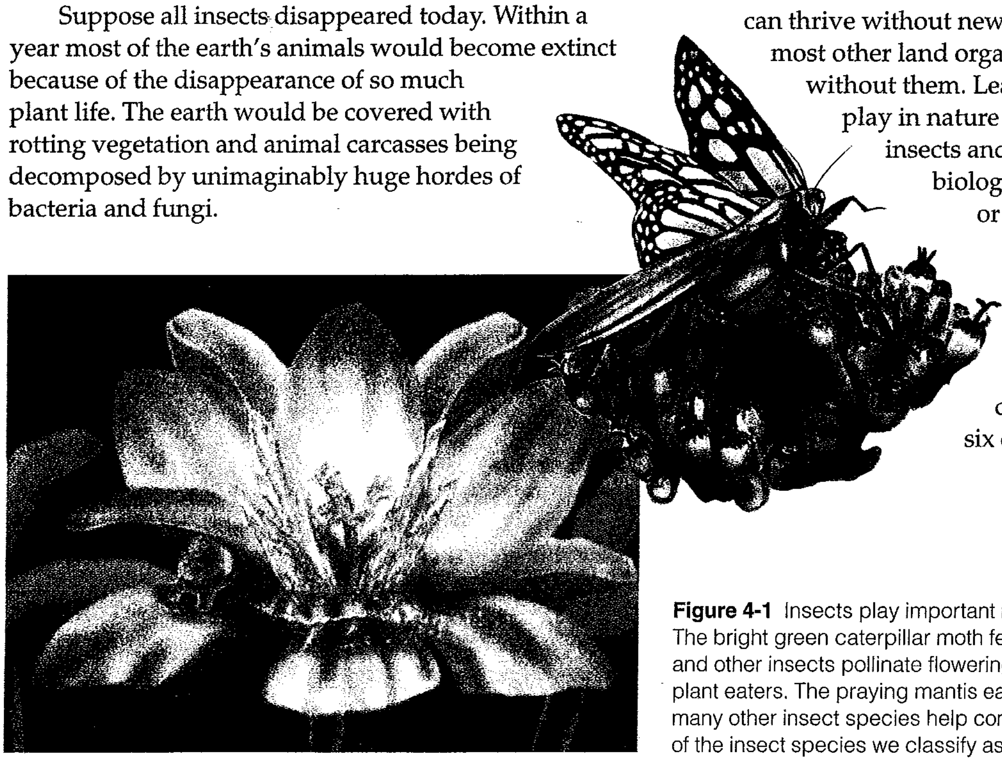


Figure 4-1 Insects play important roles in helping sustain life on earth. The bright green caterpillar moth feeding on pollen in a crocus (left) and other insects pollinate flowering plants that serve as food for many plant eaters. The praying mantis eating a monarch butterfly (right) and many other insect species help control the populations of at least half of the insect species we classify as pests.

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

G. EVELYN HUTCHINSON

This chapter addresses the following questions:

- What is ecology?
- What basic processes keep us and other organisms alive?
- What are the major components of an ecosystem?
- What happens to energy in an ecosystem?
- What happens to matter in an ecosystem?
- How do scientists study ecosystems?
- What are ecosystem services, and how do they affect the sustainability of the earth's life-support systems?

4-1 THE NATURE OF ECOLOGY

What Is Ecology? **Ecology** (from the Greek words *oikos*, "house" or "place to live," and *logos*, "study of") is the study of how organisms interact with one another and with their nonliving environment. In effect, it is a study of *connections in nature.*

What Are Organisms? Ecologists focus on trying to understand the interactions among organisms, populations, communities, ecosystems, and the biosphere (Figure 4-2, p. 66).

An **organism** is any form of life. The **cell** is the basic unit of life in organisms. Organisms may consist of a single cell (bacteria, for instance) or many cells.

On the basis of their cell structure, organisms can be classified as either *eukaryotic* or *prokaryotic.* Each cell of a **eukaryotic** organism **(1)** is surrounded by a membrane, **(2)** has a distinct *nucleus* (a membrane-bounded structure containing genetic material in the form of DNA), and **(3)** has several other internal parts called *organelles* (Figure 4-3a, p. 67). All organisms except bacteria are eukaryotic.

A membrane surrounds the cell of a **prokaryotic** organism, but inside the cell no distinct nucleus or other internal parts are enclosed by membranes (Figure 4-3b, p. 67). All bacteria are single-celled prokaryotic organisms. Although most familiar organisms are eukaryotic, they could not exist without hordes of prokaryotic organisms (bacteria; Connections, below). These bacteria are examples of *microorganisms,* so small they can be seen only with the aid of a microscope.

CONNECTIONS: Microbes: The Invisible Rulers of the Earth

They are everywhere and there are trillions of them. Billions are found inside your body, on your body, in a handful of soil, and in a cup of river water.

These mostly invisible rulers of the earth are *microbes,* a catchall term for many thousands of species of bacteria, protozoa, fungi, and yeasts, most of which are too small for us to see with the naked eye.

Most microbes do not get the respect they deserve. Most of us think of them as threats to our health in the form of **(1)** infectious bacteria or "germs," **(2)** fungi that cause athlete's foot and other skin diseases, and **(3)** protozoa that cause killer diseases such as malaria. However, these potentially harmful microbes are in the minority.

Most of the earth's hordes of microbes not only are harmless but also make the rest of life possible. Some of them play a vital role in producing foods such as bread, cheese, yogurt, vinegar, tofu, soy sauce, beer, and wine. Others provide us with food by converting nitrogen gas in the atmosphere into forms that plants can take up from the soil as nutrients.

Bacteria and fungi in the soil decompose organic wastes into nutrients that can be taken up by plants. Bacteria in your intestinal tract break down the food you eat. Some microbes in your nose prevent harmful bacteria from reaching your lungs. Other microbes have been the source of disease-fighting antibiotics, including penicillin, erythromycin, and streptomycin.

Another vital ecological service that some microbes provide is controlling some plant diseases and populations of insect species that attack food crops. Enlisting some of these microbes for pest control can reduce the use of potentially harmful chemical pesticides.

In addition, genetic engineers are developing microbes that can **(1)** extract metals from ores, **(2)** break down various pollutants, and **(3)** help clean up toxic waste sites.

Harvard biologist Edward O. Wilson, who has developed many important ecological theories and is one of the world's experts on ants, says that if he were starting over he would study microbes.

Critical Thinking

1. A bumper sticker reads, "Have You Thanked Microbes Today?" Give reasons for doing so, and explain why microbes are the real rulers of the earth.

2. What are some potentially harmful effects of **(a)** using genetic engineering to design microbes to break down oil and toxic chemicals and **(b)** overusing antibacterial soaps, sprays, and antibiotics?

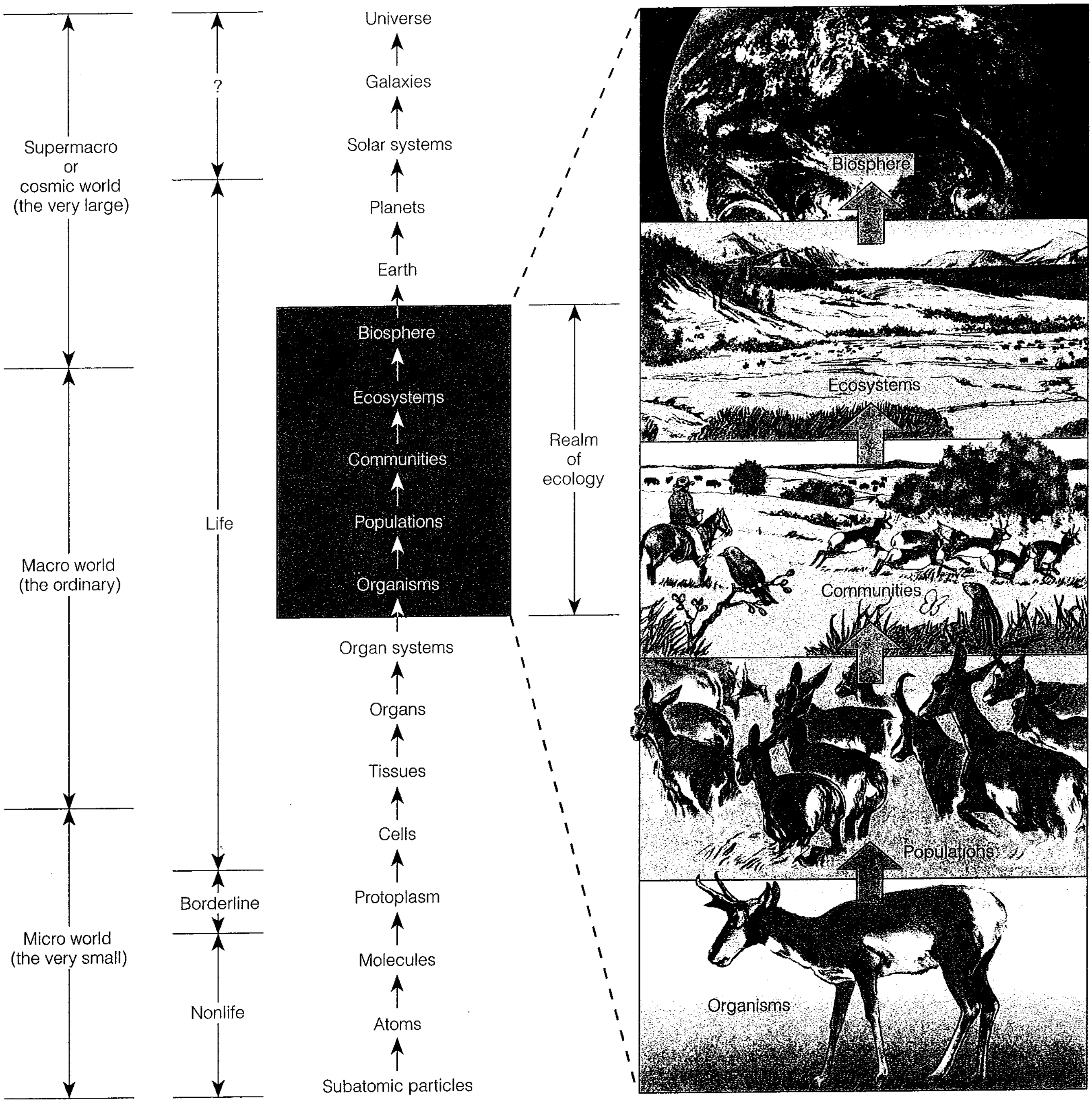
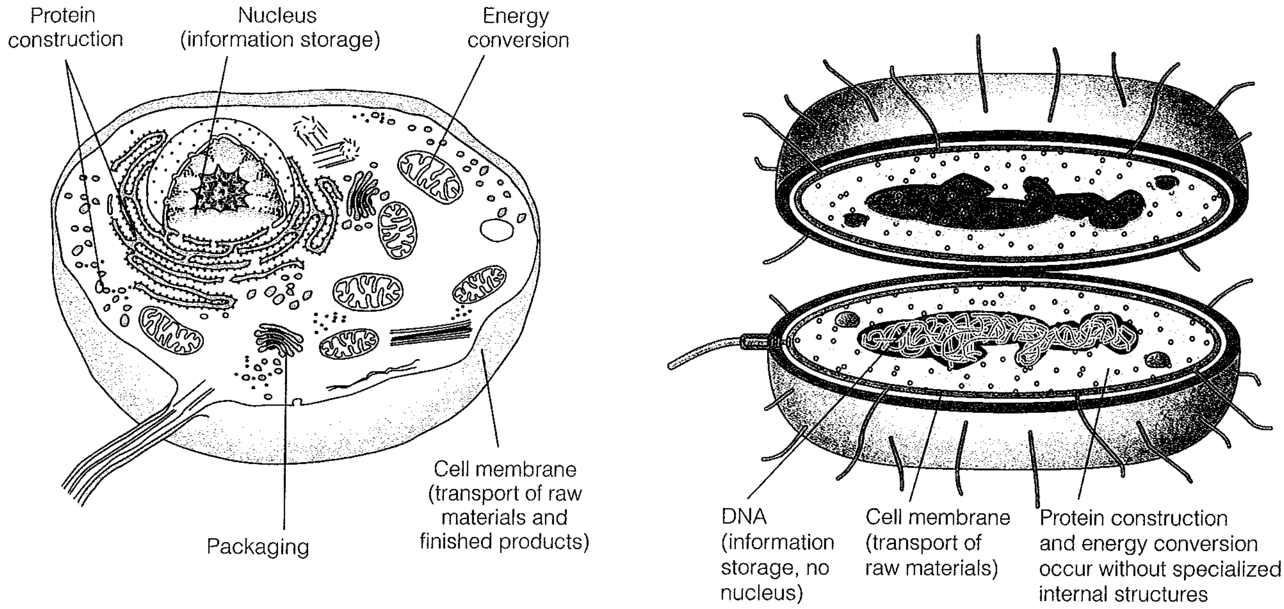


Figure 4-2 Levels of organization of matter in nature. Note the five levels that ecology focuses on.

What Are Species? Organisms can be classified into **species,** or groups of organisms that resemble one another in appearance, behavior, chemistry, and genetic makeup. Species differ in how they produce offspring. **Asexual reproduction** is common in species such as bacteria with only one cell, which divides to produce two identical cells that are clones or replicas of the original cell.

Sexual reproduction occurs in organisms that produce offspring by combining sex cells or gametes (such as ovum and sperm) from both parents. This produces offspring that have combinations of genetic traits from each parent. Sexual reproduction usually gives the species a greater chance of survival under changing environmental conditions than the genetic clones produced by asexual reproduction.

Organisms that reproduce sexually are classified as members of the same species if, under natural conditions, they can **(1)** actually or potentially breed with one another and **(2)** produce live, fertile offspring. Scientists use a special system to name each species (see Appendix 3).



(a) Eukaryotic Cell

(b) Prokaryotic Cell

Figure 4-3 **(a)** Generalized structure of a eukaryotic cell. The parts and internal structure of cells in various types of organisms such as plants and animals differ somewhat from this generalized model. **(b)** Generalized structure of a prokaryotic cell. Note that prokaryotic cells lack a distinct nucleus. (Adapted from Cecie Starr and Ralph Taggart, *Biology: The Unity and Diversity of Life*, 8th ed., Wadsworth, © 1998)

We do not know how many species exist on the earth. Estimates range from 3.6 million to 100 million. Most are insects (p. 64) and microorganisms too small to be seen with the naked eye (Connections, p. 65). Excluding hordes of bacterial species, a best guess of the number of species is about 10–14 million.

So far biologists have identified and named about 1.5–1.8 million species, not including bacteria. Biologists know a fair amount about roughly one-third of the known species but understand the detailed roles and interactions of only a few. Each year researchers identify only about 10,000 new species, so we have a long way to go to identify even a fraction of the estimated species.

What Is a Population? A **population** consists of a group of interacting individuals of the same species that occupy a specific area at the same time (Figure 4-4). Examples are all **(1)** sunfish in a pond, **(2)** white oak trees in a forest, and **(3)** people in a country. In most natural populations, individuals vary slightly in their genetic makeup, which is why they do not all look or behave exactly alike—a phenomenon called **genetic diversity** (Figure 4-5, p. 68). In response to changes in environmental conditions, populations change in **(1)** *size,* **(2)** *age distribution* (number of individuals in each age group), **(3)** *density* (number of individuals per unit of space), and **(4)** *genetic composition.*

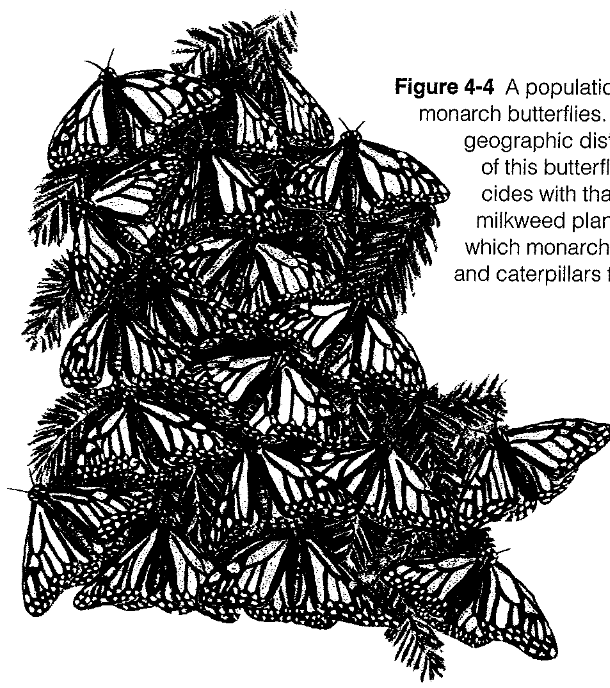


Figure 4-4 A population of monarch butterflies. The geographic distribution of this butterfly coincides with that of the milkweed plant, on which monarch larvae and caterpillars feed.

The place where a population (or an individual organism) normally lives is its **habitat.** It may be as large as an ocean or prairie or as small as the underside of a rotting log or the intestine of a termite.

What Are Communities, Ecosystems, and the Biosphere? Populations of the different species occupying a particular place make up a **community,** or

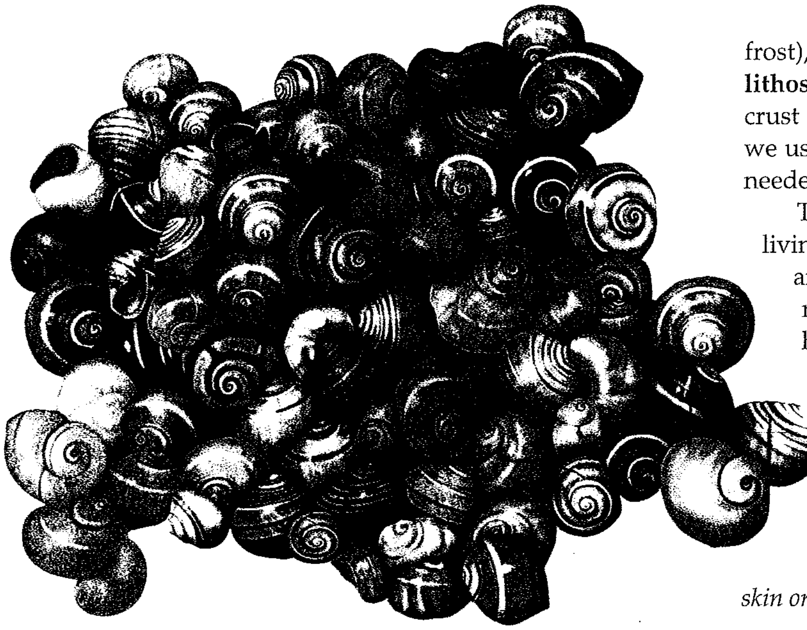


Figure 4-5 The genetic diversity among individuals of one species of Caribbean snail is reflected in the variations in shell color and banding patterns.

biological community. It is a complex interacting network of plants, animals, and microorganisms.

An **ecosystem** is a community of different species interacting with one another and with their nonliving environment of matter and energy. Ecosystems can range in size from a puddle of water to a stream, a patch of woods, an entire forest, or a desert. Ecosystems can be natural or artificial (human created). Examples of human-created ecosystems are cropfields, farm ponds, and reservoirs. All of the earth's ecosystems together make up what we call the *biosphere.*

4-2 THE EARTH'S LIFE-SUPPORT SYSTEMS

What Are the Major Parts of the Earth's Life-Support Systems? We can think of the earth as being made up of several spherical layers (Figure 4-6). The **atmosphere** is a thin envelope or membrane of air around the planet. Its inner layer, the **troposphere,** extends only about 17 kilometers (11 miles) above sea level but contains most of the planet's air, mostly nitrogen (78%) and oxygen (21%). The next layer, stretching 17–48 kilometers (11–30 miles) above the earth's surface, is the **stratosphere.** Its lower portion contains enough ozone (O_3) to filter out most of the sun's harmful ultraviolet radiation, thus allowing life to exist on land and in the surface layers of bodies of water.

The **hydrosphere** consists of the earth's **(1)** liquid water (both surface and underground), **(2)** ice (polar ice, icebergs, and ice in frozen soil layers, or permafrost), and **(3)** water vapor in the atmosphere. The **lithosphere** is the earth's crust and upper mantle; the crust contains nonrenewable fossil fuels and minerals we use as well as renewable soil chemicals (nutrients) needed for plant life.

The **biosphere** is the portion of the earth in which living (biotic) organisms exist and interact with one another and with their nonliving (abiotic) environment. The biosphere includes most of the hydrosphere and parts of the lower atmosphere and upper lithosphere. It reaches from the deepest ocean floor, 20 kilometers (12 miles) below sea level, to the tops of the highest mountains. 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, life-supporting global skin or membrane of air, water, soil, and organisms.*

What Sustains Life on Earth? Life on the earth depends on three interconnected factors (Figure 4-7):

- The *one-way flow of high-quality energy* (Figure 3-12, p. 53) from the sun, **(1)** through materials and living

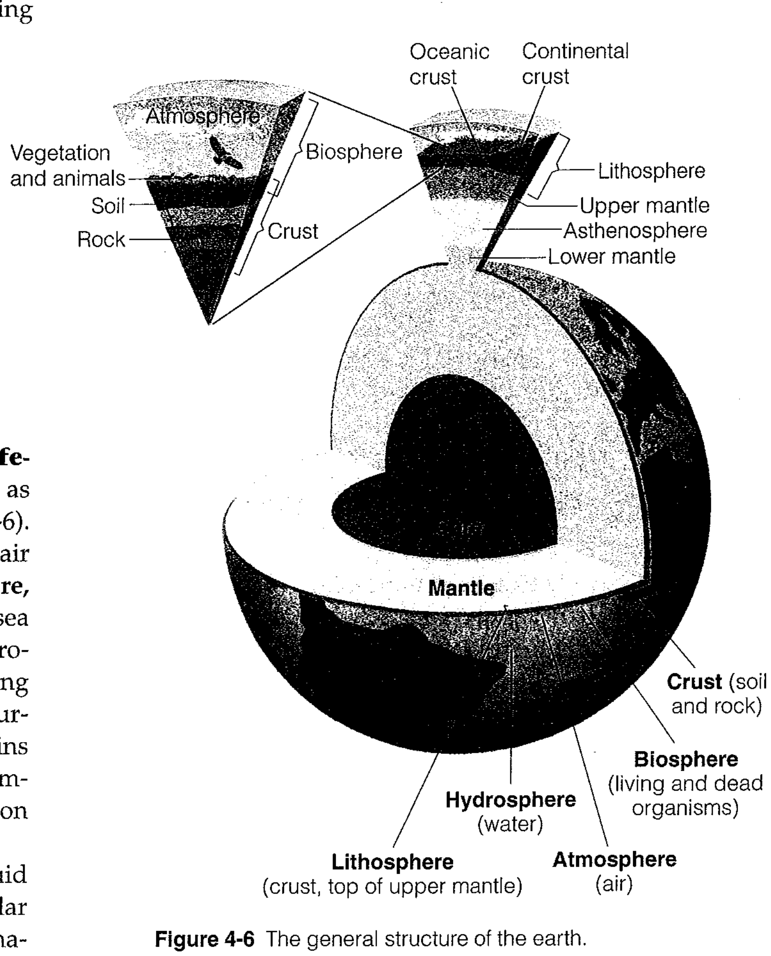


Figure 4-6 The general structure of the earth.

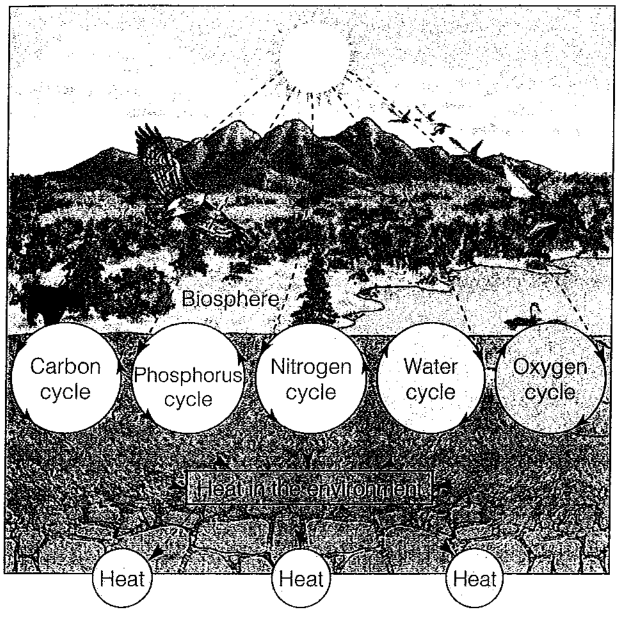


Figure 4-7 Life on the earth depends on **(1)** the *one-way flow of energy* (dashed lines) from the sun through the biosphere, **(2)** the *cycling of crucial elements* (solid lines around circles), and **(3)** *gravity,* which keeps atmospheric gases from escaping into space and draws chemicals downward in the matter cycles. This simplified model depicts only a few of the many cycling elements.

things in their feeding interactions, **(2)** into the environment as low-quality energy (mostly heat dispersed into air or water molecules at a low temperature), and **(3)** eventually back into space as heat.

- The *cycling of matter* (the atoms, ions, or molecules needed for survival by living organisms) through parts of the biosphere. The earth is closed to significant inputs of matter from space. Thus essentially all the nutrients used by organisms are already present on earth and must be recycled again and again for life to continue.
- *Gravity,* which **(1)** allows the planet to hold on to its atmosphere and **(2)** causes the downward movement of chemicals in the matter cycles.

How Does the Sun Help Sustain Life on Earth? The sun is a middle-aged star whose energy

- Lights and warms the planet.
- Supports *photosynthesis,* the process used by green plants and some bacteria to make compounds such as carbohydrates that keep them alive and feed most other organisms.
- Powers the cycling of matter.
- Drives the climate and weather systems that distribute heat and fresh water over the earth's surface.

The sun is a gigantic fireball of hydrogen (72%) and helium (28%) gases. Temperatures and pressures in its inner core are so high that hydrogen nuclei fuse to form helium nuclei (Figure 3-18, p. 58), releasing enormous amounts of energy.

Thus the sun is a gigantic nuclear fusion (thermonuclear) reactor running on hydrogen fuel. This enormous reactor radiates energy in all directions as electromagnetic radiation (Figure 3-10, p. 52). Moving at the speed of light, this radiation makes the 150-million-kilometer (93-million-mile) trip between the sun and the earth in slightly more than 8 minutes.

What Happens to Solar Energy Reaching the Earth? Because the earth is a tiny sphere in the vastness of space, it receives only about one-billionth of the sun's output of energy. Much of this energy is either reflected away or absorbed by chemicals in its atmosphere (Figure 4-8).

Most of what reaches the atmosphere is **(1)** visible light (Figure 3-10, p. 52), **(2)** infrared radiation (heat), and **(3)** the small amount of ultraviolet radiation that is not absorbed by ozone in the stratosphere (Figure 4-8). This incoming energy **(1)** warms the troposphere and land, **(2)** evaporates water and cycles it through the biosphere, and **(3)** generates winds. A tiny fraction is

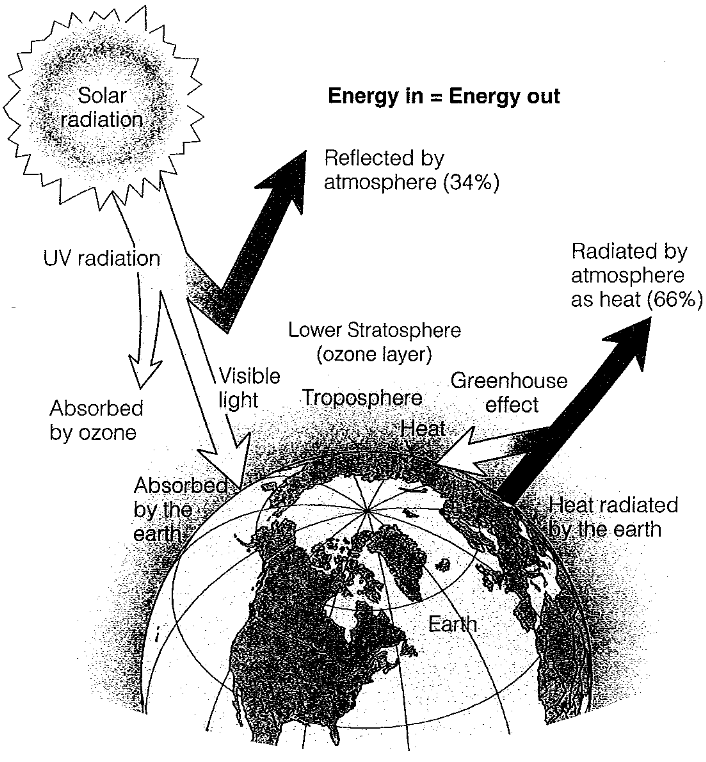


Figure 4-8 The flow of energy to and from the earth.

captured by green plants, algae, and bacteria to fuel photosynthesis and make the organic compounds that most forms of life need to survive.

Most unreflected solar radiation is degraded into infrared radiation (which we experience as heat) as it interacts with the earth. Greenhouse gases (such as water vapor, carbon dioxide, methane, nitrous oxide, and ozone) in the atmosphere reduce this flow of heat back into space. This helps warm the earth by acting somewhat like the glass in a greenhouse or the windows in a closed car, which allow a buildup of heat. Without this **natural greenhouse effect,** the earth would be too cold for life as we know it to exist.

4-3 ECOSYSTEM CONCEPTS AND COMPONENTS

What Are Biomes and Aquatic Life Systems? Viewed from outer space, the earth resembles an enormous jigsaw puzzle consisting of large masses of land and vast expanses of ocean (p. 1 and Figure 1-1, p. 2). Biologists have classified the terrestrial (land) portion of the biosphere into **biomes** ("BY-ohms"). They are large regions such as forests, deserts, and grasslands characterized by **(1)** a distinct climate and **(2)** specific life-forms (especially vegetation) adapted to it (Figure 4-9).

Climate—long-term patterns of weather—is the main factor determining what type of life, especially what plants, will thrive in a given land area. Each biome consists of a patchwork of many different ecosystems whose communities have adapted to differences in climate, soil, and other factors throughout the biome.

Marine and freshwater portions of the biosphere can be divided into **aquatic life zones,** each containing numerous ecosystems. Aquatic life zones are the aquatic equivalent of biomes. Examples include **(1)** *freshwater life zones* (such as lakes and streams) and **(2)** *ocean or marine life zones* (such as estuaries, coastlines, coral reefs, and the deep ocean).

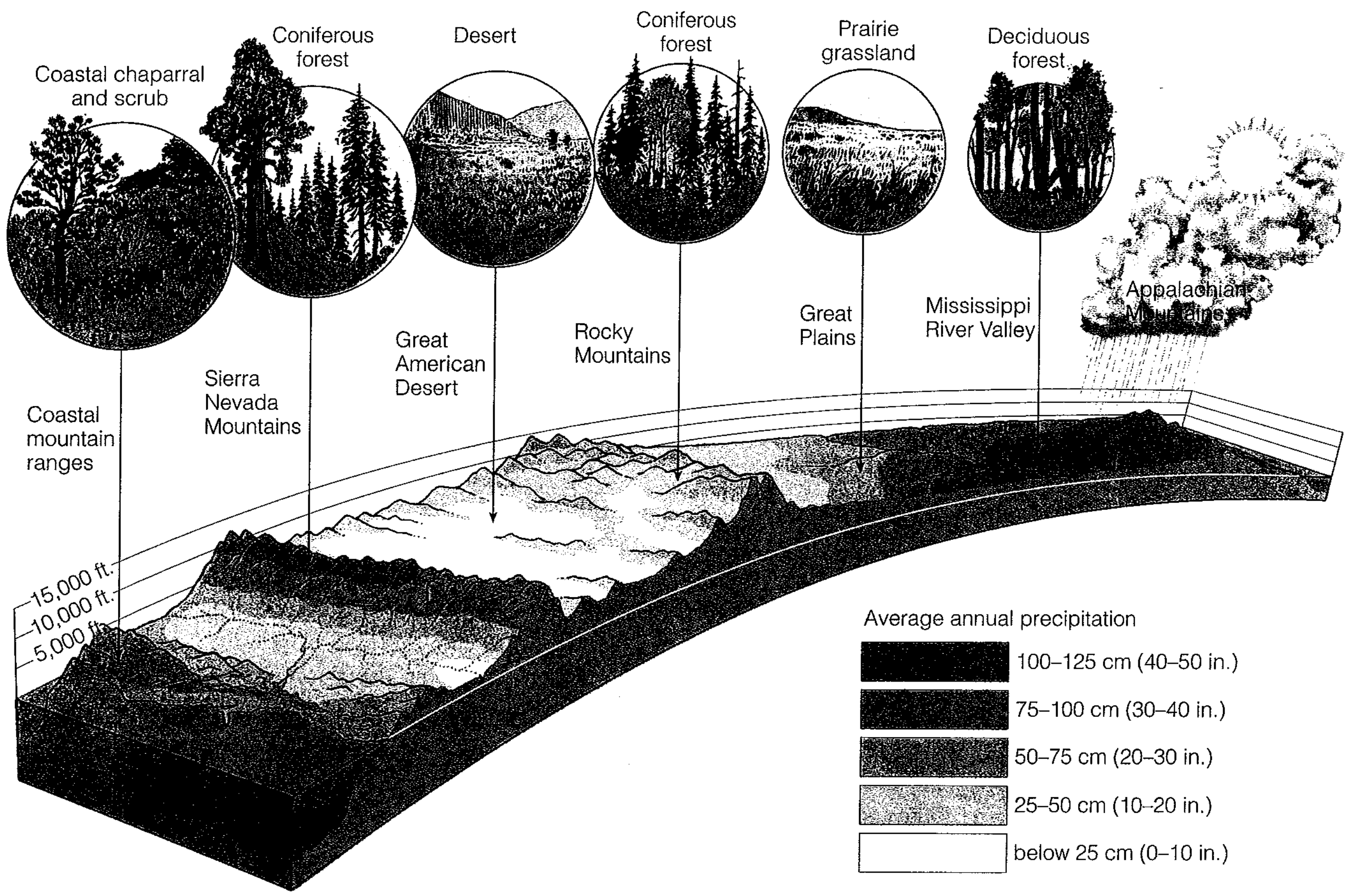


Figure 4-9 Major biomes found along the 39th parallel across the United States. The differences reflect changes in climate, mainly differences in average annual precipitation and temperature (not shown).

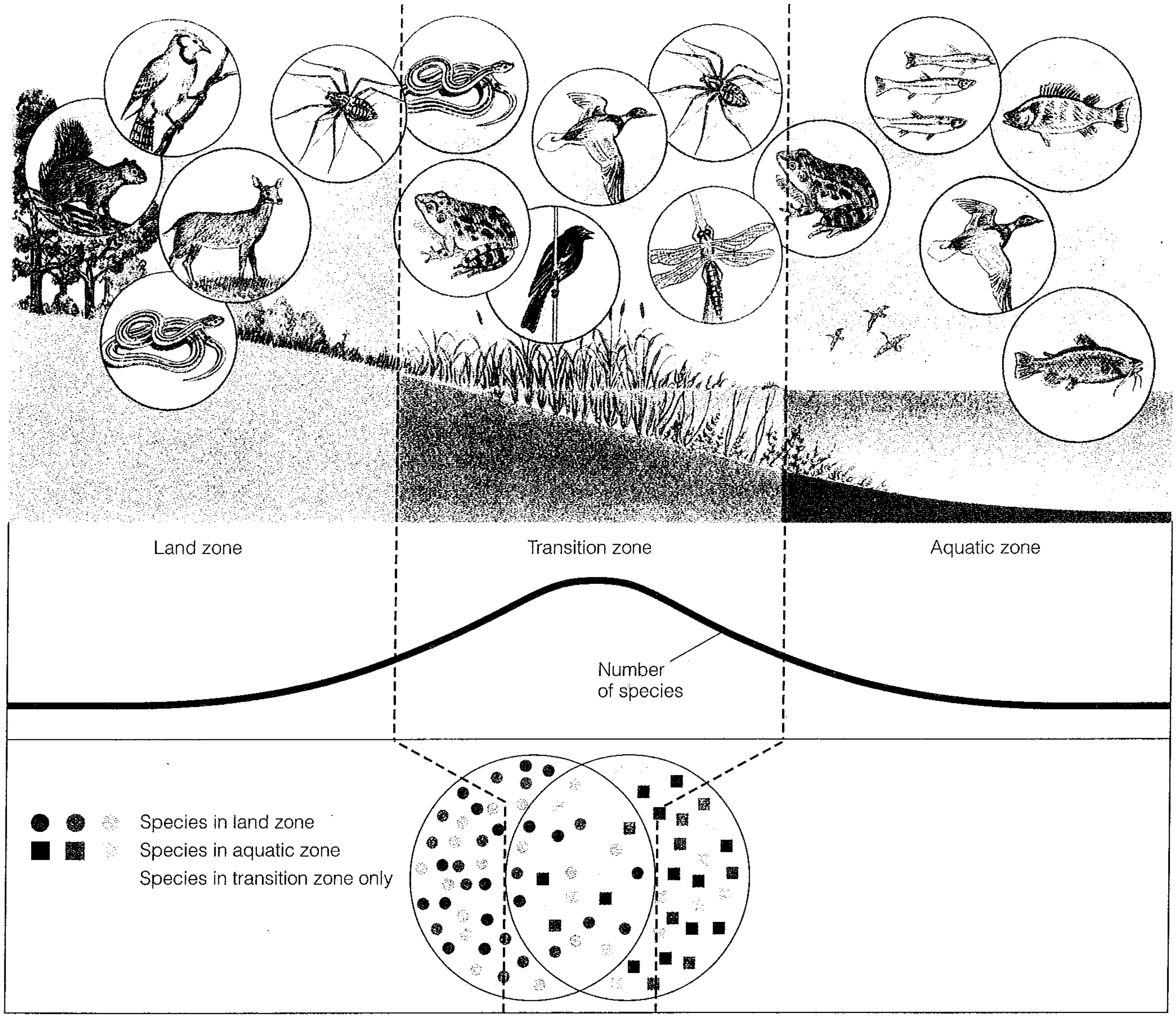


Figure 4-10 Ecosystems rarely have sharp boundaries. Two adjacent ecosystems such as dry land and an open lake often contain a marsh—an ecotone or transitional zone—between them. This zone contains a mixture of species found in each ecosystem and contains some species not found in either ecosystem.

Do Ecosystems Have Distinct Boundaries? For convenience, scientists usually consider an ecosystem under study as an isolated unit. However, natural ecosystems **(1)** rarely have distinct boundaries and **(2)** are not truly self-contained, self-sustaining systems.

Instead, one ecosystem tends to merge with the next in a transitional zone called an **ecotone,** a region containing a mixture of species from adjacent ecosystems and often species not found in either of the bordering ecosystems. For example, a marsh or wetland found between dry land and the open water of a lake or ocean is an ecotone (Figure 4-10). Another example is the zone of grasses, small shrubs, and scattered small trees found between a grassland and a forest.

What Are the Major Components of Ecosystems? The biosphere and its ecosystems can be separated into two parts: **(1) abiotic,** or nonliving, components (water, air, nutrients, and solar energy) and **(2) biotic,** or living, components (plants, animals, and microorganisms, sometimes called *biota*). Figures 4-11 and 4-12 (p. 72) are greatly simplified diagrams of some of the biotic and abiotic components in a freshwater aquatic ecosystem and a terrestrial ecosystem.

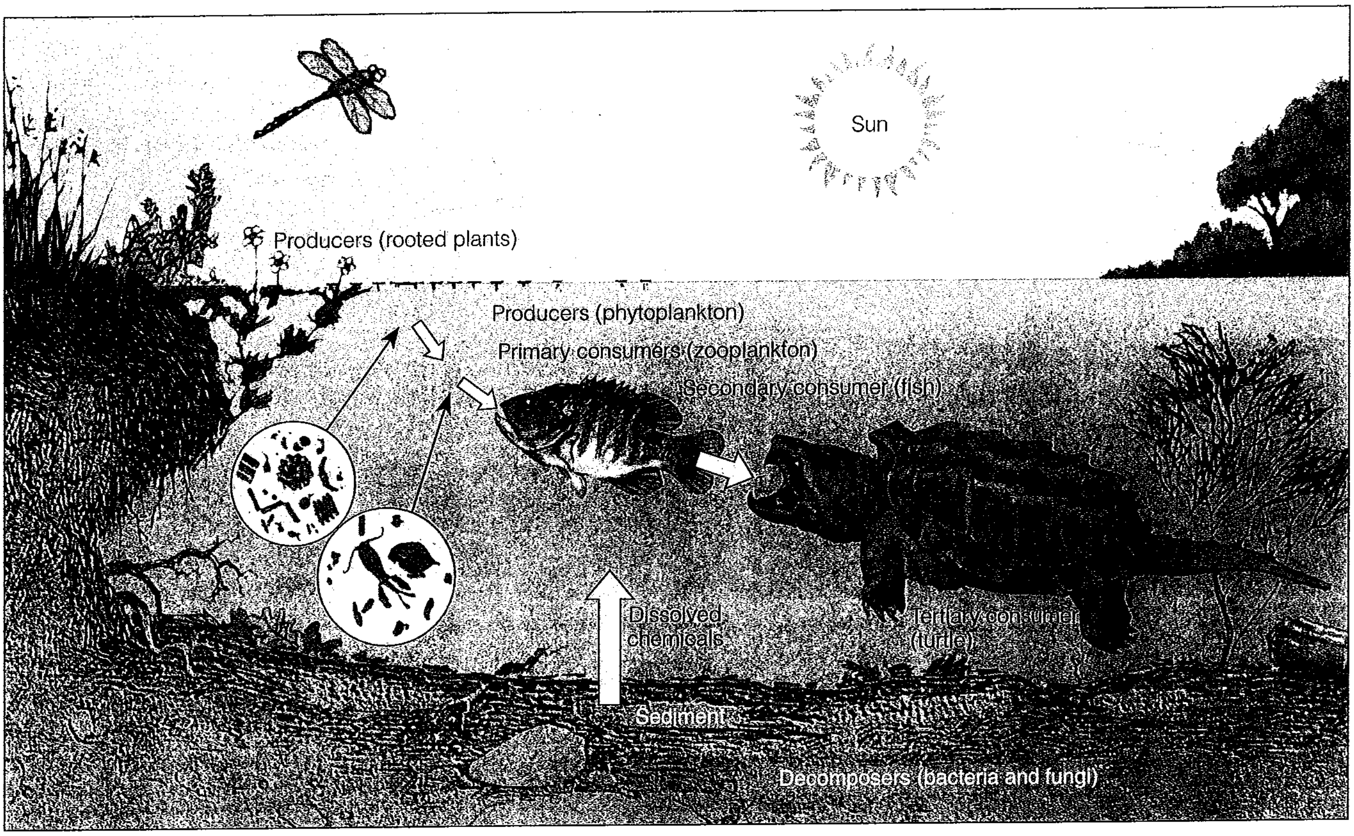


Figure 4-11 Major components of a freshwater ecosystem.

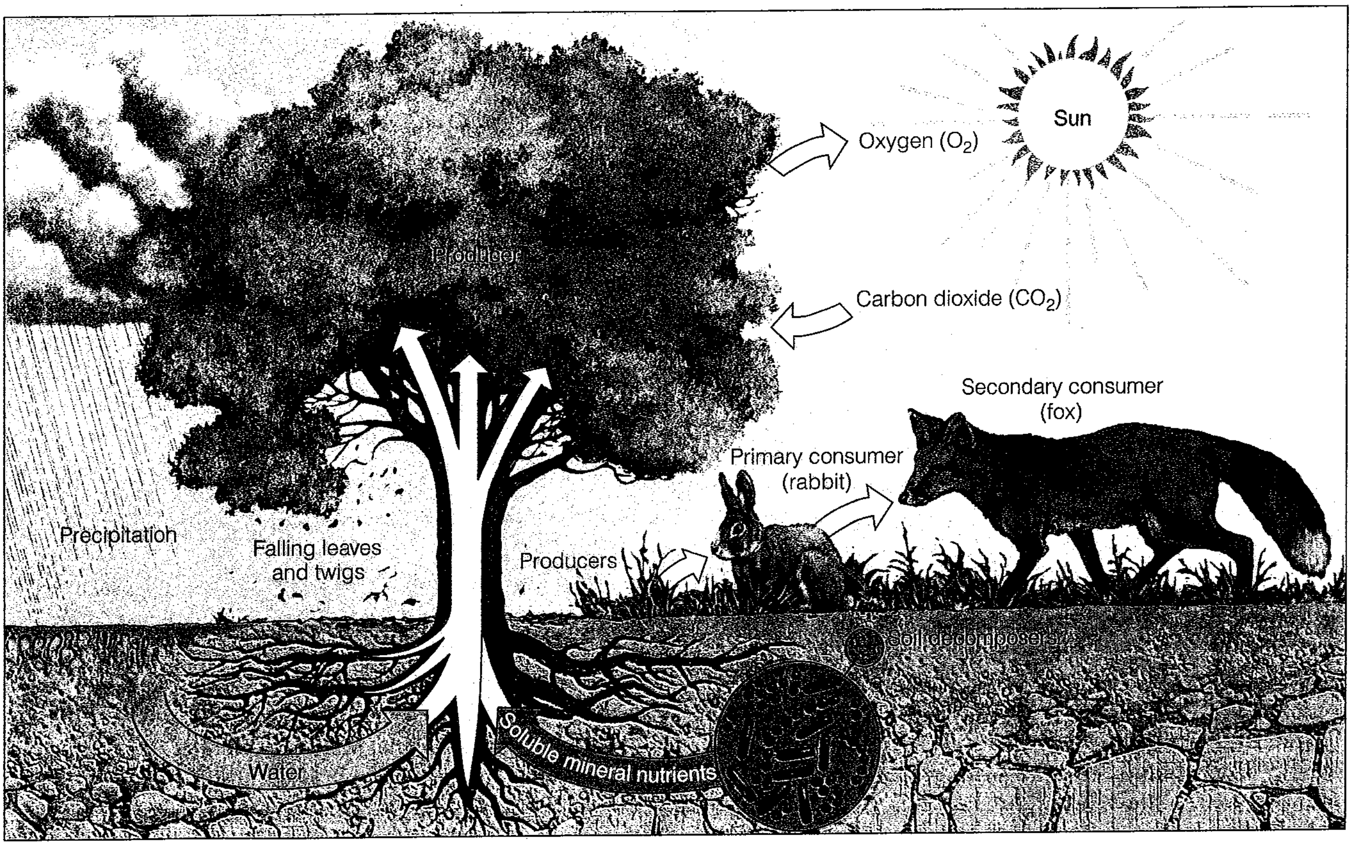


Figure 4-12 Major components of an ecosystem in a field.

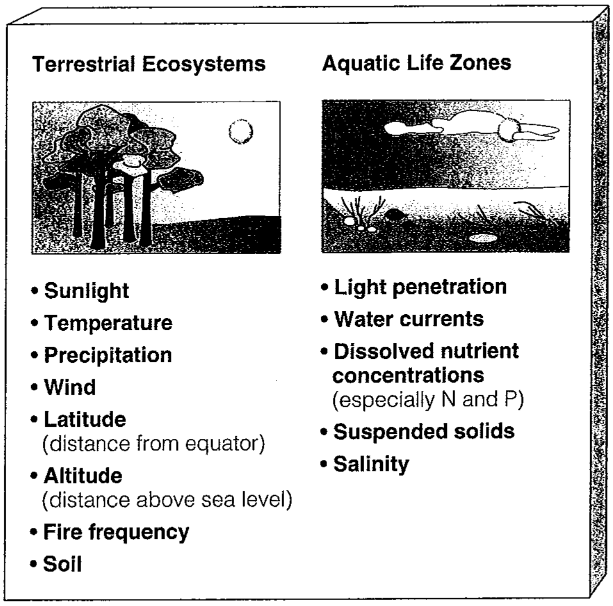


Figure 4-13 Key physical and chemical or abiotic factors affecting terrestrial ecosystems (left) and aquatic life zones (right).

What Are the Major Nonliving Components of Ecosystems? The nonliving, or abiotic, components of an ecosystem are the physical and chemical factors that influence living organisms in land (terrestrial) ecosystems and aquatic life zones (Figure 4-13).

Different species thrive under different physical conditions. Some need bright sunlight, and others thrive better in shade. Some need a hot environment and others a cool or cold one. Some do best under wet conditions and others under dry conditions.

Each population in an ecosystem has a **range of tolerance** to variations in its physical and chemical environment (Figure 4-14). 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. Thus, although a trout population may do best within a narrow band of temperatures (*optimum level* or *range*), a few individuals can survive above and below that band. As Figure 4-14 shows, tolerance has its limits, beyond which none of the trout can survive.

These observations are summarized in the **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 that species.* A species may have a wide range of tolerance to some factors and a narrow range of tolerance to others. Most organisms are least tolerant during juvenile or reproductive stages of their life cycles. *Highly tolerant species can live in a variety of habitats with widely different conditions.*

A variety of factors can affect the number of organisms in a population. However, sometimes one factor, known as a **limiting factor,** is more important

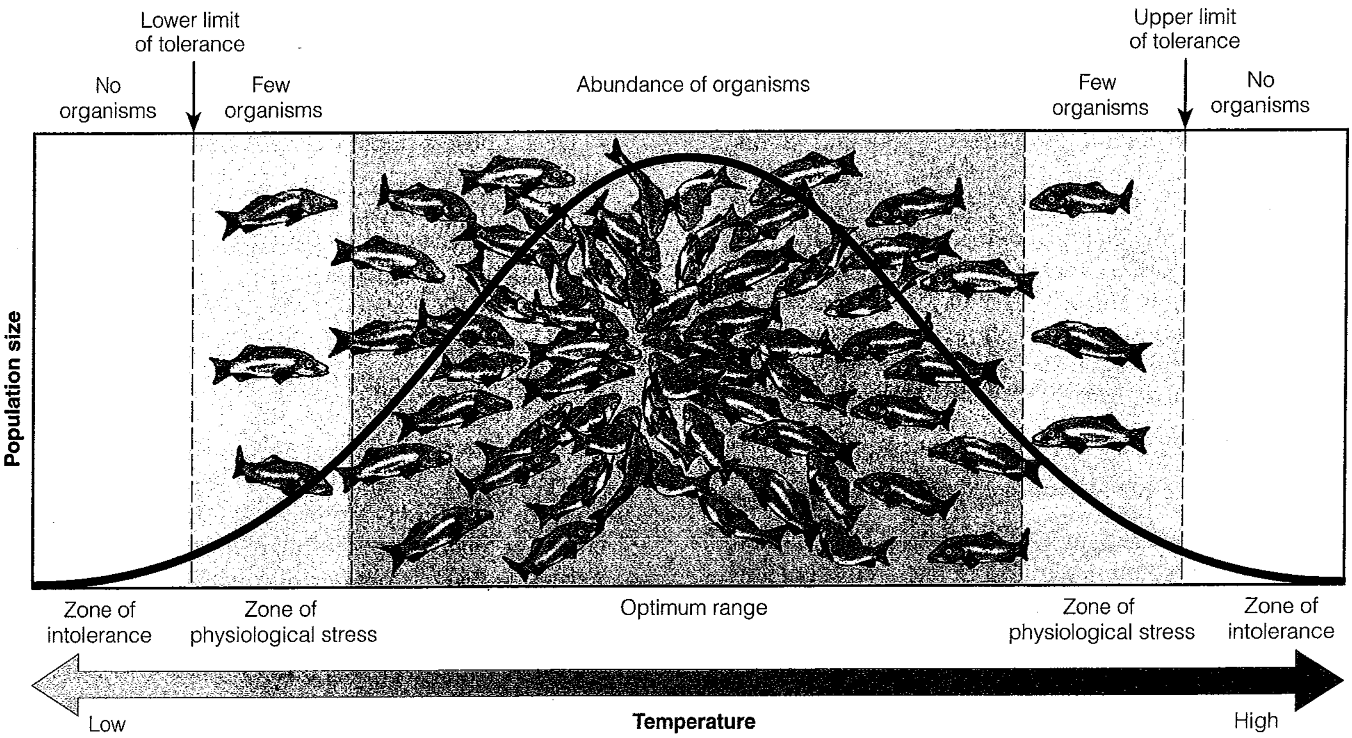


Figure 4-14 Range of tolerance for a population of organisms to an abiotic environmental factor—in this case, temperature.

in regulating population growth than other factors. This ecological principle, related to the law of tolerance, is called the **limiting factor 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 optimum range of tolerance.*

On land, precipitation often is the limiting factor. Lack of water in a desert limits plant growth. Soil nutrients also can act as a limiting factor on land. Suppose a farmer plants corn in phosphorus-poor soil. Even if water, nitrogen, potassium, and other nutrients are at optimum 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 too much fertilizer can kill plants, a common mistake of many beginning gardeners.

Important limiting factors for aquatic ecosystems include **(1)** temperature, **(2)** sunlight, **(3) dissolved oxygen (DO) content** (the amount of oxygen gas dissolved in a given volume of water at a particular temperature and pressure), and **(4)** nutrient availability. Another limiting factor in aquatic ecosystems is **salinity** (the amounts of various inorganic minerals or salts dissolved in a given volume of water).

What Are the Major Living Components of Ecosystems? Living organisms in ecosystems usually are classified as either *producers* or *consumers,* based on how they get food. **Producers,** sometimes called **autotrophs** (self-feeders), make their own food from compounds obtained from their environment. All other organisms are *consumers,* which depend directly or indirectly on food provided by producers.

On land, most producers are green plants. In freshwater and marine ecosystems, algae and plants are the major producers near shorelines. In open water, the dominant producers are *phytoplankton* (most of them microscopic) that float or drift in the water.

Most producers capture sunlight to make carbohydrates (such as glucose, $C_6H_{12}O_6$) by **photosynthesis.** Although hundreds of chemical changes take place during photosynthesis, the overall reaction can be summarized as follows:

$$\text{carbon dioxide} + \text{water} + \textbf{solar energy} \longrightarrow \text{glucose} + \text{oxygen}$$
$$6\,CO_2 + 6\,H_2O + \textbf{solar energy} \longrightarrow C_6H_{12}O_6 + 6\,O_2$$

A few producers, mostly specialized bacteria, can convert simple compounds from their environment into more complex nutrient compounds without sunlight, a process called **chemosynthesis.**

In one such case, the source of energy is heat generated by the decay of radioactive elements deep in the earth's core. This heat is released at hot-water (hydrothermal) vents in the ocean's depths, where new crust is being formed and reformed. In the pitch darkness around such vents, large populations of specialized producer bacteria use this geothermal energy to convert dissolved hydrogen sulfide (H_2S) and carbon dioxide into organic nutrient molecules. These bacteria in turn become food for a variety of aquatic animals, including huge tube worms and various clams, crabs, mussels, and barnacles.

All other organisms in an ecosystem are **consumers,** or **heterotrophs** ("other feeders"), which get their energy and nutrients by feeding on other organisms or their remains. Based on their primary source of food, consumers are classified as

- **Herbivores** (plant eaters), or **primary consumers,** which feed directly on producers.
- **Carnivores** (meat eaters), which feed on other consumers. Those feeding only on primary consumers are called **secondary consumers;** those feeding on other carnivores are called **tertiary (higher-level) consumers.**
- **Omnivores** (such as pigs, rats, foxes, bears, cockroaches, and humans), which eat plants and animals.
- **Scavengers** (such as vultures, flies, hyenas, and some species of sharks and ants), which feed on dead organisms.
- **Detritivores** (detritus feeders and decomposers), which feed on **detritus** ("di-TRI-tus"), or parts of dead organisms and cast-off fragments and wastes of living organisms (Figure 4-15).
- **Detritus feeders** (such as crabs, carpenter ants, termites, and earthworms), which extract nutrients from partly decomposed organic matter in leaf litter, plant debris, and animal dung.
- **Decomposers** (mostly certain types of bacteria and fungi), which recycle organic matter in ecosystems. They do this by **(1)** breaking down (*biodegrading*) dead organic material (detritus) to get nutrients and **(2)** releasing the resulting simpler inorganic compounds into the soil and water, where they can be taken up as nutrients by producers.

Figures 4-11 (p. 72) and 4-12 (p. 72) show various types of producers and consumers.

Both producers and consumers 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 organic nutrients back into carbon dioxide and water. The net effect of the hundreds of steps in this complex process is represented by the following reaction:

$$\text{glucose} + \text{oxygen} \longrightarrow \text{carbon dioxide} + \text{water} + \textbf{energy}$$
$$C_6H_{12}O_6 + 6\,O_2 \longrightarrow 6\,CO_2 + 6\,H_2O + \textbf{energy}$$

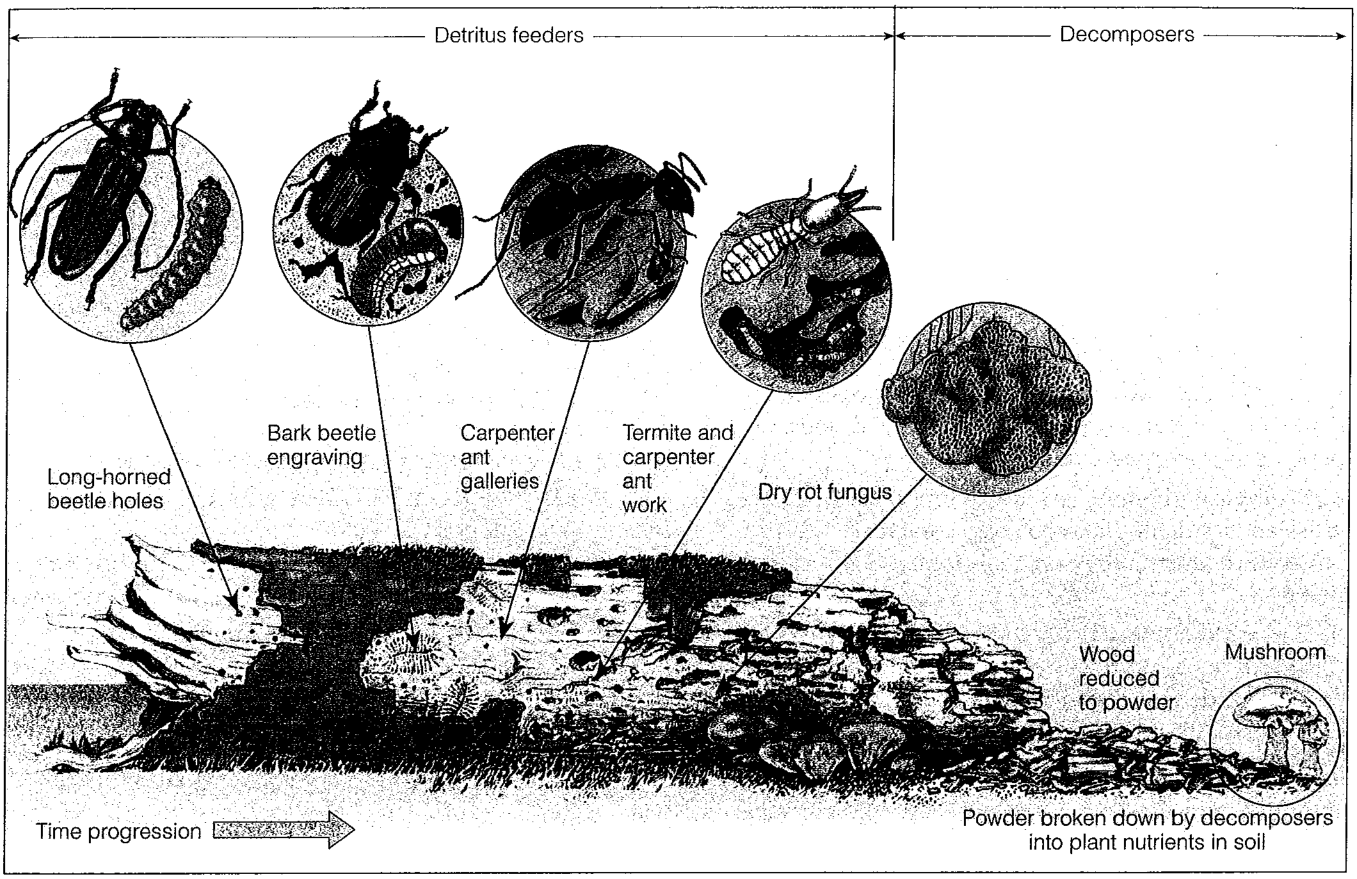


Figure 4-15 Some detritivores, called *detritus feeders,* directly consume tiny fragments of this log. Other detritivores, called *decomposers* (mostly fungi and bacteria), digest complex organic chemicals in fragments of the log into simpler inorganic nutrients. These nutrients can be used again by producers if they are not washed away or otherwise removed from the system.

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

Some decomposers get the energy they need by breaking down glucose (or other organic compounds) in the absence of oxygen. This form of cellular respiration is called **anaerobic respiration,** or **fermentation.** Instead of carbon dioxide and water, the end products of this process are compounds such as **(1)** methane gas (CH_4, the main component of natural gas), **(2)** ethyl alcohol (C_2H_6O), **(3)** acetic acid ($C_2H_4O_2$, the key component of vinegar), and **(4)** hydrogen sulfide (H_2S, when sulfur compounds are broken down).

The survival of any individual organism depends on the *flow of matter and energy* through its body. However, an ecosystem as a whole survives primarily through a combination of *matter recycling* (rather than one-way flow) and *one-way energy flow* (Figure 4-16).

Decomposers complete the cycle of matter by breaking down detritus into inorganic nutrients that are used by producers. Without decomposers, **(1)** the entire world would be knee-deep in plant litter, dead animal

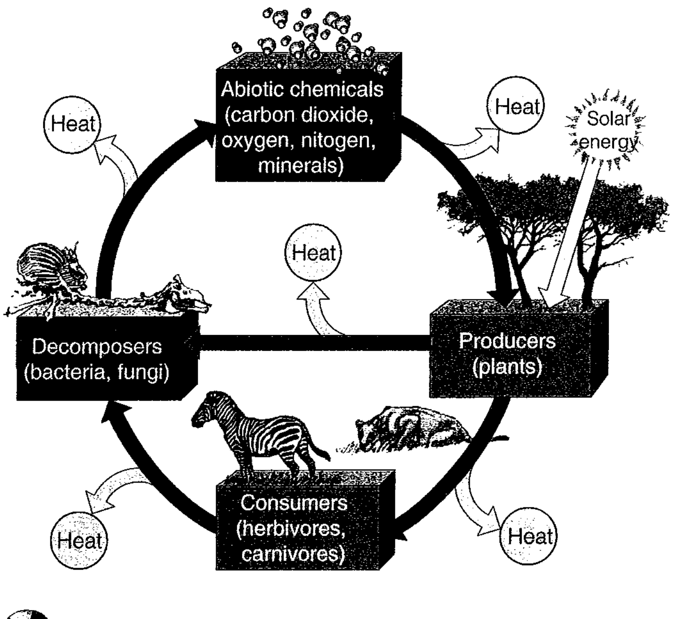


Figure 4-16 The main structural components (energy, chemicals, and organisms) of an ecosystem are linked by matter recycling and the flow of energy from the sun, through organisms, and then into the environment as low-quality heat.

bodies, animal wastes, and garbage, and **(2)** most life as we know it would no longer exist.

What Is Biodiversity and Why Is It Important?

One important renewable resource is **biological diversity, or biodiversity:** the different life-forms and life-sustaining processes that can best survive the variety of conditions currently found on the earth. Kinds of biodiversity include the following:

- **Genetic diversity** (variety in the genetic makeup among individuals within a species; Figure 4-5, p. 68)
- **Species diversity** (variety among the species or distinct types of living organisms found in different habitats of the planet; Figure 4-17)
- **Ecological diversity** (variety of forests, deserts, grasslands, streams, lakes, oceans, coral reefs, wetlands, and other biological communities; Figure 4-9, p. 70)
- **Functional diversity** (biological and chemical processes or functions such as energy flow and matter cycling needed for the survival of species and biological communities; Figure 4-16, p. 75)

This rich variety of genes, species, biological communities, and life-sustaining biological and chemical processes

- Gives us food, wood, fibers, energy, raw materials, industrial chemicals, and medicines, all of which pour hundreds of billions of dollars into the world economy each year.
- Provides us with free recycling, purification, and natural pest control services.

Every species here today **(1)** contains genetic information that represents thousands to millions of years of adaptation to the earth's changing environmental conditions and **(2)** is the raw material for future adaptations. Loss of biodiversity **(1)** reduces the availability of ecosystem services and **(2)** decreases the ability of species, communities, and ecosystems to adapt to changing environmental conditions. Biodiversity is nature's insurance policy against disasters.

Some people also include *human cultural diversity* as part of the earth's biodiversity. The variety of human cultures represents numerous social and technological solutions to changing environmental conditions.

4-4 CONNECTIONS: FOOD WEBS AND ENERGY FLOW IN ECOSYSTEMS

What Are 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. As a result, *there is little matter waste in natural ecosystems.*

The sequence of organisms, each of which is a source of food for the next, is called a **food chain.** It determines how energy and nutrients move from one organism to another through an ecosystem (Figure 4-18).

Ecologists assign each organism in an ecosystem to a *feeding level,* or **trophic level** (from the Greek word *trophos,* "nourishment"), depending on whether it is a producer or a consumer and on what it eats or decomposes. Producers belong to the first trophic level, primary consumers to the second trophic level, secondary consumers to the third, and so on. Detriti-

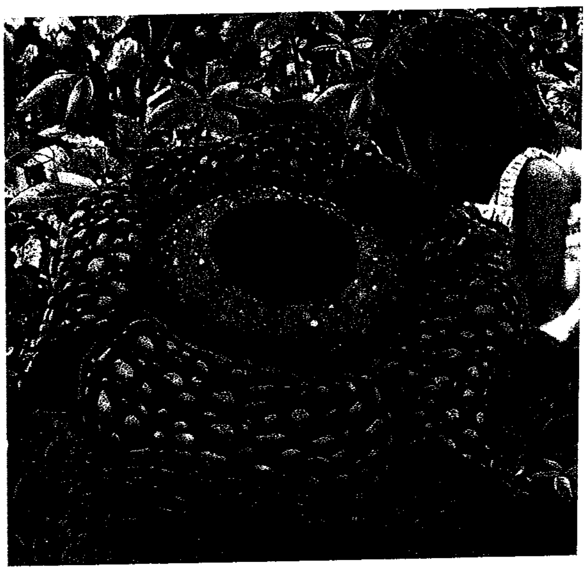


Figure 4-17 Two species found in tropical forests are part of the earth's biodiversity. On the right is the world's largest flower, the flesh flower (*Rafflesia arnoldi*), growing in a tropical rain forest in Sumatra. The flower of this leafless plant can be as large as 1 meter (4.3 feet) in diameter and weigh 7 kilograms (15 pounds). The plant gives off a smell like rotting meat, presumably to attract flies and beetles that pollinate its flower. After blossoming once a year for a few weeks, the flower dissolves into a slimy black mass. On the left is a cotton top tamarin.

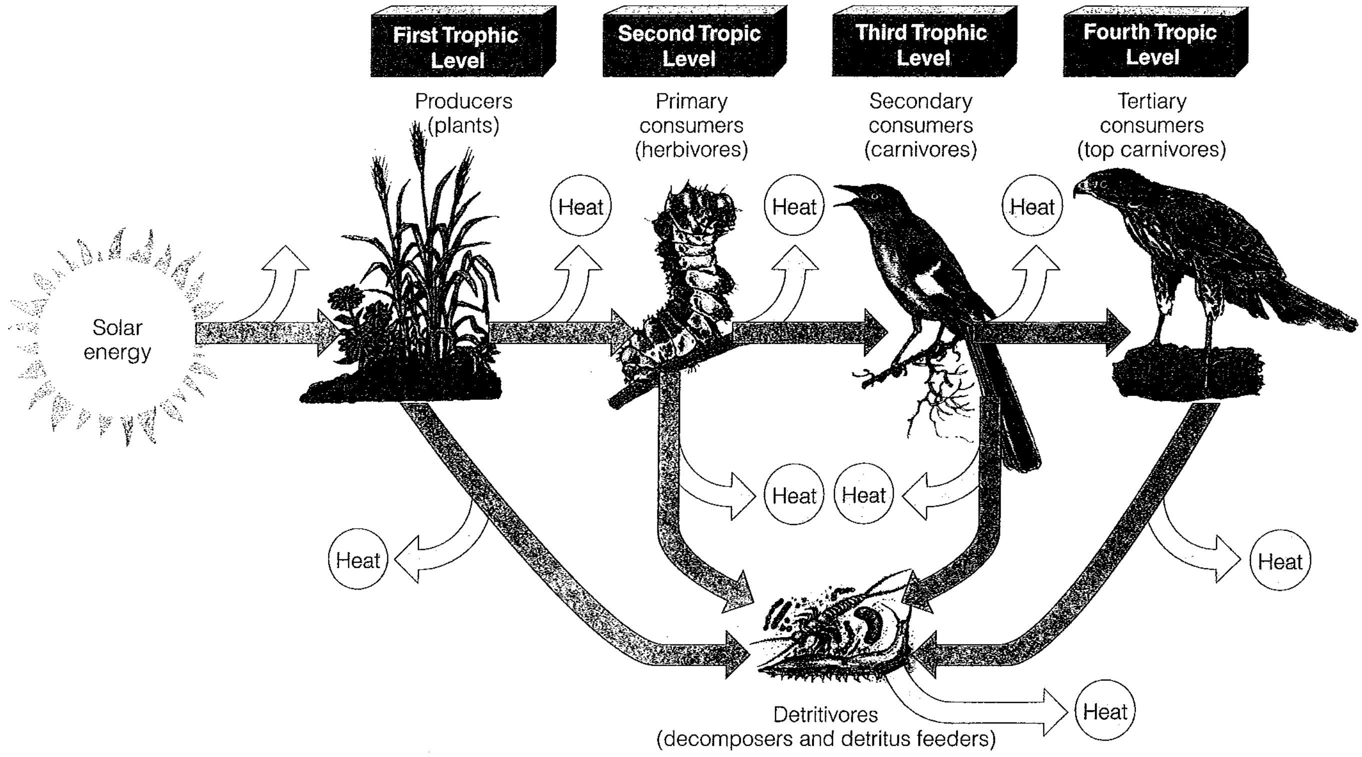


Figure 4-18 Model of a *food chain.* The arrows show how chemical energy in food flows through various *trophic levels,* or energy transfers; most of the energy is degraded to heat, in accordance with the second law of thermodynamics. Food chains rarely have more than four trophic levels.

vores and decomposers process detritus from all trophic levels.

Real ecosystems are more complex than this. Most consumers feed on more than one type of organism, and most organisms are eaten by more than one type of consumer. Because most species participate in several different food chains, the organisms in most ecosystems form a complex network of interconnected food chains called a **food web** (Figure 4-19, p. 78). Trophic levels can be assigned in food webs just as in food chains.

How Can We Represent the Energy Flow in an Ecosystem? Pyramids of Energy Flow Each trophic level in a food chain or web contains a certain amount of **biomass,** the dry weight of all organic matter contained in its organisms. In a food chain or web, chemical energy stored in biomass is transferred from one trophic level to another.

With each transfer some usable energy is degraded and lost to the environment as low-quality heat. Thus **(1)** only a small portion of what is eaten and digested is actually converted into an organism's bodily material or biomass, and **(2)** the amount of usable energy available to each successive trophic level declines.

The percentage of usable energy transferred as biomass from one trophic level to the next is called **ecological efficiency.** It ranges from 5% to 20% (that is, a loss of 80–95%) depending on the types of species and the ecosystem involved, but 10% is typical.

Assuming 10% ecological efficiency (90% loss) 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 energy will be available to support herbivores and only about 100 units to support carnivores.

The more trophic levels or steps in a food chain or web, the greater the cumulative loss of usable energy as energy flows through the various trophic levels. The **pyramid of energy flow** in Figure 4-20 (p. 79) illustrates this energy loss for a simple food chain, assuming a 90% energy loss with each transfer. Figure 4-21 (p. 79) shows the pyramid of energy flow during 1 year for an aquatic ecosystem in Silver Springs, Florida.* Pyramids of energy flow *always* have an

*Because such pyramids represent energy flows, not energy storage, they should not be called pyramids of energy (a common error in some biology and environmental science textbooks).

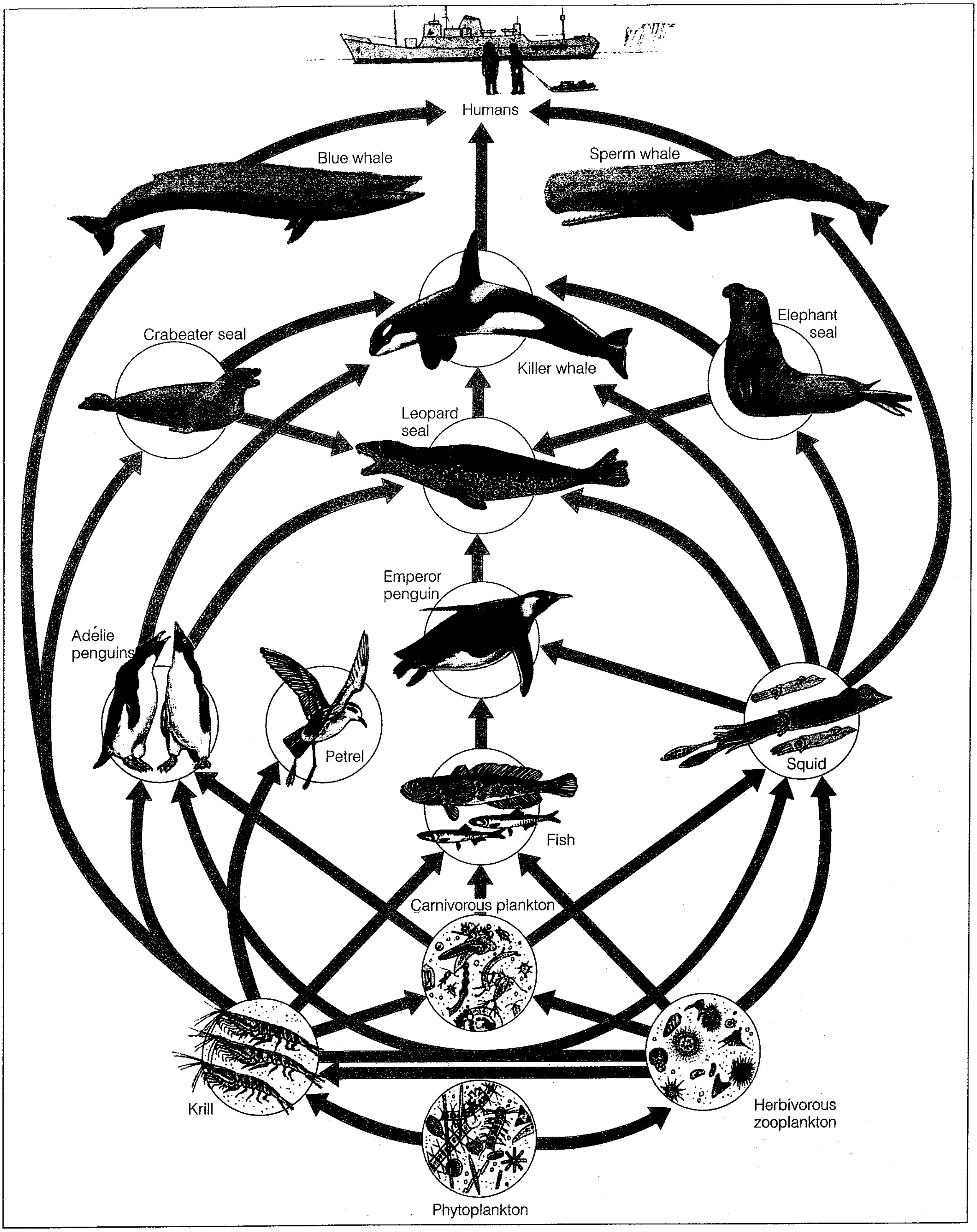


Figure 4-19 Greatly simplified food web in the Antarctic. Many more participants in the web, including an array of decomposer organisms, are not depicted here.

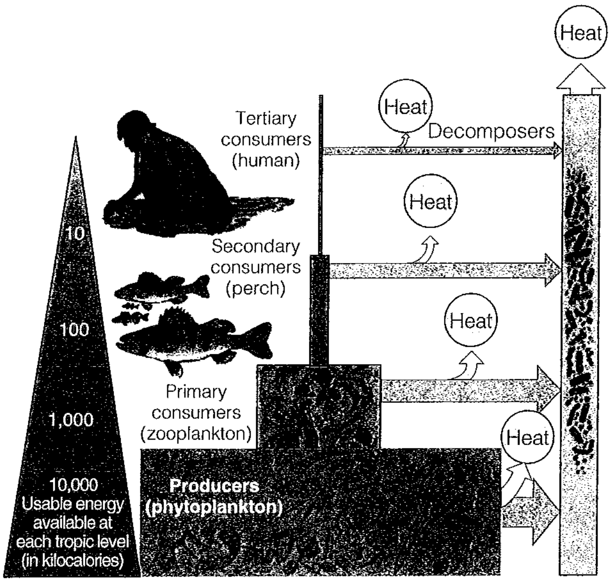


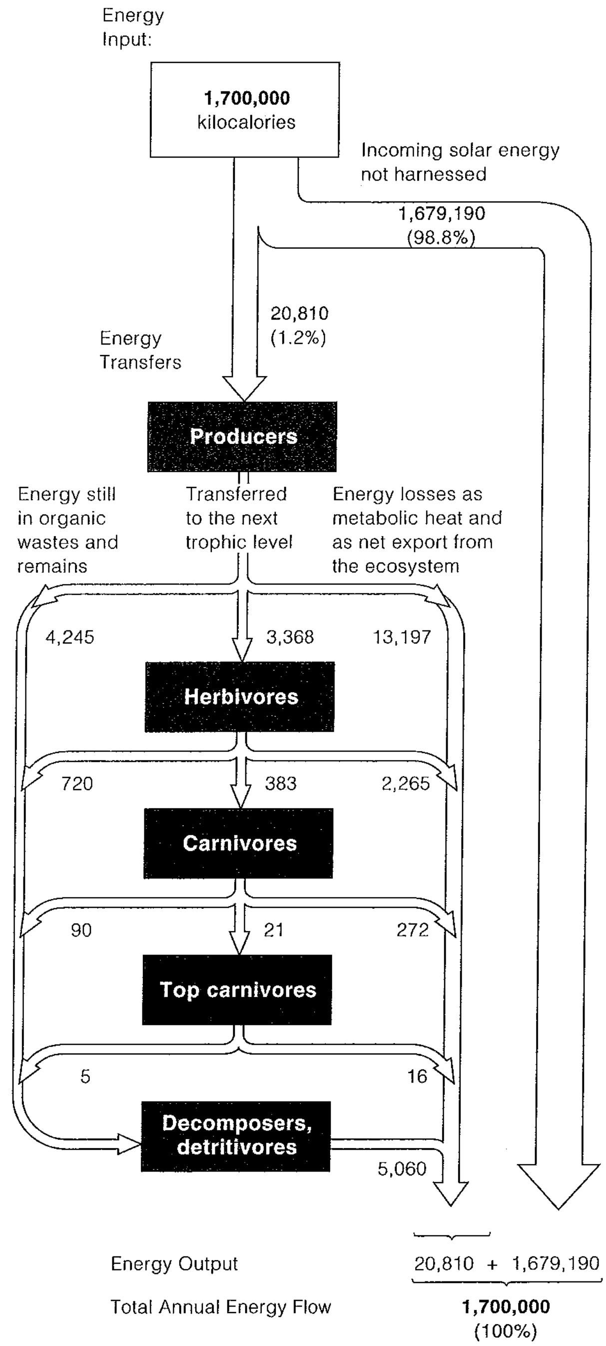
Figure 4-20 Generalized *pyramid of energy flow* showing the decrease in usable energy available at each succeeding trophic level in a food chain or web. In nature, ecological efficiency varies from 5% to 20%, with 10% efficiency being common. This model assumes a 10% ecological efficiency (90% loss in usable energy to the environment, in the form of low-quality heat) with each transfer from one trophic level to another.

upright pyramidal shape because of the automatic degradation of energy quality required by the second law of thermodynamics.

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 (for example, grain → human) rather than passing such crops through another trophic level and eating grain eaters (grain → steer → human).

The large loss in 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 energy is left after four or five transfers to support organisms feeding at these high trophic levels. This explains why **(1)** there are so few top carnivores such as eagles, hawks, tigers, and white sharks, **(2)** such species usually are the first to suffer when the ecosystems that support them are disrupted, and **(3)** these species are so vulnerable to extinction.

How Can We Represent Biomass Storage in an Ecosystem? Pyramids of Biomass and Numbers Ecologists use a **pyramid of biomass** (Figure 4-22, p. 80) to represent the storage of biomass at various trophic levels in an ecosystem. They estimate biomass by harvesting organisms from random patches or narrow strips in an ecosystem. The sample



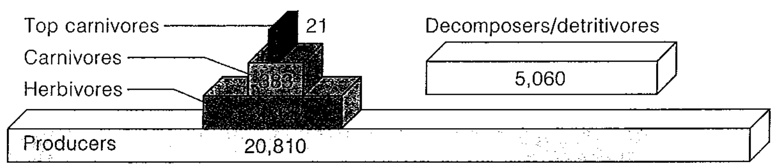


Figure 4-21 Annual pyramid of energy flow (in kilocalories per square meter per year) for an aquatic ecosystem in Silver Springs, Florida. The pyramid is constructed by using the data on energy flow through this ecosystem shown in the bottom drawing. (From Cecie Starr, *Biology: Concepts and Applications*, 4th ed., Brooks/Cole, [Wadsworth] © 2000)

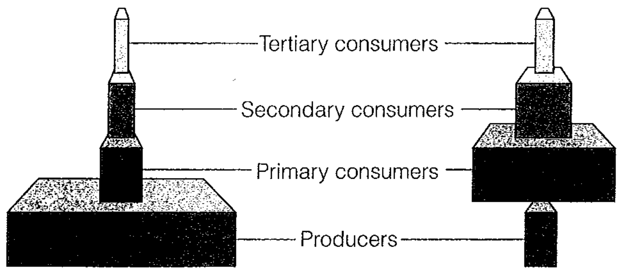


Figure 4-22 Generalized graphs of *biomass of organisms* in the various trophic levels for two ecosystems. The size of each tier in this conceptual model represents the dry weight per square meter of all organisms at that trophic level.

organisms are then sorted according to trophic levels, dried, and weighed. These data are used to plot a pyramid of biomass.

For most land ecosystems, the total biomass at each successive trophic level decreases. This yields a pyramid of biomass with a large base of producers, topped by a series of increasingly smaller biomasses at higher trophic levels (Figure 4-22, left). In the open waters of aquatic ecosystems, however, the biomass of primary consumers (zooplankton) can exceed that of producers. The reason is that the producers are microscopic phytoplankton that grow and reproduce rapidly, not large plants that grow and reproduce slowly. The graph is not an upright pyramid (Figure 4-22, right) because the zooplankton eat the phytoplankton almost as fast as they are produced so the producer population is never very large.

By estimating the number of organisms at each trophic level, ecologists can also create a **pyramid of numbers** for an ecosystem (Figure 4-23). Numbers of organisms for grasslands and many other ecosystems taper off from the producer level to the higher trophic levels, forming an upright pyramid (Figure 4-23, left).

For other ecosystems the graph can take a different shape. For example, a temperate forest (Figure 4-23, right) has a few large producers (the trees) that support a much larger number of small primary consumers (insects) that feed on the trees.

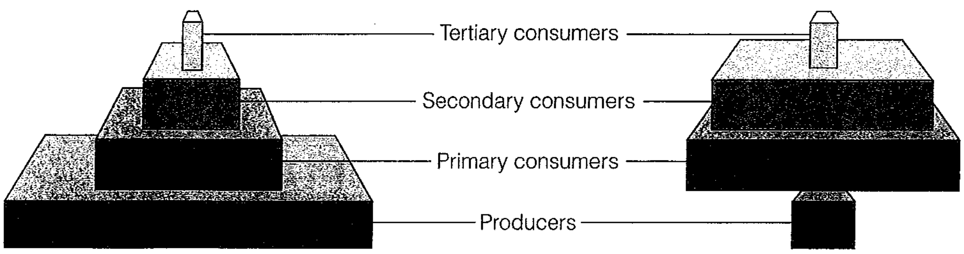


Figure 4-23 Generalized graphs of *numbers of organisms* in the various trophic levels for two ecosystems.

4-5 PRIMARY PRODUCTIVITY OF ECOSYSTEMS

How Rapidly Do Producers in Different Ecosystems Produce Biomass? The *rate* at which an ecosystem's producers convert solar energy into chemical energy as biomass is the ecosystem's **gross primary productivity (GPP).** In effect, it is the rate at which plants or other producers use photosynthesis to make more plant material (biomass).

Figure 4-24 shows how this productivity varies across the earth. This figure shows that GPP generally is greatest **(1)** in the shallow waters near continents, **(2)** along coral reefs where abundant light, heat, and nutrients stimulate the growth of algae, and **(3)** where upwelling currents bring nitrogen and phosphorus from the ocean bottom to the surface. The lowest GPP is in **(1)** deserts and other arid regions because of their low precipitation and high temperatures and **(2)** the open ocean because of a lack of nutrients and sunlight except near the surface.

To stay alive, grow, and reproduce, an ecosystem's producers must use some of the total biomass they produce for their own respiration. Only what is left, called **net primary productivity (NPP),** is available for use as food by other organisms (consumers) in an ecosystem:

Net primary productivity = Rate at which producers store chemical energy as biomass (produced by photosynthesis) − Rate at which producers use chemical energy stored as biomass (through aerobic respiration)

NPP is the *rate* at which energy for use by consumers is stored in new biomass (cells, leaves, roots, and stems). It is measured in units of the energy or biomass available to consumers in a specified area over a given time. Various ecosystems and life zones differ in their NPP (Figure 4-25). The most productive are **(1)** estuaries, **(2)** swamps and marshes, and **(3)** tropical rain forests. The least productive are **(1)** open ocean, **(2)** tundra (arctic and alpine grasslands), and **(3)** desert. Despite its low net primary productivity, there is so much open ocean that it produces more of the earth's NPP per year than any of the other ecosystems and life zones shown in Figure 4-25.

Agricultural land is a highly modified and managed ecosystem. The goal is to increase the NPP and biomass of selected crop plants by adding water (irrigation) and nutrients (fertilizers). Nitrogen as nitrate (NO_3^-)

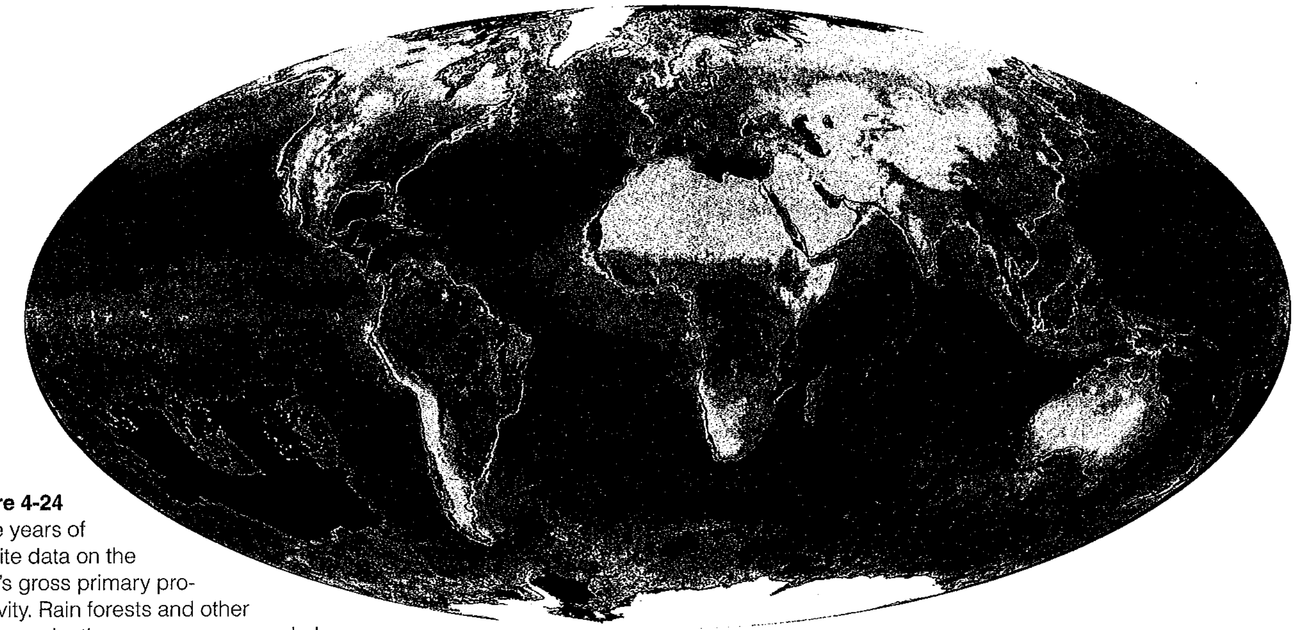


Figure 4-24 Three years of satellite data on the earth's gross primary productivity. Rain forests and other highly productive areas appear as dark green and deserts as yellow. The concentration of phytoplankton, a primary indicator of ocean productivity, ranges from red (highest) to orange, yellow, green, and blue (lowest). (Gene Carl Feldman, Compton J. Tucker—NASA/Goddard Space Flight Center)

and phosphorus as phosphate (PO_4^{3-}) are the most common nutrients in fertilizers because they are most often the nutrients limiting crop growth. Despite such inputs, the NPP of agricultural land is not particularly high compared with that of other ecosystems (Figure 4-25).

How Does the World's Net Rate of Biomass Production Limit the Populations of Consumer Species? As we have seen, producers are the source of all food in an ecosystem. Thus the planet's NPP ultimately limits the number of consumers (including humans) that can survive on the earth. It is tempting to

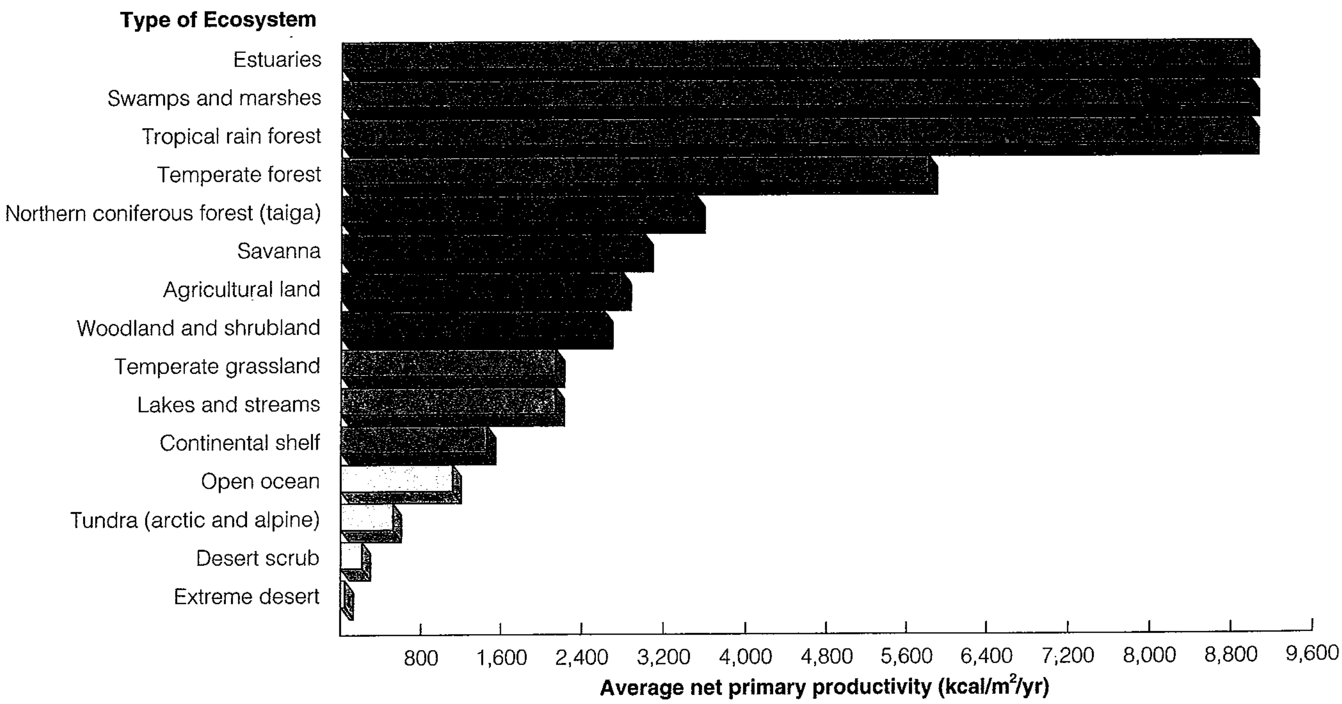


Figure 4-25 Estimated annual average *net primary productivity* (NPP) per unit of area in major life zones and ecosystems, expressed as kilocalories of energy produced per square meter per year (kcal/m^2/yr). (Data from *Communities and Ecosystems,* 2nd ed., by R. H. Whittaker, 1975. New York: Macmillan)

conclude from Figure 4-25 that a good way to feed the world's hungry millions would be to harvest plants in estuaries, swamps, and marshes. But ecologists point out that **(1)** most plants in these areas cannot be eaten by people, and **(2)** these plants are vital food sources (and spawning areas) for fish, shrimp, and other aquatic life-forms that provide us and other consumers with protein.

We might also conclude from Figure 4-25 that we could grow more food for human consumption by clearing tropical forests and planting food crops. According to most ecologists, this is also a bad idea. In tropical forests most of the nutrients needed to grow food crops are stored in the vegetation rather than in the soil. When the trees are removed, the nutrient-poor soils are rapidly depleted by frequent rains and growing crops. Crops can be grown only for a short time without massive and expensive applications of commercial fertilizers.

Because the earth's vast open oceans provide the largest percentage of the earth's net primary productivity, why not harvest its primary producers (floating and drifting phytoplankton) to help feed the rapidly growing human population? The problem is that harvesting the widely dispersed, tiny floating producers in the open ocean would **(1)** take much more fossil fuel and other types of energy than the food energy we would get and **(2)** disrupt the food webs of the open ocean (Figure 4-19) that provide us and other consumer organisms with important sources of energy and protein from fish and shellfish.

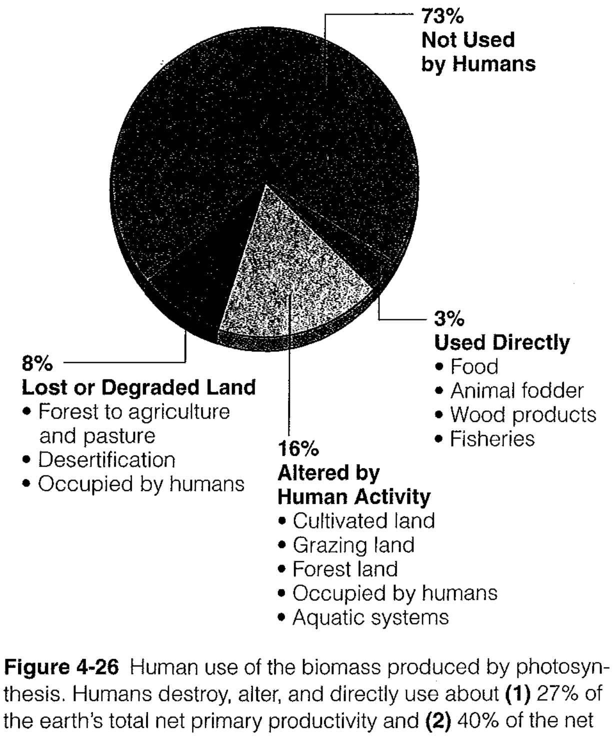


Figure 4-26 Human use of the biomass produced by photosynthesis. Humans destroy, alter, and directly use about **(1)** 27% of the earth's total net primary productivity and **(2)** 40% of the net primary productivity of the earth's terrestrial ecosystems. (Data from Peter Vitousek)

How Much of the World's Net Rate of Biomass Production Do We Use? Peter Vitousek and other ecologists estimate that humans now use, waste, or destroy about **(1)** 27% of the earth's total potential NPP and **(2)** 40% of the NPP of the planet's terrestrial ecosystems (Figure 4-26).

This is the main reason why we are crowding out or eliminating the habitats and food supplies of a growing number of other species. What might happen to us and to other consumer species if **(1)** the human population doubles over the next 40–50 years and **(2)** per capita consumption of resources such as food, timber, and grassland rises sharply?

4-6 CONNECTIONS: MATTER CYCLING IN ECOSYSTEMS

What Are Biogeochemical Cycles? The nutrient atoms, ions, and molecules that organisms need to live, grow, and reproduce are continuously cycled from the nonliving environment (air, water, soil, and rock) to living organisms (biota) and then back again in what are called **nutrient cycles,** or **biogeochemical cycles** (literally, life–earth–chemical cycles). These cycles, driven directly or indirectly by incoming solar energy and gravity, include the carbon, oxygen, nitrogen, phosphorus, and hydrologic (water) cycles (Figure 4-7).

The earth's chemical cycles also 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, Plato, or a hunter–gatherer who lived 25,000 years ago may have inhaled some of the oxygen molecules you just inhaled.

How Is Water Cycled in the Biosphere? The **hydrologic cycle,** or **water cycle,** which collects, purifies, and distributes the earth's fixed supply of water, is shown in simplified form in Figure 4-27.

The main processes in this water recycling and purifying cycle are **(1)** *evaporation* (conversion of water into water vapor), **(2)** *transpiration* (evaporation from leaves of water extracted from soil by roots and transported throughout the plant), **(3)** *condensation* (conversion of water vapor into droplets of liquid water), **(4)** *precipitation* (rain, sleet, hail, and snow), **(5)** *infiltration* (movement of water into soil), **(6)** *percolation* (downward flow of water through soil and permeable rock formations to groundwater storage areas called aquifers), and (7) *runoff* (downslope surface movement back to the sea to resume the cycle).

The water cycle is powered by energy from the sun and by gravity. Incoming solar energy evaporates water from oceans, streams, lakes, soil, and vegetation. About 84% of water vapor in the atmosphere comes from the oceans, and the rest comes from land.

The amount of water vapor air can hold depends on its temperature, with warm air holding more water vapor than cold air. **Absolute humidity** is the amount of water vapor found in a certain mass of air and is usually expressed as grams of water per kilogram of air. **Relative humidity** is the amount of water vapor in a certain mass of air, expressed as a percentage of the maximum amount it could hold at that temperature. For example, a relative humidity of 60% at 27°C (80°F) means that each kilogram (or other unit of mass) of air contains 60% of the maximum amount of water vapor it could hold at that temperature.

Winds and air masses transport water vapor over various parts of the earth's surface, often over long distances. Falling temperatures cause the water vapor to condense into tiny droplets that form clouds or fog. For precipitation to occur, air must contain **condensation nuclei:** tiny particles on which droplets of water vapor can collect. Sources of such particles include (1) volcanic ash, (2) soil dust, (3) smoke, (4) sea salts, and (5) particulate matter emitted by factories, coal-burning power plants, and motor vehicles. The temperature at which condensation occurs is called the **dew point.**

Some of the fresh water returning to the earth's surface as precipitation becomes locked in glaciers. Most of the precipitation falling on terrestrial ecosystems becomes *surface runoff* flowing into streams and lakes, which eventually carry water back to the oceans, where it can be evaporated to cycle again.

Besides replenishing streams and lakes, surface runoff also causes soil erosion, which moves soil and weathered rock fragments from one place to another. Water is thus 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 act to 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 purified by chemical and biological processes. Thus the hydrologic cycle also can be viewed as a cycle of natural renewal of water quality.

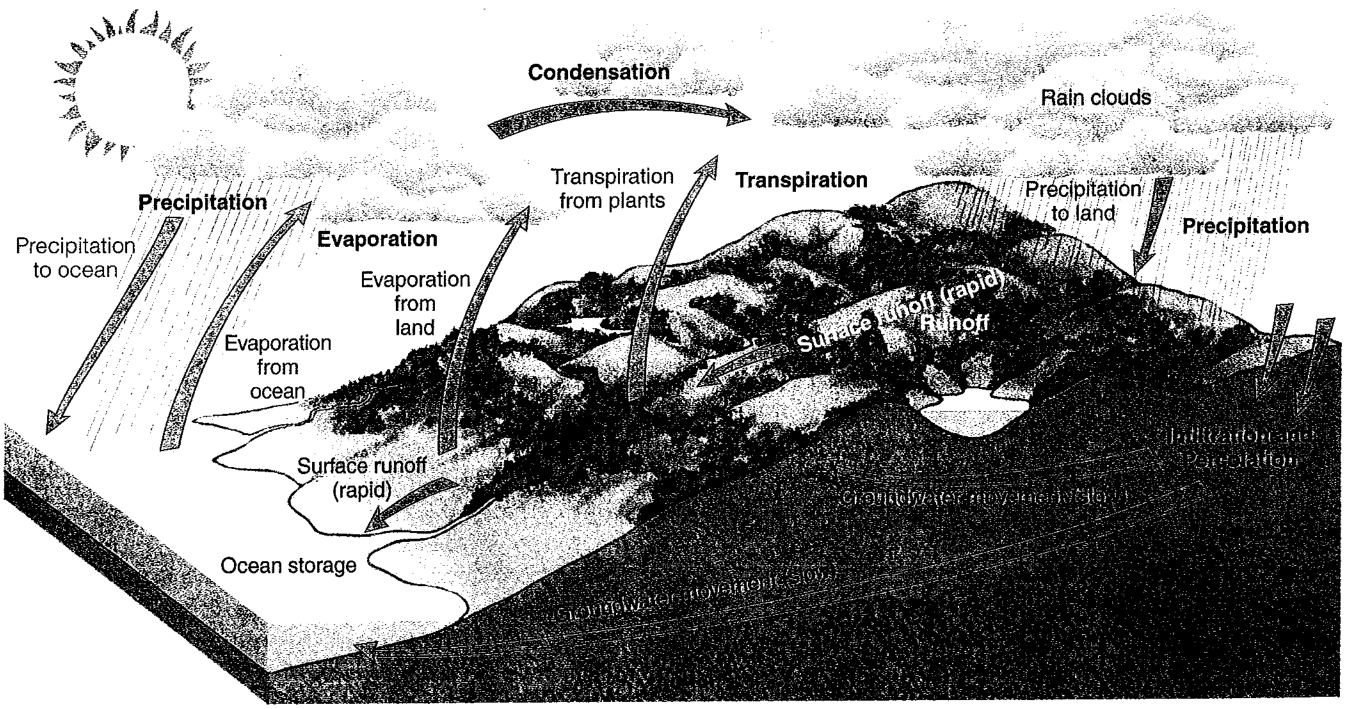
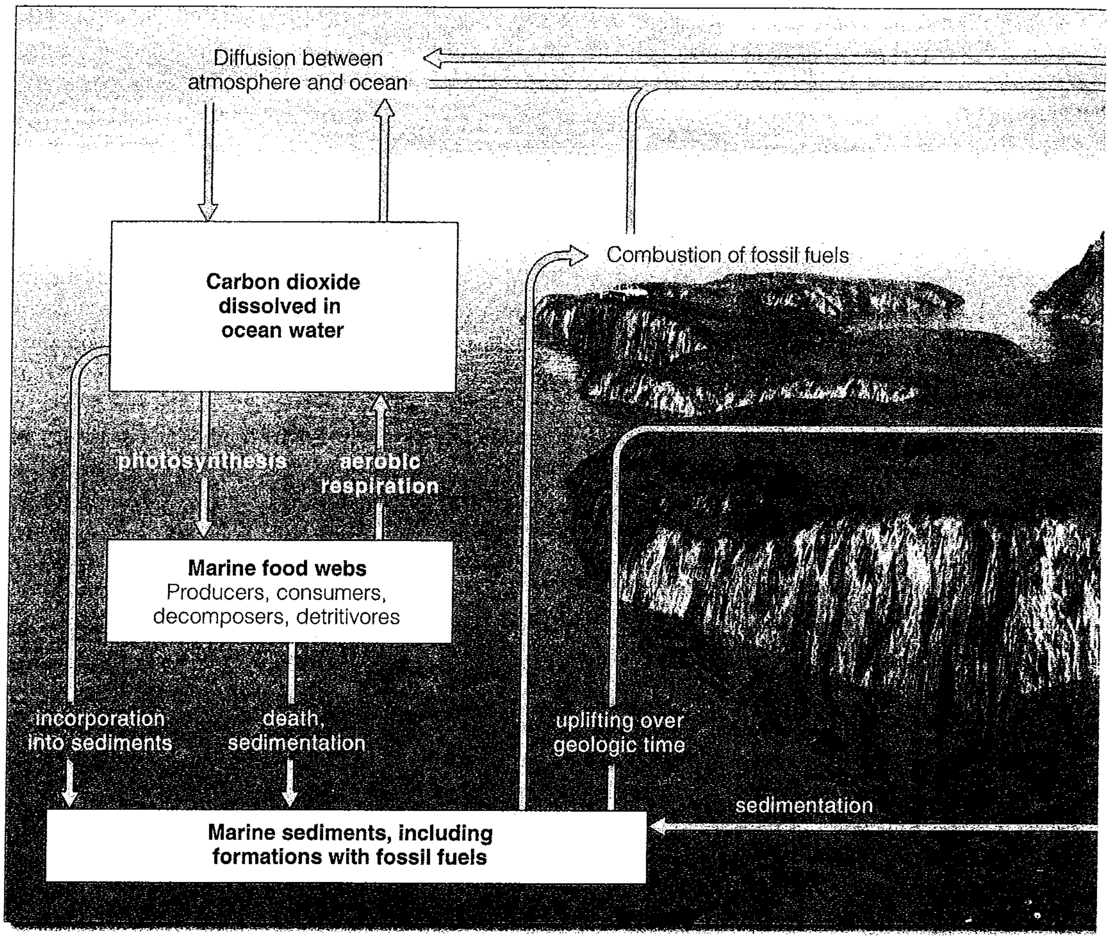


Figure 4-27 Simplified model of the hydrologic cycle.

Figure 4-28 Simplified model of the global carbon cycle. The left portion shows the movement of carbon through marine systems, and the right portion shows its movement through terrestrial ecosystems. Carbon reservoirs are shown as boxes; processes that change one form of carbon to another are shown in unboxed print. (From Cecie Starr, *Biology: Concepts and Applications*, 4th ed., Brooks/Cole, [Wadsworth] © 2000)



How Are Human Activities Affecting the Water Cycle? During the past 100 years, we have been intervening in the earth's current water cycle in several ways:

- Withdrawing large quantities of fresh water from streams, lakes, and underground sources. In some heavily populated or heavily irrigated areas, withdrawals have led to groundwater depletion or intrusion of ocean salt water into underground water supplies.

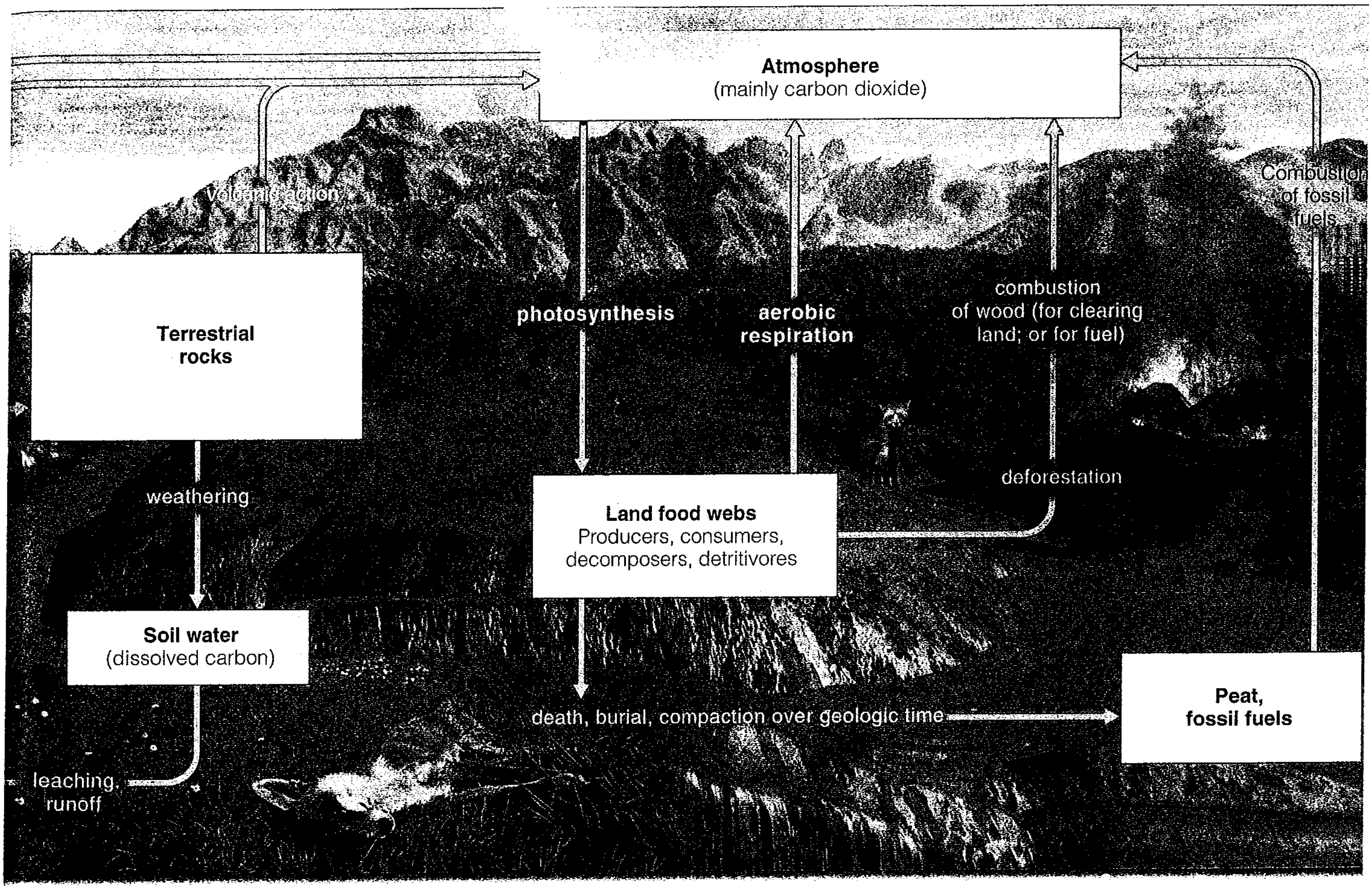
- Clearing vegetation from land for agriculture, mining, road and building construction, and other activities. This **(1)** increases runoff, **(2)** reduces infiltration that recharges groundwater supplies, **(3)** increases the risk of flooding, and **(4)** accelerates soil erosion and landslides.

- Modifying water quality by **(1)** adding nutrients (such as phosphates and nitrates found in fertilizers) and other pollutants and **(2)** changing ecological processes that purify water naturally.

How Is Carbon Cycled in the Biosphere? Carbon is essential to life as we know it. It is the basic building block of the carbohydrates, fats, proteins, DNA, and other organic compounds necessary for life.

The **carbon cycle** (Figure 4-28) is based on carbon dioxide gas, which makes up 0.036% of the volume of the troposphere 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; if the cycle generates too much, the atmosphere will get warmer. Thus even slight changes in the carbon cycle can affect climate and ultimately the types of life that can exist on various parts of the planet.

Terrestrial producers remove CO_2 from the atmosphere, and aquatic producers remove it from the



water. They then use photosynthesis to convert CO_2 into simple carbohydrates such as glucose ($C_6H_{12}O_6$).

The cells in oxygen-consuming producers, consumers, and decomposers then carry out aerobic respiration. This 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 and is a major part of the global carbon cycle. Oxygen and hydrogen, the other elements in carbohydrates, cycle almost in step with carbon.

Over millions of years, buried deposits of dead plant matter and bacteria are compressed between layers of sediment, where they form carbon-containing *fossil fuels* such as coal and oil (Figure 4-28, above). This carbon is not released to the atmosphere as CO_2 for recycling until **(1)** these fuels are extracted and burned, or **(2)** long-term geological processes expose these deposits to air. In only a few hundred years, we have extracted and burned fossil fuels that took millions of years to form. This is why fossil fuels are nonrenewable resources on a human time scale.

The oceans are a major carbon-storage reservoir in the carbon cycle. Oceans also play a major role in regulating the level of carbon dioxide in the atmosphere. Some carbon dioxide gas, which is readily soluble in water, **(1)** stays dissolved in the sea, **(2)** some is removed by photosynthesizing producers, and **(3)** some reacts with seawater to form carbonate ions (CO_3^{2-}) and bicarbonate ions (HCO_3^-). As water warms, more dissolved CO_2 returns to the atmosphere, just as more carbon dioxide fizzes out of a carbonated beverage when it warms.

In marine ecosystems, some organisms take up dissolved CO_2 molecules, carbonate ions, or bicarbonate ions from ocean water. These ions can then react with calcium ions (Ca^{2+}) in seawater to form slightly soluble carbonate compounds such as calcium carbonate ($CaCO_3$) to build the shells and skeletons of marine organisms. When these organisms die, tiny particles of

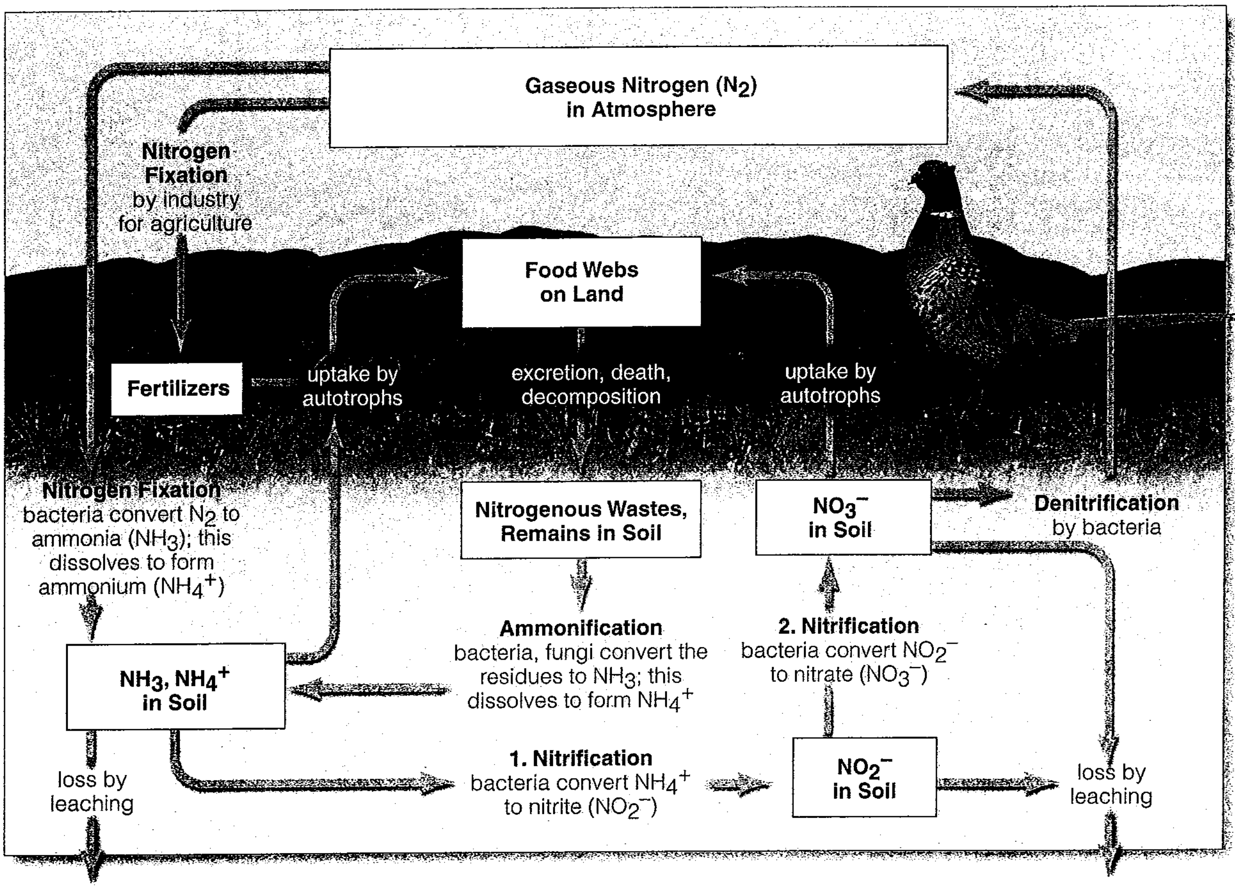


Figure 4-29 Greatly simplified model of the nitrogen cycle in a terrestrial ecosystem. Nitrogen reservoirs are shown as boxes; processes changing one form of nitrogen to another are shown in unboxed print. (Adapted from Cecie Starr and Ralph Taggart, *Biology: The Unity and Diversity of Life*, 9th ed. Starr & Taggart. Wadsworth © 2001)

their shells and bone drift slowly to the ocean depths. There they are buried for eons (as long as 400 million years) in deep bottom sediments (Figure 4-28, left), where under immense pressure they are converted into limestone rock.

How Are Human Activities Affecting the Carbon Cycle? Since 1800 and especially since 1950, we have been intervening in the earth's carbon cycle in two ways that add carbon dioxide to the atmosphere:

- Clearing trees and other plants that absorb CO_2 through photosynthesis
- Adding large amounts of CO_2 by burning fossil fuels and wood

Computer models of the earth's climate systems suggest that increased concentrations of atmospheric CO_2 and other gases we are adding to the atmosphere could enhance the planet's *natural greenhouse effect* that helps warm the lower atmosphere (troposphere) and the earth's surface (Figure 4-8). The resulting *global warming* could **(1)** disrupt global food production and wildlife habitats and **(2)** raise the average sea level in various parts of the world.

How Is Nitrogen Cycled in the Biosphere? Bacteria in Action Nitrogen is the atmosphere's most abundant element, with chemically unreactive nitrogen gas (N_2) making up 78% of the volume of the troposphere. However, N_2 cannot be absorbed and used (metabolized) directly as a nutrient by multicellular plants or animals.

Fortunately, **(1)** atmospheric electrical discharges in the form of lightning (that causes nitrogen and oxygen in the atmosphere to react and produce oxides of nitrogen, such as $N_2 + O_2 \longrightarrow 2NO$) and **(2)** certain bacteria in the soil and aquatic systems convert nitrogen gas into compounds that can enter food webs as part of the **nitrogen cycle** (Figure 4-29).

The nitrogen cycle consists of several major steps:

- *Nitrogen fixation,* in which specialized bacteria convert gaseous nitrogen (N_2) to ammonia (NH_3) that can be used by plants by the reaction $N_2 + 3H_2 \longrightarrow 2NH_3$. This is done mostly by **(1)** cyanobacteria in soil and water and **(2)** *Rhizobium* bacteria living in small nodules (swellings) on the root systems of a wide variety of plant species, including soybeans and alfalfa.
- *Nitrification,* a two-step process in which most of the ammonia in soil is converted by specialized aerobic bacteria to **(1)** nitrite ions (NO_2^-), which are toxic to plants and **(2)** nitrate ions (NO_3^-), which are easily taken up by plants as a nutrient.
- *Assimilation,* in which plant roots absorb inorganic ammonia, ammonium ions, and nitrate ions formed by nitrogen fixation and nitrification in soil water. They use these ions to make nitrogen-containing organic molecules such as DNA, amino acids, and proteins. Animals in turn get their nitrogen by eating plants or plant-eating animals.
- *Ammonification,* in which vast armies of specialized decomposer bacteria convert the nitrogen-rich organic compounds, wastes, cast-off particles, and dead bodies of organisms into **(1)** simpler nitrogen-containing inorganic compounds such as ammonia (NH_3) and **(2)** water-soluble salts containing ammonium ions (NH_4^+).
- *Denitrification,* in which other specialized bacteria (mostly anaerobic bacteria in waterlogged soil or in the bottom sediments of lakes, oceans, swamps, and bogs) convert NH_3 and NH_4^+ back into nitrite (NO_2^-) and nitrate (NO_3^-) ions and then into nitrogen gas (N_2) and nitrous oxide gas (N_2O). These are then released to the atmosphere to begin the cycle again.

How Are Human Activities Affecting the Nitrogen Cycle? Major human interventions in the earth's current nitrogen cycle over the past 100 years include

- Adding large amounts of nitric oxide (NO) into the atmosphere when we burn any fuel ($N_2 + O_2 \longrightarrow 2NO$). In the atmosphere, this nitric oxide combines with oxygen to form nitrogen dioxide gas (NO_2), which can react with water vapor to form nitric acid (HNO_3). Droplets of HNO_3 dissolved in rain or snow are components of *acid deposition,* commonly called *acid rain.* Nitric acid, along with other air pollutants, can **(1)** damage and weaken trees, **(2)** upset aquatic ecosystems, **(3)** corrode metals, and **(4)** damage marble, stone, and other building materials.
- Adding nitrous oxide (N_2O) to the atmosphere through the action of anaerobic bacteria on livestock wastes and commercial inorganic fertilizers applied to the soil. When N_2O reaches the stratosphere, it can **(1)** help warm the atmosphere by enhancing the natural greenhouse effect and **(2)** contribute to depletion of the earth's ozone shield, which filters out harmful ultraviolet radiation from the sun.
- Removing nitrogen from topsoil when we **(1)** harvest nitrogen-rich crops, **(2)** irrigate crops, and **(3)** burn or clear grasslands and forests before planting crops (Case Study, p. 90).
- Adding nitrogen compounds to aquatic ecosystems in agricultural runoff and discharge of municipal sewage. This excess of plant nutrients stimulates rapid growth of photosynthesizing algae and other aquatic plants. The subsequent breakdown of dead algae by aerobic decomposers can **(1)** deplete the water of dissolved oxygen and **(2)** disrupt aquatic ecosystems by killing some types of fish and other oxygen-using (aerobic) organisms.
- Accelerating the deposition of acidic nitrogen compounds (such as NO_2 and HNO_3) from the atmosphere onto terrestrial ecosystems. This excessive input of nitrogen can stimulate the growth of weedy plant species, which can outgrow and perhaps eliminate other plant species that cannot take up nitrogen as efficiently.

How Is Phosphorus Cycled in the Biosphere? Phosphorus circulates through water, the earth's crust, and living organisms in the **phosphorus cycle** (Figure 4-30, p. 88). Bacteria are less important here than in the nitrogen cycle. Very little phosphorus circulates in the atmosphere because at the earth's normal temperatures and pressures, phosphorus and its compounds are not gases. Phosphorus is found in the atmosphere only as small particles of dust. In contrast to the carbon cycle, the phosphorus cycle is slow, and on a short human time scale much phosphorus flows one way from the land to the oceans.

Phosphorous typically is found as phosphate salts containing phosphate ions (PO_4^{3-}) in terrestrial rock formations and ocean bottom sediments. 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. This explains why adding phosphate compounds to lakes greatly increases their biological productivity.

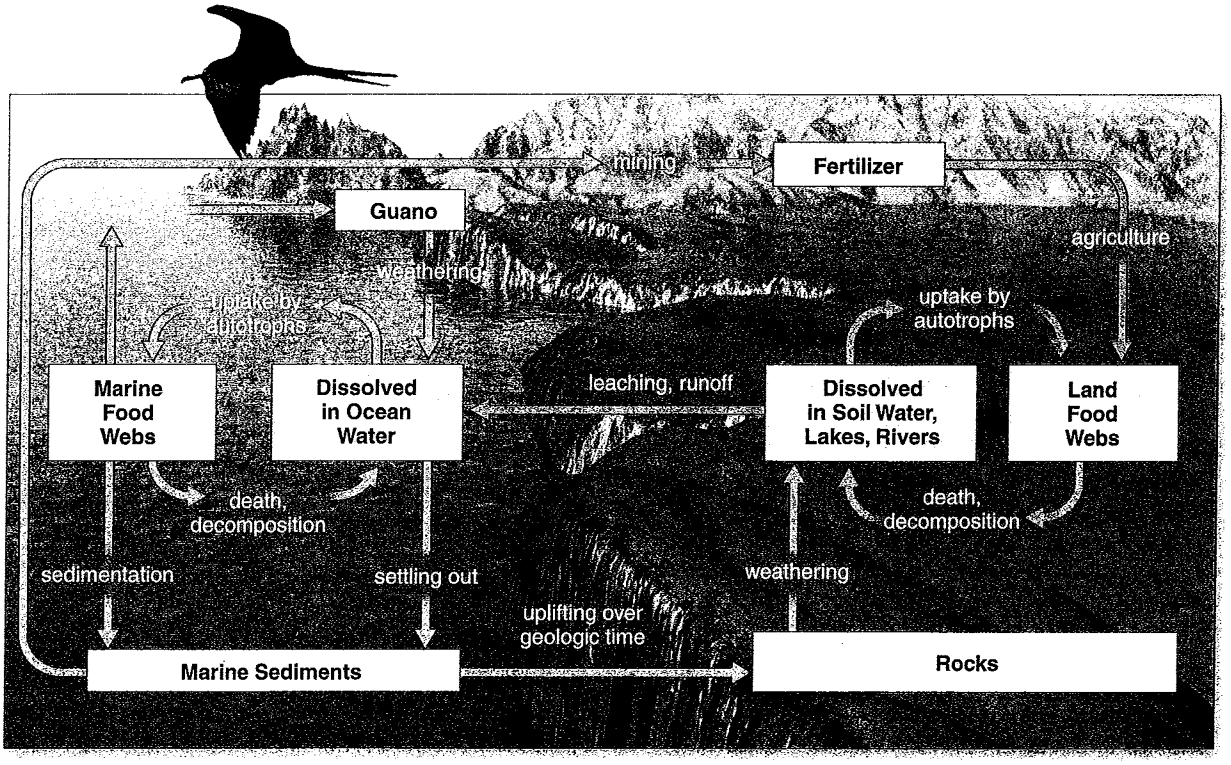


Figure 4-30 Simplified model of the phosphorus cycle. Phosphorus reservoirs are shown as boxes; processes that change one form of phosphorus to another are shown in unboxed print. (From Cecie Starr and Ralph Taggart, *The Unity and Diversity of Life*, 9th ed., Starr & Taggart. Wadsworth © 2001)

How Are Human Activities Affecting the Phosphorus Cycle? We intervene in the earth's phosphorus cycle by

- Mining large quantities of phosphate rock for use in commercial inorganic fertilizers and detergents.
- Reducing the available phosphate in tropical forests by removing trees. When such forests are cut and burned, most remaining phosphorus and other soil nutrients are washed away by heavy rains, and the land becomes unproductive.
- Adding excess phosphate to aquatic ecosystems in **(1)** runoff of animal wastes from livestock feedlots, **(2)** runoff of commercial phosphate fertilizers from cropland, and **(3)** discharge of municipal sewage. Too much of this nutrient causes explosive growth of cyanobacteria, algae, and aquatic plants. When these plants die and are decomposed, they use up dissolved oxygen and disrupt aquatic ecosystems.

How Is Sulfur Cycled in the Biosphere? Sulfur circulates through the biosphere in the **sulfur cycle** (Figure 4-31). 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) is a colorless, highly poisonous gas with a rotten-egg smell. It is released from active volcanoes and by the breakdown of organic matter in swamps, bogs, and tidal flats caused by decomposers that do not use oxygen (anaerobic decomposers). Sulfur dioxide (SO_2), a colorless, suffocating gas, also comes from volcanoes. Particles of sulfate (SO_4^{2-}) salts, such as ammonium sulfate, enter the atmosphere from sea spray.

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. Thus changes in DMS emissions can affect cloud cover and climate.

In the atmosphere, sulfur dioxide reacts with oxygen to produce sulfur trioxide gas (SO_3). Some of the sulfur trioxide then reacts with water droplets in the atmosphere to produce tiny droplets of sulfuric acid (H_2SO_4). Sulfur dioxide also reacts with other chemicals in the atmosphere such as ammonia to produce tiny particles of sulfate salts. These droplets and particles fall to the earth as components of *acid deposition,* which along with other air pollutants can harm trees and aquatic life.

How Are Human Activities Affecting the Sulfur Cycle? We intervene in the atmospheric phase of the earth's sulfur cycle by

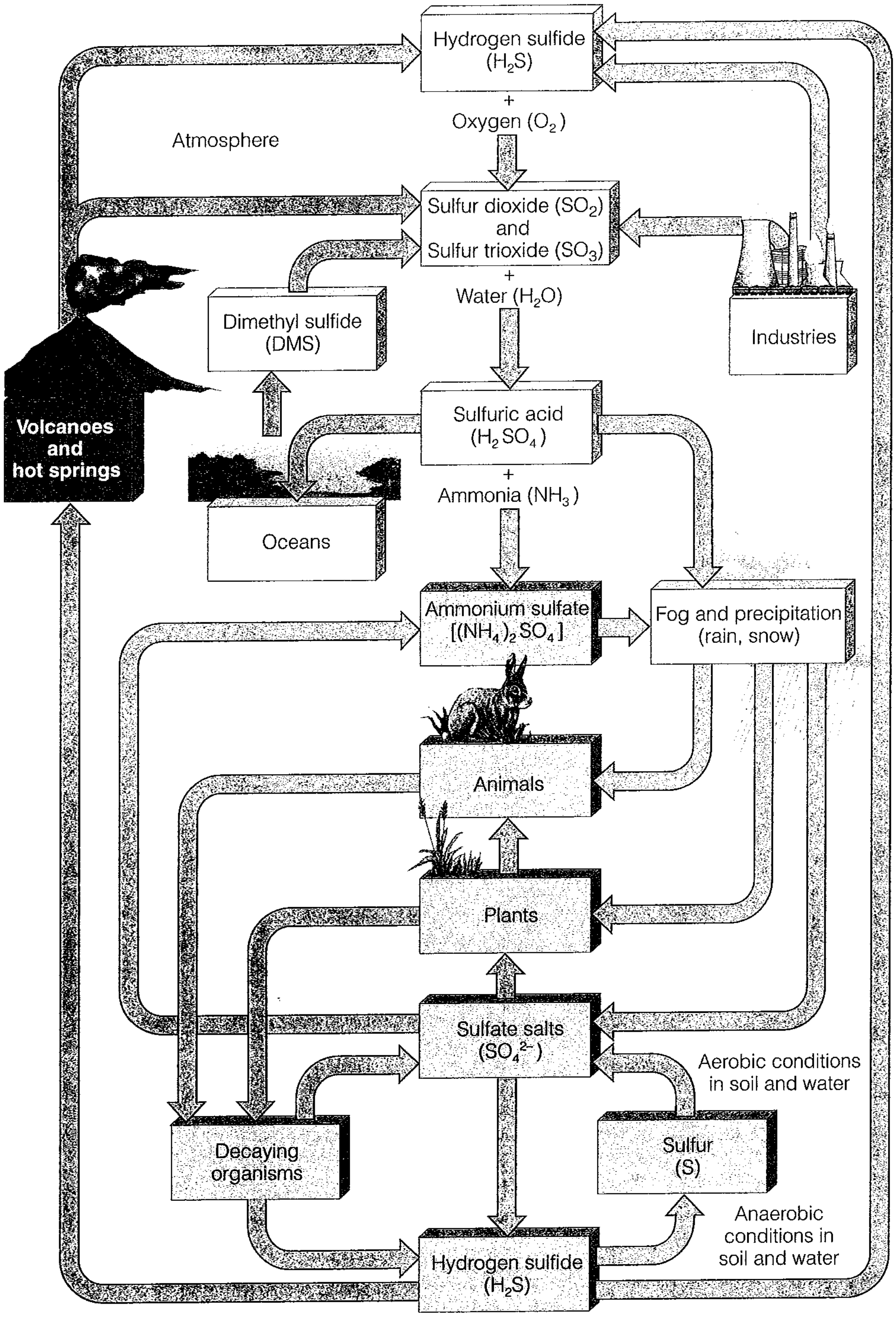


Figure 4-31 Simplified model of the sulfur cycle. Green shows the movement of sulfur compounds in living organisms, blue in aquatic systems, and orange in the atmosphere.

- Burning sulfur-containing coal and oil to produce electric power, producing about two-thirds of the human inputs of sulfur dioxide.
- Refining sulfur-containing petroleum to make gasoline, heating oil, and other useful products.
- Using smelting to convert sulfur compounds of metallic minerals into free metals such as copper, lead, and zinc.

4-7 HOW DO ECOLOGISTS LEARN ABOUT ECOSYSTEMS?

What Is Field Research? *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 described in this chapter has come from such research.

Effects of Deforestation on Nutrient Cycling

CASE STUDY

In the 1960s, F. H. Bormann of Yale University, Gene Likens of Cornell University, and their colleagues began carrying out a controlled experiment to compare the loss of water and nutrients from an uncut forest ecosystem (the *control system*) with one that was stripped of its trees (the *experimental system*).

To do this, V-shaped concrete catchment dams were built across the creeks at the bottom of several valleys in the Hubbard-Brook Experimental Forest in New Hampshire. The dams were anchored on impenetrable bedrock so all surface water leaving each forested valley ecosystem had to flow across the dams, where scientists could measure its volume and dissolved nutrient content.

The first project measured the amounts of water that entered and left an undisturbed (control) forest and the amount of dissolved nutrients in this inflow and outflow. These baseline data showed that an undisturbed mature forest ecosystem is very efficient at retaining chemical nutrients (blue area in figure).

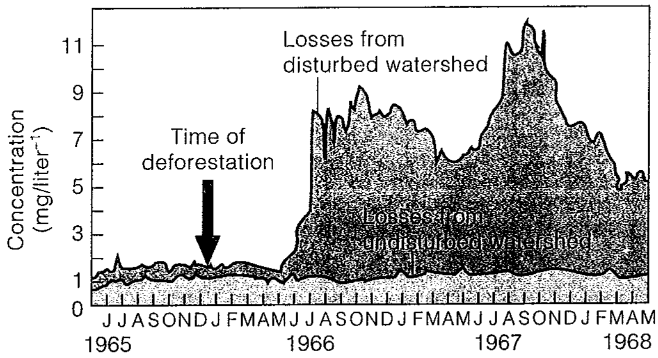
The next experiment disturbed the system and observed any changes that occurred. One winter the investigators **(1)** cut down all trees and shrubs in one valley, **(2)** left them where they fell, and **(3)** sprayed with herbicides to prevent regrowth. They then compared the inflow and outflow of water and nutrients in this modified experimental valley with those in the control valley for 3 years.

With no plants to absorb and transpire water from the soil, water runoff 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 nutrients out of the ecosystem. Overall, the loss of minerals from the cut forest was six to eight times that in a nearby undisturbed forest.

For example, chemical analysis of the water flowing through the dams showed a 60-fold rise in the concentration of nitrate ions (NO_3^-) (purple area in figure below). So much nitrogen as nitrate (NO_3^-) was lost from the experimental valley that **(1)** the water flowing out of it was unsafe to drink, and **(2)** the overfertilized stream below this valley became covered with populations of cyanobacteria and algae. After a few years, however, vegetation grew back, and nitrate levels returned to normal.

Critical Thinking

What do you think would be the effect on phosphate levels in runoff water from a Hubbard-Brook valley whose trees were destroyed by a major forest fire?



Loss of nitrate ions (NO_3^-) from a deforested watershed in the Hubbard-Brook Experimental Forest in New Hampshire. 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. (Data from F. H. Bormann and Gene Likens)

Increasingly, ecologists are using new technologies to collect field data. These include **(1)** *remote sensing* from aircraft and satellites and **(2)** *geographic information systems (GISs)*, in which information gathered from broad geographic regions is stored in spatial databases (Figure 4-32). Then computers and GIS software can analyze and manipulate the data and combine them with ground and other data to produce computerized maps of **(1)** forest cover and health, **(2)** water resources, **(3)** air pollution emissions, **(4)** coastal changes, **(5)** relationships between cancer and other health effects and sources of pollution, and **(6)** changes in global sea temperatures.

Most satellite sensors use either reflected light or reflected infrared radiation to gather data. However, some new satellites have radar sensors that measure the reflection of microwave energy from the earth. These microwaves can "see" in the dark and penetrate smoke, clouds, haze, and water. This method is also being used to map the topography of the ocean floor and provide information about ocean currents and upward flows of nutrients from the ocean bottom (upwellings) that sustain fisheries.

What Is Laboratory Research? In the past 50 years, ecologists have increasingly supplemented field

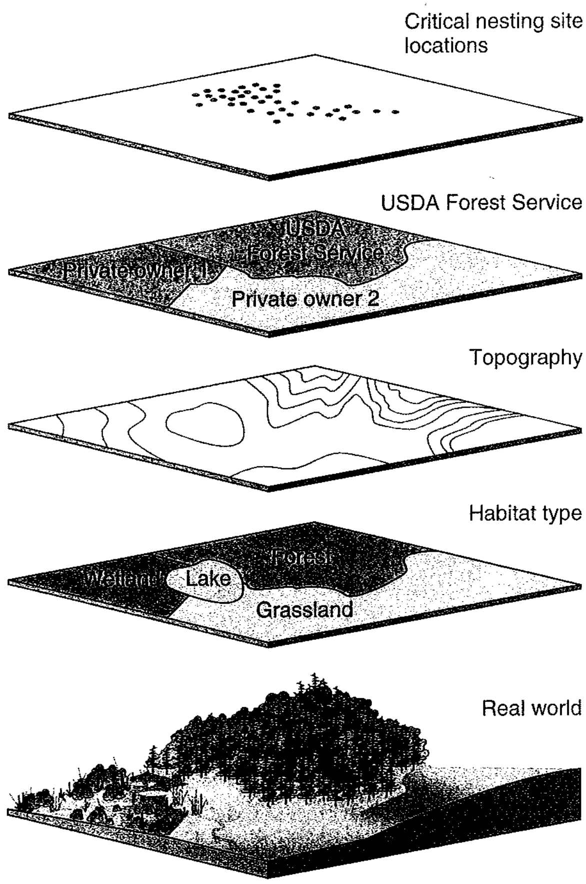


Figure 4-32 Geographic information systems (GISs) provide the computer technology for organizing, storing, and analyzing complex data collected over broad geographic areas. GISs enable scientists to overlay many layers of data (such as soils, topography, distribution of endangered populations, and land protection status).

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 set up in containers such as **(1)** culture tubes, **(2)** bottles, **(3)** aquarium tanks, and **(4)** greenhouses and in indoor and outdoor chambers where temperature, light, CO_2, humidity, and other variables can be controlled carefully.

In such systems, it is easier for scientists to carry out controlled experiments. In addition, such laboratory experiments often are quicker and cheaper than similar experiments in the field.

But we must consider whether what scientists observe and measure in a simplified, controlled system under laboratory conditions takes place in the same way in the more complex and dynamic conditions found in nature. Thus the results of laboratory research must be coupled with and supported by field research.

What Is Systems Analysis? Since the late 1960s, ecologists have made increasing use of *systems analysis* to develop mathematical and other models that simulate ecosystems. Computer simulation of such models can help us understand large and very complex systems (such as rivers, oceans, forests, grasslands, cities, and climate) that cannot be adequately studied and modeled in field and laboratory research. Figure 4-33 outlines the major stages of systems analysis.

Researchers can change values of the variables in their computer models to **(1)** project possible changes in environmental conditions, **(2)** help anticipate environmental surprises, and **(3)** analyze the effects of various alternative solutions to environmental problems.

However, simulations and predictions made using ecosystem models are no better than the data and assumptions used to develop the models. Thus careful

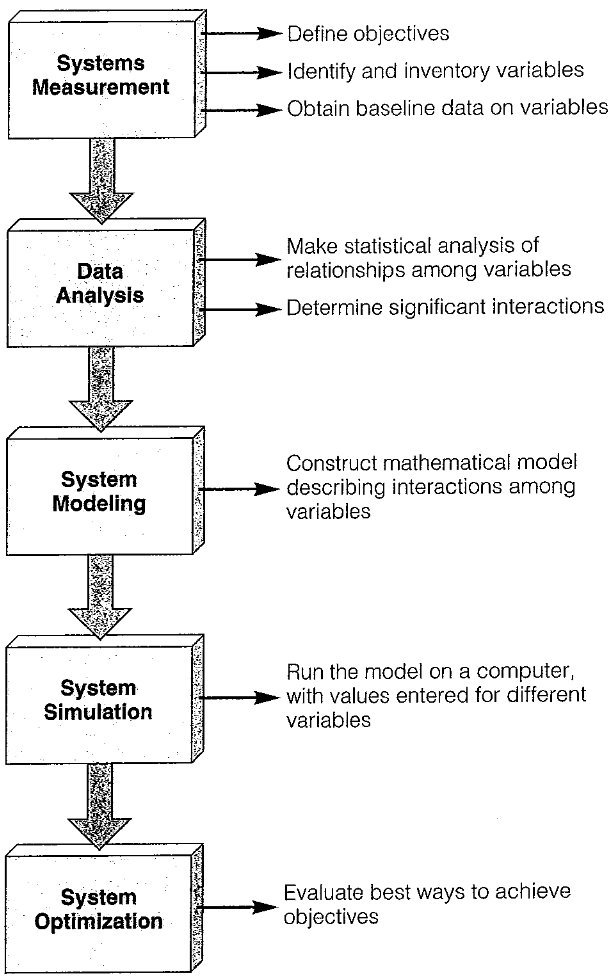


Figure 4-33 Major stages of systems analysis. (Modified data from Charles Southwick)

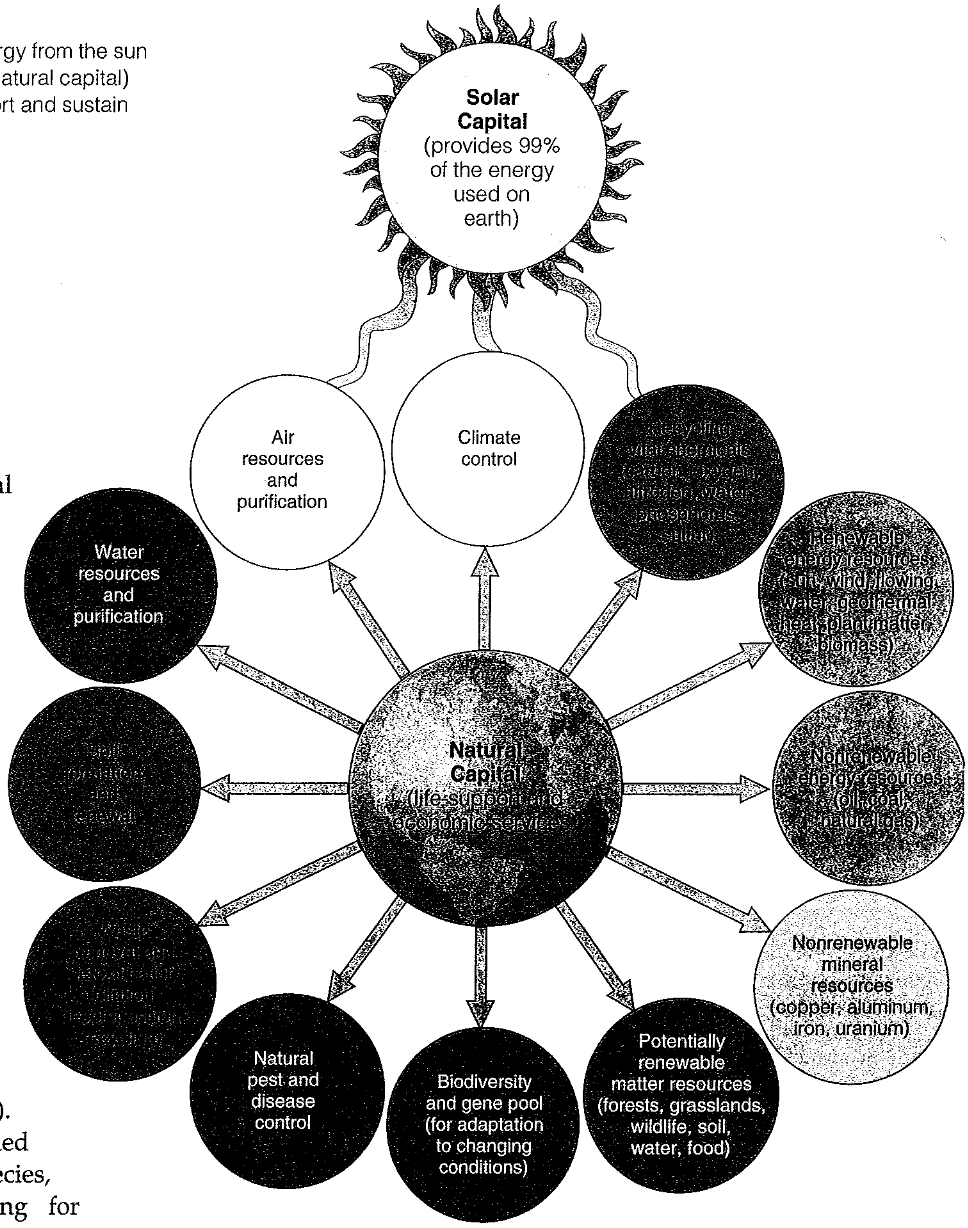


Figure 4-34 *Ecosystem services.* Energy from the sun (solar capital) and natural resources (natural capital) provide ecological services that support and sustain the earth's life and economies.

field and laboratory ecological research must be used to provide the baseline data and determine the causal relationships between key variables needed to develop and test ecosystem models.

4-8 ECOSYSTEM SERVICES AND SUSTAINABILITY

What Are Ecosystem Services? We depend on nature for food, air, water, and almost everything else we use. Ecosystems provide us and other species with a number of **ecosystem services** (Figure 4-34). Without these services performed by diverse communities of species, we would be starving, gasping for breath, and drowning in our own wastes.

It is very expensive to **(1)** build sewage treatment plants to replace free water purification services provided by wetlands, **(2)** rely mostly on pesticides rather than natural biological controls to control crop and forest pests, **(3)** try to save species whose premature extinction could have been prevented, and **(4)** try to restore ecosystems that we have degraded. In addition, these costly replacements are rarely as effective as the free ecological services that nature provides.

What Are Two Basic Principles of Ecosystem Sustainability? In this chapter we have seen that almost all natural ecosystems and the biosphere itself achieve *sustainability* by

- Using renewable solar energy as their energy source.
- Recycling the chemical nutrients its organisms need for survival, growth, and reproduction.

These two principles for sustainability arise from the **(1)** structure and function of natural ecosystems (Figures 4-7 and 4-16), **(2)** law of conservation of matter (p. 55), and **(3)** the two laws of thermodynamics (p. 59). Thus the results of basic research in both the physical and biological sciences provide us with the same guidelines or lessons from nature on how we can live more sustainably on the earth, as summarized in Figure 3-21, p. 61.

In this chapter we have learned about **(1)** how the earth's life-support systems work, **(2)** the living and nonliving components of ecosystems, **(3)** how energy flows through ecosystems, **(4)** how rapidly biomass is produced in different ecosystems, **(5)** how matter cycles in ecosystems, **(6)** how ecologists learn about ecosystems, and **(7)** how ecosystem services sustain life.

All things come from earth, and to earth they all return.
MENANDER (342–290 B.C.)

REVIEW QUESTIONS

1. Define the boldfaced terms in this chapter.

2. Why are insects important for many forms of life and for you and your lifestyle?

3. What is *ecology?* What five levels of the organization of matter are the main focus of ecology?

4. Distinguish among *organism, eukaryotic organism, prokaryotic organism, species, population, genetic diversity, habitat, community, ecosystem,* and *biosphere.*

5. Explain why microbes (microorganisms) are so important.

6. Distinguish among the *atmosphere, troposphere, stratosphere, hydrosphere, lithosphere,* and *biosphere.*

7. What three processes sustain life on earth?

8. How does the sun help sustain life on the earth? How is this related to the earth's natural greenhouse effect?

9. What are *biomes,* and how are they related to climate? What are *aquatic life zones?* What is an *ecotone?*

10. Distinguish between the *abiotic* and *biotic* components of ecosystems, and give three examples of each.

11. Distinguish among *range of tolerance* for a population in an ecosystem, the *law of tolerance,* and *tolerance limits.* How does each of these factors affect the composition (structure) of ecosystems? What is a *limiting factor,* and how do such factors affect the composition of ecosystems? What are two important limiting factors for terrestrial ecosystems and for aquatic ecosystems?

12. Distinguish between *producers* and *consumers* in ecosystems, and give three examples of each type. What is *photosynthesis,* and why is it important to both producers and consumers? What is *chemosynthesis?*

13. Distinguish among *primary consumers (herbivores), secondary consumers (carnivores), tertiary consumers, omnivores, scavengers, detritivores, detritus feeders,* and *decomposers.* Why are decomposers important, and what would happen without them?

14. Distinguish between *aerobic respiration* and *anaerobic respiration.*

15. What are the four components of biodiversity? Why is biodiversity important to **(a)** the earth's life-support systems and **(b)** the economy?

16. Distinguish between a *food chain* and a *food web.*

17. What is *biomass?* What is the *pyramid of energy flow* for an ecosystem? What is the effect of the second law of thermodynamics on **(a)** the flow of energy through an ecosystem and **(b)** the amount of food energy available to top carnivores and humans?

18. Distinguish between the *pyramid of biomass* and the *pyramid of numbers.*

19. Distinguish between *gross primary productivity* and *net primary productivity.* Explain how net primary productivity affects the number of consumers in an ecosystem and on the earth. List two of the most productive ecosystems or aquatic life zones and two of the least productive ecosystems or aquatic life zones. Use the concept of net primary productivity to explain why harvesting plants from estuaries, clearing tropical forests to grow crops, and harvesting the primary producers in oceans to feed the human population are not good ideas.

20. About what percentages of total potential net primary productivity of **(a)** the entire earth and **(b)** the earth's terrestrial ecosystems are used, wasted, or destroyed by humans?

21. What is a *biogeochemical cycle?* How do such cycles connect past, present, and future forms of life?

22. Describe the *water cycle.* Distinguish between *absolute humidity* and *relative humidity* and between *condensation nuclei* and *dew point.* What is *groundwater?* What is an *aquifer?*

23. List three human activities that alter the water cycle.

24. Describe the *carbon cycle,* and list two human activities that alter this cycle.

25. Describe the *nitrogen cycle.* Distinguish among *nitrogen fixation, nitrification, assimilation, ammonification,* and *denitrification.* Explain why the level of nitrogen in soil often limits plant growth. List five ways in which humans alter this cycle.

26. Describe the controlled ecological experiment carried out at the Hubbard-Brook Experimental Forest in New Hampshire and summarize the results.

27. Describe the *phosphorus cycle.* Explain why the level of phosphorus in soil often limits plant growth on land and why phosphorus also limits the growth of producers in many freshwater streams and lakes. List three ways in which humans alter this cycle.

28. Describe the *sulfur cycle,* and list three ways in which humans alter this cycle.

29. Distinguish among *field research, laboratory research,* and *systems analysis* as methods for learning about ecosystems. What are *geographic information systems,* and how are they used to learn about ecosystems?

30. Define *ecosystem services,* and list nine examples of such services.

31. What are two basic principles of ecosystem sustainability?

CRITICAL THINKING

1. **(a)** A bumper sticker asks, "Have you thanked a green plant today?" Give two reasons for appreciating a green plant. **(b)** Trace the sources of the materials that make up the bumper sticker, and decide whether the sticker itself is a sound application of the slogan. **(c)** Explain how decomposers help keep you alive.

2. **(a)** How would you set up a self-sustaining aquarium for tropical fish? **(b)** Suppose you have a balanced aquarium sealed with a clear glass top. Can life continue in the aquarium indefinitely as long as the sun shines regularly on it? **(c)** A friend cleans out your aquarium and removes all the soil and plants, leaving only the fish and water. What will happen?

3. Using the second law of thermodynamics, explain why there is such a sharp decrease in usable energy as energy flows through a food chain or web. Doesn't an energy loss at each step violate the first law of thermodynamics? Explain.

4. Using the second law of thermodynamics, explain why many poor people in developing countries live on a mostly vegetarian diet.

5. Why do farmers not need to apply carbon to grow their crops but often need to add fertilizer containing nitrogen and phosphorus?

6. Carbon dioxide (CO_2) in the atmosphere fluctuates significantly on a daily and seasonal basis. Why are CO_2 levels higher during the day than at night?

7. Why could the total amount of animal flesh on the earth never exceed the total amount of plant flesh, even if all animals were vegetarians?

8. Which causes a larger loss of energy from an ecosystem: a herbivore eating a plant or a carnivore eating an animal? Explain.

9. Why are there more mice than lions in an African ecosystem supporting both types of animals?

10. What would happen to an ecosystem if **(a)** all its decomposers and detritus feeders were eliminated or **(b)** all its producers were eliminated?

PROJECTS

1. Visit several types of nearby aquatic life zones and terrestrial ecosystems. For each site, try to determine **(a)** the major producers, consumers, detritivores, and decomposers and **(b)** the shapes of the pyramids of energy flow, biomass, and numbers.

2. Write a brief scenario describing the sequence of consequences to us and to other forms of life if each of the following nutrient cycles stopped functioning: **(a)** carbon, **(b)** nitrogen, **(c)** phosphorus, and **(d)** water.

3. Use the library or the Internet to find out bibliographic information about *G. Evelyn Hutchinson* and *Menander,* whose quotes are found at the beginning and end of this chapter.

4. Make a concept map of this chapter's major ideas using the section heads and subheads and the key terms (in boldface). Look on the website for this book for information about making concept maps.

INTERNET STUDY RESOURCES AND RESOURCES FOR FURTHER READING AND RESEARCH

The website for this book contains helpful study aids and many ideas for further reading and research. Log on to

www.info.brookscole.com/miller13

and click on the Chapter-by-Chapter area. Choose Chapter 4 and select a resource:

- Flash Cards allows you to test your mastery of the Terms and Concepts to Remember for this chapter.
- Tutorial Quizzes provides a multiple-choice practice quiz.
- Student Guide to InfoTrac will lead you to Critical Thinking Projects that use InfoTrac College Edition as a research tool.
- References lists the major books and articles consulted in writing this chapter.
- Hypercontents takes you to an extensive list of sites with news, research, and images related to individual sections of the chapter.

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Improve your skills with InfoTrac College Edition, a searchable online database of articles from more than 700 periodicals. Log on to

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or access InfoTrac through the website for this book. Try to find the following articles:

1. Pauly, D., V. Christensen, R. Froese, and M. L. Palomares. 2000. Fishing down aquatic food webs. *American Scientist* 88: 46. *Keywords:* "fishing" and "aquatic food webs." As pressure on fishing becomes more intense, humans are catching and keeping ever smaller fish. This has implications for the entire aquatic food web, including the recovery of higher-trophic-level species. This work presents a new way of looking at fisheries science using basic ecological principles.

2. Lockaby, B. G., and W. H. Conner. 1999. N:P balance in wetland forests: Productivity across a biogeochemical continuum. *The Botanical Review* 65: 171. *Keywords:* "wetland forests" and "productivity." This paper integrates the concepts of biogeochemical cycling, limiting factors, and productivity by looking at differences among wetland forests.

5 EVOLUTION AND BIODIVERSITY: ORIGINS, NICHES, AND ADAPTATION

Earth: The Just-Right, Resilient Planet

Life on the earth as we know it (Figure 5-1) needs a certain temperature range: Venus is much too hot and Mars is much too cold, but the earth is *just right*. (Otherwise, you would not be reading these words.)

Life as we know it depends on the liquid water that dominates the earth's surface. Again, temperature is crucial; life on the earth needs average temperatures between the freezing and boiling points of water, between 0°C and 100°C (32°F and 212°F) at the earth's range of atmospheric pressures.

The earth's orbit is the right distance from the sun to provide these conditions. If the earth were much closer, it would be too hot—like Venus—for water vapor to condense to form rain. If it were much farther away, its 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 earth is also the right size; that is, it has enough gravitational mass to keep its iron and nickel core molten and to keep the gaseous molecules in its atmosphere from flying off into space. (A much smaller earth would be unable to hold on to an atmosphere consisting of such light molecules as N_2, O_2, CO_2, and H_2O.)

The slow transfer of its internal heat (geothermal energy) to the surface also helps keep the planet at the right temperature for life. And thanks to the development of photosynthesizing bacteria more than 2 billion years ago, an ozone sunscreen protects us and many other forms of life from an overdose of ultraviolet radiation.

On a time scale of millions of years, the earth is 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. In short, the earth is just right for life as we know it.

We can summarize the 3.7-billion-year biological history of the earth in one sentence: *Organisms convert solar energy to food, chemicals cycle, and a variety of species with different biological roles (niches) has evolved in response to changing environmental conditions.*

Each species here today represents a long chain of evolution, and each of these species plays a unique ecological role in the earth's communities and ecosystems. These species, communities, and ecosystems also are essential for future evolution as the earth continues its long history of environmental change.

This chapter discusses how the earth's species evolved and the nature of their niches or biological roles. This information is important for helping us **(1)** understand the effects of human actions on wild species and **(2)** protect species—including the human species—from premature extinction.

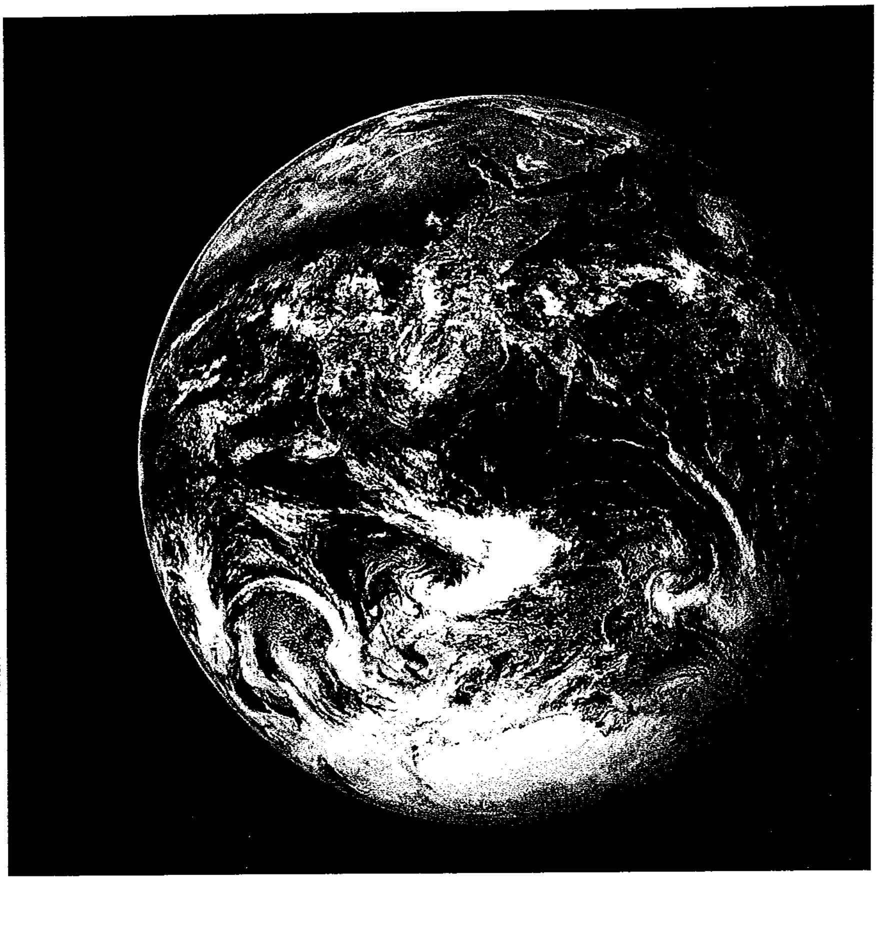

Figure 5-1 The earth is a blue and white planet in the black void of space. Currently, it has the right physical and chemical conditions to allow the development of life as we know it today.

NASA

There is a 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

This chapter addresses the following questions:

- How do scientists account for the emergence of life on the earth?
- What is evolution, and how has it led to the current diversity of organisms on the earth?
- How does evolution affect the way organisms fit into their environment?
- What is an ecological niche, and how does it relate to adaptation to changing environmental conditions?
- How do extinction of species and formation of new species affect biodiversity?

5-1 ORIGINS OF LIFE

How Did Life Emerge on the Earth? How did a barren planet become a living jewel in the vastness of space (Figure 5-1)? How did life on the earth evolve to its present incredible diversity of species, living in an interlocking network of matter cycles, energy flows, and species interactions? We do not know the full answer to these questions, but a growing body of evidence suggests what might have happened.

Evidence about the earth's early history comes from chemical analysis and measurements of radioactive elements in primitive rocks and fossils. Chemists have also conducted laboratory experiments showing how simple inorganic compounds in the earth's early atmosphere might have reacted to produce amino acids, simple sugars, and other organic molecules used as building blocks for the protein, complex carbohydrate, RNA, and DNA molecules needed for lif (Figure 3-6, p. 50).

From this diverse evidence scientists have hypoth esized that life on the earth developed in two phase over the past 4.7–4.8 billion years (Figure 5-2):

- *Chemical evolution* of the organic molecules, biopolymers, and systems of chemical reactions needed to form the first protocells (taking about 1 billion years)
- *Biological evolution* from single-celled prokaryotic bacteria (Figure 4-3b, p. 67), to single-celled eukaryotic creatures (Figure 4-3a, p. 67), and then to multicellular organisms (taking about 3.7–3.8 billion years)

How Did Chemical Evolution Take Place Here is an overview of how scientists believe chemica evolution occurred. Some 4.6–4.7 billion years ago, cloud of cosmic dust condensed into the earth, whic soon turned molten from **(1)** meteorite impacts an **(2)** the heat produced by the radioactive decay of chem ical elements in its interior. About 3.7 billion years ag the outermost portion of the molten sphere had coole enough to form a thin, solid crust of rock, devoid o atmosphere and oceans.

Comets hitting the lifeless earth pierced its thi crust, and energy from the earth's highly radioactiv contents released water vapor, carbon dioxide, an other gases from the molten interior. Eventually th crust cooled enough for the water vapor to conden and fall to the surface as rain. This rain eroded mine als from rocks, and solutions of these minerals co lected in depressions to form the early oceans that co ered most of the globe.

As gases were released from the earth's interio they formed the planet's first atmosphere. The exa composition of this primitive atmosphere is unknow

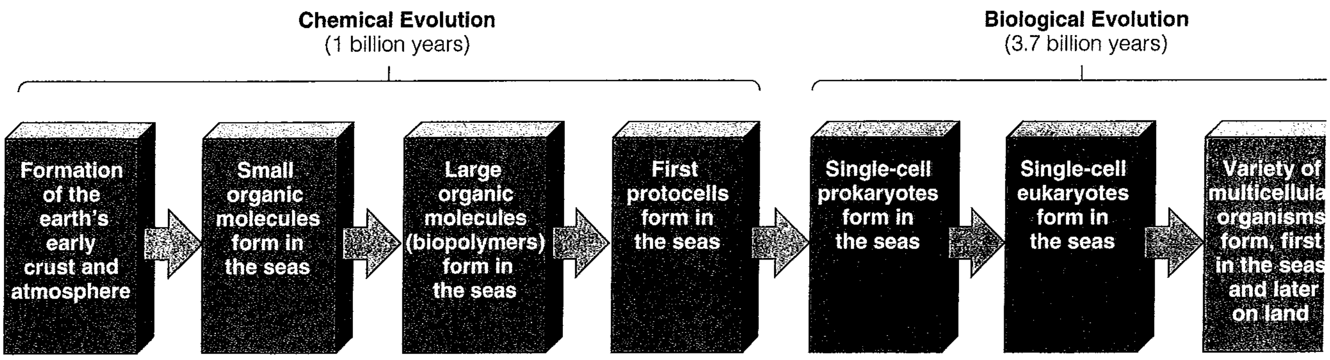

Figure 5-2 Summary of the hypothesized chemical and biological evolution of the earth. This drawing is not to scale. Note that the time span for biological evolution is almost four times longer than that for chemical evolution.

However, atmospheric scientists believe it was dominated by carbon dioxide (CO_2), nitrogen (N_2), and water vapor (H_2O) and trace amounts of several other gases such as methane (CH_4), ammonia (NH_3), hydrogen sulfide (H_2S), and hydrogen chloride (HCl).

Whatever its composition, scientists agree that this primitive atmosphere had no oxygen gas (O_2) because this element is so chemically reactive that it would have combined into compounds. The only reason today's atmosphere has so much O_2 is that plants and some aerobic bacteria produce it in vast quantities through photosynthesis. But we are getting ahead of the story.

Scientists have come up with several explanations of how the **(1)** amino acids (the building-block molecules of proteins), **(2)** simple carbohydrates, **(3)** nucleic acids (the building-block molecules of DNA and RNA; Appendix 2), and **(4)** other small organic compounds necessary for life may have formed.

The most widely believed hypothesis is that the building-block *organic* molecules needed for life formed from the *inorganic* chemicals found in the earth's primitive atmosphere under the influence of readily available **(1)** energy from electrical discharges (lightning), **(2)** heat from volcanoes, **(3)** intense ultraviolet (UV) light, and **(4)** other forms of solar radiation.

In a number of experiments conducted since 1953, scientists placed various mixtures of gases believed to have been in the earth's early atmosphere in closed, sterilized glass containers. Then they subjected the gases in the containers to spark discharges to simulate lightning and heat (Figure 5-3). In these experiments, the building-block molecules necessary for life formed from the inorganic gaseous molecules.

Other possibilities are that the building-block organic molecules necessary for life

- Formed on dust particles in space and reached the earth on meteorites or comets (or on countless interplanetary dust particles floating around in space when the earth was formed). In 1997, researchers found amino acids on a meteorite that struck Australia in 1969.
- Formed deep within the earth.
- Formed around mineral-rich and very hot *hydrothermal vents,* which sit atop cracks in the ocean floor leading to subterranean chambers of molten rock.

However these building-block organic molecules formed, scientists hypothesize that they accumulated and underwent countless chemical reactions for several hundred million years. This led to the formation of conglomerates of proteins, RNA, and other biopolymers that may have then combined to form membrane-bound *protocells:* small globules that could take up materials from their environment and grow and divide (much like living cells).

These reactions could have occurred **(1)** in the earth's warm shallow waters, **(2)** deep within the earth, or **(3)** around thermal hydrothermal vents on the ocean bottom. With these forerunners of living cells, the stage was set for the drama of biological evolution (Figure 5-4, p. 98, and Spotlight, p. 99).

How Do We Know What Organisms Lived in the Past? Most of what we know of the earth's life history comes from **fossils:** mineralized or petrified replicas of skeletons, bones, teeth, shells, leaves, and seeds, or impressions of such items. Such fossils

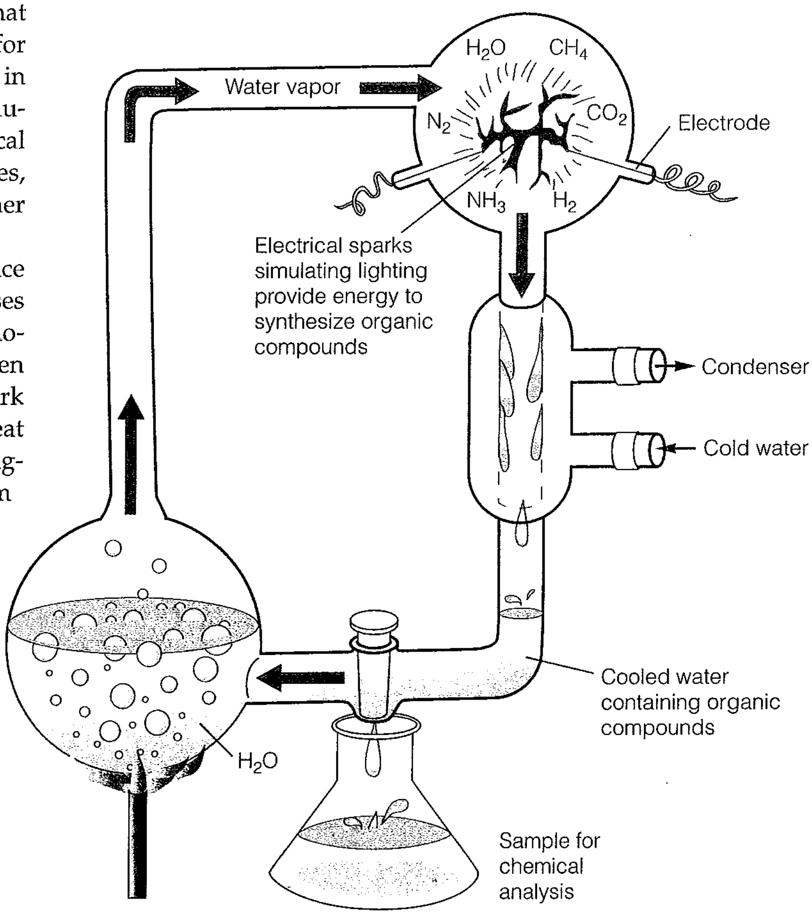

Figure 5-3 Synthesis of organic compounds necessary for life from the gases believed to be in the earth's primitive atmosphere. Stanley Miller and Harold Urey used a similar apparatus to show that under the influence of electrical sparks simulating lightning, simple inorganic compounds believed to be in the earth's primitive atmosphere could be converted into amino acids (the building blocks of proteins) and a variety of other simple organic chemicals necessary for life.

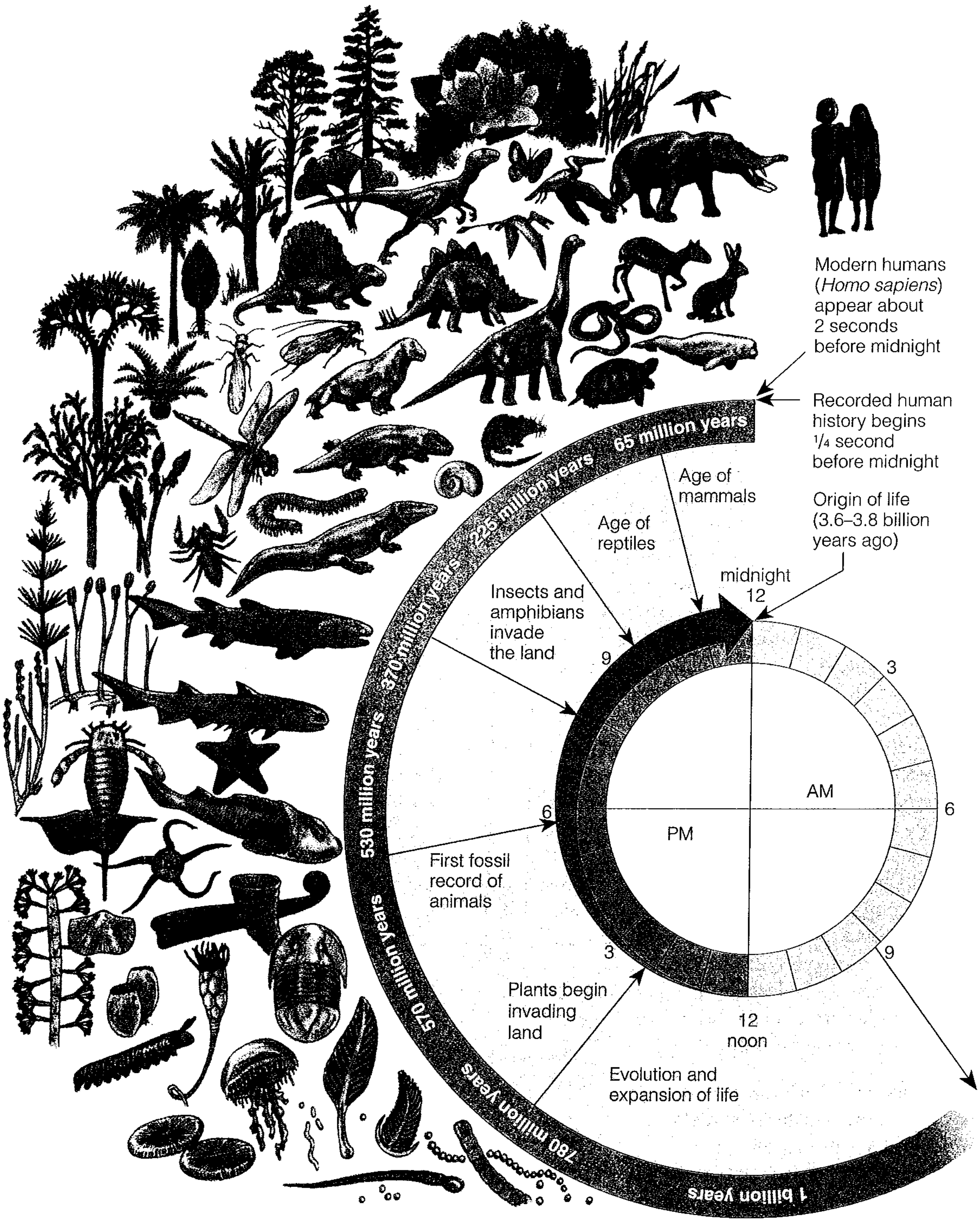

Figure 5-4 Greatly simplified overview of the biological evolution of life on the earth, which was preceded by about 1 billion years of chemical evolution. Evidence indicates that the early span of biological evolution on the earth, between about 3.7 billion and 1 billion years ago, was dominated by microorganisms (mostly bacteria and, later, protists) that lived in water. Plants and animals evolved first in the seas. Fossil and recent DNA evidence suggests that plants began moving onto land about 780 million years ago, and animals began invading the land about 370 million years ago. Humans arrived on the scene only a very short time ago. If we compress the earth's roughly 3.7-billion-year history of biological evolution to a 24-hour time scale, the first human species (*Homo habilis*) appeared about 47–94 seconds before midnight, and our species (*Homo sapiens sapiens*) appeared about 2 seconds before midnight. Agriculture began only 0.25 second before midnight, and the industrial revolution has been around for only 0.007 second. (Adapted from George Gaylord Simpson and William S. Beck, *Life: An Introduction to Biology,* 2nd ed. New York: Harcourt, Brace, Jovanovich, 1965)

How Did Life First Evolve?

SPOTLIGHT

About 3.2 billion years ago, the earth was a very hostile environment for life. Hot lava spewed from its surface and beneath the sea, much of the land was dotted with boiling hot springs, and the atmosphere was thick with steam and carbon dioxide.

Over time, it is believed that early protocells evolved into single-celled, bacterialike prokaryotes (Figure 4-3b, p. 67) having the properties we describe as life. However, scientists hotly debate the details of how this might have happened.

These anaerobic cells probably evolved **(1)** in the muddy sediments of tidal flats, **(2)** at least 10 meters (30 feet) below the ocean's surface, or **(3)** in the deep ocean near hydrothermal vents. All these environments would have protected these single-celled forms of life from the intense UV radiation that bathed the earth at that time.

The early single-celled organisms probably obtained their energy directly by absorbing hydrogen sulfide molecules. Soon thereafter, they developed the process of *fermentation,* or anaerobic respiration, to **(1)** break down sugars and other organic compounds, **(2)** release energy for their use, and **(3)** store some of this energy in adenosine triphosphate (ATP) molecules.

Scientists believe these single-celled anaerobic bacteria multiplied and underwent genetic changes (mutated) for about a billion years in the earth's warm, shallow seas or in the deep ocean. The result was a variety of new types of prokaryotic cells that began forming about 2.8–3.5 billion years ago.

Eventually the population of these fermenter bacteria expanded to the point at which they exceeded their food supplies. This created the world's first *population crisis.*

This crisis was relieved when different types of bacteria evolved that produced their food through *photosynthesis* (p. 74). About 2.3–2.7 billion years ago, the evolution of these photosynthetic prokaryotes, called *cyanobacteria,* in the ocean drastically changed the earth. These cells could **(1)** remove carbon dioxide from the water and **(2)** use sunlight to combine it with water to make the carbohydrates they needed, and **(3)** release oxygen (O_2) into the ocean and the atmosphere.

As these photosynthesizers multiplied for almost 2 billion years in the water and mud, they created large amounts of dissolved oxygen and oxygen that escaped into the atmosphere. This oxygen reacted with the food molecules used by both fermenting and photosynthesizing bacteria. This resulted in the world's first *pollution crisis,* which caused a huge dieback of both types of bacteria.

This spurred a new round of biological innovation. Fermenters survived by living in deep water and mud flats to avoid contact with the oxygen-rich air. However, the most significant event was the development of bacteria that used *aerobic respiration,* in which oxygen molecules are used to break up food molecules to obtain energy (p. 74). At this point, the earth's single-celled organisms had developed three ways to feed themselves: *fermentation, photosynthesis,* and *aerobic respiration.*

Over the next half a billion years, the oxygen released by photosynthesizers built up in the atmosphere. The resulting *oxygen revolution* opened the way for the evolution of a great variety of oxygen-using (aerobic) bacteria. Complex organisms came later, first in the seas and then increasingly on land (after a protective ozone layer formed in the stratosphere).

Fossil evidence indicates that at least 1.2 billion years ago, the first *eukaryotic cells* (with nuclei, Figure 4-3a, p. 67) emerged in earth's shallow seas. Because eukaryotes could reproduce sexually, they produced a variety of offspring with different genetic characteristics. These first eukaryotes were the building blocks for the more complex multicelled life-forms that followed (Figure 5-4).

As oxygen accumulated in the atmosphere, some was converted by incoming solar energy into ozone (O_3), which began forming in the lower stratosphere. This shield protected life-forms from the sun's deadly UV radiation, allowing green plants to live closer to the ocean's surface.

Fossil evidence and recent DNA evidence suggests that about 780 million years ago, UV levels were low enough for the first plants (probably waxy-coated algae) to emerge from the underwater world and exist on the land. Over the next several hundred million years, a variety of land plants and animals arose, followed by mammals and eventually the first humans (Figure 5-4).

Critical Thinking

If photosynthesizing bacteria had not developed, what kinds of life would you expect to find on the earth today? Where would most of it be found?

(1) give us physical evidence of organisms that lived long ago and **(2)** show us what their internal structures looked like.

Despite its importance, the fossil record is uneven and incomplete. Some life-forms left no fossils, some fossils have decomposed, and others are yet to be found. So far we have found fossils representing only about 1% of the species believed to have ever lived.

Other sources of information include **(1)** chemical and radioactive dating of fossils, **(2)** nearby ancient rocks, **(3)** material in cores drilled out of buried ice, and **(4)** the DNA of organisms alive today.

5-2 EVOLUTION AND ADAPTATION

What Is Evolution? According to scientific evidence, the major driving force of adaptation to changes in environmental conditions is **biological evolution,** or **evolution:** the change in a population's genetic makeup (gene pool) through successive generations. Note that *populations, not individuals, evolve by becoming genetically different.*

According to the **theory of evolution,** all species descended from earlier, ancestral species. This widely accepted scientific theory explains how life has changed over the past 3.7 billion years (Figure 5-4) and why life is so diverse today.

Biologists use the term **microevolution** to describe the small genetic changes that occur in a population. The term **macroevolution** is used to describe long-term, large-scale evolutionary changes through which **(1)** new species are formed from ancestral species and **(2)** other species are lost through extinction.

How Does Microevolution Work? The first step in evolution is the development of *genetic variability* in a population. Recall that **(1)** genetic information in *chromosomes* is contained in various sequences of chemical units (called *nucleotides*) in DNA molecules (Appendix 2), and **(2)** genes found in chromosomes are segments of DNA coded for certain traits that can be passed on to offspring (Figure 3-6, p. 50).

A population's **gene pool** is the set of all genes in the individuals of the population of a species. *Microevolution* is a change in a population's gene pool over time.

Although members of a population generally have the same number and kinds of genes, a particular gene may have two or more different molecular forms, called **alleles.** Sexual reproduction leads to a random shuffling or recombination of alleles. As a result, each individual in a population has a different combination of alleles.

Genetic variability in a population originates through **mutations:** random changes in the structure or number of DNA molecules in a cell. Mutations can occur in two ways:

- Exposure of DNA to external agents such as radioactivity, X rays, and natural and human-made chemicals (called *mutagens*)
- Random mistakes that sometimes occur in coded genetic instructions when DNA molecules are copied each time a cell divides and whenever an organism reproduces

Mutations can occur in any cells, but only those in reproductive cells are passed on to offspring.

Some mutations are harmless, but most are harmful and alter traits so that an individual cannot survive (lethal mutations). Every so often, a mutation is beneficial. The result is new genetic traits that give their bearer and its offspring better chances for survival and reproduction, **(1)** under existing environmental conditions or **(2)** when such conditions change.

Mutations are **(1)** random and unpredictable, **(2)** the only source of totally new genetic raw material (alleles), and **(3)** rare events. Once created by mutation, new alleles can be shuffled together or recombined *randomly* to create new combinations of genes in populations of sexually reproducing species.

What Is Artificial Selection?

Artificial selection is the process by which humans **(1)** select one or more desirable genetic traits in the population of a plant or animal and **(2)** use *selective breeding* to end up with populations of the species containing large numbers of individuals with the desired traits. This process has been used to develop essentially all of the domesticated breeds of plants and animals from wild populations.

Artificial selection involves several steps:

1. Choose the genetic traits desired in a particular species. Examples might be **(1)** wheat that grows short so it will not topple over, **(2)** cattle that need less water, or **(3)** dogs with short legs.
2. Examine existing populations of species (such as wheat, cattle, or dogs) to identify individuals that exhibit more of the desired genetic trait than other members of the population.
3. Select offspring that exhibit more of the desired trait than their parents to be breeders for the next generation, and prevent other offspring from breeding.

When this process of selection and breeding is carried out over many generations, more and more of the offspring have the selected or desired traits.

Artificial selection results in many different domesticated breeds or hybrids of the same species, all originally developed from a particular wild species. For example, despite their widely different genetic traits, all of the hundreds of different breeds of dogs are members of the same species because they can potentially interbreed and produce fertile offspring.

Critical Thinking

How does artificial selection differ from natural selection (p. 101)?

What Role Does Natural Selection Play in Microevolution? The process of **natural selection** occurs when some individuals of a population have genetically based traits that increase their chances of survival and their ability to produce offspring. Three conditions are necessary for evolution of a population by natural selection to occur:

- There must be natural *variability* for a trait in a population.
- The trait must be *heritable,* meaning it must have a genetic basis such that it can be passed from one generation to another.
- The trait must somehow lead to **differential reproduction,** meaning it must enable individuals with the trait to leave more offspring than other members of the population.

Natural selection causes **(1)** any allele or set of alleles that result in a beneficial trait to become more common in succeeding generations and **(2)** other alleles to become less common. A heritable trait that enables organisms to better survive and reproduce under a given set of environmental conditions is called an **adaptation,** or **adaptive trait.**

When faced with a change in environmental conditions, a population of a species can **(1)** adapt to the new conditions through natural selection, **(2)** migrate (if possible) to an area with more favorable conditions, or **(3)** become extinct.

The process of microevolution can be summarized as follows: *Genes mutate, individuals are selected, and populations evolve.* The genetic characteristics of populations of a species also can be changed through *artificial selection* (Spotlight, left).

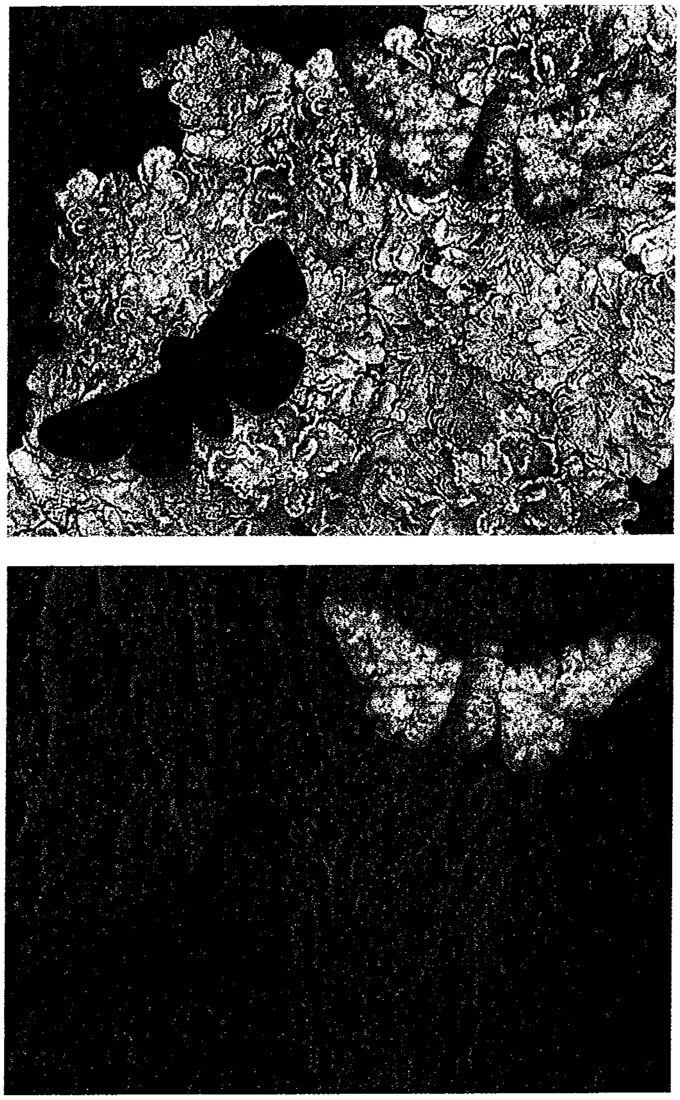

Figure 5-5 Two varieties of peppered moths found in England illustrate one kind of adaptation: camouflage. Before the industrial revolution in the mid-1800s, the speckled light-gray form of this moth was prevalent. When these night-flying moths rested on light-gray lichens on tree trunks during the day, their color camouflaged them from their predators (top). A dark-gray form also existed but was quite rare. During the industrial revolution, soot and other pollutants from factory smokestacks began killing lichens and darkening tree trunks. As a result, the dark form of moth became the common one, especially near industrial cities. In this new environment, the dark form of moth blended in with the blackened trees, whereas the light form of moth was highly visible to predators (bottom). Through natural selection, the dark form began to survive and reproduce at a greater rate than its light-colored kin. (Both varieties appear in each diagram. Can you spot them?)

What Is an Example of Microevolution by Natural Selection? One of the best-documented examples of microevolution by natural selection involves camouflage coloration in the peppered moth, which is found in England (Figure 5-5).

Natural selection occurred because **(1)** there were two color forms (*variability*), **(2)** color form was genetically based (*heritability*), and **(3)** there was greater survival and reproduction by one of the color forms (*differential reproduction*). First an environmental change in the form of soot caused a change in the background color of tree trunks. This environmental change then allowed bird predators to find and eat the moths with the coloration that no longer blended in with the background (Figure 5-5).

What Are Three Types of Natural Selection? Biologists recognize three types of natural selection (Figure 5-6, p. 102):

- *Directional natural selection* (Figure 5-6, left), in which changing environmental conditions cause allele frequencies to shift so individuals with traits at one end of the normal range become more common than midrange forms. Examples of this "it pays to be different" type of natural selection are **(1)** the changes in the

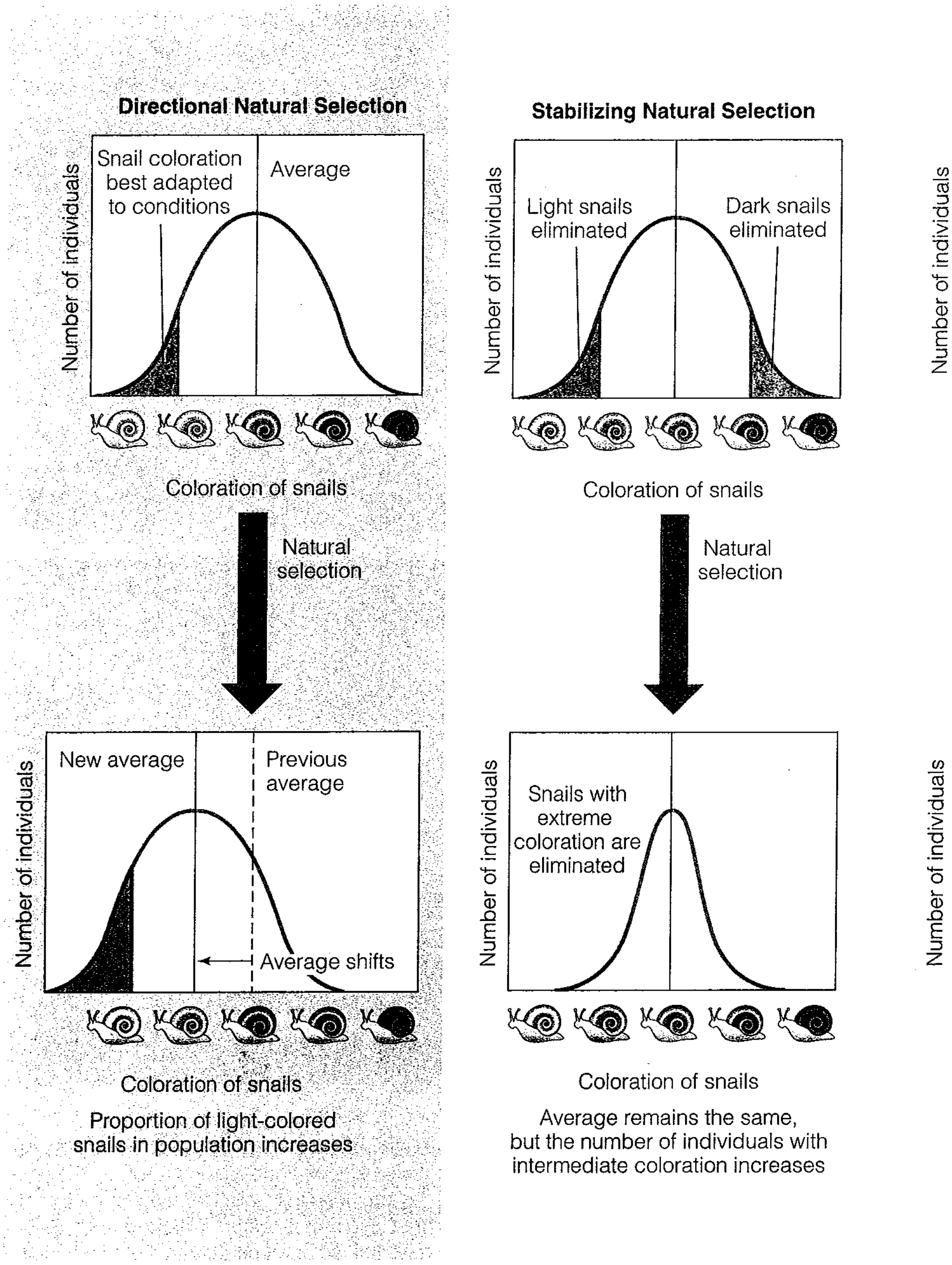

Figure 5-6 Three ways in which natural selection can occur, using the trait of coloration in a population of snails. In *directional natural selection*, changing environmental conditions select organisms with alleles that deviate from the norm so their offspring (lighter-colored snails) make up a larger proportion of the population. In *stabilizing selection*, environmental factors eliminate fringe individuals (light- and dark-colored snails) and increase the number of individuals with average genetic makeup (intermediate-colored snails). In *diversifying natural selection*, environmental factors favor individuals with uncommon traits (light- and dark-colored snails) and greatly reduce those with average traits (intermediate-colored snails).

varieties of peppered moths (Figure 5-5) and **(2)** the evolution of genetic resistance to pesticides among insects and to antibiotics among disease-carrying bacteria. This type of natural selection is most common during periods of environmental change or when members of a population migrate to a new habitat with different environmental conditions.

- *Stabilizing natural selection,* which tends to eliminate individuals on both ends of the genetic spectrum and favor individuals with an average genetic makeup (Figure 5-6, center). This "it pays to be average" type of natural selection occurs when **(1)** an environment changes little, and **(2)** most members of the population are well adapted to that environment.

- *Diversifying natural selection,* which occurs when environmental conditions favor individuals at both extremes of the genetic spectrum and eliminate or sharply reduce numbers of individuals with normal or intermediate genetic traits (Figure 5-6, right). In this "it does not pay to be normal" type of natural selection, a population is split into two groups.

What Is Coevolution? Some biologists have proposed that *interactions between species* also can result in microevolution in each of their populations. According to this hypothesis, when populations of two different species interact over a long time, changes in the gene pool of one species can lead to changes in the gene pool of the other species. This process is called **coevolution.**

Suppose that certain individuals in a population of carnivores (such as owls) become better at hunting prey (such as mice). Because of genetic variation, certain individuals of the prey have traits that allow them to escape or hide from their predators, and they pass these adaptive traits on to some of their offspring. However, a few individuals in the predator population also may have traits (such as better eyesight or quicker reflexes) that allow them to hunt the better-adapted prey successfully. They would then pass these traits on to some of their offspring.

Similarly, individual plants in a population may evolve defenses, such as camouflage, thorns, or poisons, against efficient herbivores. In turn, some herbivores in the population may have genetic characteristics that enable them to overcome these defenses and produce more offspring than those without such traits.

In coevolution, adaptation follows adaptation in something like an ongoing, long-term arms race between individuals in interacting populations of different species.

5-3 ECOLOGICAL NICHES AND ADAPTATION

What Is an Ecological Niche? 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"), the species' way of life or functional role in an ecosystem. A species' niche involves everything that affects its survival and reproduction. This includes **(1)** its range of tolerance for various physical and chemical conditions, such as temperature or water availability (Figure 4-14, p. 73), **(2)** the types and amounts of resources it uses, such as food or nutrients and space, **(3)** how it interacts with other living and nonliving components of the ecosystems in which it is found, and **(4)** the role it plays in the energy flow and matter cycling in an ecosystem (Figure 4-16, p. 75).

The ecological niche of a species is different from its **habitat,** or physical location, where it lives. Ecologists often say that a niche is like a species' occupation, whereas habitat is like its address.

A species' ecological niche represents the *adaptations* or *adaptive traits* that its members have acquired through evolution. These traits enable its members to survive and reproduce more effectively under a given set of environmental conditions.

Understanding a species' niche is important because it can help us **(1)** prevent it from becoming prematurely extinct and **(2)** assess the environmental changes we make in terrestrial and aquatic systems. For example, how will the niches of various species be changed by clearing a forest, plowing up a grassland, filling in a wetland, or dumping pollutants into a lake or stream?

What Is the Difference Between a Species' Fundamental Niche and Its Realized Niche? A species' **fundamental niche** is the full potential range of physical, chemical, and biological conditions and resources it could theoretically use if there were no direct competition from other species. But in a particular ecosystem, species often compete with one another for one or more of the same resources. This means the niches of competing species overlap.

To survive and avoid competition for the same resources, a species usually occupies only part of its fundamental niche in a particular community or ecosystem—what ecologists call its **realized niche.** By analogy, you may be capable of being president of a particular company (your *fundamental professional niche*), but competition from others may mean you may become only a vice president (your *realized professional niche*).

Is It Better to Be a Generalist or a Specialist Species? Broad and Narrow Niches The niches of species can be used to broadly classify them as *generalists* or *specialists.* **Generalist species** have broad niches (Figure 5-7, right curve, p. 104). They can **(1)** live in many different places, **(2)** eat a variety of foods, and **(3)** tolerate a wide range of environmental conditions. Flies, cockroaches (Spotlight, p. 105), mice, rats, white-tailed deer, raccoons, coyotes, copperheads, channel catfish, and humans are generalist species.

Specialist species have narrow niches (Figure 5-7, left curve, p. 104). They may be able to **(1)** live in only one type of habitat, **(2)** use only one or a few types of food, or **(3)** tolerate only a narrow range of climatic and other environmental conditions. This makes them more prone to extinction when environmental conditions change. Examples of specialists are **(1)** *tiger salamanders,* which can breed only in fishless ponds so their larvae will not be eaten, **(2)** *red-cockaded woodpeckers,* which carve nest holes almost exclusively in old (at least 75 years) longleaf pines, **(3)** *spotted owls,* which

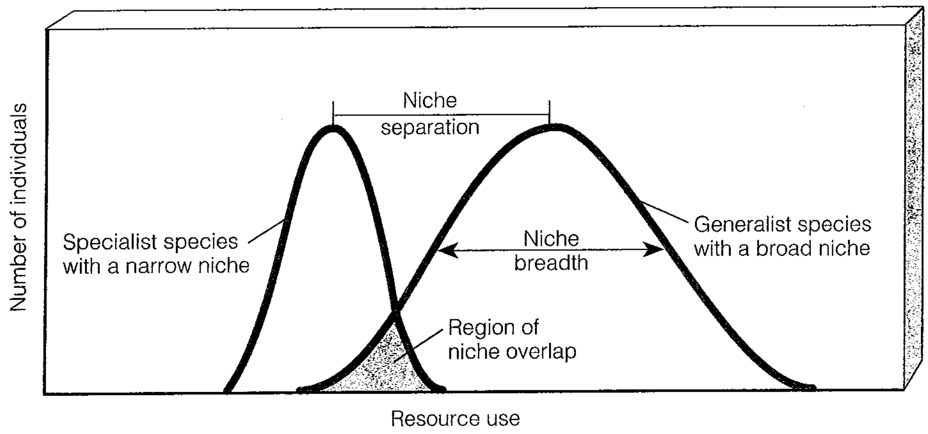

Figure 5-7 Overlap of the niches of two different species: a specialist and a generalist. In the overlap area the two species compete for one or more of the same resources. As a result, each species can occupy only a part of its fundamental niche and thus occupy its realized niche. Generalist species have a broad niche (right), and specialist species have a narrow niche (left).

need old-growth forests in the Pacific Northwest for food and shelter, and **(4)** China's highly endangered *giant pandas,* which feed almost exclusively on various types of bamboo.

Is it better to be a generalist than 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.

What Limits Adaptation? Shouldn't evolution lead to perfectly adapted organisms? Shouldn't adaptations to new environmental conditions allow **(1)** our skin to become more resistant to the harmful effects of ultraviolet radiation, **(2)** our lungs to cope with air pollutants, and **(3)** our livers to become better at detoxifying pollutants? The answer to these questions is *no* because of the following limits to adaptations in nature:

- *A change in environmental conditions can lead to adaptation only for traits already present in the gene pool of a population.*
- *Even if a beneficial heritable trait is present in a population, that population's ability to adapt can be limited by its reproductive capacity.* Populations of genetically diverse species that reproduce quickly—such as weeds, mosquitoes, rats, bacteria, or cockroaches—often can adapt to a change in environmental conditions in a short time. In contrast, populations of species such as elephants, tigers, sharks, and humans, which cannot produce large numbers of offspring rapidly, take a long time (typically thousands or even millions of years) to adapt through natural selection.
- *Even if a favorable genetic trait is present in a population, most of the population would have to die or become sterile so individuals with the trait could predominate and pass the trait on.* This is hardly a desirable solution to the environmental problems the human species faces.

What Are Two Common Misconceptions About Evolution? Two common misconceptions about evolution are as follows:

- "Survival of the fittest" means "survival of the strongest." To biologists, *fitness* is a measure of reproductive success not strength. Thus the fittest individuals are those that leave the most descendants.
- Evolution involves some grand plan of nature in which species become progressively more perfect. From a scientific standpoint, no plan or goal of perfection exists in the evolutionary process. However, some people (creationists) believe there is a conflict between the scientific theory of evolution and their religious beliefs about how life was created on the earth.

5-4 SPECIATION, EXTINCTION, AND BIODIVERSITY

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.

The most common mechanism of speciation (especially among animals) takes place in two phases: geographic isolation and reproductive isolation. **Geographic isolation** occurs when groups of the same population of a species become physically separated 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 (Figure 5-8). Populations also may become separated **(1)** by a physical barrier (such as a mountain range, stream, lake, or road), **(2)** by a change such as a volcanic eruption or earthquake, or **(3)** when a few individuals are carried to a new area by wind or water.

The second phase of speciation is **reproductive isolation.** It occurs when mutation and natural selection operate independently in two geographically isolated populations and change the allele frequencies in different ways. If this process, called *divergence,* continues long enough, members of the geographically and reproductively isolated populations may become so different in genetic makeup that **(1)** they cannot interbreed, or **(2)** if they do, they cannot produce live, fer-

Cockroaches: Nature's Ultimate Survivors

SPOTLIGHT

Cockroaches, the bugs many people love to hate, have **(1)** been around for about 350 million years and **(2)** are one of the great success stories of evolution. They are so successful because they are *generalists.*

The earth's 4,000 cockroach species can **(1)** eat almost anything (including algae, dead insects, fingernail clippings, salts in tennis shoes, electrical cords, glue, paper, and soap) and **(2)** live and breed almost anywhere except in polar regions.

Some species can go for months 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.

They usually can evade their predators and a human foot in hot pursuit because **(1)** the antennae of most cockroach species can detect minute movements of air, **(2)** they have vibration sensors in their knee joints, and **(3)** their rapid response times (faster than you can blink). Some even have wings.

They also have high reproductive rates. In only a year, a single Asian cockroach (especially prevalent in Florida) and its young can add about 10 million new cockroaches to the world. Their high reproductive rate also helps them quickly develop genetic resistance to almost any poison we throw at them.

Most cockroaches also sample food before it enters their mouths and learn to shun foul-tasting poisons. They also clean up after themselves by eating their own dead and, if food is scarce enough, their living.

Only about 25 species of cockroach live in homes. However, such species can **(1)** carry viruses and bacteria that cause diseases such as hepatitis, polio, typhoid fever, plague, and salmonella and **(2)** cause people to have allergic reactions ranging from watery eyes to severe wheezing. Indeed, about 60% of the 12 million Americans suffering from asthma are allergic to dead or live cockroaches.

Critical Thinking

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

tile offspring. Then one species has become two, and *speciation* has occurred through *divergent evolution.*

For some rapidly reproducing organisms, this type of speciation may occur within hundreds of years. However, for most species such speciation takes from tens of thousands to millions of years. Given this time scale, it is difficult to observe and document the appearance of a new species. As a result, there are many controversial hypotheses about the details of speciation.

How Do Species Become Extinct? After speciation, the second process affecting the number and types of species on the earth is **extinction.** When environmental conditions change, a species must **(1)** evolve (become better adapted), **(2)** move to a more favorable area (if possible), or **(3)** cease to exist (become extinct).

The earth's long-term patterns of speciation and extinction have been affected by several major factors: **(1)** large-scale movements of the continents (continental drift) over millions of years (Figure 5-9, p. 106),

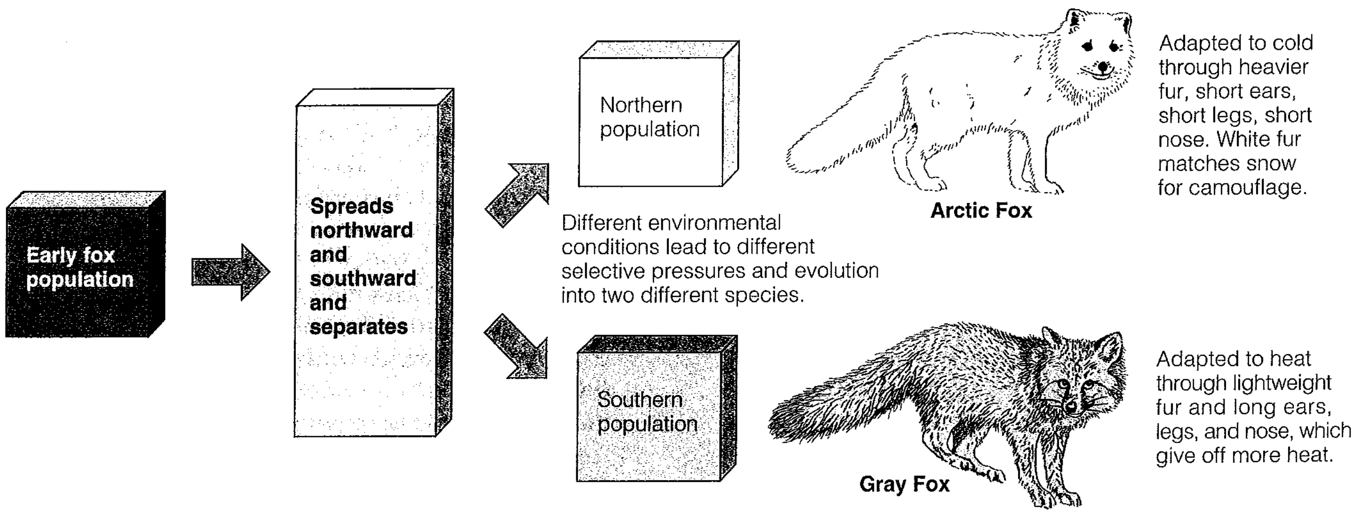

Figure 5-8 How geographic isolation can lead to reproductive isolation, divergence, and speciation.

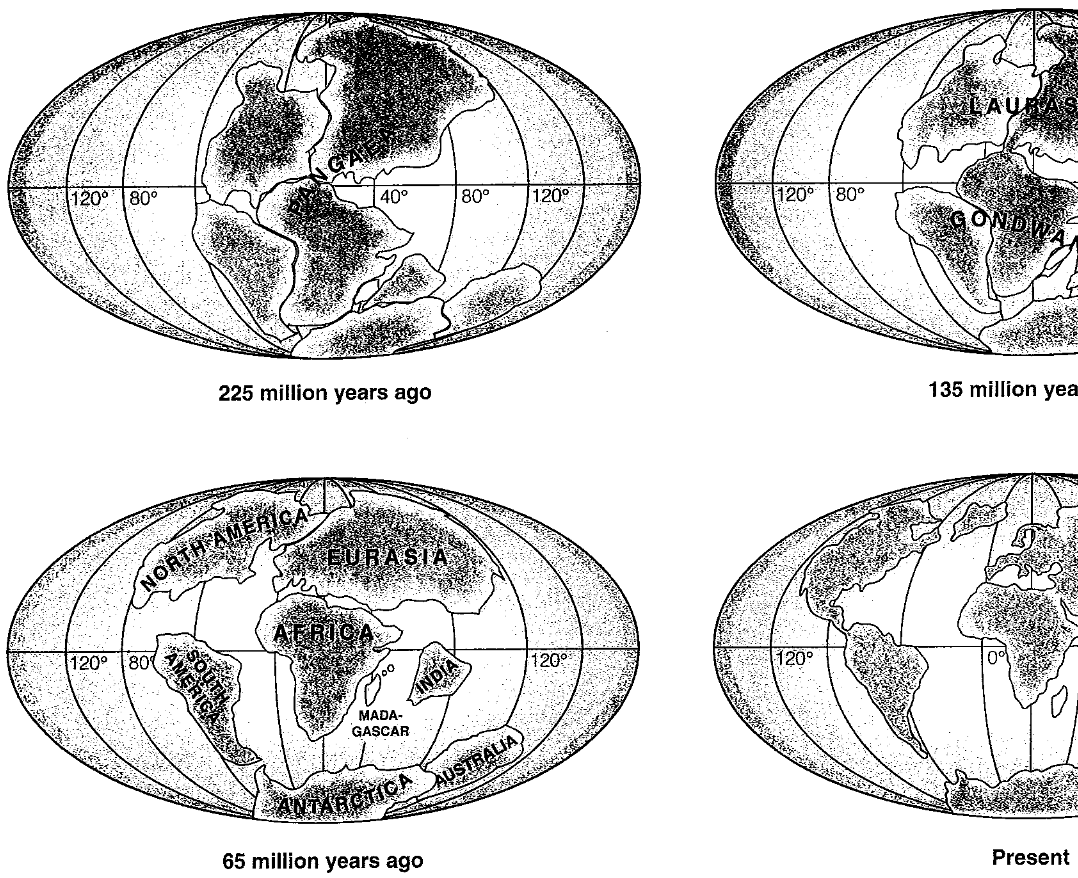

Figure 5-9 *Continental drift*, the extremely slow movement of continents over millions of years on several gigantic plates. This process plays a role in the extinction of species and the rise of new species. Populations are geographically and eventually reproductively isolated as land masses float apart and new coastal regions are created. Rock and fossil evidence indicates that about 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 eventually resulted in today's locations of the continents (bottom right).

(2) gradual climate changes caused by continental drift and slight shifts in the earth's orbit around the sun, and **(3)** rapid climate change caused by catastrophic events (such as large volcanic eruptions, huge meteorites and asteroids crashing into the earth, and release of large amounts of methane trapped beneath the ocean floor). Some of these events create dust clouds that shut down or sharply reduce photosynthesis long enough to eliminate huge numbers of producers and, soon thereafter, the consumers that fed on them.

Extinction is the ultimate fate of all species, just as death is for all individual organisms. Biologists estimate that 99.9% of all the species that have ever existed are now extinct.

As local environmental conditions change, a certain number of species disappear at a low rate, called **background extinction.** In contrast, **mass extinction** is a significant rise in extinction rates above the background level. It is a catastrophic, widespread (often global) event in which large groups of existing species (perhaps 25–70%) are wiped out. Scientists have also identified periods of **mass depletion** in which extinction rates are higher than normal but not high enough to classify as a mass extinction. Recent fossil and geological evidence casts doubt on the hypothesis that there have been five mass extinctions over the past 500 million years. The new evidence suggests that there have been two mass extinctions and three mass depletions during this period.

A mass extinction or mass depletion crisis for one species is an opportunity for another. The existence of millions of species today means that speciation, on average, has kept ahead of extinction. Evidence shows that the earth's mass extinctions and depletions have been followed by periods of recovery called **adaptive radiations** in which numerous new species evolve to fill new or vacated ecological roles or niches in changed environments. Fossil records suggest that it takes 5 million years or more for adaptive radiations to rebuild biological diversity after a mass extinction or depletion.

How Do Speciation and Extinction Affect Biodiversity? Speciation minus extinction equals *biodiversity*, the planet's genetic raw material for future evolution in response to changing environmental conditions. In this long-term give-and-take between extinction and speciation, mass extinctions and mass depletions temporarily reduce biodiversity. However, they also create evolutionary opportunities for surviving species to undergo adaptive radiations to fill unoccupied and new biological roles or niches.

Although extinction is a natural process, much evidence indicates that humans have become a major force in the premature extinction of species. Biologist Stuart Primm estimates that during the 20th century, extinction rates increased by 100–1,000 times the natural background rate. As human population and resource consumption increase over the next 50–100 years, we are expected to take over more of the earth's surface (Figure 1-5, p. 7) and net primary productivity (Figure 4-25, p. 81, and Figure 4-26, p. 82). During this century, this may cause the premature extinction of up to a quarter of the earth's current species. This could constitute a new *mass depletion* and possibly a new *mass extinction* (Guest Essay, p. 108).

On our short time scale, such major losses cannot be recouped by formation of new species; it took millions of years after each of the earth's past mass extinctions and depletions for life to recover to the previous level of biodiversity. Genetic engineering cannot stop this loss of biodiversity because genetic engineers do not create new genes. Rather, they transfer existing genes or gene fragments from one organism to another and thus rely on natural biodiversity for their raw material.

Nothing in biology makes sense except in the light of evolution.
THEODOSIUS DOBZHANSKY

REVIEW QUESTIONS

1. Define the boldfaced terms in this chapter.

2. Describe the conditions that make life on the earth just right for life as we know it.

3. Distinguish between *chemical evolution* and *biological evolution.*

4. Summarize how scientists think chemical evolution took place on the earth.

5. Summarize how scientists think biological evolution took place on the earth. What was the *oxygen revolution,* and what is its importance to life as we know it?

6. What are *fossils,* and how do they help us formulate ideas about how life developed on the earth?

7. Distinguish among *biological evolution, the theory of evolution, microevolution,* and *macroevolution.*

8. Distinguish among *genes, gene pool, alleles, mutations, natural selection,* and *differential reproduction,* and explain their roles in microevolution.

9. Give an example of microevolution by natural selection. Describe three types of natural selection.

10. What is *coevolution,* and what is its importance?

11. What is the *ecological niche* of a species, and why is it important to understand the niches of species? What is the difference between a species' *habitat* and its *niche?* What is the difference between a species' *fundamental niche* and its *realized niche?*

12. Distinguish between the niches of specialist and generalist species. Explain why cockroaches have been such a successful species.

13. List three factors that limit adaptation.

14. What are two common misconceptions about evolution?

15. What is *speciation?* Distinguish between *geographic isolation* and *reproductive isolation,* and explain how they can lead to speciation through divergent evolution.

16. What is *extinction?* List three factors that have affected the earth's long-term patterns of speciation and extinction.

17. Distinguish among *background extinction, mass extinction,* and *mass depletion.*

18. What is an *adaptive radiation?* How can such a radiation lead to recovery after a mass extinction or depletion?

19. What evidence suggests that human activities may be bringing about a new mass depletion or extinction?

20. Explain how speciation and extinction result in the planet's biodiversity.

CRITICAL THINKING

1. How would you respond to someone who tells you **(a)** that he or she does not believe in biological evolution because it is "just a theory," and **(b)** we should not worry about air pollution because through natural selection the human species will develop lungs that can detoxify pollutants?

2. What would happen if extinction had never occurred during evolutionary history? Do you think we would have more species than we do now? Why?

3. How would you respond to someone who says that because extinction is a natural process, we should not worry about the loss of biodiversity?

4. Why is it important for somebody studying environmental science to understand the basics of evolution?

5. Why is the realized niche of a species narrower, or more specialized, than its fundamental niche?

6. As well as you can, 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?

7. In what ways do humans occupy generalist niches and in what ways do they occupy specialist niches?

8. By analogy, use the concepts of generalist and specialist to evaluate the roles of humans in today's societies. In general, the role of college and graduate education is to create specialists in a particular field or a narrow portion of a field. What are the pros and cons of relying mainly on this approach? Is there a need for

GUEST ESSAY

The Future of Evolution

Norman Myers

Norman Myers is a tropical ecologist and international consultant in environment and development, with emphasis on conservation of wildlife species and tropical forests. He is one of the world's leading environmental experts. His research and consulting have taken him to 80 countries. Myers has served as a consultant for many development agencies and research organizations, including the U.S. National Academy of Sciences, the World Bank, the Organization for Economic Cooperation and Development, various UN agencies, and the World Resources Institute. Among his many publications (see Further Readings on the website for this book) are The Primary Source: Tropical Forests and Our Future *(1992),* The Gaia Atlas of Planet Management *(1993),* Scarcity or Abundance: A Debate on Environment *(1994),* Ultimate Security: The Environmental Basis of Political Security *(1996), and* Perverse Subsidies *(2001).*

Human activities have brought the earth to a biotic crisis. Many biologists have commented that this crisis will result in the loss of large numbers of species, possibly 25–50%, within the lifetimes of students reading this book. However, surprisingly few biologists have recognized that in the longer term these extinctions will impoverish evolution's course for several million years.

So the future of evolution should be regarded as one of the most challenging issues humankind has ever encountered because currently we are the world's greatest evolutionary force. After all, we are effectively conducting a planet-scale experiment, with little clue as to how it might turn out, except that it will prove irreversible and will severely reduce human well-being. We could get by without half of all mammals and other vertebrates, but if we lost half of all insects with their pollinating functions [p. 64], let alone their many other services, we would be in trouble in the first crop-growing season.

In addition, the mass extinction or depletion under way is the biggest of our environmental problems in terms of the duration of its impact and the numbers of people to be affected. All our other problems are potentially reversible. If we wanted to clean up acid deposition, we could do it within a few decades. We could push back the deserts, restore topsoil, and allow the ozone layer to be repaired within a century or so. We could probably restore climate stability in the wake of global warming within a thousand years. But once a species is gone, it is gone for good.

Of course, in the long run evolution will generate replacement species with numbers and variety to match today's. But that is likely to take millions of years. We are witnessing the gross reduction if not the elimination of entire sectors of biomes, notably tropical forests, coral reefs, and wetlands, all of which may have served as powerhouses of evolution—centers of new speciation—in the prehistoric past.

Suppose, as has happened after the mass extinctions and depletions of the prehistoric past, that the bounce-back period lasts at least 5 million years. This would be 20 times longer than humans have been a species. Suppose that the average number of people on the earth during that period is 2.5 billion people, as opposed to the 6.2 billion today. Then the total number of people affected

For scientific details, see Norman Myers, "The Biodiversity Crisis and the Future of Evolution," *The Environmentalist* 16 (1996): 37–47.

more generalists? Or are they people who may know a lot about many things (and about connections between things) but not enough about anything in particular? Can they serve a useful role and make a satisfactory living in today's increasingly specialized societies? Explain your answers.

PROJECTS

1. An important adaptation of humans is a strong opposable thumb, which allows us to grip and manipulate things with our hands. As a demonstration of the importance of this trait, fold each of your thumbs into the palm of its hand and then tape them securely in that position for an entire day. After the demonstration, make a list of the things you could not do without the use of your thumbs.

2. Visit a local forest, pond, or lake, choose a particular organism, and then use the library or the Internet to describe as much as you can about its niche, including what species it depends on and what species help support its survival. Predict what might happen if your selected species disappeared from the local environment.

3. Use the library or the Internet to find out bibliographic information about *Charles Darwin* and *Theodosius Dobzhansky,* whose quotes appear at the beginning and end of this chapter.

4. Make a concept map of this chapter's major ideas, using the section heads and subheads and the key terms (in boldface). Look on the website for this book for information about making concept maps.

INTERNET STUDY RESOURCES AND RESOURCES FOR FURTHER READING AND RESEARCH

The website for this book contains helpful study aids and many ideas for further reading and research. Log on to

www.info.brookscole.com/miller13

and click on the Chapter-by-Chapter area. Choose Chapter 5 and select a resource:

by what we do (or don't do) to protect the biosphere during the next few decades will be about 500 trillion, in contrast with the 50 billion people who have ever existed. Even 1 trillion is a big number: Figure out how long a period of time in years is made up of 1 trillion seconds.

In short, we are engaged in by far the biggest decision ever made by one human community on behalf of future human communities. Yet the issue is almost entirely disregarded, whether scientifically, ethically, or otherwise. How often do you hear leading scientists even mention the issue?

Despite our gross ignorance of what lies ahead, we can venture a few hypotheses:

- *A temporary outburst of speciation.* As large numbers of niches are vacated, there could be an outburst of speciation, although not nearly enough to match the extinction spasm.
- *A proliferation of opportunistic species* such as cockroaches [Spotlight, p. 105], rats, flies, and others that prosper when new niches open up. This proliferation will be enhanced by the likely elimination of species that naturally control opportunistic species.
- *An end to large vertebrates.*
- *An end to speciation of large vertebrates.* Even if larger vertebrates were to survive the extinction spasm ahead, our largest protected areas will prove far too small for further speciation of elephants, rhinoceroses, apes, bears, and the bigger cats, among other large vertebrates.

What does all this imply for our conservation efforts? By far the predominant strategy of conservationists is to save as many species as possible. But we now need to safeguard evolutionary processes as well. A prime goal is to look out especially for endemic species (found only in a particular place) or species confined to small habitats. Examples include the California condor, the black-footed ferret, the giant panda, and the gorilla.

However, the fossil record shows that endemic species often turn out to be evolutionary dead ends: Generally they do not throw off new species. So should we shift our conservation priority from endemic species to broader-ranging species in the hope that they have more genetic variability and thus more of a diversified resource stock on which natural selection can work its creative impact?

Similarly, should we devote more attention to protecting the evolutionary powerhouses such as the forests, coral reefs, and wetlands of the tropics? All these are in dire trouble and may be all but eliminated within just a few decades. Do they deserve preferential treatment ahead of, say, temperate-zone woodlands and grasslands and boreal forests with their lack of species, ecological complexity, and evolutionary potential?

If within your lifetime we allow the current biotic crisis to proceed unchecked (which is what the recent record suggests), it is possible that your children will ask you a key question: "When the evolutionary debacle was becoming all too plain at the start of the new millennium, what did you do to help ward off this disaster?" I hope you will engage yourself in dealing with this crucial issue.

Critical Thinking

1. Do you agree or disagree with the thesis of this essay? Explain.

2. If you agree, list three things you could do to help prevent the outcomes described in this essay.

- Flash Cards allows you to test your mastery of the Terms and Concepts to Remember for this chapter.
- Tutorial Quizzes provides a multiple-choice practice quiz.
- Student Guide to InfoTrac will lead you to Critical Thinking Projects that use InfoTrac College Edition as a research tool.
- References lists the major books and articles consulted in writing this chapter.
- Hypercontents takes you to an extensive list of sites with news, research, and images related to individual sections of the chapter.

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http://www.infotrac-college.com

or access InfoTrac through the website for this book. Try to find the following articles:

1. Becker, L. 2002. Repeated blows: Did extraterrestrial collisions capable of causing widespread extinctions pound the earth not once, but twice—or even several times? *Scientific American* 286: 76. *Keywords:* "collisions" and "extinction." Mounting evidence suggests that collisions with space debris have occurred many times, and new techniques are demonstrating close links between such collisions and mass extinctions.

2. Peterson, A. T., and D. A. Vieglais. 2001. Predicting species invasions using ecological niche modeling: New approaches from bioinformatics attack a pressing problem. *BioScience* 51: 363. *Keywords:* "invasive species" and "niche." Invasive exotic species are rapidly becoming one of the greatest threats to biodiversity. This paper shows how invasiveness of a species can be predicted based upon studies of its ecological niche.

6 BIOGEOGRAPHY: CLIMATE, BIOMES, AND TERRESTRIAL BIODIVERSITY

Connections: Blowing in the Wind

Wind, a vital part of the planet's circulatory system, connects most life on the earth. 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. Dust rich in phosphates blows across the Atlantic from the Sahara Desert in Africa (Figure 6-1). This helps replenish rain forest soils in Brazil and build up agricultural soils in the Bahamas. Iron-rich dust blowing from China's Gobi Desert falls into the Pacific Ocean between Hawaii and Alaska. This input of iron stimulates the growth of phytoplankton, the minute producers that support ocean food webs. This is the *good news.*

The *bad news* is that wind also transports harmful viruses, bacteria, fungi, and particles of long-lived pesticides and toxic metals. 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 Florida. This **(1)** makes it difficult for the state to meet federal air pollution standards during summer months, and **(2)** fungi in this dust is a suspected factor in degrading or killing coral reefs in the Florida Keys and 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. Europe anc the Middle East also receive African dust.

Pollution and dust from rapidly industrializing China and central Asia blow across the Pacific Ocea and degrade air quality over the western United States. In 2001, climate scientists reported that a hug dust storm of soil particles blown from northern China had blanketed areas from Canada to Arizona with a layer of dust. Studies show that Asian polluti contributes as much as 10% to West Coast smog, a threat expected to increase as China industrializes.

We have *mixed news* as well. Particles from volcanic eruptions ride the winds, circle the globe, and change the earth's climate for a while. Emissions frc the 1991 eruption of Mount Pinatubo in the Philippines cooled the earth slightly for 3 years, temporar masking signs of global warming. On the other han volcanic ash, like the blowing desert dust, adds valı able trace minerals to the soil where it settles.

The lesson, once again, is that there is *no away.* Wind acts as part of the planet's circulatory system heat, moisture, plant nutrients, and long-lived pollı tants we put into the air. Movement of soil particles from one place to another by wind and water is a na ural phenomenon, but when we disturb the soil anc leave it unprotected we hasten the process.

Wind is also an important factor in climate through its influence on global air circulation patte Climate, in turn, is crucial for determining what kir of plant and animal life are found in the major bior of the biosphere, as we shall see in this chapter.

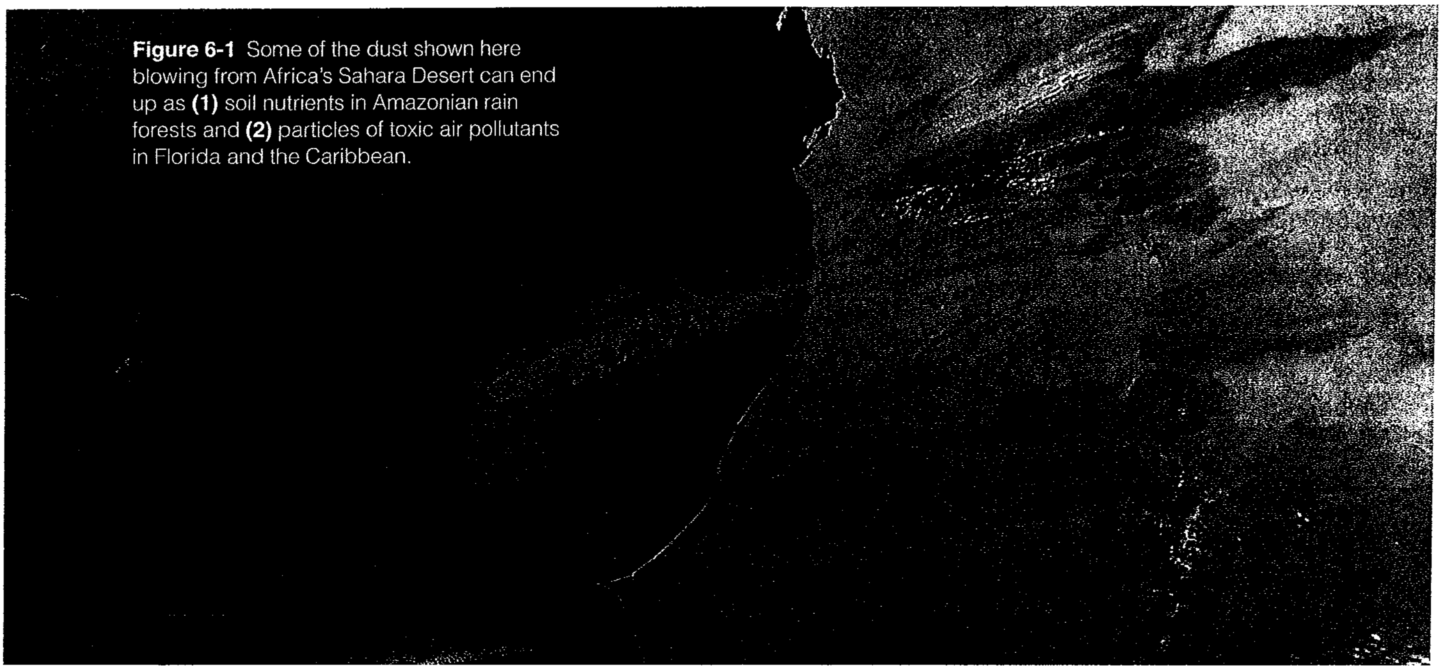


Figure 6-1 Some of the dust shown here blowing from Africa's Sahara Desert can end up as **(1)** soil nutrients in Amazonian rain forests and **(2)** particles of toxic air pollutants in Florida and the Caribbean.

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

This chapter addresses the following broad questions about geographic patterns of ecology:

- What key factors determine the earth's weather?
- What key factors determine the earth's climate?
- How does climate determine where the earth's major biomes are found?
- What are the major types of desert biomes, and how do human activities affect them?
- What are the major types of grassland biomes and how do human activities affect them?
- What are the major types of forest biomes, and how do human activities affect them?
- Why are mountain and arctic biomes important, and how do human activities affect them?
- What lessons can we learn from a geographic perspective of ecology?

6-1 WEATHER: A BRIEF INTRODUCTION

What Is Weather? At every moment at any spot on the earth, the *troposphere* (the inner layer of the atmosphere containing most of the earth's air) has a particular set of physical properties. Examples are **(1)** temperature, **(2)** pressure, **(3)** humidity, **(4)** precipitation, **(5)** sunshine, **(6)** cloud cover, and **(7)** wind direction and speed. These short-term properties of the troposphere at a particular place and time are **weather.**

Meteorologists use weather balloons, aircraft, ships, radar, satellites, and other devices to obtain data on variables such as **(1)** atmospheric pressures, **(2)** precipitation, **(3)** temperatures, **(4)** wind speeds, and **(5)** locations of air masses and fronts.

These data are fed into computer models to draw weather maps for each of seven levels of the troposphere, ranging from the ground to 19 kilometers (12 miles) up. Computer models use the map data to forecast the weather in each box of the seven-layer grid for the next 12 hours. 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.

What Are Warm Fronts and Cold Fronts? Masses of air that are warm or cold, wet or dry, and contain air at high or low pressure constantly move across the land and sea. 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 6-2, top). Because warm air is less dense (weighs less per unit of volume) than cool air, an advancing warm front will rise up over a mass of cool air.

As the warm front rises, its moisture begins condensing into droplets to form layers of clouds at different altitudes. High, wispy clouds are the first signs of an advancing warm front. 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 6-2, bottom) is the leading edge of an advancing mass of cold air. Because cold air

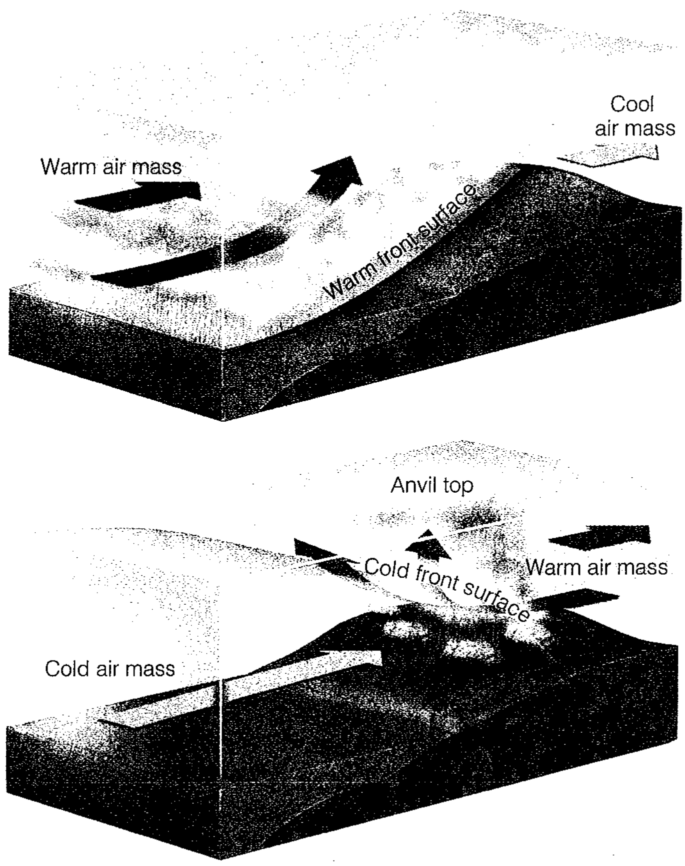


Figure 6-2 A *warm front* (top) occurs when an advancing mass of warm air meets and rises up over a retreating mass of more dense cool air. A *cold front* (bottom) is the boundary formed when a mass of cold air wedges beneath a retreating mass of less dense warm air.

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 the overlying mass of warm air is pushed upward, it cools and its water vapor condenses to form large and heavy droplets that fall to the earth's surface as precipitation. As a cold front passes through, we often experience high surface winds and thunderstorms. After the front passes through, we usually have cooler temperatures and a clear sky.

What Are Highs and Lows? Weather is also affected by changes in atmospheric pressure. Air pressure results from the zillions of tiny molecules of the gases (mostly nitrogen and oxygen) in the atmosphere zipping around at incredible speeds and hitting and bouncing off of anything they encounter.

Gravity affects atmospheric pressure. Pressure is greater near the earth's surface because the molecules in the atmosphere are squeezed together under the weight of the air above.

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 the high-pressure air mass remains over an area.

In contrast, a low-pressure air mass, called a **low,** produces cloudy and sometimes stormy weather. This happens because less dense warm air spirals inward toward the center of a low-pressure air mass. Because of its low pressure and low density, the center of the low rises, and its warm air expands and cools. When

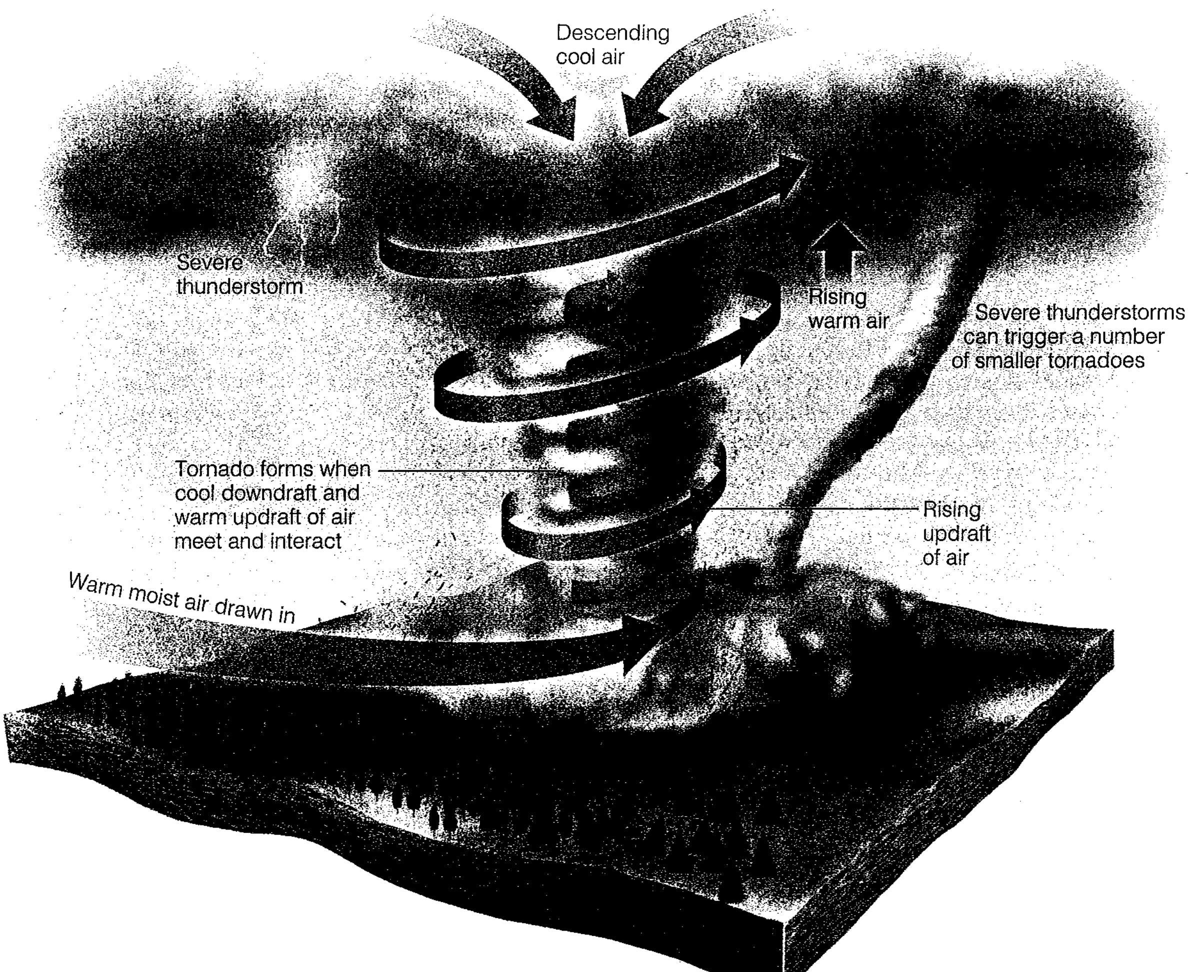


Figure 6-3 Formation of a *tornado* or *twister.* Although twisters can form any time of the year, the most active tornado season in the United States is usually March through August. Each year more than 800 tornadoes strike the United States. Meteorologists cannot predict with great accuracy when and where most tornadoes will form.

the temperature drops below the dew point, the moisture in the air condenses and forms clouds. If the droplets in the clouds coalesce into large and heavy drops, precipitation occurs.

What Causes Tornadoes and Tropical Cyclones?

In addition to normal weather, we sometimes experience *weather extremes.* Two examples are violent storms called **(1)** *tornadoes* (which form over land) and **(2)** *tropical cyclones* (which form over warm ocean waters and sometimes pass over coastal land).

Figure 6-3 shows how the vortex of a *tornado* (or twister) forms. Strong tornadoes often have two or more smaller vortexes or funnel-shaped clouds that move around the center of a larger vortex. These funnel-shaped clouds often are black or red because of the dust and dirt sucked up from the ground. The United States is the world's most tornado-prone country, followed by Australia.

Figure 6-4 shows the formation and structure of a *tropical cyclone.* Tropical cyclones that form in the Atlantic Ocean are called *hurricanes;* those forming in the Pacific Ocean are called *typhoons.* Tropical cyclones take a long time to form and gain strength. As a result, meteorologists can **(1)** track their path and wind speeds and **(2)** warn people in areas likely to be hit by these violent storms. Figure 6-5 (p. 114) shows the areas of North America most susceptible to tropical cyclones (hurricanes on the East Coast and typhoons on the West Coast).

Hurricanes and typhoons can kill and injure people and damage property and agricultural production. In some cases, however, a tropical cyclone can have long-term ecological and economic benefits that can exceed its short-term negative effects.

For example, in parts of Texas along the Gulf of Mexico, coastal bays and marshes normally are closed off from freshwater and saltwater inflows. In August

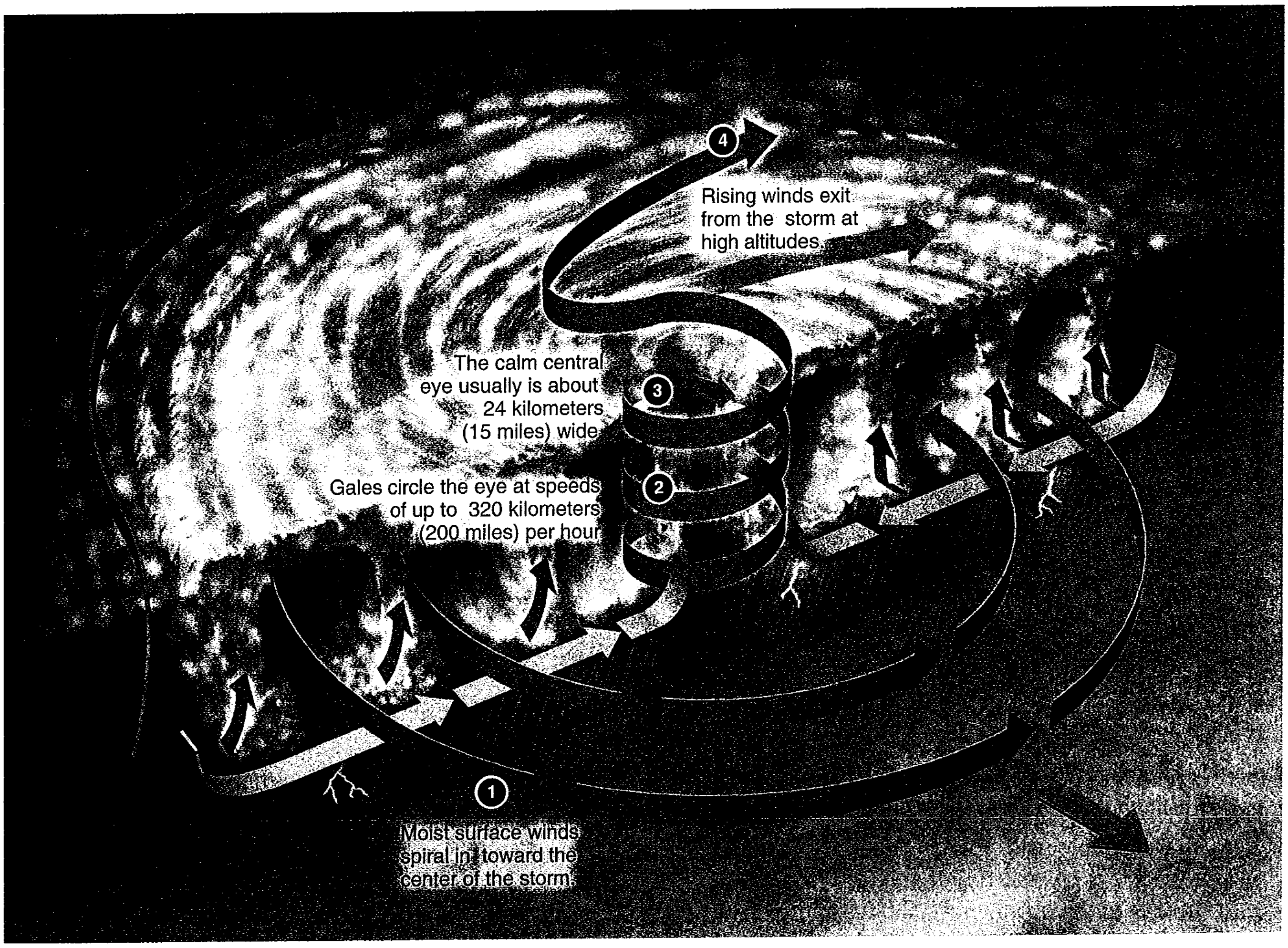


Figure 6-4 Formation of a *tropical cyclone.* Those forming in the Atlantic Ocean are called *hurricanes;* those forming in the Pacific Ocean are called *typhoons.*

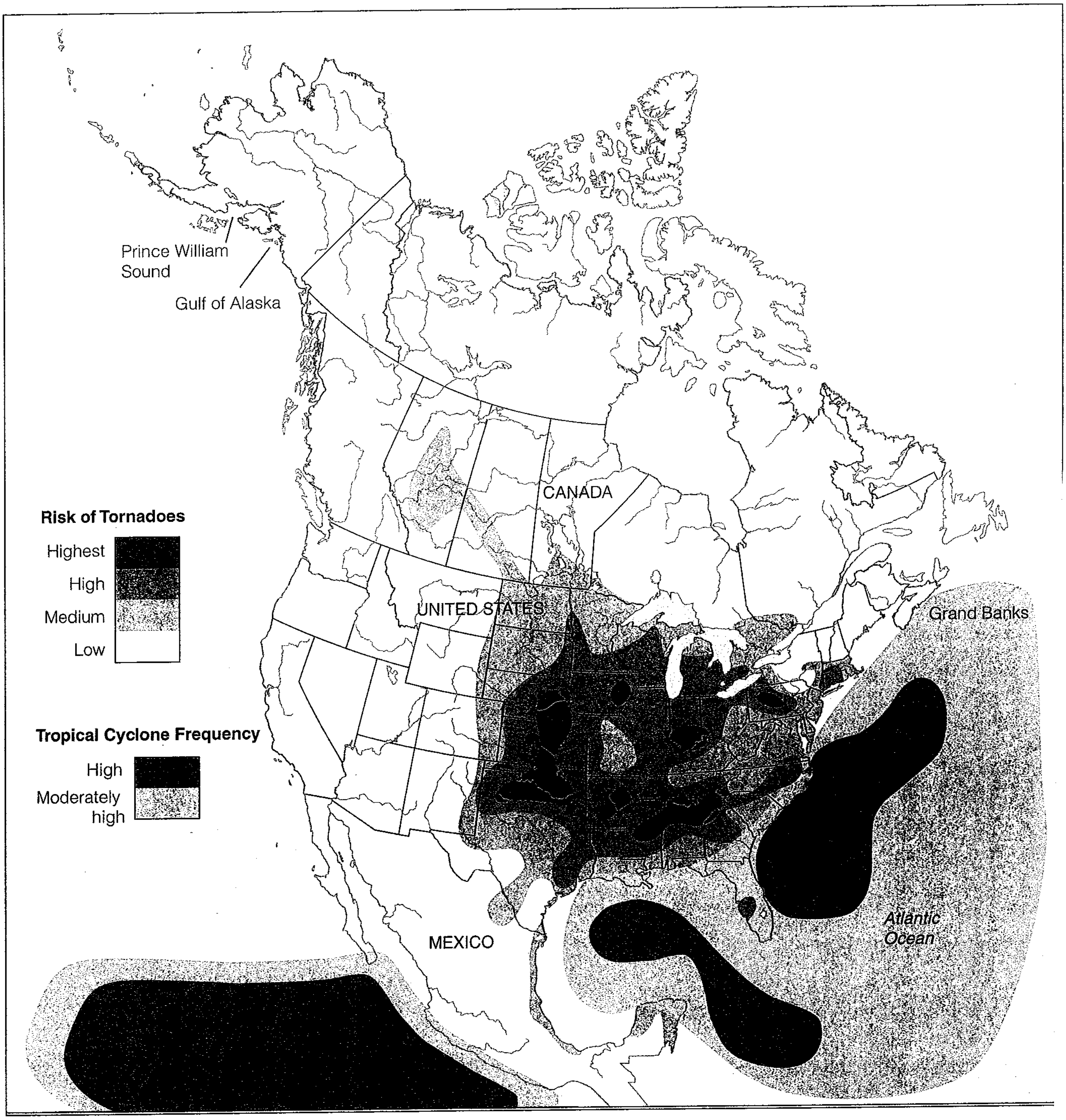


Figure 6-5 Areas of North America most susceptible to tornadoes and tropical cyclones (hurricanes and typhoons). (Data from NOAA and U.S. Geological Survey)

1999, Hurricane Brett struck this coastal area. According to marine biologists, this hurricane **(1)** flushed excess nutrients from land runoff and dead sea grasses and rotting vegetation from coastal bays and marshes and **(2)** carved 12 channels through the barrier islands along the coast that allowed huge quantities of fresh seawater to flood the bays and marshes. This flushing out **(1)** reduced brown tides, consisting of explosiv growth of algae feeding on excess nutrients, **(2)** ir creased growth of sea grasses, which serve as nurs eries for shrimp, crabs, and fish and food for million of ducks wintering in Texas bays, and **(3)** increase production of commercially important species of shel fish and fish.

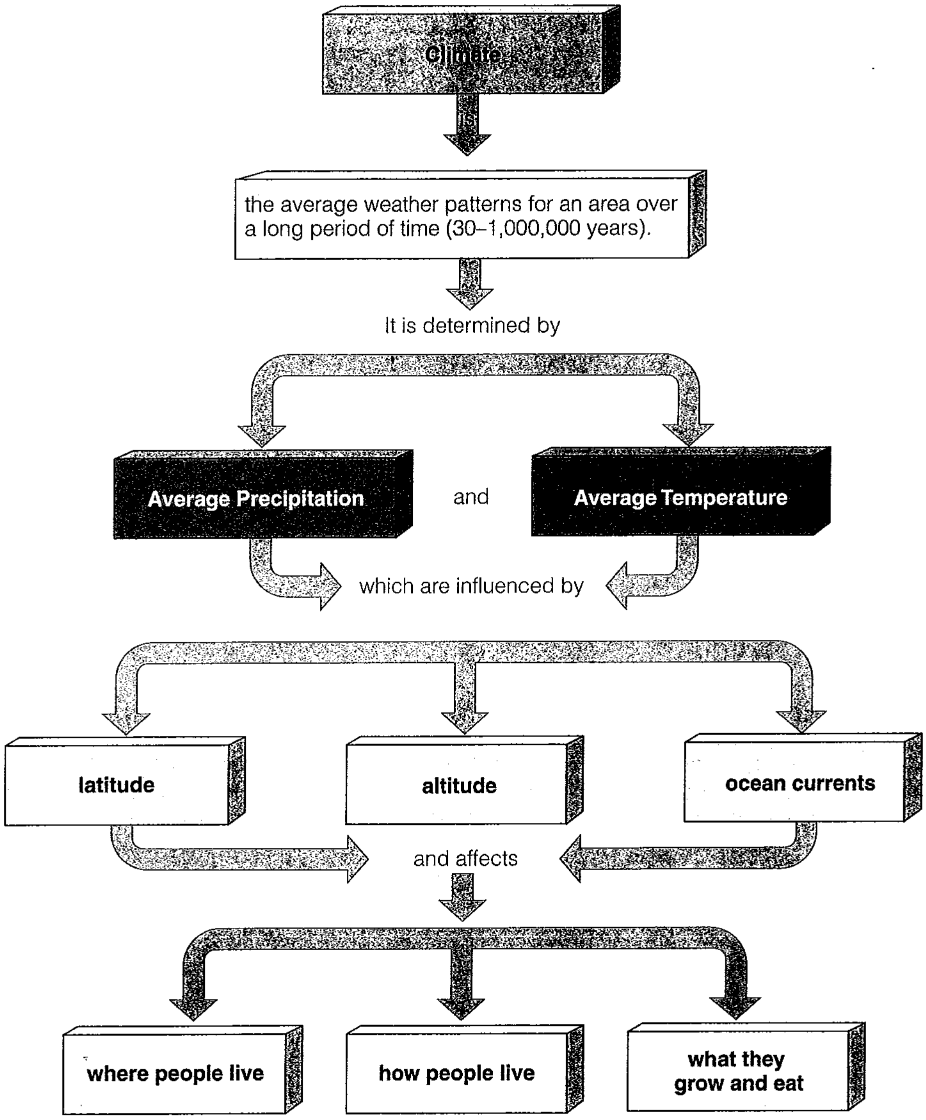


Figure 6-6 Climate and its effects. (Data from National Oceanic and Atmospheric Administration)

6-2 CLIMATE: A BRIEF INTRODUCTION

What Is Climate? **Climate** is a region's general pattern of atmospheric or weather conditions over a long period. *Average temperature* and *average precipitation* are the two main factors determining a region's climate and its effects on people (Figure 6-6). Figure 6-7 (p. 116) is a generalized map of the earth's major climate zones.

How Does Global Air Circulation Affect Regional Climates? The temperature and precipitation patterns that lead to different climates (Figure 6-7) are caused primarily by the way air circulates over the earth's surface. The following factors determine global air circulation patterns:

- *Uneven heating of the earth's surface* because air is heated much more at the equator (where the sun's rays strike directly throughout the year) than at the poles (where sunlight strikes at an angle and thus is spread out over a much greater area). These differences in incoming solar energy help explain why **(1)** tropical regions near the equator are hot, **(2)** polar regions are cold, and **(3)** temperate regions in between generally have intermediate average temperatures (Figure 6-7).

- *Seasonal changes in temperature and precipitation* because the earth's axis (an imaginary line connecting the north and south poles) is tilted. As a result, various regions are tipped toward or away from the sun as the earth makes its yearlong revolution around the sun

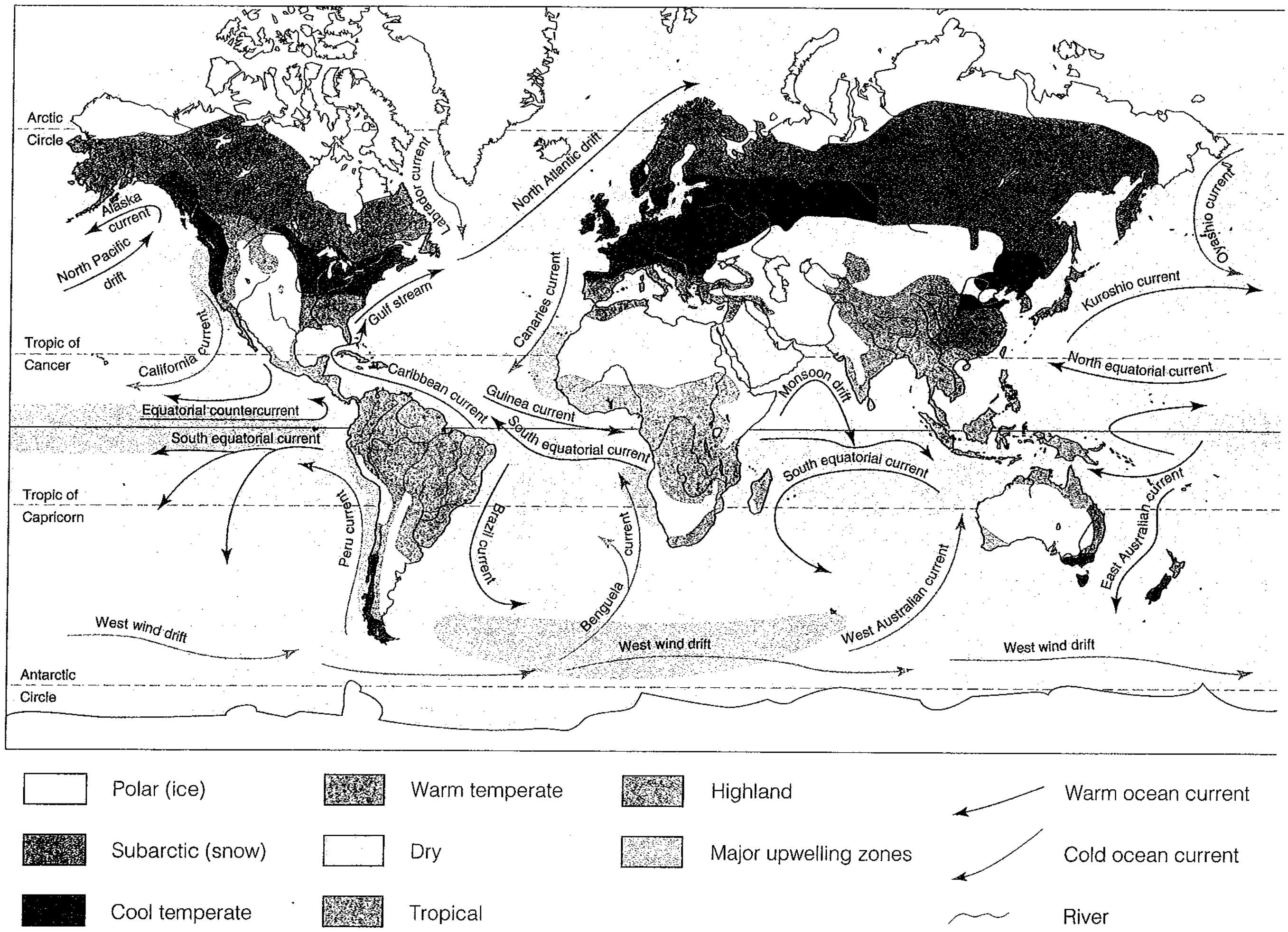


Figure 6-7 Generalized map of global climate zones, showing the major contributing ocean currents and drifts.

(Figure 6-8). This creates opposite seasons in the northern and southern hemispheres.

- *Rotation of the earth on its axis,* which prevents air currents from moving due north and south from the equator. Forces in the atmosphere created by this rotation deflect winds (moving air masses) to the right in the northern hemisphere and to the left in the southern hemisphere. This results in the formation of six huge convection cells of swirling air masses (three north and three south of the equator) that transfer heat and water from one area to another (Figure 6-9, right).

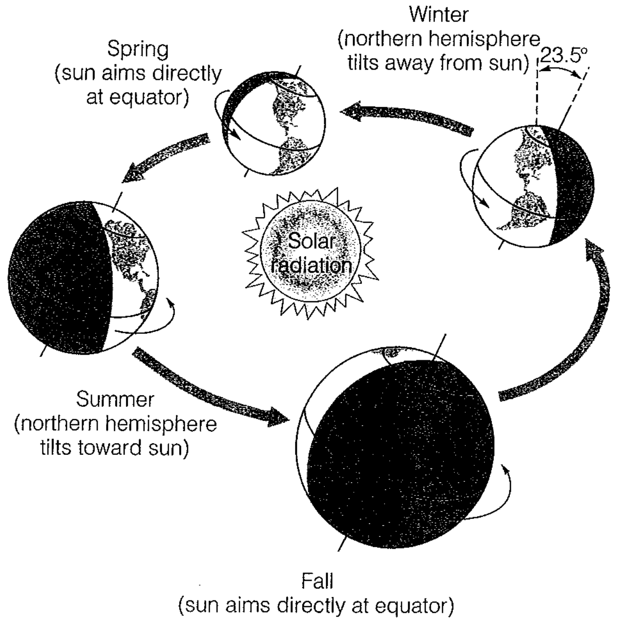
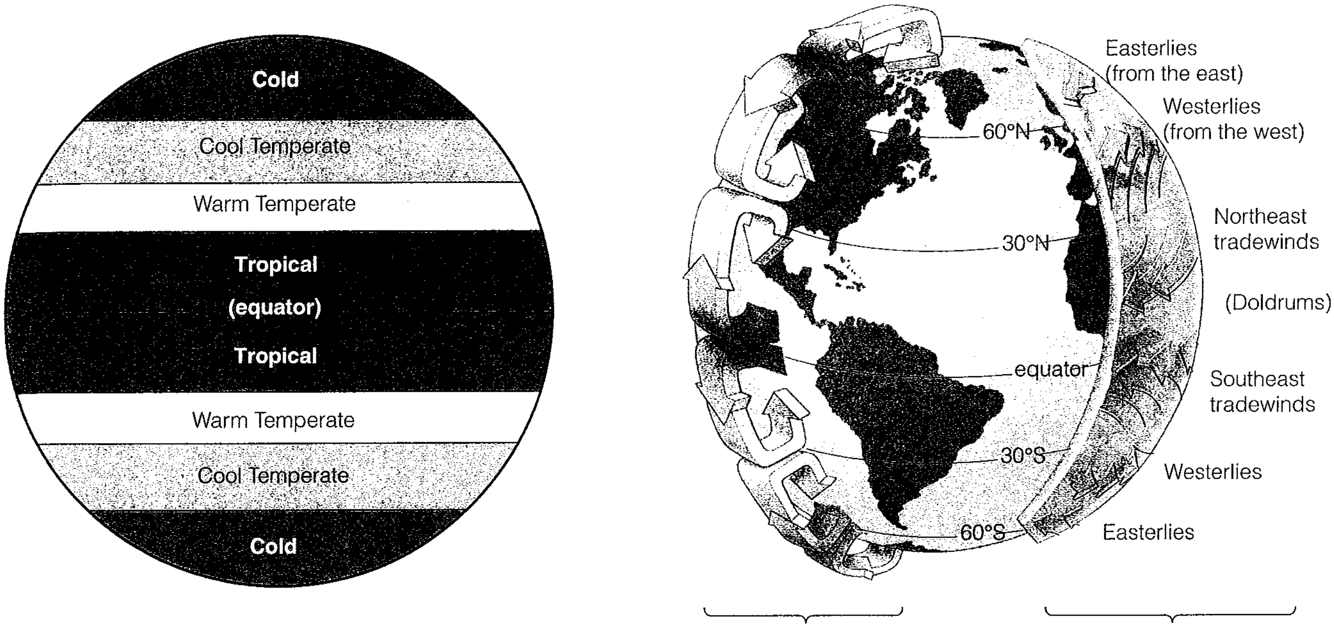


Figure 6-8 The effects of the earth's tilted axis on climate. As the planet makes its annual revolution around the sun on an axis tilted about 23.5°, various regions are tipped toward or away from the sun. The resulting variations in the amount of solar energy reaching the earth create the seasons.

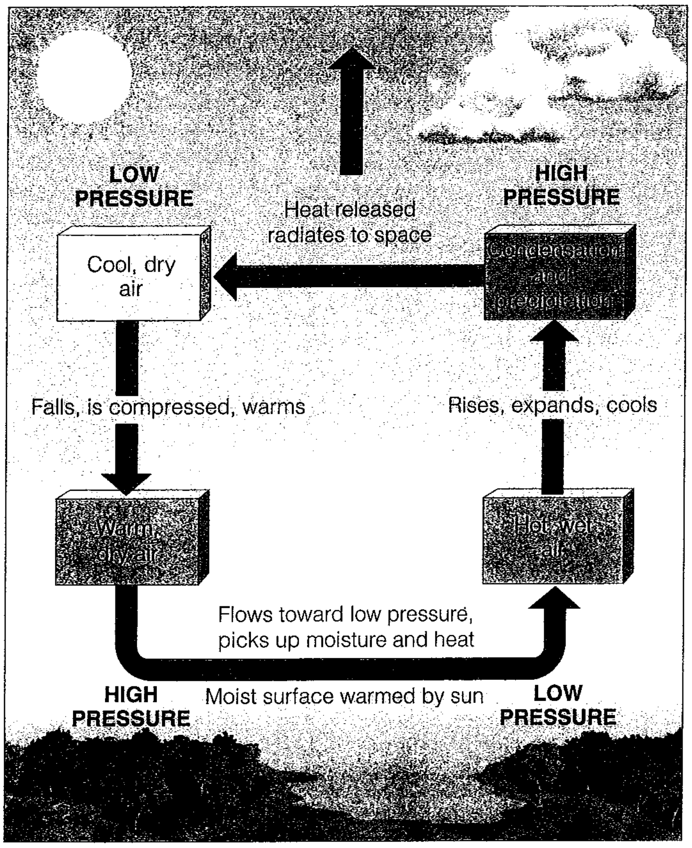


(a) Climate type

(b) Initial pattern of air circulation

(c) Deflections in the paths of air flow near the earth's surface

Figure 6-9 Formation of prevailing surface winds, which disrupt the general flow of air from the equator to the poles and back to the equator **(b)**. As the earth rotates, its surface turns faster beneath air masses at the equator and slower beneath those at the poles. This deflects air masses moving north and south to the west or east, creating six huge convection cells in which air swirls upward and then descends toward the earth's surface at different latitudes. The direction of air movement in these cells sets up belts of prevailing winds **(c)** that distribute air and moisture over the earth's surface. These winds affect the general types of climate found in different areas **(a)** and drive the circulation of ocean currents. (From Cecie Starr, *Biology: Concepts and Applications*, 4th ed., Brooks/Cole [Wadsworth] © 2000)



- *Long-term variations in the amount of solar energy striking the earth.* These are caused by occasional changes in solar output and slight planetary shifts in which the earth's axis wobbles (22,000-year cycle) and tilts (44,000-year cycle) as it revolves around the sun.
- *Properties of air and water.* Heat from the sun evaporates ocean water and transfers heat from the oceans to the atmosphere, especially near the hot equator. This creates cyclical convection cells that transport heat and water from one area to another (Figure 6-10). The resulting convection cells circulate air, heat, and moisture both vertically and from place to place in the troposphere. This leads to different climates and patterns of vegetation (Figure 6-11, p. 118).

Figure 6-10 Transfer of energy by convection in the atmosphere. *Convection* occurs when a matter warms, becomes less dense, and rises within its surroundings. This efficient means of heat transfer occurs in the planet's interior, oceans, and atmosphere (as shown here). Distribution of heat and water occurs in the atmosphere because vertical convection currents stir up air in the troposphere and transport heat and water from one area to another in circular convection cells. The relative humidity increases as the air rises (right side) and decreases as it falls (left side).

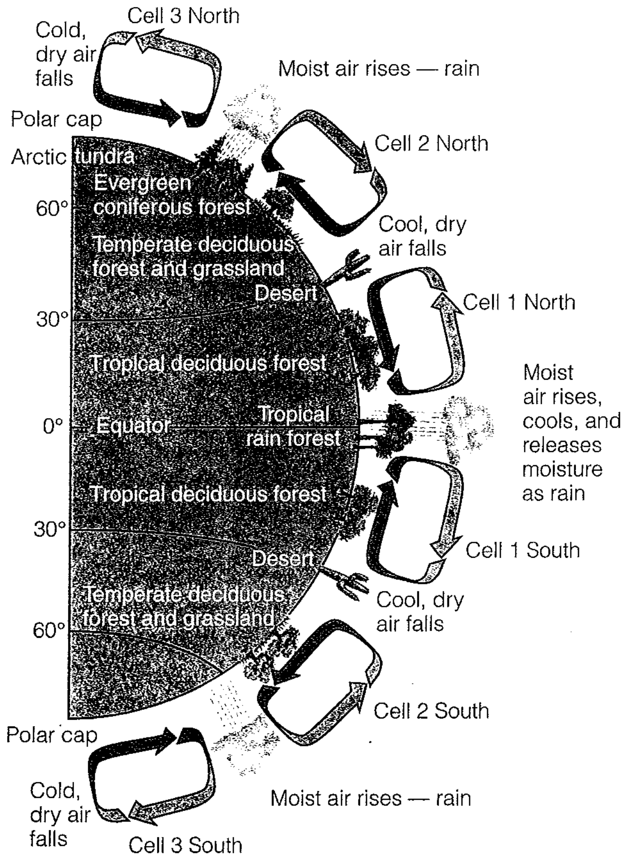


Figure 6-11 Model of global air circulation and biomes. Heat and moisture are distributed over the earth's surface by vertical currents that form six large convection cells (called Hadley cells) at different latitudes. The direction of air flow and the ascent and descent of air masses in these convection cells determine the earth's general climatic zones. 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.

How Do Ocean Currents Form, and How Do They Affect Regional Climates? The factors just listed, plus differences in water density, create warm and cold ocean currents (Figures 6-7 and 6-12) These currents, driven by winds and the earth's rotation (Figure 6-9) **(1)** redistribute heat received from the sun and **(2)** thus influence climate and vegetation, especially near coastal areas.

For example, without the warm Gulf Stream, which transports 25 times more water than all the world's rivers, the climate of northwestern Europe would be subarctic. If the ocean's currents suddenly stopped flowing, there would be deserts in the tropics and thick ice sheets over northern Europe, Siberia, and Canada. Currents also help mix ocean waters and distribute nutrients and dissolved oxygen needed by aquatic organisms.

What Are Upwellings? The winds blowing along some steep western coasts of continents towards the equator create an effect (called the Ekman spiral) that pushes surface water at right angles from the wind flow away from the land. This outgoing surface water is replaced by an **upwelling** of cold, nutrient-

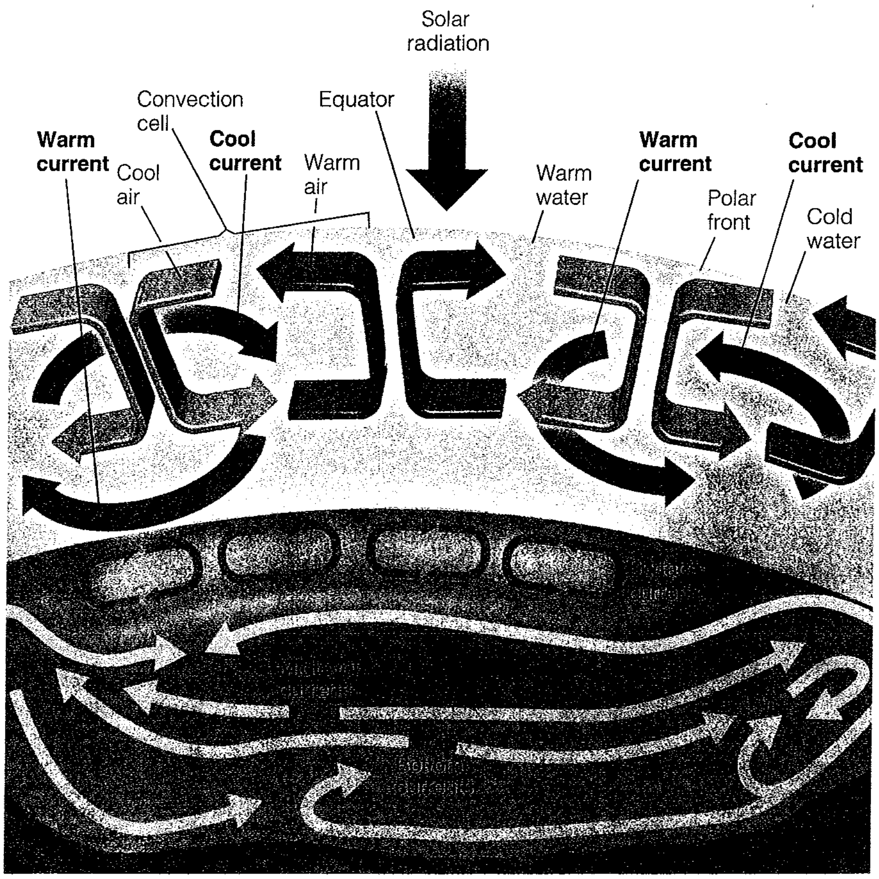


Figure 6-12 Formation of warm and cool *ocean currents.* Energy from the sun drives convection cells, which produce prevailing winds and ocean currents. Figure 6-7 (p. 116) shows the locations and flow directions of some of the earth's major warm and cool currents.

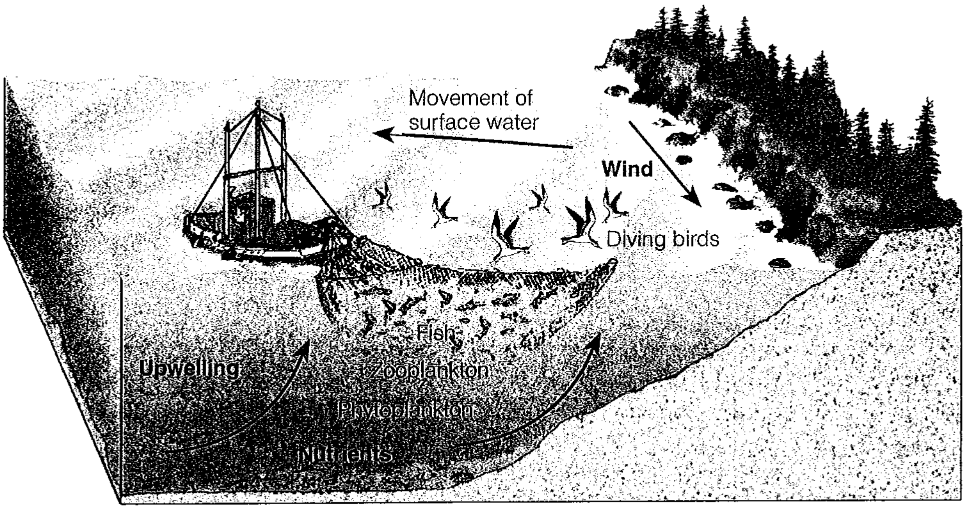


Figure 6-13 A *shore upwelling* (shown here) occurs when deep, cool, nutrient-rich waters are drawn up to replace surface water moved away from a steep coast by wind flowing along the coast toward the equator. Such areas support large populations of phytoplankton, zooplankton, fish, and fish-eating birds. *Equatorial upwellings* occur in the open sea near the equator when northward and southward currents interact to push deep waters and their nutrients to the surface, thus greatly increasing primary productivity in such areas.

rich bottom water (Figure 6-13). Upwellings, whether far from shore or near shore (Figure 6-7), **(1)** bring plant nutrients from the deeper parts of the ocean to the surface and **(2)** support large populations of phytoplankton, zooplankton, fish, and fish-eating seabirds.

What Is the El Niño–Southern Oscillation?

Every few years in the Pacific Ocean, normal shore upwellings (Figure 6-14, left) are affected by changes in climate patterns called the *El Niño–Southern Oscillation,* or *ENSO* (Figure 6-14, right). In an ENSO, often called *El Niño,* **(1)** the prevailing westerly winds weaken or cease, **(2)** surface water along the South and North American coasts becomes warmer, and **(3)** the normal upwellings of cold, nutrient-rich water are suppressed, which reduces primary productivity and causes a sharp decline in the populations of some fish species.

A strong ENSO can trigger extreme weather changes over at least two-thirds of the globe, especially in lands along the Pacific and Indian Oceans

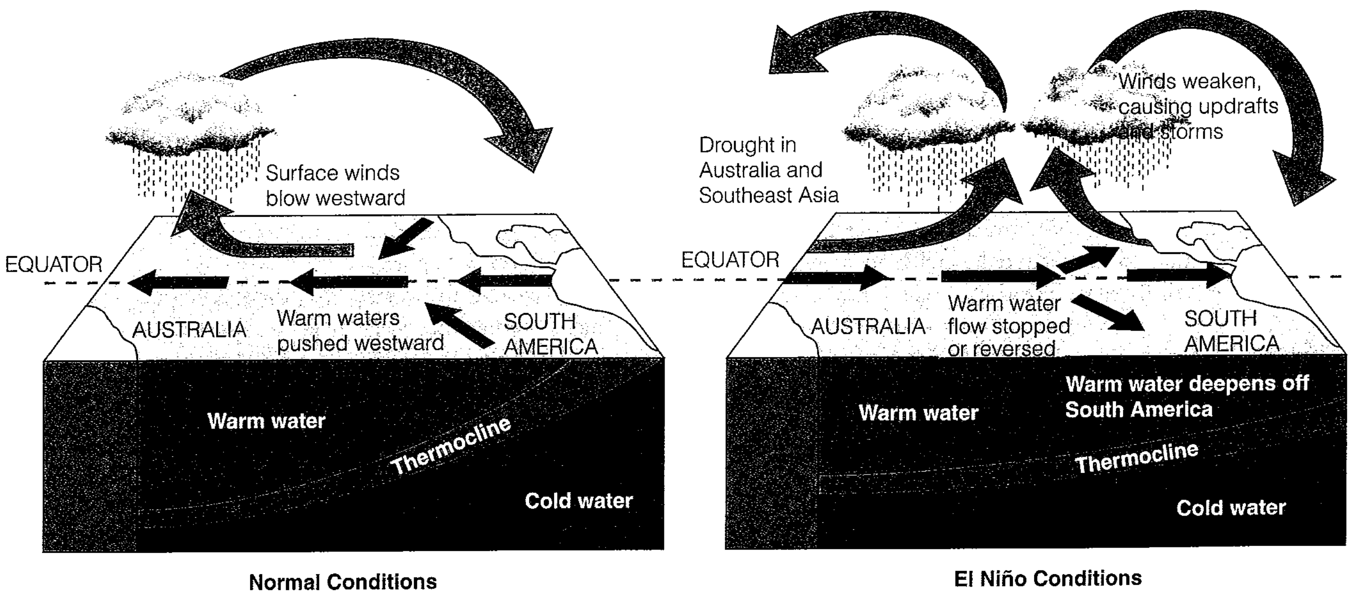


Figure 6-14 Normal surface winds blowing westward cause shore upwellings of cold, nutrient-rich bottom water in the tropical Pacific Ocean near the coast of Peru (left). A zone of gradual temperature change called the *thermocline* separates the warm and cold water. Every few years a climate shift known as the El Niño–Southern Oscillation (ENSO) disrupts this pattern. Westward surface winds weaken, 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 trigger extreme weather changes over much of the globe (Figure 6-15, p. 120).

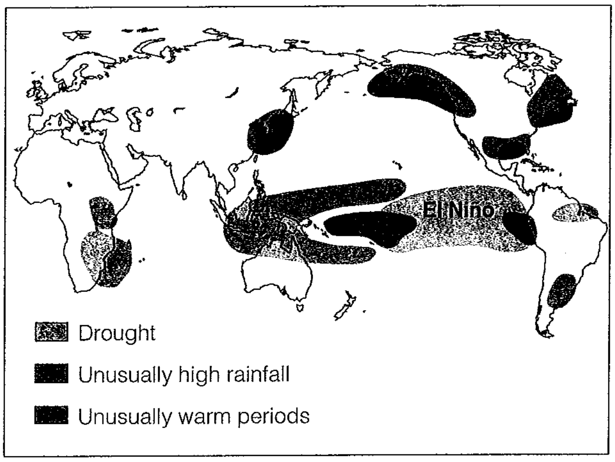


Figure 6-15 Typical global climatic effects of an El Niño–Southern Oscillation. During the 1996–98 ENSO, huge waves battered the California coast, and torrential rains caused widespread flooding and mudslides. In Peru, floods and mudslides killed hundreds of people, left about 250,000 people homeless, 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. (Data from United Nations Food and Agriculture Organization)

(Figure 6-15). Figure 6-16 shows the occurrence of ENSOs (red) between 1950 and 1999.

What Is La Niña? Sometimes an El Niño is followed by its cooling counterpart, *La Niña* (Figure 6-16, yellow). Typically a La Niña means **(1)** more Atlantic Ocean hurricanes, **(2)** colder winters in Canada and the Northeast, **(3)** warmer and drier winters in the southeastern and southwestern United States, **(4)** wetter winters in the Pacific Northwest, **(5)** torrential rains in Southeast Asia, **(6)** lower wheat yields in Argentina, and **(7)** more wildfires in Florida.

How Does the Chemical Makeup of the Atmosphere Lead to the Greenhouse Effect? Small amounts of certain gases play a key role in determining the earth's average temperatures and thus its climates. These gases include **(1)** water vapor (H_2O), **(2)** carbon dioxide (CO_2), **(3)** methane (CH_4), **(4)** nitrous oxide (N_2O), and **(5)** synthetic chlorofluorocarbons (CFCs).

Together, these gases, known as **greenhouse gases,** act somewhat like the glass panes of a greenhouse: They allow mostly visible light and some infrared radiation and ultraviolet (UV) radiation from the sun (Figure 3-10, p. 52) to pass through the troposphere. The earth's surface absorbs much of this solar energy. This transforms it to longer wavelength infrared radiation (heat), which then rises into the troposphere (Figure 4-8, p. 69).

Some of this heat escapes into space, and some is absorbed by molecules of greenhouse gases and emitted into the troposphere as even longer wavelength infrared radiation, which warms the air. This natural warming effect of the troposphere is called the **greenhouse effect*** (Figure 6-17, p. 121).

The basic principle behind the natural greenhouse effect is well established. Indeed, without its current greenhouse gases (especially water vapor, which is found in the largest concentration), 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. There is concern that large inputs of these greenhouse gases into the troposphere can enhance the earth's natural greenhouse effect and lead to *global warming.* If correct, this could **(1)** alter precipitation patterns, **(2)** shift areas where we can grow crops, **(3)** raise average sea levels, and **(4)** shift areas where some types of plants and animals can live.

How Does the Chemical Makeup of the Atmosphere Create the Ozone Layer? In a band of the stratosphere 16–26 kilometers (11–16 miles) above the earth's surface, oxygen (O_2) is continuously converted to ozone (O_3) and back to oxygen by a sequence of reactions initiated by UV radiation from the sun ($3O_2 + UV \rightleftharpoons 2O_3$). The result is a thin veil of protective ozone at very low concentrations (up to 12 parts per million).

Normally, the average levels of ozone in this life-saving layer do not change much because the rate of ozone destruction is equal to its rate of formation. This stratospheric ozone prevents at least 95% of the sun's harmful UV radiation from reaching the earth's surface (Figure 4-8, p. 69).

This ozone layer also creates warm layers of air that prevent churning gases in the troposphere from entering the stratosphere. This *thermal cap* is important in determining the average temperature of the troposphere and thus the earth's current climates. Much evidence indicates that chemicals added to the atmosphere by human activities are decreasing levels of protective ozone in the stratosphere.

*To say the earth's atmosphere *traps* heat or *reradiates* heat it has absorbed back toward the earth's surface is scientifically incorrect. Molecules of greenhouse gases absorb various wavelengths of infrared radiation and transform them into infrared radiation with different (longer) wavelengths. Because the originally absorbed wavelengths of infrared radiation no longer exist, it is incorrect to say they have been trapped or reradiated.

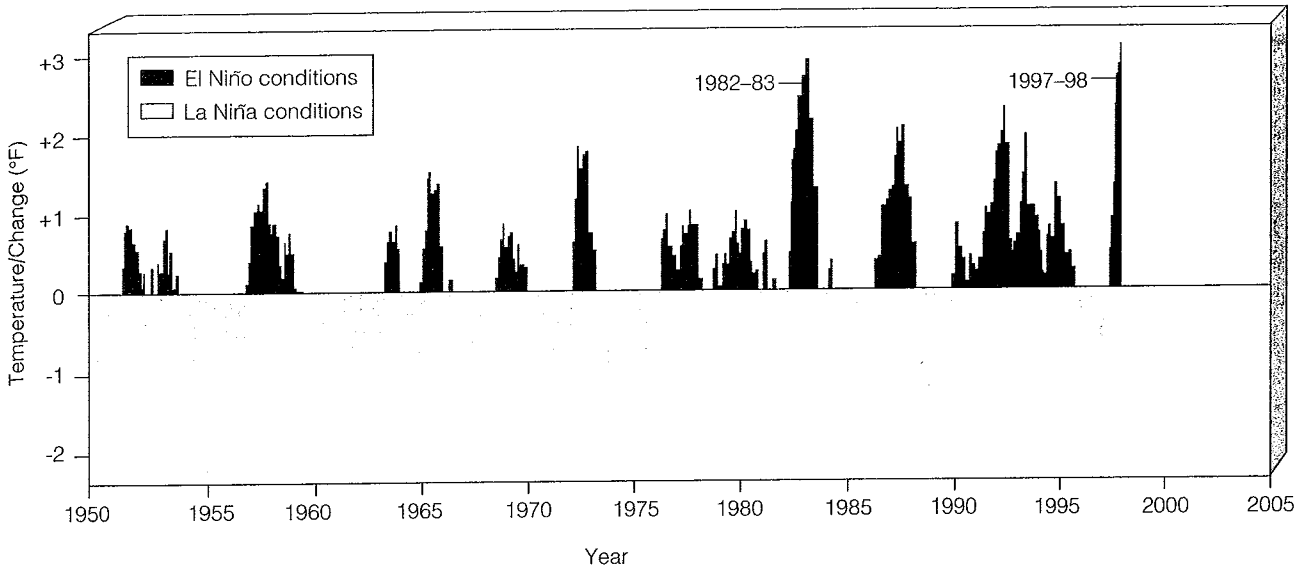
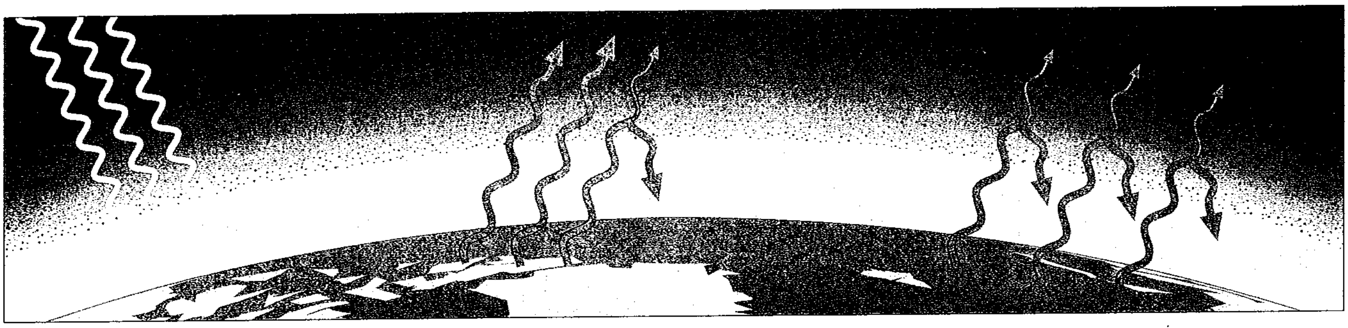


Figure 6-16 El Niño and La Niña conditions between 1950 and 1999. (Data from U.S. National Weather Service)



(a) Rays of sunlight penetrate the lower atmosphere and warm the earth's surface.

(b) The earth's surface absorbs much of the incoming solar radiation and degrades it to longer-wavelength infrared radiation (heat), which rises into the lower atmosphere. Some of this heat escapes into space and some is absorbed by molecules of greenhouse gases and emitted as infrared radiation, which warms the lower atmosphere.

(c) As concentrations of greenhouse gases rise, their molecules absorb and emit more infrared radiation, which adds more heat to the lower atmosphere.

Figure 6-17 The *greenhouse effect.* Without the atmospheric warming provided by this natural effect, the earth would be a cold and mostly lifeless planet. According to the widely accepted greenhouse theory, when concentrations of greenhouse gases in the atmosphere rise, the average temperature of the troposphere rises. (Modified by permission from Cecie Starr, *Biology: Concepts and Principles,* 4th ed., Pacific Grove, Calif.: Brooks/Cole, 2000)

How Do Topography and Other Features of the Earth's Surface Create Microclimates? Various topographic features of the earth's surface create local climatic conditions, or **microclimates,** 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 cools as it is forced to rise and expand. This causes the air to lose most of its moisture as rain and snow on the windward (wind-facing) slopes. As the drier air mass flows down the leeward (away from the wind) slopes, it draws moisture out of the plants and soil over which it passes. The lower precipitation and the resulting semiarid or arid conditions on the leeward side of high mountains are called the **rain shadow effect** (Figure 6-18, p. 122).

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

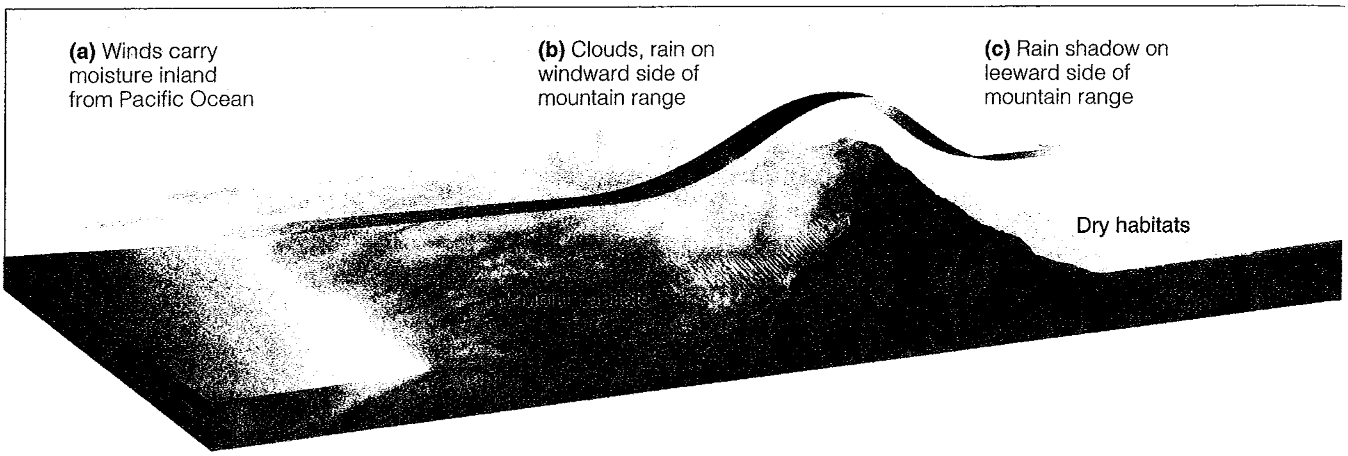


Figure 6-18 The *rain shadow effect* is a reduction of rainfall on the side of high mountains facing away from prevailing surface winds. It occurs when warm, moist air in prevailing onshore winds loses most of its moisture as rain and snow on the windward (wind-facing) slopes of a mountain range. This leads to semiarid and arid conditions on the leeward side of the mountain range and the land beyond. The Mojave Desert, east of the Sierra Nevada in California, is produced by this effect.

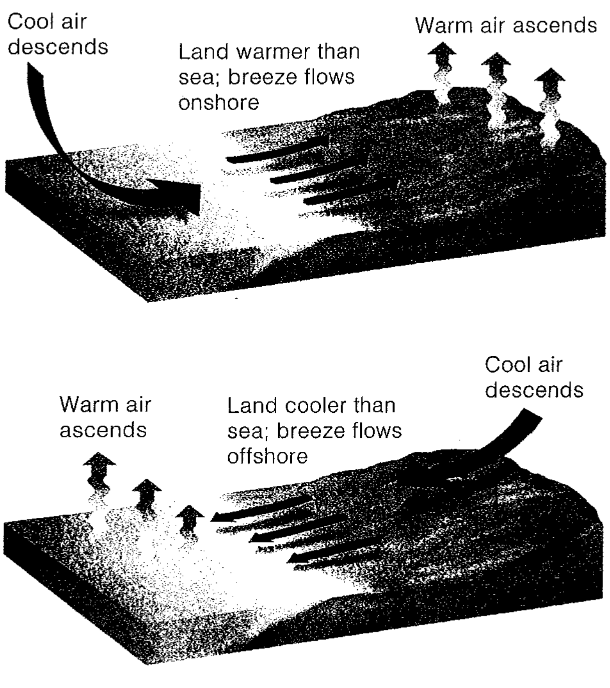


Figure 6-19 *Sea and land breezes.* Land heated by the sun during the day heats ground-level air, which rises and is replaced by cooler air drawn from the ocean. As a result, surface wind blows from the ocean to the land, creating a *sea breeze* (top). At night the land loses its heat quickly through radiation while the ocean water remains at about the same temperature. As the land surface cools below the sea surface temperature, warmer air rises over the ocean and is replaced by air from the land. Thus surface wind blows from the land to the ocean, creating a *land breeze* (bottom). (Used by permission from Cecie Starr, *Biology: Concepts and Principles,* 4th ed., Pacific Grove, Calif.: Brooks/Cole, 2000)

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.

Land–ocean interactions affect the local climates of coastal areas by creating **(1)** ocean-to-land breezes (called *sea breezes*) during the day (Figure 6-19, top) and **(2)** land-to-ocean breezes (called *land breezes*) at night (Figure 6-19, bottom).

6-3 BIOMES: CLIMATE AND LIFE ON LAND

Why Do Different Organisms Live in Different Places? Why is one area of the earth's land surface a desert, another a grassland, and another a forest? Why do different types of deserts, grasslands and forests exist?

The general answer to these questions is differences in *climate* (Figure 6-7), caused mostly by differences in average temperature and precipitation caused by global air circulation (Figures 6-9 and 6-11). Different climates promote different communities of organisms.

Figure 6-20 and the photo on p. 1 show global distributions of *biomes:* terrestrial regions with characteristic types of natural, undisturbed ecological communities adapted to the climate of the region. By comparing Figure 6-20 with Figure 6-7, you can see how the world's major biomes vary with climate. Figure 4-9 (p. 70) shows major biomes in the United States as one moves through different climates along the 39th parallel. Take

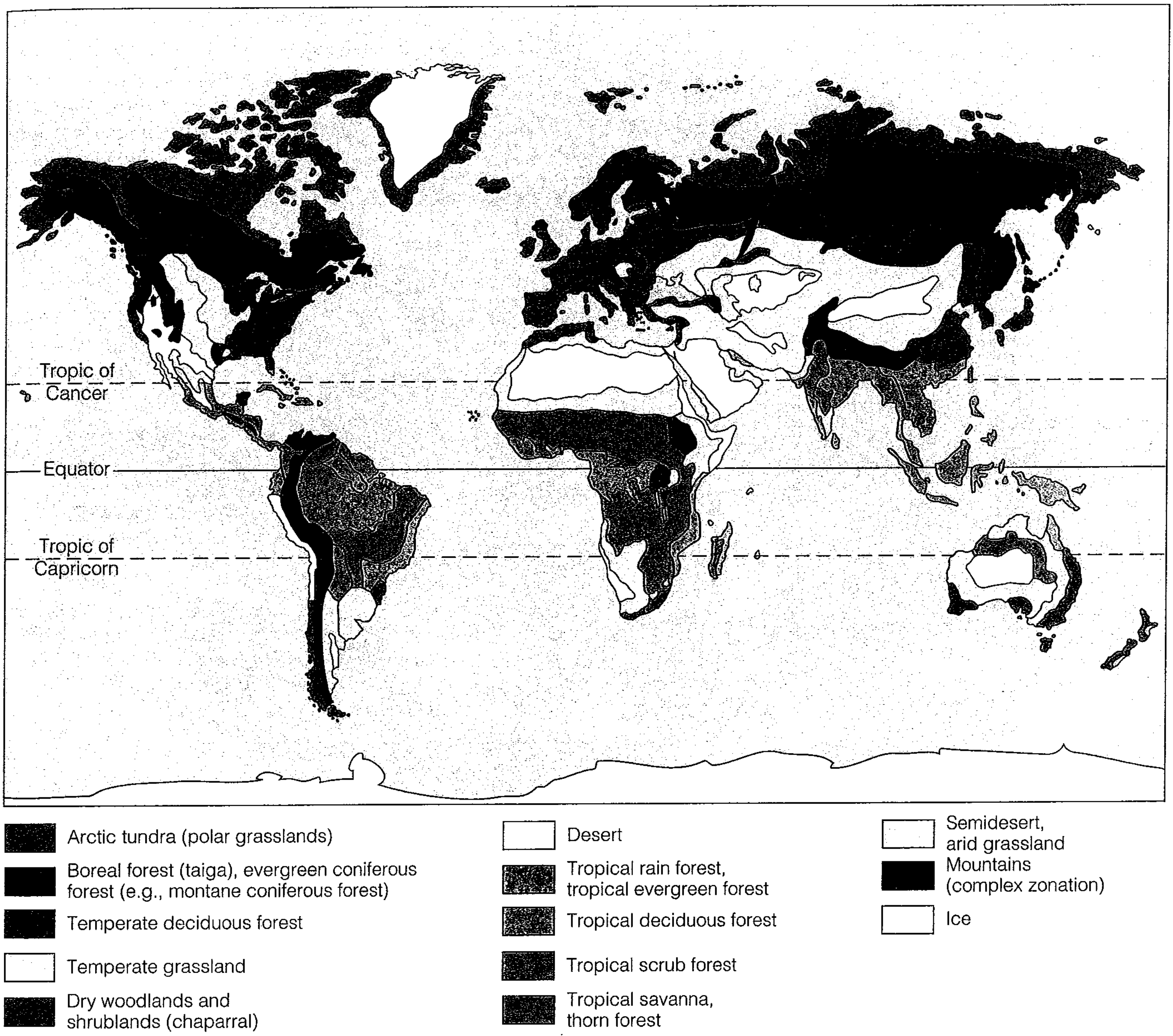


Figure 6-20 The earth's major *biomes*—the main types of natural vegetation in different undisturbed land areas—result primarily from differences in climate (Figure 6-7). Each biome contains many ecosystems whose communities have adapted to differences in climate, soil, and other environmental factors. In reality, people have removed or altered much of this natural vegetation in some areas for farming, livestock grazing, lumber and fuelwood, mining, and construction, thereby altering the biomes (Figure 1-5, p. 7).

together, average annual precipitation and temperature (along with soil type) are the most important factors in producing tropical, temperate, or polar deserts, grasslands, and forests (Figure 6-21, p. 124).

On maps such as the one in Figure 6-20, biomes are presented as **(1)** having sharp boundaries and **(2)** being covered with the same general type of vegetation. In reality, most biomes do not have sharp boundaries and blend into one another in transitional zones, or *ecotones* (Figure 4-10, p. 71). Also, the types and numbers of plants in a biome vary from one location to another because of variations in **(1)** local climate (microclimates), **(2)** soil types, and **(3)** natural and human-caused disturbances (Figure 1-5, p. 7). As a result, *biomes are not uniform.* They consist of a *mosaic of patches,* all with somewhat different biological communities but with similarities unique to the biome.

Figure 6-22 (p. 124) shows how climate and vegetation vary with **latitude** (distance from the equator) and **altitude** (elevation above sea level). If you travel from the equator toward either pole, you will generally encounter colder climates and zones of vegetation

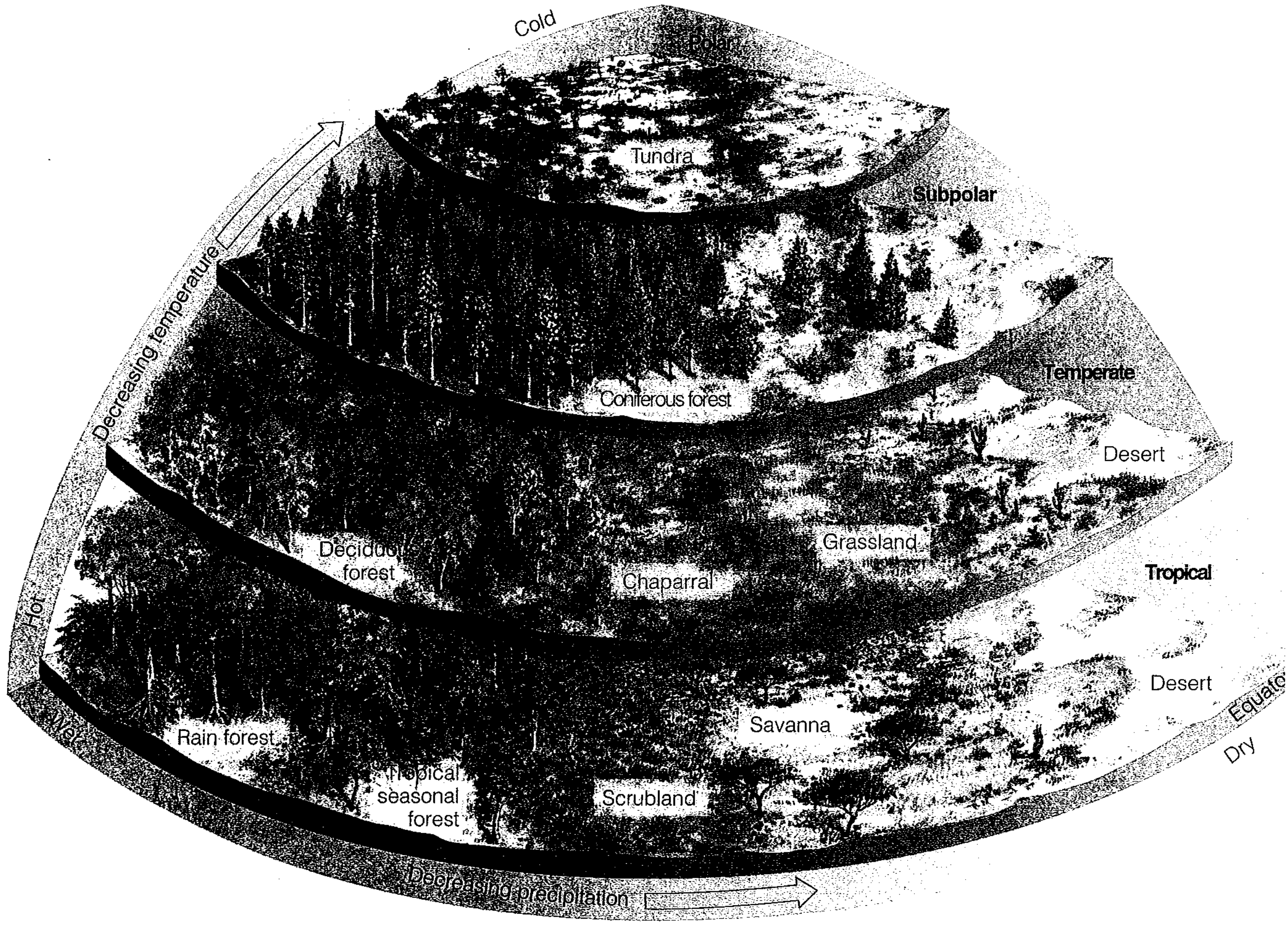


Figure 6-21 Average precipitation and average temperature, acting together as limiting factors over a period of 30 or more years, determine the type of desert, grassland, or forest biome in a particular area. Although the actual situation is much more complex, this simplified diagram explains how climate determines the types and amounts of natural vegetation found in an area left undisturbed by human activities. (Used by permission of Macmillan Publishing Company, from Derek Elsom, *The Earth*, New York: Macmillan, 1992. Copyright © 1992 by Marshall Editions Developments Limited)

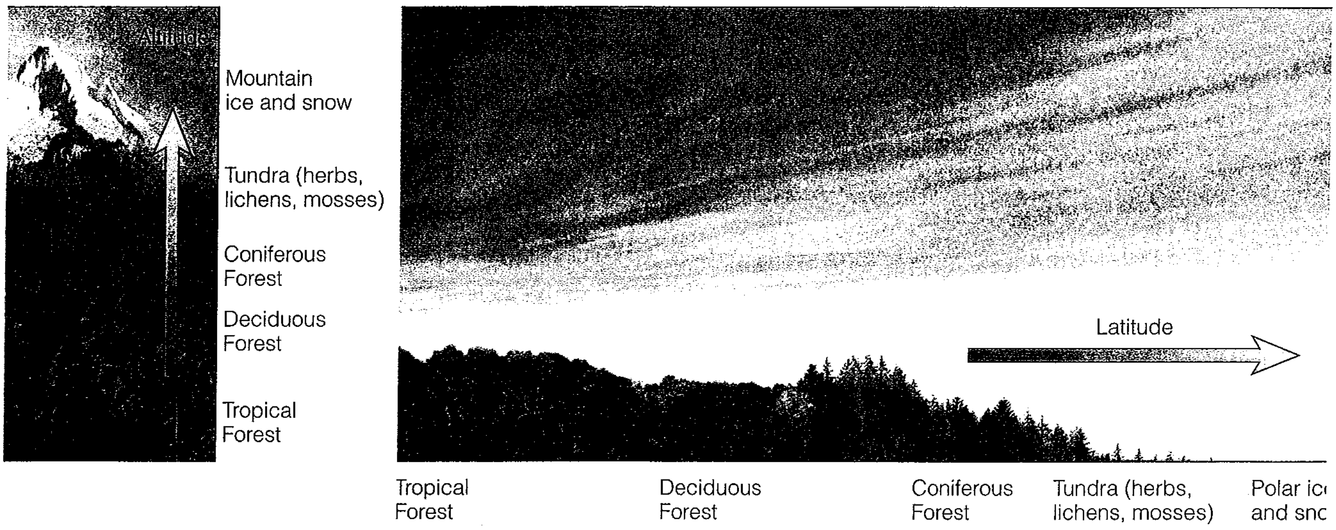


Figure 6-22 Generalized effects of altitude (left) and latitude (right) on climate and biomes. Parallel changes in vegetation type occur when we travel from the equator to the poles or from lowlands to mountaintops.

adapted to those climates (Figure 6-22, right). Similarly, as elevation above sea level increases, climate becomes colder (Figure 6-22, left). Thus, if you climb a tall mountain from its base to its summit, you can observe changes in plant life similar to those you would encounter in traveling from the equator to the earth's poles (Figure 6-22).

Why Do Plant Sizes, Shapes, and Survival Strategies Differ? Arctic soils are wet and nutrient rich. So why are there no trees in the Arctic, and why are the plants there so close to the ground? Why are there no leaves on desert plants such as cacti? Why do trees in most forests found in both the warm tropics and in cold areas such as Canada and Sweden keep their leaves year round, whereas most trees in temperate forests lose their leaves in winter?

The answers to these questions involve evolutionary responses of plants to different climates.

- Plants exposed to cold air year round or during winter have traits that keep them from losing too much heat and water. For example, trees or tall plants cannot survive in the cold, windy arctic grasslands (tundra) because they would lose too much of their heat.
- Desert plants exposed to the sun all day long must **(1)** be able to lose enough heat so they do not overheat and die and **(2)** conserve enough water for survival. **Succulent** (fleshy) **plants,** such as the saguaro ("sah-WAH-row") cactus, survive in dry climates by **(1)** having no leaves, **(2)** storing water and synthesizing food in their expandable, fleshy tissue, and **(3)** reducing water loss by opening their pores (stomata) to take up carbon dioxide (CO_2) only at night.
- Trees of wet tropical rain forests tend to be **broadleaf evergreen plants,** which keep most of their broad leaves year round. The large surface area of the leaves allows them to **(1)** collect ample sunlight for photosynthesis and **(2)** radiate heat during hot weather.
- In a climate with a cold (and sometimes dry) winter, keeping such leaves would cause plants to lose too much heat and water for survival. In such climates, **broadleaf deciduous plants,** such as oak and maple trees, survive drought and cold by shedding their leaves and becoming dormant during such periods.
- If we move further north to areas such as Canada and Sweden, where summers are cool and short, this strategy is less successful. Instead evolution has favored **coniferous** (cone-bearing) **evergreen plants** (such as spruces, pines, and firs). These plants keep some of their narrow-pointed leaves (needles) all year. The waxy coating, shape, and clustering of conifer needles slow down heat loss and evaporation during the long, cold winter. Additionally, by keeping their leaves all winter, such trees are ready to take advantage of the brief summer without having to take time to grow new needles.

6-4 DESERT BIOMES

What Are the Major Types of Deserts? A **desert** is an area where evaporation exceeds precipitation. Precipitation typically is **(1)** less than 25 centimeters (10 inches) a year and **(2)** often scattered unevenly throughout the year. Deserts have sparse, widely spaced, mostly low vegetation.

Deserts cover about 30% of the earth's land and are situated mainly between tropical and subtropical regions north and south of the equator, at about 30° north and 30° south latitude (Figure 6-23, p. 126). The largest deserts are in the interiors of continents, far from moist sea air and moisture-bearing winds. Other, more local deserts form on the downwind sides of mountain ranges because of the rain shadow effect (Figure 6-18).

The baking sun warms the ground in the desert during the day. At night, however, most of the heat stored in the ground radiates quickly into the atmosphere because desert soils have little vegetation and moisture to help store the heat and the skies usually are 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 6-21 and 6-24, p. 126).

- In *tropical deserts,* such as the southern Sahara in Africa, **(1)** temperatures usually are high year round and **(2)** there is little rain, which typically falls during only 1 or 2 months of the year (Figure 6-24, left, p. 126). These driest places on earth typically have few plants and a hard, windblown surface strewn with rocks and some sand.
- In *temperate deserts,* such as the Mojave in southern California, **(1)** daytime temperatures are high in summer and low in winter and **(2)** there is more precipitation than in tropical deserts (Figure 6-24, center). The vegetation is sparse, consisting mostly of widely dispersed, drought-resistant shrubs and cacti or other succulents, and animals are adapted to the lack of water and temperature variations (Figure 6-25, p. 127).
- In *cold deserts,* such as the Gobi Desert in China, **(1)** winters are cold, **(2)** summers are warm or hot, and **(3)** precipitation is low (Figure 6-24, right).

In the semiarid zones between deserts and grasslands, we find *semidesert.* This biome is dominated by thorn trees and shrubs adapted to a long dry spells followed by brief, sometimes heavy rains.

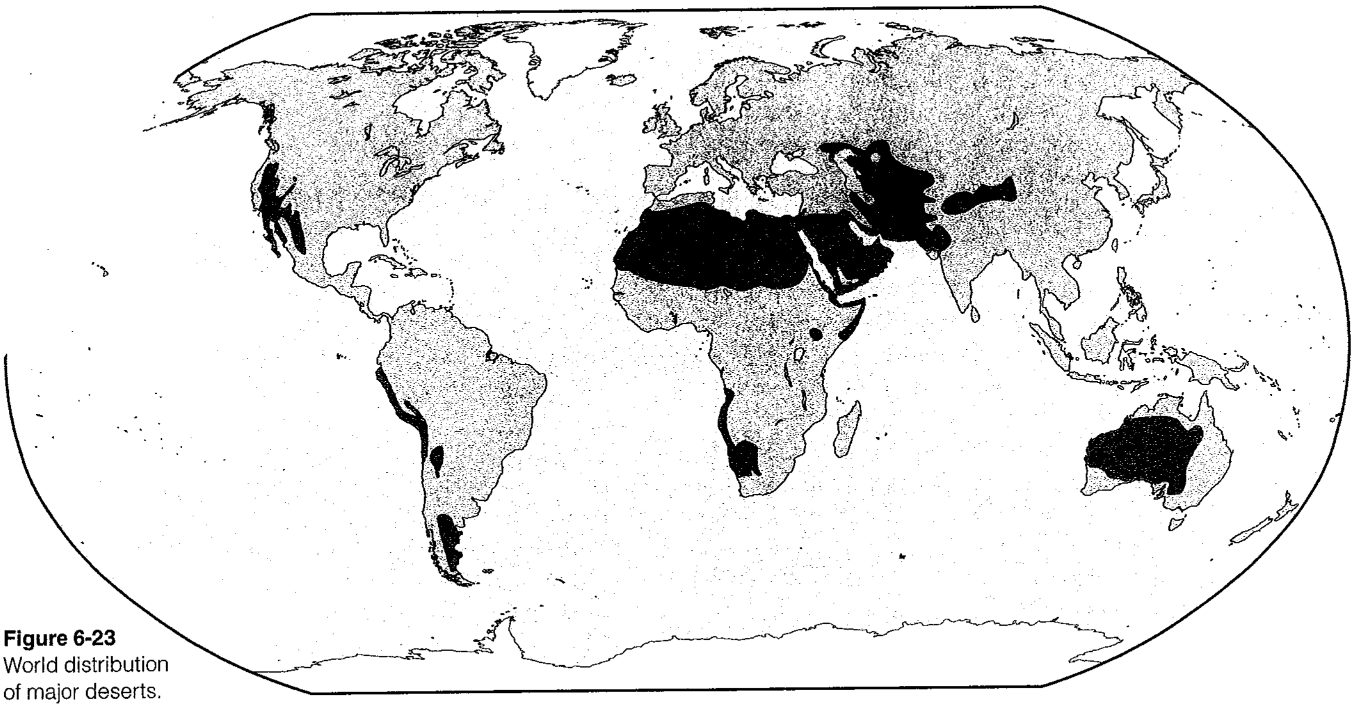


Figure 6-23
World distribution of major deserts.

How Do Desert Plants and Animals Survive?

Adaptations for survival in the desert have two themes: *Beat the heat* and *Every drop of water counts.* These adaptations include:

- Having wax-coated leaves that minimize transpiration (evergreens such as the creosote bush)
- Using deep roots to tap into groundwater
- Using widely spread, shallow roots to collect water after brief showers and store it in their spongy tissue (prickly pear, Figure 6-25, and saguaro cacti)
- Dropping their leaves to survive in a dormant state during long drying spells (mesquite and creosote plants)
- Becoming dormant during dry periods (mosses and lichens)
- Storing much of their biomass in seeds during dry periods and remaining inactive (sometimes for years) until they receive enough water to germinate (annual wildflowers and grasses). Shortly after a rain the seeds **(1)** germinate, **(2)** grow, **(3)** carpet such deserts

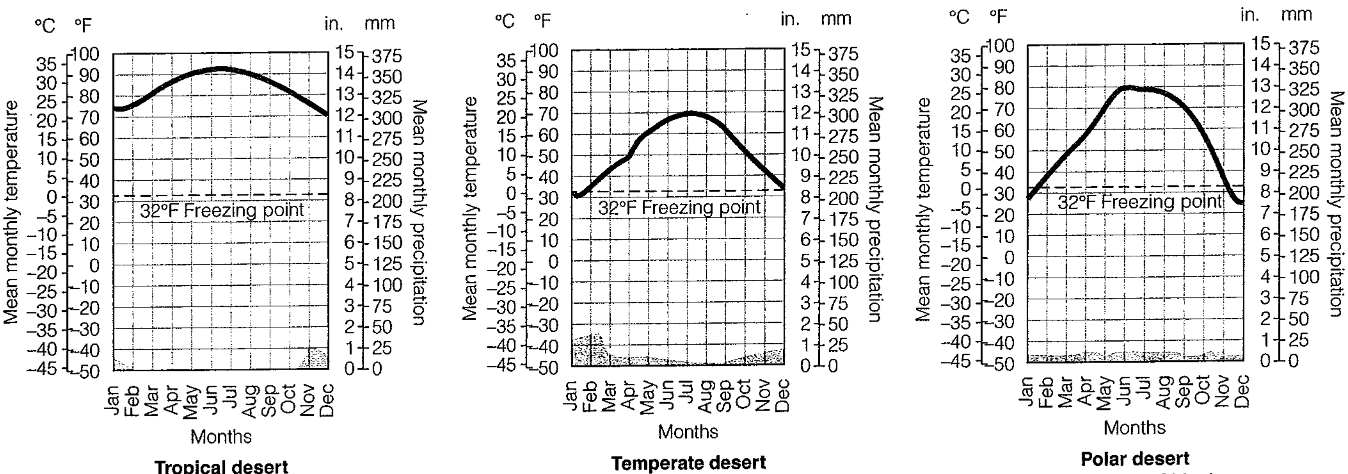


Figure 6-24 Climate graphs showing typical variations in annual temperature and precipitation in tropical, temperate, and polar (cold) deserts.

Figure 6-25 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.

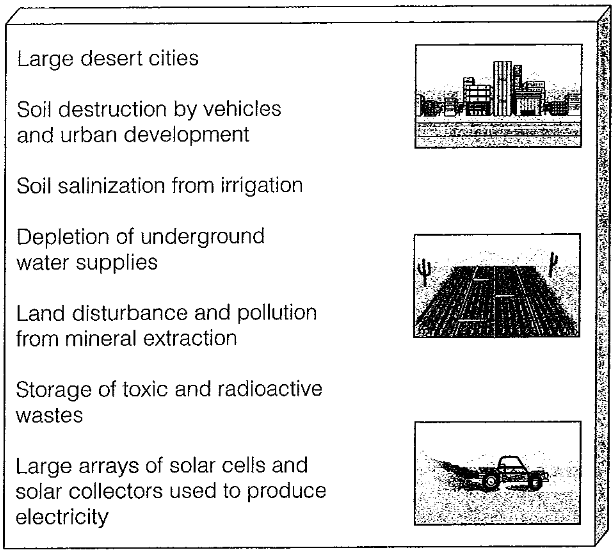


Figure 6-26 Major human impacts on the world's deserts.

with a dazzling array of colorful flowers, **(4)** produce new seed, and **(5)** die, all in only a few weeks.

Most desert animals are small and beat the heat and reduce water loss by evaporative cooling by

- Hiding in cool burrows or rocky crevices by day and coming out at night or in the early morning.
- Having physical adaptations for conserving water. Insects and reptiles **(1)** have thick outer coverings to minimize water loss through evaporation and **(2)** reduce water loss by having dry feces and excreting a dried concentrate of urine.
- Getting their water from dew or from the food they eat (many spiders and insects). Arabian oryxes survive by licking the dew that accumulates at night on rocks and on one another's hair.
- Becoming dormant during periods of extreme heat or drought.

Figure 6-26 shows major human impacts on deserts. Deserts take a long time to recover from disturbances because of their **(1)** slow plant growth, **(2)** low species diversity, **(3)** slow nutrient cycling (because of little bacterial activity in their soils), and **(4)** water shortages. Desert vegetation destroyed by livestock overgrazing and off-road vehicles may take decades to grow back.

6-5 GRASSLAND, TUNDRA, AND CHAPARRAL BIOMES

What Are the Major Types of Grasslands? **Grasslands** are regions with enough average annual precipitation to allow grass (and in some areas, a few trees) to prosper but with precipitation so erratic that drought and fire prevent large stands of trees from growing. Most grasslands are found in the interiors of continents (Figure 6-27).

Grasslands persist because of a combination of **(1)** seasonal drought, **(2)** grazing by large herbivores, and **(3)** occasional fires, all of which keep large numbers of shrubs and trees from invading and becoming established. If not overgrazed by large herbivores, grasses in these biomes are renewable resources because these plants grow out from the bottom. This allows their stems to grow again after being nibbled off by grazing animals.

The three main types of grasslands—tropical, temperate, and polar (tundra)—result from combinations of low average precipitation and various average temperatures (Figures 6-21 and 6-28).

What Are Tropical Grasslands and Savannas? *Tropical grasslands* are found in areas with **(1)** high average temperatures, **(2)** low to moderate precipitation, and **(3)** a prolonged dry season. They occur in a wide belt on either side of the equator beyond the borders of tropical rain forests (Figure 6-27).

One type of tropical grassland, called a *savanna,* usually has **(1)** warm temperatures year round, **(2)** two prolonged dry seasons, and **(3)** abundant rain the rest of the year (Figure 6-28, left). The largest savannas are in central and southern Africa, but they are also found in central South America, Australia, and Southeast Asia (Figure 6-27).

African tropical savannas contain enormous herds of **(1)** *grazing* (grass- and herb-eating) and **(2)** *browsing* (twig- and leaf-nibbling) hoofed animals, including wildebeests, gazelles, zebras, giraffes, and antelopes (Figure 6-29, p. 130). These and other large herbivores have evolved specialized eating habits that minimize competition between species for vegetation. For example, **(1)** giraffes eat leaves and shoots from the tops of trees, **(2)** elephants eat leaves and branches further down, **(3)** Thompson's gazelles and wildebeests prefer short grass, and **(4)** zebras graze on longer grass and stems.

During the dry season, wildebeest and other large grazing animals migrate to find enough water and high-quality grasses, and smaller animals become dormant or survive by eating plant seeds. Predators such as cheetahs, lions, hyenas, eagles, and hawks prey on the large grazing animals (and many small ones). Many large savanna animal species are killed for their economically valuable coats and parts (tigers), tusks (rhinoceroses), and ivory tusks (elephants).

What Are Temperate Grasslands? *Temperate grasslands* cover vast expanses of plains and gently rolling hills in the interiors of North and South America, Europe, and Asia (Figure 6-27). In these grass

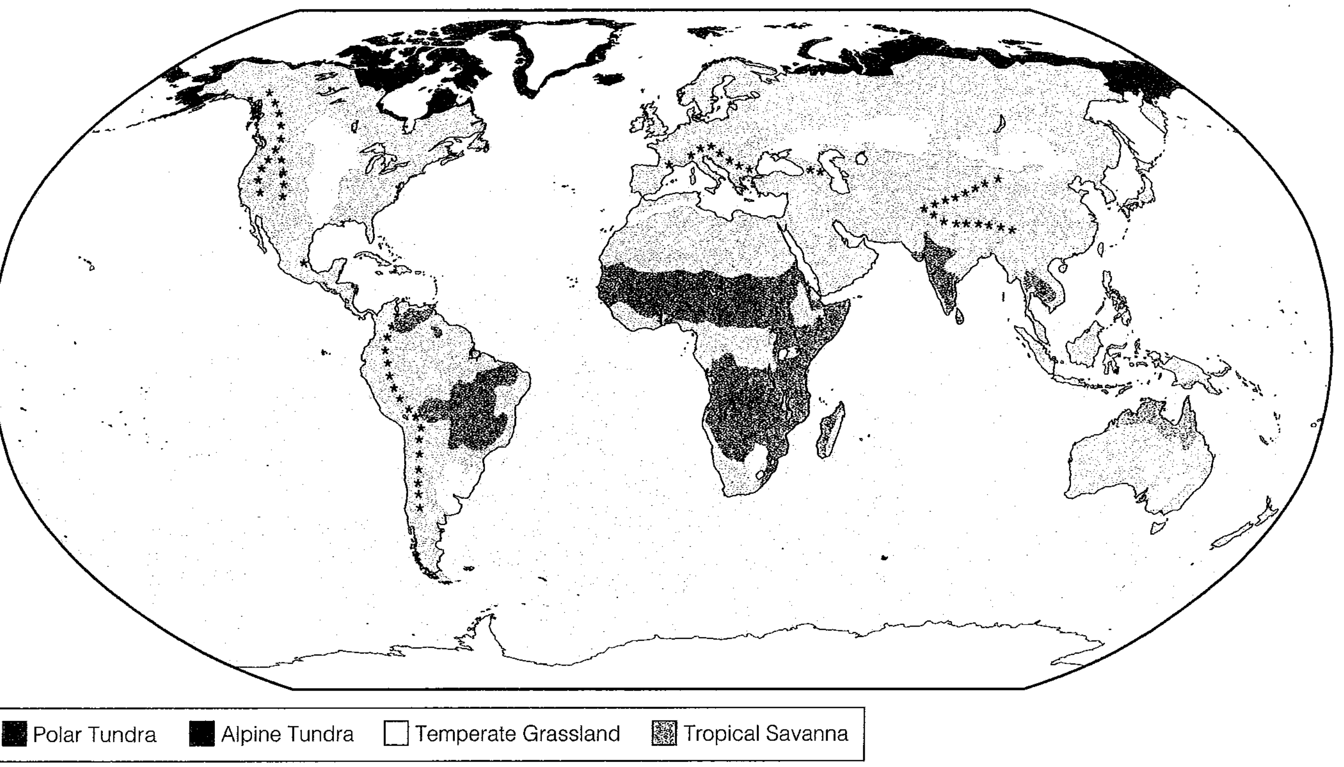


Figure 6-27 World distribution of major grasslands.

lands, **(1)** winters are bitterly cold, **(2)** summers are hot and dry, and **(3)** annual precipitation is fairly sparse and falls unevenly through the year (Figure 6-28, center).

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 and allowed to blow away by prolonged exposure to high winds found in these biomes.

Types of temperate grasslands are the **(1)** *tall-grass prairies* (Figure 6-30, p. 131) and *short-grass prairies* of the midwestern and western United States and Canada,

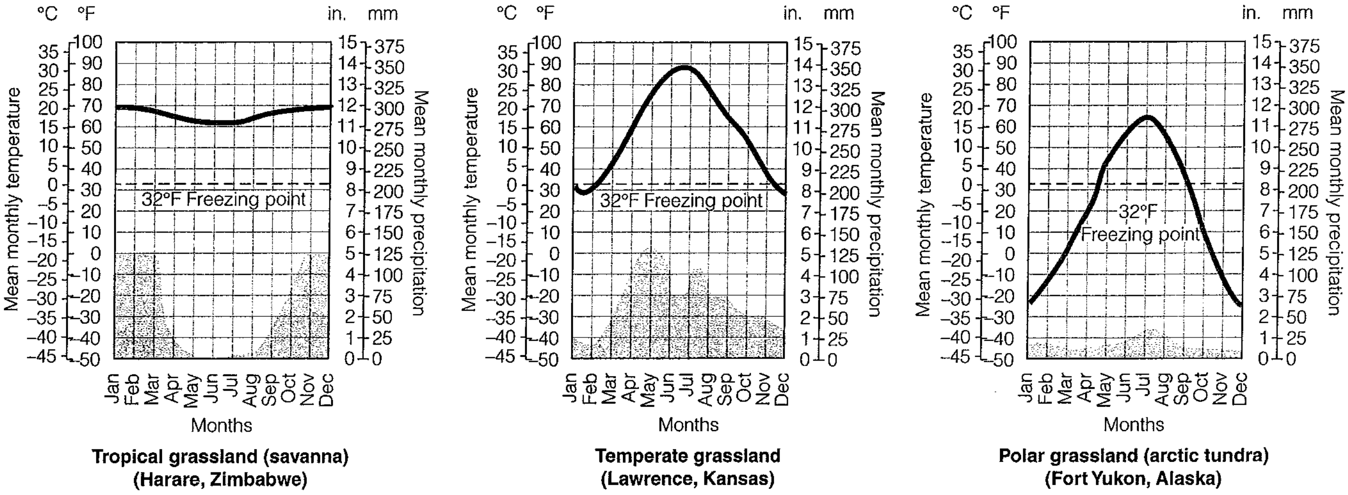


Figure 6-28 Climate graphs showing typical variations in annual temperature and precipitation in tropical, temperate, and polar (arctic tundra) grasslands.

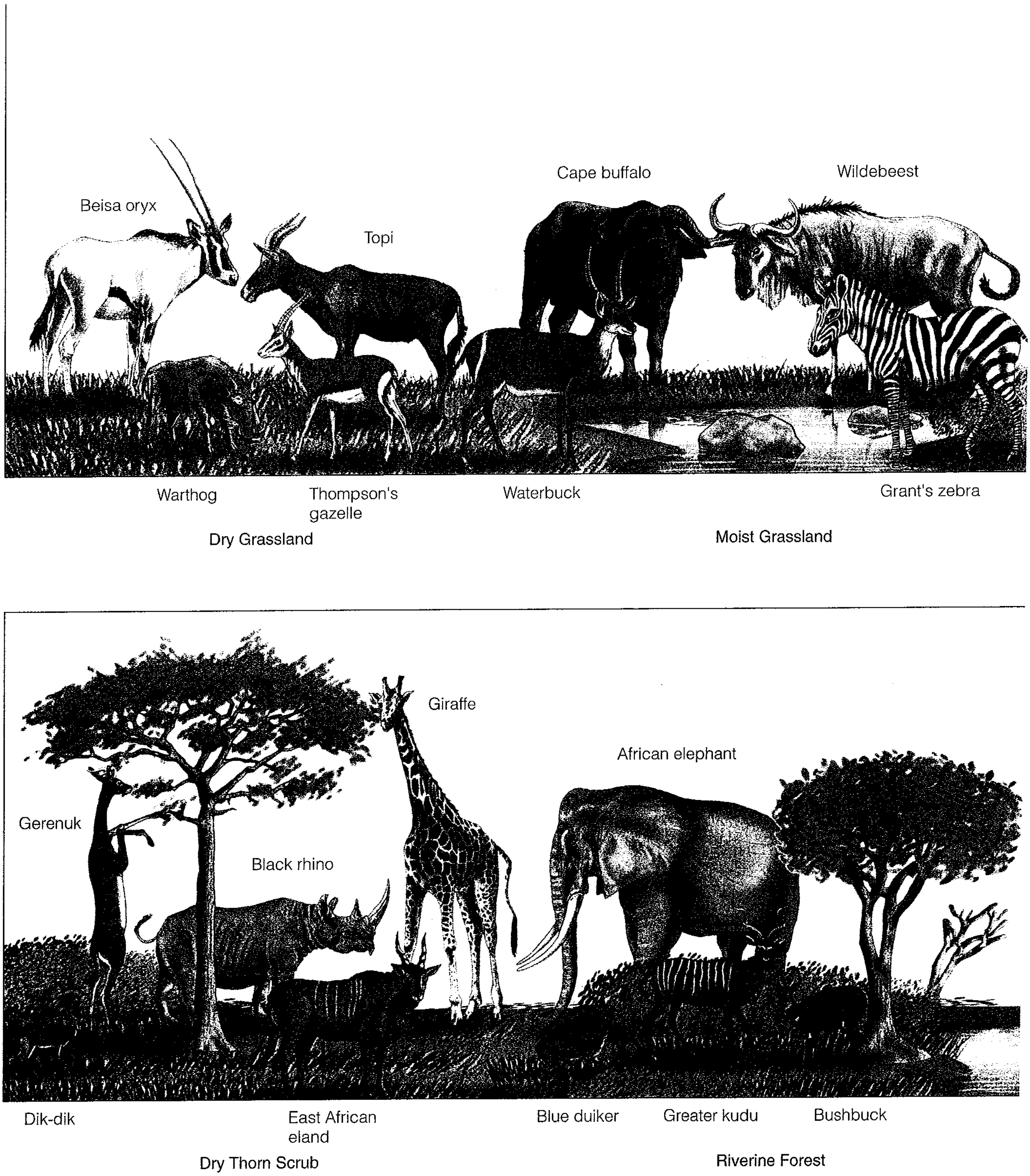


Figure 6-29 Some of the grazing animals found in different parts of the African savanna. These species share vegetation resources by having different feeding niches.

Producer to primary consumer

Primary to secondary consumer

Secondary to higher-level consumer

All producers and consumers to decomposers

Figure 6-30 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 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.

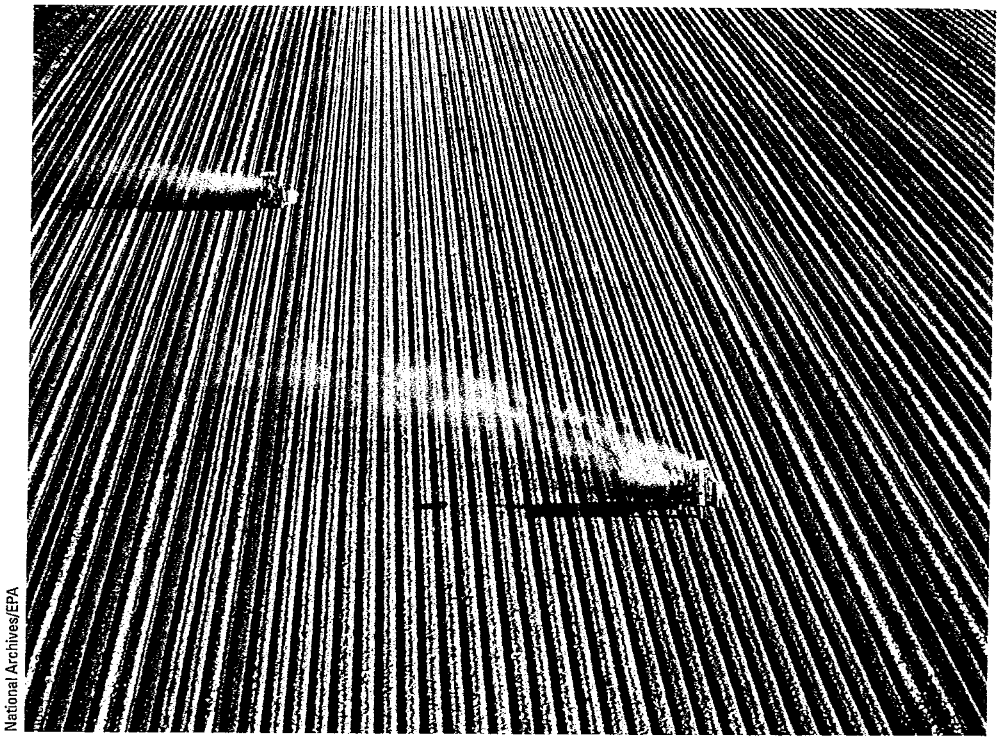


Figure 6-31 Replacement of a temperate grassland with a monoculture crop in California. When the tangled root network of natural grasses is removed, the fertile topsoil is subject to severe wind erosion unless it is covered with some type of vegetation.

(2) South American *pampas,* **(3)** African *veldt,* and **(4)** *steppes* of central Europe and Asia. Here winds blow almost continuously, and evaporation is rapid, often leading to fires in the summer and fall.

Because of their thick and fertile soils, temperate grasslands are plowed up and widely used to grow crops (Figure 6-31). However, plowing breaks up the soil and leaves it vulnerable to erosion by wind and water.

What Are Polar Grasslands? *Polar grasslands,* or *arctic tundra,* occur just south of the arctic polar ice cap (Figure 6-27). During most of the year these treeless plains are **(1)** bitterly cold, **(2)** swept by frigid winds, and **(3)** covered with ice and snow (Figure 6-28, right). Winters are long and dark, and the scant precipitation falls mostly as snow.

This biome is carpeted with a thick, spongy mat of low-growing plants, primarily grasses, mosses, and dwarf woody shrubs (Figure 6-32). Most of the annual growth of these plants occurs during the 6- to 8-week summer, when sunlight shines almost around the clock.

To retain water and survive the winter cold, most tundra plants grow close to the ground, and some have leathery evergreen leaves coated by waxes that reduce heat loss. Other plants survive the long, cold winter underground as roots, stems, bulbs, and tubers; some, such as lichens, dehydrate during winter to avoid frost damage.

One effect of the extreme cold is **permafrost,** a perennially frozen layer of the soil that forms when the water there freezes. In summer, water near the surface thaws, but the permafrost soil layer below stays frozen and prevents liquid water at the surface from seeping into the ground. Thus, during the brief summer, the soil above the permafrost layer remains waterlogged, forming a large number of shallow lakes, marshes, bogs, ponds, and other seasonal wetlands. Hordes of mosquitoes, blackflies, and other insects thrive in these shallow surface pools. They feed large colonies of migratory birds (especially waterfowl) that return from the south to nest and breed in the bogs and ponds.

In North American arctic tundra, caribou herds arrive to feed on the summer vegetation, bringing with them their wolf predators. In arctic tundra in Europe and Asia, reindeer occupy the grazing niche of caribou.

The arctic tundra's permanent animal residents are mostly small herbivores such as lemmings, hares, voles, and ground squirrels that burrow underground to escape the cold. Predators such as the lynx, weasel, snowy owl, and arctic fox (Figure 5-8, p. 105) eat them. Most tundra animals do not hibernate because the summer is too short for them to accumulate adequate fat reserves. Animals in this biome survive the intense winter cold through adaptations such as **(1)** thick coats of fur (arctic wolf, arctic fox, and musk oxen), **(2)** feathers (snowy owl), **(3)** compact bodies to expose as little

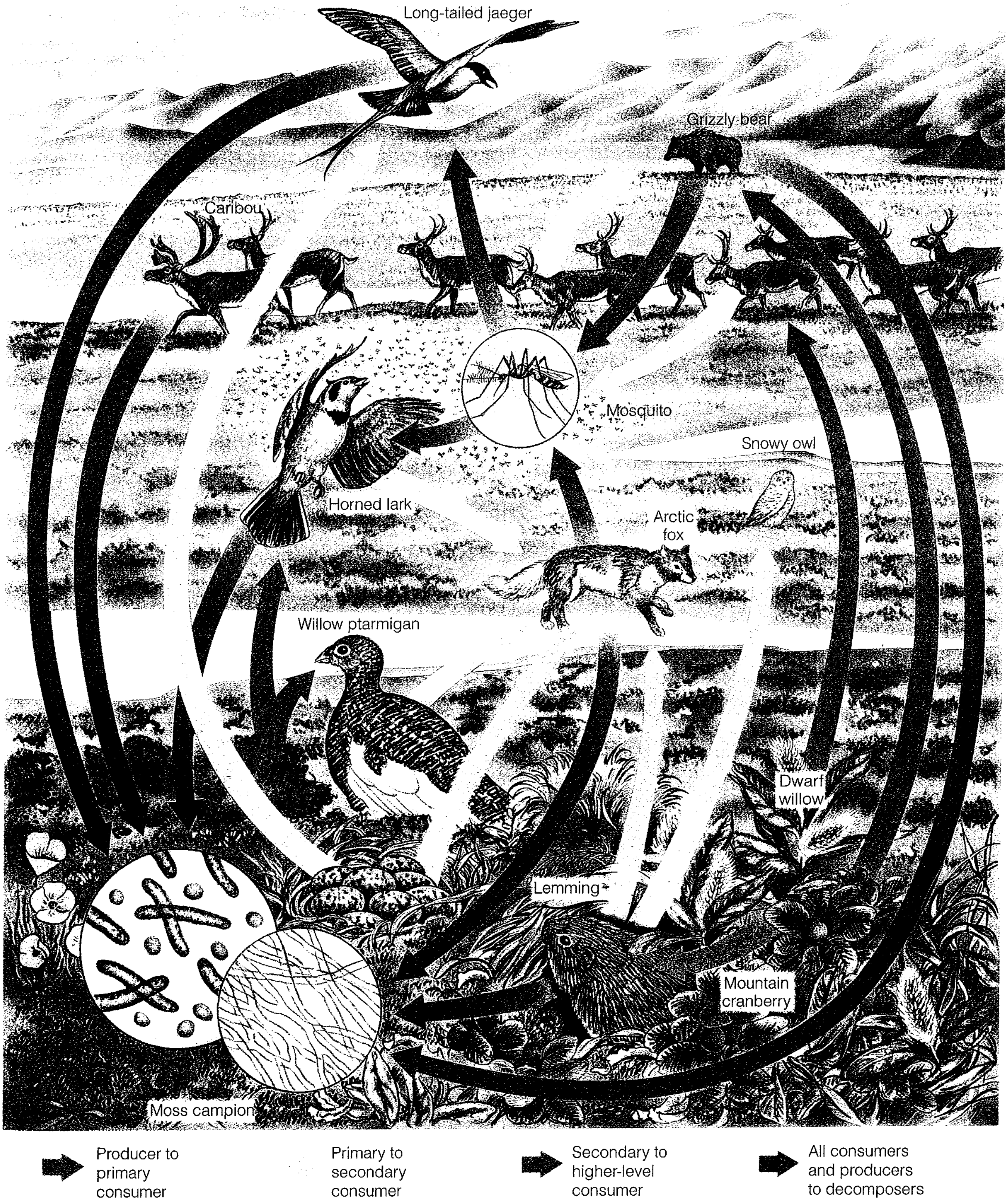
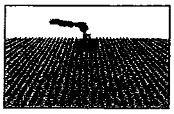


Figure 6-32 Some components and interactions in an *arctic tundra (polar grassland) ecosystem*. When these organisms die, decomposers break down their organic matter into minerals that plants use. Colored arrows indicate transfers of matter and energy between producers, primary consumers (herbivores), secondary (or higher-level) consumers (carnivores), and decomposers. Organisms are not drawn to scale.

Conversion of savanna and temperate grassland to cropland



Release of CO_2 to atmosphere from burning and conversion of grassland to cropland

Overgrazing of tropical and temperate grasslands by livestock

Damage to fragile arctic tundra by oil production, air and water pollution, and vehicles

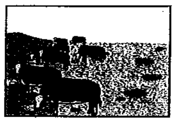


Figure 6-33 Major human impacts on the world's grasslands.

surface as possible to the air, and **(4)** living underground (arctic lemming).

Because of the cold, decomposition is slow. Because of low decomposer populations, the soil is poor in organic matter and in nitrates, phosphates, and other minerals.

What Is Alpine Tundra? Another type of tundra, called *alpine tundra,* occurs above the limit of tree growth but below the permanent snow line on high mountains (Figures 6-22, left, and 6-27). The vegetation there is similar to that found in arctic tundra, but it gets more sunlight than arctic vegetation and has no permafrost layer.

Figure 6-33 lists major human impacts on grasslands.

What Is Chaparral? Some temperate areas have a biome known as *temperate shrubland* or *chaparral.* This biome occurs along coastal areas with what is called a *Mediterranean climate:* winters are mild and moderately rainy, and summers are long, hot, and dry. It is found mainly along **(1)** parts of the Pacific coast of North America, **(2)** in southern Texas and northeastern Mexico, and **(3)** in the coastal hills of Chile, the Mediterranean, southwestern Africa, and southwestern Australia (Figure 6-20).

This biome usually is dominated by a dense growth of low-growing evergreen shrubs with leathery leaves that resist water loss and have large underground root systems. Some areas also have a sprinkling of small drought-resistant trees such as pines and scrub oak.

During the long, hot dry season, chaparral vegetation is dormant and becomes very dry and brittle. In the fall, fires started by lightning or human activities spread with incredible swiftness through the dry brush and litter of leaves and fallen branches.

Research reveals that chaparral is adapted to and maintained by periodic fires. Many of the shrubs **(1)** store food reserves in their fire-resistant roots and **(2)** have seeds that sprout only after a hot fire. With the first rain, annual grasses and wildflowers spring up and use nutrients released by the fire. New shrubs grow quickly and crowd out the grasses.

People like living in this biome because of its favorable climate. However, those living in chaparral assume the high risk of losing their homes (and possibly their lives) to the frequent fires associated with it. After fires often comes the hazard of flooding; when heavy rains come, great torrents of water pour off the unprotected burned hillsides to flood lowland areas.

6-6 FOREST BIOMES

What Are the Major Types of Forests? Undisturbed areas with moderate to high average annual precipitation tend to be covered with **forest,** which contains various species of trees and smaller forms of vegetation. The three main types of forest—*tropical, temperate,* and *boreal* (polar)—result from combinations of this precipitation level and various average temperatures (Figures 6-21 and 6-36, p. 136).

What Are Tropical Rain Forests? *Tropical rain forests* are a type of broadleaf evergreen forest (Figure 6-34) found near the equator (Figure 6-35, p. 136), where hot, moisture-laden air rises and dumps its moisture (Figure 6-11). These forests have **(1)** a warm annual mean temperature (which varies little, daily or seasonally), **(2)** high humidity, and **(3)** heavy rainfall almost daily (Figure 6-36, left, p. 136).

Tropical rain forests have incredible biological diversity. These diverse forms of life occupy a variety of specialized niches in distinct layers, based mostly on their need for sunlight (Figure 6-37, p. 137). 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 (Figure 6-37). To study life in the canopy, ecologists climb trees and build platforms and boardwalks in the upper canopy.

The stratification of specialized plant and animal niches in various layers of a tropical rain forest enables coexistence of a great variety of species (biodiversity). Although tropical rain forests cover only about 2% of the earth's land surface, they are habitats for 50–80% of the earth's terrestrial species.

Figure 6-34 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.

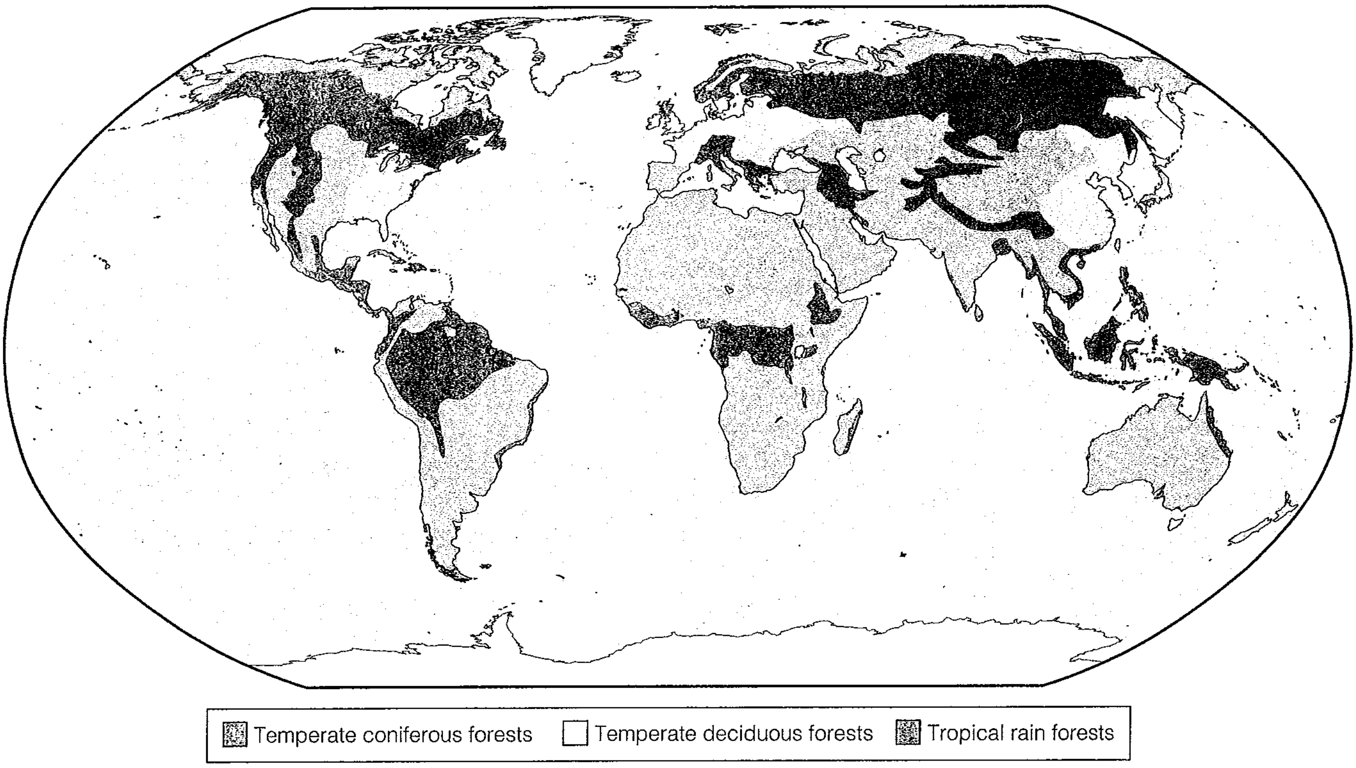


Figure 6-35 World distribution of major forests.

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 is why little litter is found on the ground. Instead of being stored in the soil, most minerals released by decomposition are taken up quickly by plants. Thus most of a tropical rain forest's nutrients are stored in the biomass of its living organisms.

Because of the dense vegetation, little wind blows in tropical rain forests, eliminating the possibility of wind pollination. Many of the plants have evolved

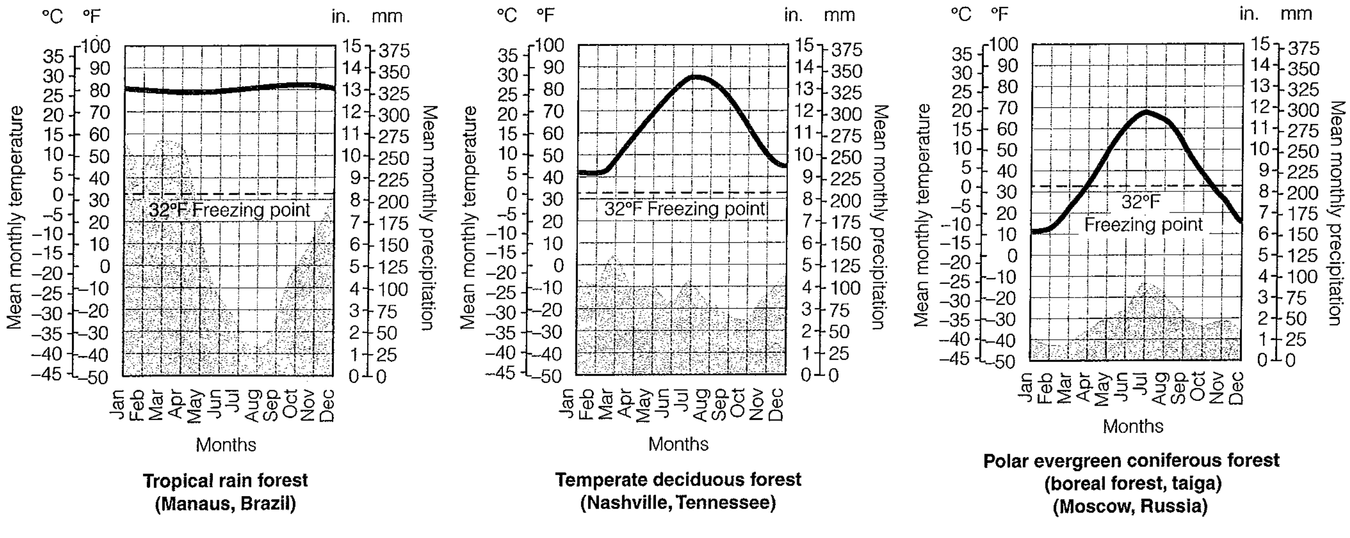


Figure 6-36 Climate graphs showing typical variations in annual temperature and precipitation in tropical, temperate, and polar forests.

Figure 6-37 Stratification of specialized plant and animal niches in various layers of a *tropical rain forest.* The presence of these specialized niches enables species to avoid or minimize competition for resources and results in the coexistence of a great variety of species (biodiversity).

elaborate flowers (Figure 4-17, right, p. 76) that attract particular insects, birds, or bats as pollinators.

What Are Tropical Deciduous Forests? Moving a little farther from the equator (Figure 6-20), we find *tropical deciduous forests* (sometimes called *tropical monsoon forests* or *tropical seasonal forests*). These forests are **(1)** warm year round and **(2)** get most of their plentiful rainfall during a wet (monsoon) season that is followed by a long dry season.

Tropical deciduous forests have a lower canopy than tropical rain forests. They contain a mixture of **(1)** deciduous trees (which lose their leaves to survive the dry season) and **(2)** drought-tolerant evergreen trees (which retain most of their leaves year round). Where the dry season is especially long, we find *tropical scrub forests* (Figure 6-20) containing mostly small deciduous trees and shrubs.

What Are Temperate Deciduous Forests? *Temperate deciduous forests* (Figures 6-35 and 6-38, p. 138) grow in areas with moderate average temperatures that change significantly with the season (Figure 6-36, center). These areas have **(1)** long, warm summers, **(2)** cold but not too severe winters, and **(3)** abundant precipitation, often spread fairly evenly throughout the year.

This biome is dominated by a few species of broadleaf deciduous trees such as oak, hickory, maple, poplar, and sycamore. They survive cold winters by dropping their leaves in the fall and becoming dormant. Each spring they grow new leaves that change in the fall into an array of reds and golds before dropping.

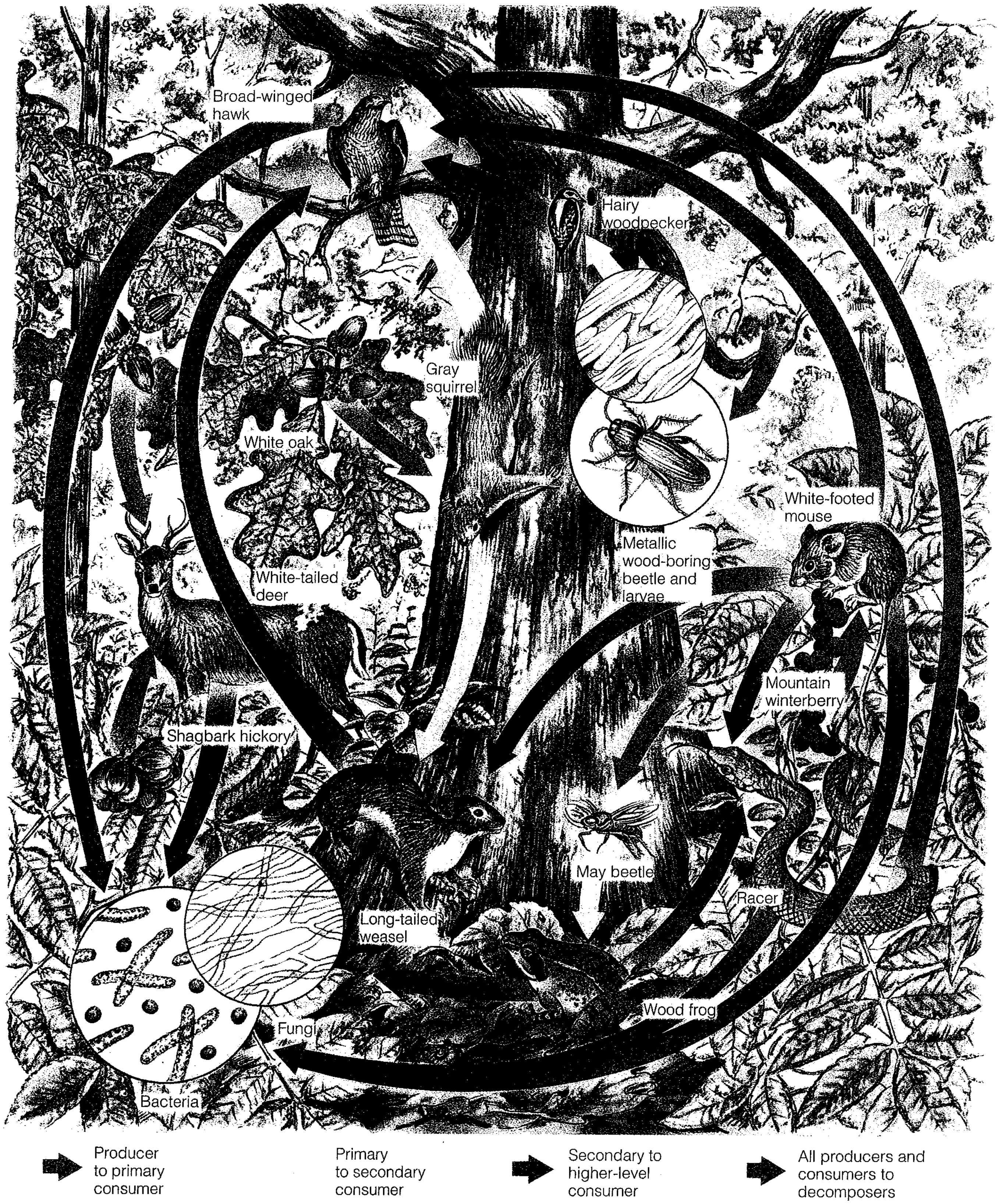
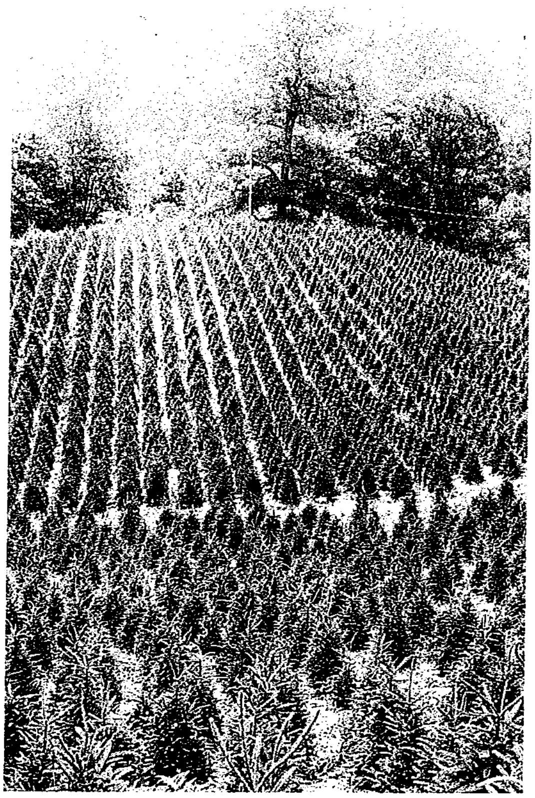


Figure 6-38 Some components and interactions in a *temperate deciduous forest ecosystem.* When these organisms die, decomposers break down their organic matter into minerals that plants use. Colored arrows indicate transfers of matter and energy between producers, primary consumers (herbivores), secondary (or higher-level) consumers (carnivores), and decomposers. Organisms are not drawn to scale.

Compared with tropical rain forests, temperate deciduous forests have a simpler structure and contain fewer tree species. However, the penetration of more sunlight supports a richer diversity of plant life at ground level. Because of the fairly low rate of decomposition, these forests accumulate a thick layer of slowly decaying leaf litter that is a storehouse of nutrients.

The temperate deciduous forests of the eastern United States were once home for such large predators as bears, wolves, foxes, wildcats, and mountain lions (pumas). Today most of the predators have been killed or displaced, and the dominant mammal species often is the white-tailed deer, along with smaller mammals such as squirrels, rabbits, opossums, raccoons, and mice. Some of these diverse forests have been cleared and replaced with *tree plantations* consisting of a single tree species (Figure 6-39).

Warblers, robins, and other bird species migrate to these forests during the summer to feed and breed. Many of these species are declining in numbers because of loss or fragmentation of their summer and winter habitats, which also makes them more vulnerable to predators and parasitic cowbirds. Small mammals and birds are preyed on by owls, hawks, and, in remote areas, bobcats and foxes.



Gene Alexander/USDA

Figure 6-39 *Tree plantation* in North Carolina. Some diverse virgin (old-growth) and second-growth forests are cleared and replanted with a single tree species (monoculture), often for harvest as Christmas trees, timber, or wood converted to pulp to make paper.

What Are Evergreen Coniferous Forests? *Evergreen coniferous forests,* also called *boreal forests* and *taigas* (pronounced TIE-guhs), are found just south of the arctic tundra in northern regions across North America, Asia, and Europe (Figures 6-20 and 6-35). In this subarctic climate, winters are long, dry, and extremely cold; in the northernmost taiga, sunlight is available only 6–8 hours a day. Summers are short, with mild to warm temperatures (Figure 6-36, right), and the sun typically shines 19 hours a day.

Most boreal forests are dominated by a few species of coniferous (cone-bearing) evergreen trees such as spruce, fir, cedar, hemlock, and pine that keep some of their narrow-pointed leaves (needles) all year long. The small, needle-shaped, waxy-coated leaves of these trees **(1)** can withstand the intense cold and drought of winter when snow blankets the ground and **(2)** are ready to take advantage of the brief summers in these areas without having to take time to grow new needles. Plant diversity is low in these forests 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 and leaf litter. Decomposition is slow because of the **(1)** low temperatures, **(2)** waxy coating of conifer needles, and **(3)** high soil acidity. As the conifer needles decompose, they 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 (Figure 6-40, p. 140). During the brief summer the soil becomes waterlogged, forming acidic bogs, or *muskegs,* in low-lying areas of these forests. Warblers and other insect-eating birds feed on hordes of flies, mosquitoes, and caterpillars.

What Are Temperate Rain Forests? *Coastal coniferous forests* or *temperate rain forests* 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 dominate undisturbed areas of biomes along the coast of North America, from Canada to northern California.

The ocean moderates the temperature so winters are mild and summers are cool. The trees in these moist forests depend on frequent rains and moisture from summer fog that rolls in off the Pacific.

Figure 6-41 (p. 141) lists major human impacts on the world's forests.

Producer to primary consumer — Primary to secondary consumer — Secondary to higher-level consumer — All producers and consumers to decomposers

Figure 6-40 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.

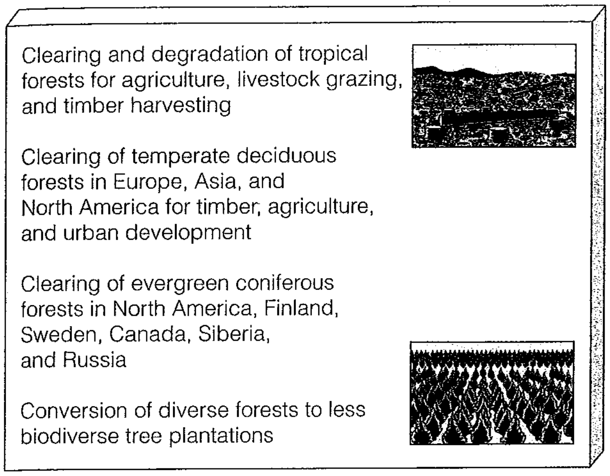


Figure 6-41 Major human impacts on the world's forests.

6-7 MOUNTAIN BIOMES

Why Are Mountains Ecologically Important? Some of the world's most spectacular and important environments are mountains, which make up about 20% of the earth's land surface. Mountains are places where dramatic changes in altitude, climate, soil, and vegetation take place over a very short distance (Figure 6-22, left). Above a certain altitude, known as the *snow line,* temperatures are so cold that the mountain is almost permanently covered by snow and ice (except in places too steep for snow to stick).

Because of the steep slopes, mountain soils are especially prone to erosion when the vegetation holding them in place is removed by **(1)** natural disturbances (such as landslides and avalanches) or **(2)** human activities (such as timber cutting and agriculture).

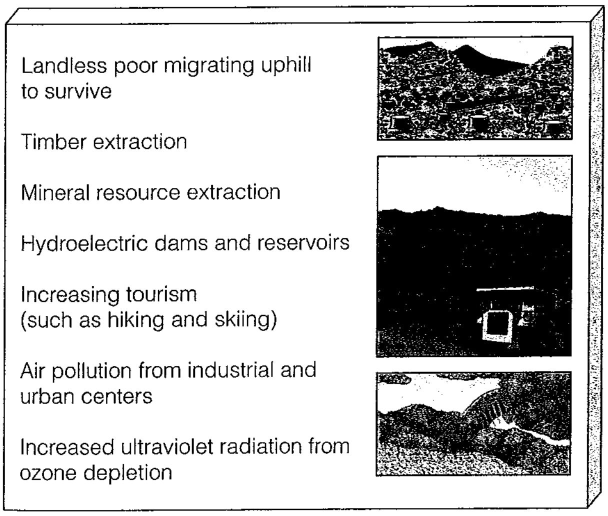


Figure 6-42 Major human impacts on the world's mountains.

Many freestanding mountains are *islands of biodiversity* surrounded by a sea of lower elevation landscapes transformed by human activities. Mountains play a number of important ecological roles by:

- Containing the majority of the world's forests, which are habitats for much of the world's terrestrial biodiversity.
- Often containing endemic species found nowhere else on earth.
- Serving as sanctuaries for animal species driven from lowland areas.
- Helping regulate the earth's climate when mountaintops covered with ice and snow reflect solar radiation back into space.
- Affecting sea levels as a result of decreases or increases in glacial ice, most of which is locked up in Antarctica, the most mountainous of all continents.
- Playing a critical role in the hydrologic cycle (Figure 4-27, p. 83) by gradually releasing melting ice, snow, and water stored in the soils and vegetation of mountainsides to small streams.

Despite their ecological, economic, and cultural importance, the fate of mountain ecosystems has not been a high priority of governments or many environmental organizations. Mountain ecosystems are coming under increasing pressure from several human activities (Figure 6-42).

6-8 LESSONS FROM GEOGRAPHIC ECOLOGY

In this chapter we examined the connections among weather, climate, and the distribution of the earth's biomes. Three general ecological lessons emerge from this study:

- Different climates occur as a result of currents of air and water flowing over an unevenly heated planet spinning on a tilted axis.
- Different climates result in different communities of organisms, or biomes.
- Everything is connected.

Several more particular lessons are as follows:

- A general climate map for the earth (Figure 6-7) can be drawn based on broad patterns of temperature and precipitation.

- A general biome map for the earth (Figure 6-20) can be drawn that largely follows the general climate map (Figure 6-7).
- Understanding the general characteristics of each biome leads to a general understanding of **(1)** the range of biodiversity on the earth, **(2)** how this biodiversity is distributed, and **(3)** how all biomes are connected through global climate patterns, energy flow, and chemical cycling (Figure 4-7, p. 69, and Figure 4-16, p. 75).

Scientists have made a good start in understanding important aspects of geographic ecology. However, to further our understanding of ecological connections in time and space we need more studies and accurate maps of **(1)** species distributions, **(2)** changes in climate, **(3)** changes in species distribution, and **(4)** how and where human activities are affecting climate, biomes, and species distribution. Obtaining and analyzing such information is vital in helping us learn how to live more sustainably.

When we try to pick out anything by itself, we find it hitched to everything else in the universe.
JOHN MUIR

REVIEW QUESTIONS

1. Define the boldfaced terms in this chapter.

2. How does wind affect climate, global distribution of nutrients, and pollution?

3. What is *weather?*

4. Distinguish between **(a)** a *warm front* and a *cold front,* **(b)** a *high-pressure* and a *low-pressure* air mass, **(c)** a *tornado* and a *tropical cyclone,* and **(d)** a *hurricane* and a *typhoon.*

5. What is *climate?* What two main factors determine a region's climate?

6. What five factors affect global air circulation? How does each factor affect global air circulation? What causes opposite seasons in the northern and southern hemispheres?

7. How do warm and cool ocean currents form? How do oceans affect regional climates? What would happen to the climate of northwestern Europe if the Gulf Stream did not exist? What is an *upwelling,* and why are upwellings important to life?

8. What is *the El Niño–Southern Oscillation (ENSO)?* How does it affect ocean life and weather in various parts of the world? What is *La Niña,* and how does it affect weather in various parts of the world?

9. What are *greenhouse gases?* List four greenhouse gases. What is the *greenhouse effect,* and how does it affect the earth's climate?

10. What is the *ozone layer?* How does it **(a)** help protect life on the earth and **(b)** affect the earth's climate?

11. What are *microclimates?* What is the *rain shadow effect,* and how can it affect the microclimate on each side of high mountains? Why do urban areas have different microclimates than surrounding areas, and how do these microclimates differ from those of surrounding areas? How do *land breezes* and *sea breezes* affect the microclimates of coastal areas?

12. What is a *biome?* What two factors determine whether an area of the earth's surface is a tropical, temperate, or polar desert, grassland, or forest? How do climate and vegetation vary with latitude and altitude?

13. What are the following types of plants, where is each found, and how does each survive: **(a)** *broadleaf evergreen plants,* **(b)** *broadleaf deciduous plants,* and **(c)** *coniferous evergreen plants.*

14. What is a *desert?* What are the three major types of desert, and how do they differ in climate and biological makeup? How do desert plants and animals survive heat and a lack of water? Why are desert ecosystems vulnerable to disruption. List seven types of human activities that have harmful impacts on deserts.

15. What is *grassland?* What are the three major types of grassland, and how do they differ in climate and biological makeup? Distinguish between *arctic tundra* and *alpine tundra.* Why are grasslands vulnerable to disruption? List four types of human activities that have harmful impacts on grasslands. What is *chaparral,* and what is the importance of fire in this biome?

16. What is a *forest?* What are the three major types of forest, and how do they differ in climate and biological makeup? Distinguish among *tropical rain forests, tropical deciduous forests,* and *temperate rain forests.* List four types of human activities that have harmful impacts on forests.

17. Why are *mountains* ecologically important, and what factors make them vulnerable to ecological disruption? List seven types of human activities that have harmful impacts on mountains.

18. List three general lessons and three specific lessons we can learn from geographic ecology.

CRITICAL THINKING

1. Why might **(a)** the microclimate of a north-facing slope differ from that of a south-facing slope, **(b)** a ridge top differ from that of a valley bottom, and **(c)** an isolated mountaintop differ from a mountaintop surrounded by other mountains?

2. 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, and **(e)** a temperate deciduous forest.

3. Why do deserts and arctic tundra support a much smaller biomass of animals than do tropical forests?

4. Well drilling for water in desert areas has allowed many traditional nomadic tribes to raise more livestock by not having to migrate to find water. Is this desirable or undesirable from **(a)** an ecological standpoint, **(b)** an economic standpoint, and **(c)** a cultural standpoint? Explain.

5. Why do you think no amphibians and reptiles live in arctic tundra?

6. Some biologists have suggested restoring large herds of bison on public lands in the North American plains as a way of restoring remaining tracts of tall-grass prairie. Ranchers with permits to graze cattle and sheep on federally managed lands have strongly opposed this idea. What do you think about the idea of restoring large numbers of bison to the plains of North America? Explain.

7. Why do most animals in a tropical rain forest live in its trees?

8. What factors in your lifestyle contribute to the destruction and degradation of some tropical forests?

9. What biomes are best suited for **(a)** raising crops and **(b)** grazing livestock?

10. How might technologies such as remote sensing and geographic information systems (GIS; Figure 4-32, p. 91) help our understanding of ecology and the environment? Do you think it is worth investing in such expensive technologies to help solve environmental problems, or can we find better ways to spend our money? Explain.

PROJECTS

1. How has the climate changed in the area where you live during the past 50 years? Investigate the beneficial and harmful effects of these changes. How have these changes benefited or harmed you personally?

2. What type of biome do you live in? What have been the major effects of human activities over the past 50 years on the characteristic vegetation and animal life normally found in the biome you live in? How is your own lifestyle affecting this biome?

3. Use the library or the Internet to find bibliographic information about *Robert H. MacArthur* and *John Muir,* whose quotes appear at the beginning and end of this chapter.

4. Make a concept map of this chapter's major ideas, using the section heads and subheads and the key terms (in boldface). Look on the website for this book for information about making concept maps.

INTERNET STUDY RESOURCES AND RESOURCES FOR FURTHER READING AND RESEARCH

The website for this book contains helpful study aids and many ideas for further reading and research. Log on to

www.info.brookscole.com/miller13

and click on the Chapter-by-Chapter area. Choose Chapter 6 and select a resource:

- Flash Cards allows you to test your mastery of the Terms and Concepts to Remember for this chapter.
- Tutorial Quizzes provides a multiple-choice practice quiz.
- Student Guide to InfoTrac will lead you to Critical Thinking Projects that use InfoTrac College Edition as a research tool.
- References lists the major books and articles consulted in writing this chapter.
- Hypercontents takes you to an extensive list of sites with news, research, and images related to individual sections of the chapter.

INFOTRAC COLLEGE EDITION

Improve your skills with InfoTrac College Edition, a searchable online database of articles from more than 700 periodicals. Log on to

http://www.infotrac-college.com

or access InfoTrac through the website for this book. Try to find the following articles:

1. del Tredici, P. 2001. Sprouting in temperate trees: A morphological and ecological review. *The Botanical Review* 67: 121. *Keywords:* "temperate trees" and "ecology." Sprouting in trees is an adaptation to several stressful conditions. These conditions can include competition, limiting factors, natural disturbance, and human disturbance. This article looks at ways in which trees in temperate forests resprout in response to various types of disturbance.

2. Petit, C. W. 2002. Perilous waters: Influx of fresh water in North Atlantic Ocean could disrupt world climate patterns. *U.S. News & World Report* (April 1): 64. *Keywords:* "North Atlantic Ocean" and "climate." Climate change is a major environmental issue in the beginning of the 21st century, but it may not all be due to humans and greenhouse gas emissions. This article looks at the effects of water density on a major ocean current system, and the potential effects on climate of changes in this system.

7 AQUATIC ECOLOGY: BIODIVERSITY IN AQUATIC SYSTEMS

Why Should We Care About Coral Reefs?

In the shallow coastal zones of warm tropical and subtropical oceans we often find **coral reefs** (Figure 7-1, left). These beautiful natural wonders are among the world's oldest, most diverse, and most productive ecosystems.

Coral reefs are formed by massive colonies of tiny animals called *polyps* that are close relatives of jellyfish. They slowly build reefs by secreting a protective crust of limestone (calcium carbonate) around their soft bodies.

When the corals die, their empty crusts or outer skeletons remain as a platform for more reef growth. The result is an elaborate network of crevices, ledges, and holes that serve as calcium carbonate "condominiums" for a variety of marine animals.

Coral reefs involve a mutually beneficial relationship between the polyps and tiny single-celled algae called *zooxanthellae* ("zoh-ZAN-thel-ee") that live in the tissues of the polyps. The algae provide the polyps with color, food, and oxygen through photosynthesis. The polyps in turn provide a well-protected home for the algae.

Coral reefs provide a number of important ecological and economic services valued conservatively at $375 billion a year. These services include the following:

- Removing some of the carbon dioxide from the atmosphere as part of the carbon cycle (when coral polyps form limestone shells)
- Acting as natural barriers that **(a)** help protect 15% of the world's coastlines from erosion by battering waves and storms and **(b)** allow the ocean to replenish nearby beaches with sand
- Supporting at least one-fourth of all identified marine species and 65% of marine fish species even though such reefs occupy less than 1% of the ocean floor
- Producing roughly 10% of the global fish catch and 25% of the catch in developing countries
- Providing fish and shellfish, jobs, and building materials for some of the world's poorest countries
- Supporting fishing and tourism industries worth billions of dollars each year
- Giving us an underwater world to study and enjoy

More than one-fourth of the world's coral reefs have been lost to coastal development, pollution, overfishing, warmer ocean temperatures, and other stresses that are increasing. One problem is *coral bleaching* (Figure 7-1, right), which occurs when a coral becomes stressed and expels most of its colorful algae. This occurs because of stresses such as increased water temperature and runoff of silt that covers the coral and prevents photosynthesis.

This loss of algae exposes the colorless coral animals and the underlying ghostly white skeleton of calcium carbonate. Unable to grow or repair themselves, the corals eventually die unless the stress is removed and algae recolonize them.

Coral reefs sometimes are called the aquatic equivalent of tropical rain forests because they harbor such a high species biodiversity with myriad ecological interrelationships. The decline and degradation of these colorful oceanic sentinels should serve as a warning about the health of their habitats.

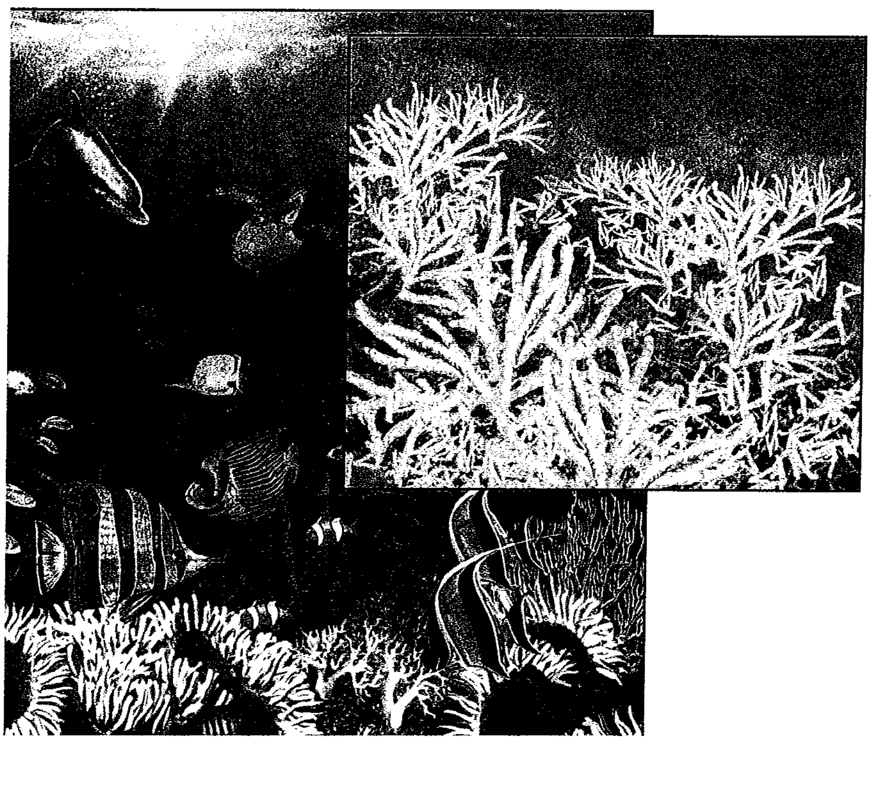


Figure 7-1 A healthy coral reef covered by colorful algae (left) and a bleached coral reef that has lost most of its algae (right) because of changes in the environment (such as cloudy water or too warm temperatures). With the algae gone, the white limestone of the coral skeleton becomes visible. If the environmental stress is not removed and no other alga species fill the abandoned niche, the corals die. These diverse and productive ecosystems are being damaged and destroyed at an alarming rate.

If there is magic on this planet, it is contained in water.

LOREN EISLEY

This chapter addresses the following questions:

- What are the basic types of aquatic life zones, and what factors influence the kinds of life they contain?
- What are the major types of saltwater life zones, and how do human activities affect them?
- What are the major types of freshwater life zones, and how do human activities affect them?
- How can we help sustain aquatic life zones?

7-1 AQUATIC ENVIRONMENTS: TYPES AND CHARACTERISTICS

What Are the Two Major Types of Aquatic Life Zones? 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 divided into two major types: **(1)** *saltwater* or *marine* (particularly estuaries, coastlines, coral reefs, coastal marshes, mangrove swamps, and oceans) and **(2)** *freshwater* (particularly lakes and ponds, streams and rivers, and inland wetlands). Figure 7-2 shows the distribution of the world's major oceans, lakes, rivers, coral reefs, and mangroves.

What Are the Main Kinds of Organisms in Aquatic Life Zones? Saltwater and freshwater life zones contain several major types of organisms:

- **Phytoplankton** ("FIE-toe-plank-ton"), or *plant plankton:* free-floating microscopic cyanobacteria and many types of algae that are the producers supporting most aquatic food chains and food webs (Figure 4-19, p. 78).
- **Zooplankton** ("ZOE-oh-plank-ton"), or *animal plankton:* a mixture of **(1)** nonphotosynthetic primary consumers (herbivores) that feed on phytoplankton and **(2)** secondary consumers that feed on other zooplankton. They range from single-celled protozoa to large invertebrates such as jellyfish.
- **Nekton:** strongly swimming consumers such as fish, turtles, and whales.
- **Benthos:** bottom-dwellers such as **(1)** barnacles and oysters that anchor themselves to one spot, **(2)** worms that burrow into the sand or mud, and **(3)** lobsters and crabs that walk about on the bottom. Some of these species get food by filtering it from water (Spotlight, p. 149).
- **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 producers.

What Are Key Characteristics of Aquatic Organisms and Systems? Living in an aquatic environment has advantages and disadvantages (Figure 7-3, p. 146). Aquatic systems also

- Have less pronounced and fixed physical boundaries than terrestrial ecosystems. This makes it difficult to count and manage populations of aquatic organisms.
- Have more complex and longer food chains and food webs (Figure 4-19, p. 78) than most terrestrial food chains and webs. One reason is that the fluid medium of water systems and the variety of bottom

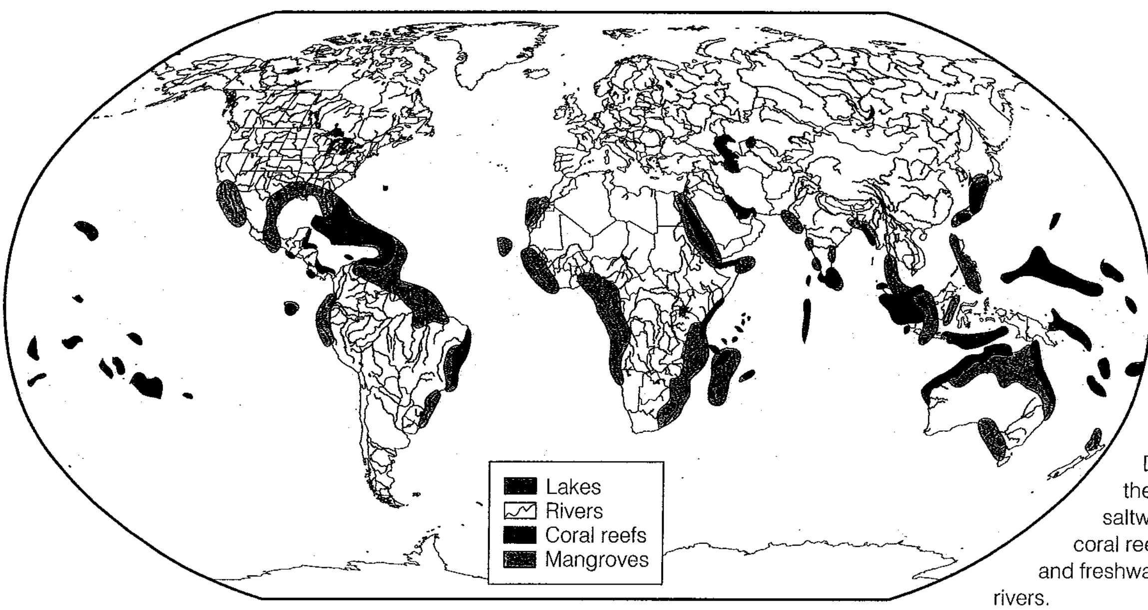


Figure 7-2 The aquatic world. Distribution of the world's major saltwater oceans, coral reefs, mangroves, and freshwater lakes and rivers.

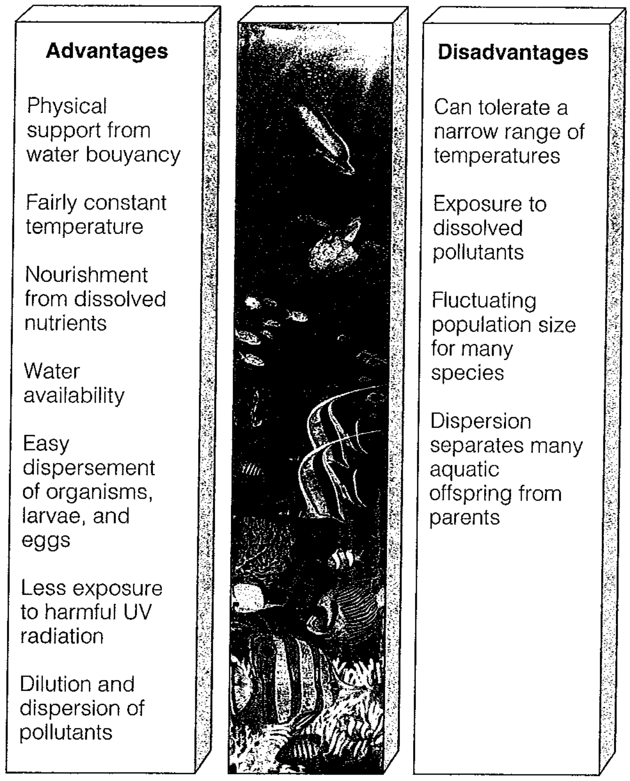


Figure 7-3 Advantages and disadvantages of living in water.

habitats open up ways of getting food that are not available on land.

- Are more difficult to monitor and study (especially marine systems) because of their size and because they are largely hidden from view.

What Factors Limit Life at Different Depths in Aquatic Life Zones? Most aquatic life zones can be divided into three layers: **(1)** surface, **(2)** middle, and **(3)** bottom. Important environmental factors determining the types and numbers of organisms found in these layers are **(1)** *temperature,* **(2)** *access to sunlight for photosynthesis,* **(3)** *dissolved oxygen content,* and **(4)** *availability of nutrients* such as carbon (as dissolved CO_2 gas), nitrogen (as NO_3^-), and phosphorus (mostly as PO_4^{3-}) for producers.

Photosynthesis is confined mostly to the upper layer, or **euphotic zone,** of deep aquatic systems through which sunlight can penetrate. The depth of the euphotic zone in oceans and deep lakes can be reduced by excessive algal growth (algal blooms) that make water cloudy.

O_2 enters an aquatic system from the atmosphere and through photosynthesis by aquatic producers and is removed by aerobic respiration of producers, consumers, and decomposers. CO_2 enters an aquatic system from the atmosphere and through aerobic respiration by producers, consumers, and decomposers and is removed by photosynthesizing producers. This removal of some of the greenhouse gas CO_2 in the atmosphere by aquatic producers helps keep the earth's average atmospheric temperature from rising as a result of the natural greenhouse effect (Figure 6-17, p. 121).

Some dissolved CO_2 forms carbonate ions (CO_3^{2-}). They are stored mostly as calcium carbonate ($CaCO_3$) for long periods in sediments, minerals, and the shells and skeletons of living aquatic animals as part of the carbon cycle (Figure 4-28, p. 84). The concentration of oxygen in the atmosphere varies little. However, the amount of oxygen dissolved in water can vary widely, depending on factors such as **(1)** temperature, **(2)** number of producers (which add O_2), **(3)** number of consumers and aerobic decomposers (which remove O_2), and **(4)** deep ocean circulation (which can cause oxygen-saturated surface water in some areas to sink and spread).

Many aquatic organisms, especially fish, die when dissolved oxygen levels fall below 5 ppm. The concentrations of dissolved O_2 and CO_2 in water vary in different ways with depth (Figure 7-4).

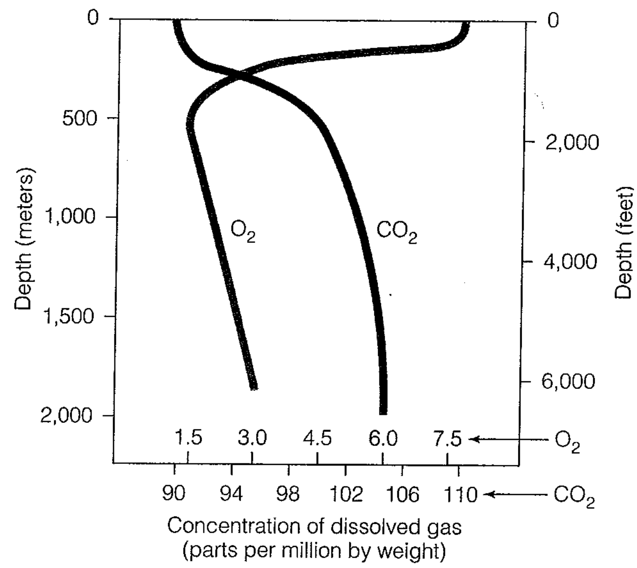


Figure 7-4 Variations in concentrations of dissolved oxygen (O_2) and carbon dioxide (CO_2) in parts per million (ppm) with water depth. Dissolved O_2 is high near the surface because oxygen-producing photosynthesis takes place there. Because photosynthesis cannot take place below the sunlit layer, O_2 levels fall because of aerobic respiration by aquatic animals and decomposers. They also fall because **(1)** less oxygen gas dissolves in the deeper and colder water than in warmer surface water and **(2)** deep ocean circulation causes oxygen-saturated ocean surface water to sink and spread in some areas. In contrast, levels of dissolved CO_2 are **(1)** low in surface layers because producers use CO_2 during photosynthesis and **(2)** high in deeper, dark layers where aquatic animals and decomposers produce CO_2 through aerobic respiration.

In shallow waters in streams, ponds, and oceans, ample supplies of nutrients for primary producers are usually available. By contrast, in the open ocean, nitrates, phosphates, iron, and other nutrients often are in short supply and limit net primary productivity (NPP) (Figure 4-25, p. 81). However, NPP is much higher in parts of the open ocean where upwellings (Figure 6-7, p. 116, and Figure 6-13, p. 119) bring such nutrients from the ocean bottom to the surface for use by producers.

Most creatures living on the bottoms of the deep ocean and deep lakes depend on animal and plant plankton that die and fall into deep waters. Because this food is limited, deep-dwelling species tend to reproduce slowly. Thus they are especially vulnerable to depletion from overfishing.

7-2 SALTWATER LIFE ZONES

Why Are the Oceans Important? A more accurate name for Earth would be *Ocean* because saltwater oceans cover about 71% of the planet's surface (Figure 7-5). The world's oceans **(1)** make up 99.5% of the world's habitable volume, **(2)** contain about 250,000 known species of marine plants and animals, and **(3)** provide many important ecological and economic services (Figure 7-6).

Despite its ecological and economic importance less than 5% of the earth's global ocean has been explored and mapped with the same level of detail as the surface of the moon and Mars. According to aquatic scientists, the scientific investigation of poorly understood marine and freshwater aquatic systems is a greatly underfunded *research frontier* whose study could result in immense ecological and economic benefits.

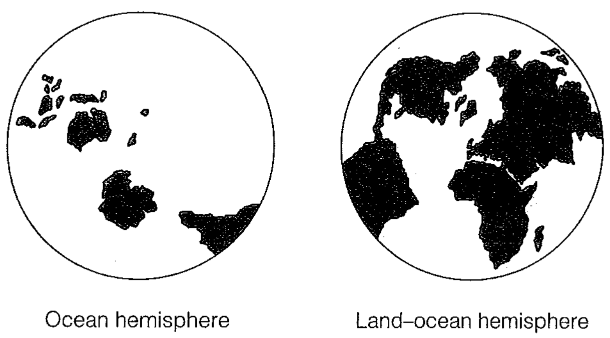


Figure 7-5 The ocean planet. The salty oceans cover about 71% of the earth's surface. About 97% of the earth's water is in the interconnected oceans, which cover 90% of the planet's mostly ocean southern hemisphere (left) and 50% of its land–ocean northern hemisphere (right).

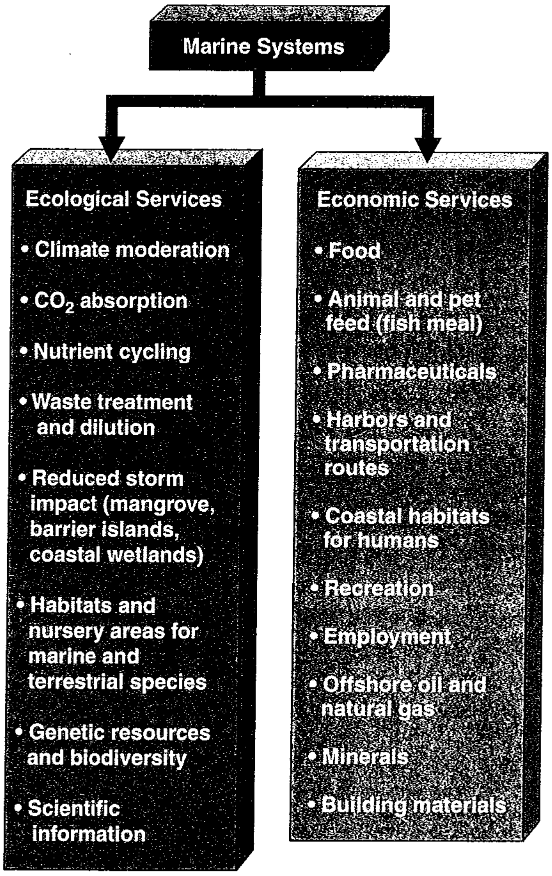


Figure 7-6 Major ecological and economic services provided by marine systems.

What Is the Coastal Zone? Oceans have two major life zones: the *coastal zone* and the *open sea* (Figure 7-7, p. 148). 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). This zone has numerous interactions with the land and thus human activities easily affect it.

Although it makes up less than 10% of the world's ocean area, the coastal zone contains 90% of all marine species and is the site of most large commercial marine fisheries. Most ecosystems found in the coastal zone have a very high net primary productivity per unit of area (Figure 4-25, p. 81). This occurs because of the zone's ample supplies of **(1)** sunlight and **(2)** plant nutrients (flowing from land and distributed by wind and ocean currents).

What Are Estuaries and Coastal Wetlands? One highly productive area in the coastal zone is an **estuary,** a partially enclosed area of coastal water where seawater mixes with fresh water and nutrients from rivers, streams, and runoff from land (Figure 7-8, p. 148). It is an ecotone (Figure 4-10, p. 71) between

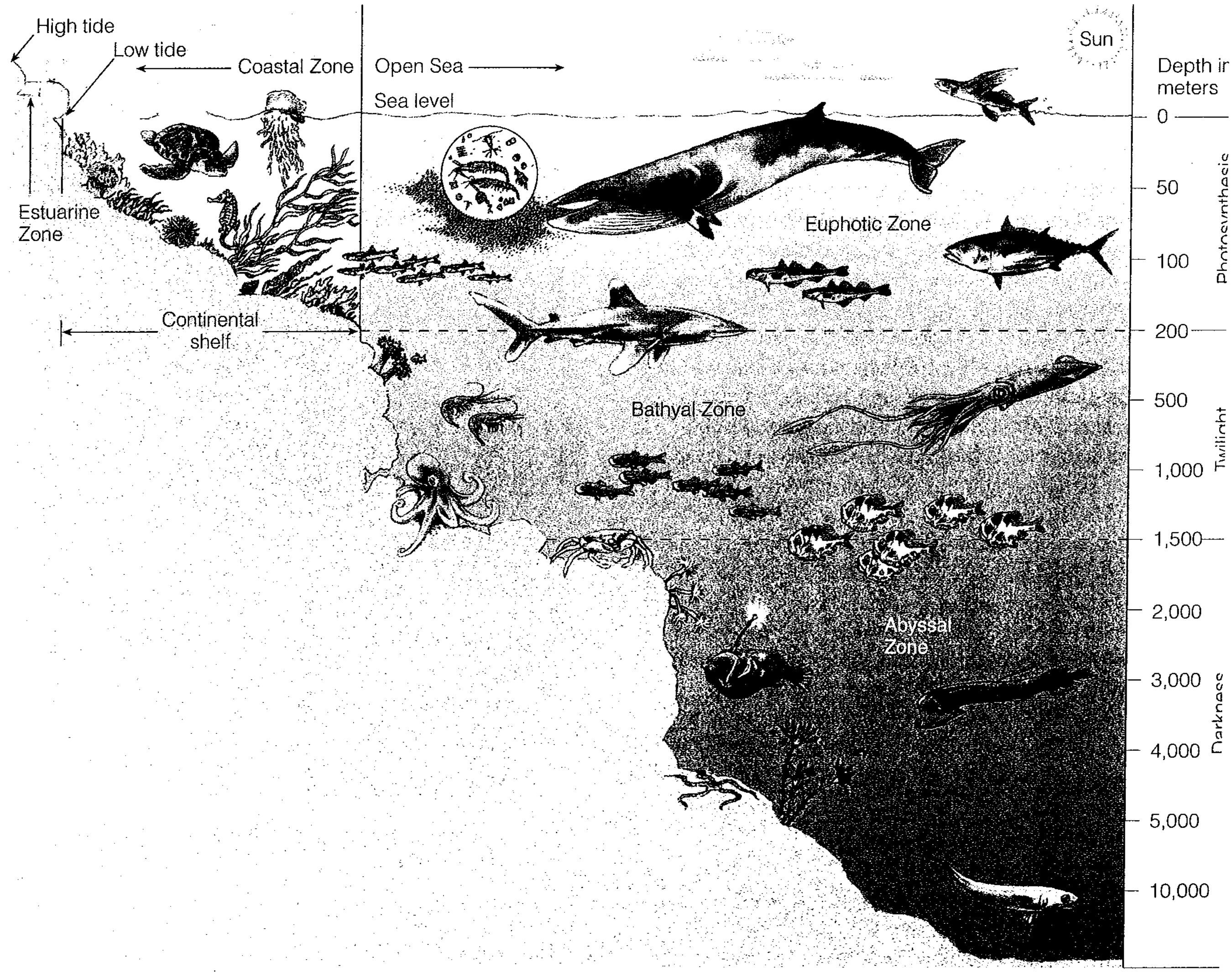


Figure 7-7 Major life zones in an ocean (not drawn to scale). Actual depths of zones may vary.


NASA

the marine environment and the land where larg volumes of fresh water from land and salty ocea water mix.

Estuaries and their associated **coastal wetland** (land areas covered with water all or part of the year include **(1)** river mouths, **(2)** inlets, **(3)** bays, **(4)** sounds **(5)** mangrove forest swamps in tropical waters (Figures 7-2 and 7-9), and **(6)** salt marshes in temperat zones (Figure 7-10 and Figure 7-11, p. 150).

Temperature and salinity levels vary widely in estuaries and coastal wetlands because of **(1)** the dail

Figure 7-8 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.

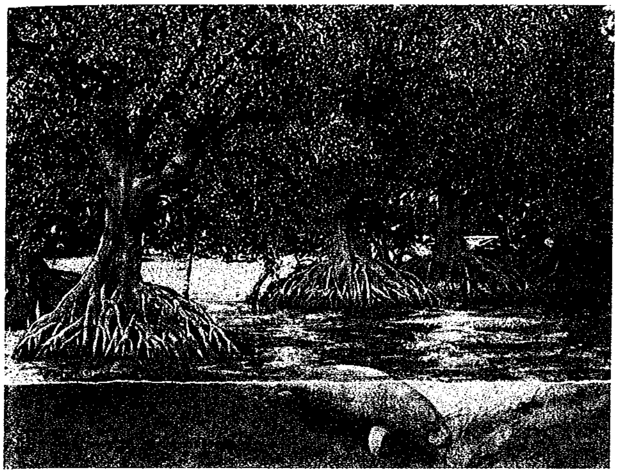


Figure 7-9 *Mangroves* (Figure 7-2) are important coastal systems that **(1)** protect coastlines and coral reefs (Figure 7-1) and **(2)** provide important habitats for aquatic species. At least 35% of the world's mangroves have been cleared since 1980, mostly for growing crops and raising shrimp in aquaculture ponds.

rhythms of the tides, **(2)** seasonal variations in the flow of fresh water into the estuary, and **(3)** unpredictable flows of fresh water from coastal land and rivers after heavy rains and of salt water from the ocean as a result of storms, hurricanes, and typhoons.

The constant water movement stirs up the nutrient-rich silt, making it available to producers. This explains why estuaries and their associated coastal wetlands are **(1)** some of the earth's most productive ecosystems (Figure 4-25, p. 81) and **(2)** provide other important ecological and economic services (Figure 7-6).

What Are Rocky and Sandy Shores? The area of shoreline between low and high tides is called the **intertidal zone.** Organisms living in this stressful zone must be able to avoid being **(1)** swept away or crushed by waves, **(2)** immersed during high tides, and **(3)** left high and dry (and much hotter) at low tides. They must also cope with changing levels of salinity when heavy rains dilute salt water. To deal with such stresses, most intertidal organisms hold on to something, dig in, or hide in protective shells.

The fluctuating tides expose different parts of the intertidal zone to different levels of water, sunlight, and air. This leads to a variety of ecological niches found in fairly clear zones or different-colored bands reflecting the colors of dominant species.

Some coasts have steep *rocky shores* pounded by waves. The numerous pools and other niches in the

Biofiltration

SPOTLIGHT

Some aquatic organisms get food by filtering it out of water. Examples of such *filter feeders* are barnacles, clams, oysters, sponges, and baleen whales.

Some species do this by passively sieving the water and others by actively pumping it through their bodies. One of the most efficient biofilter species is the sponge, which is capable of **(1)** pumping an amount of water equal to its own body volume every 10–20 seconds and **(2)** filtering out 99% of the particulate matter.

While feeding themselves, sponges also play an important role in keeping water over coral reefs (Figure 7-1) clean and clear. Most of the water overlying a coral reef could be filtered through its existing sponges in 2–3 days!

Some shellfish such as clams use their muscular foot to burrow down into the sand or mud and then extend input and output tubes, called siphons, up into the water. Water is **(1)** "inhaled" through an incoming siphon, **(2)** filtered for food particles and dissolved oxygen, and **(3)** then "exhaled" through an outgoing siphon.

As huge baleen whales (such as the blue whale) move through the water, tons of speck-sized zooplankton (such as krill) are trapped in large comblike filters, called *baleen,* found in their mouths (Figure 4-19, p. 78). The whales then use their tongues to slurp down the trapped zooplankton.

No equivalent types of filter-feeding organisms exist in terrestrial ecosystems. However, humans have copied nature by developing fishnets to strain food from the water.

Critical Thinking

Why do some health scientists warn us not to eat raw shellfish such as clams and oysters?

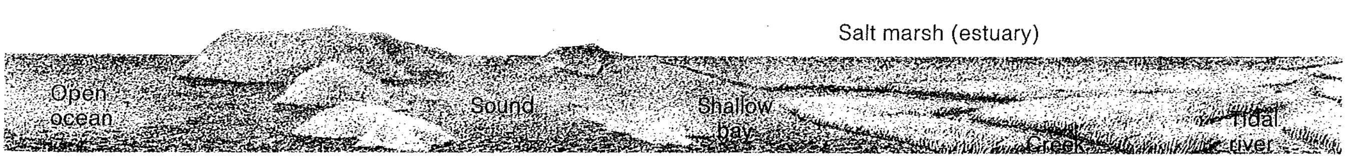


Figure 7-10 *Salt marsh* of an estuary in a temperate area consists of several connected coastal life zones. (From Cecie Starr, *Biology: Concepts and Applications*, 4th ed., Brooks/Cole [Wadsworth] © 2000)

rocks in the intertidal zone of rocky shores contain a great variety of species (Figure 7-12, top).

Other coasts have gently sloping *barrier beaches,* or *sandy shores,* with niches for different marine organisms, including crabs, lugworms, clams, ghost shrimp, sand dollars, and flounder (Figure 7-12, bottom). Most of them are 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

Figure 7-11 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.

feed in specialized niches on crustaceans, insects, and other organisms (Figure 7-13, p. 152).

One or more rows of natural sand dunes on undisturbed barrier beaches (with the sand held in place by the roots of grasses) serve as the first line of defense against the ravages of the sea (Figure 7-14, p. 152). But when coastal developers remove the protective dunes or build behind the first set of dunes, storms can flood and even sweep away seaside buildings and severely erode the sandy beaches.

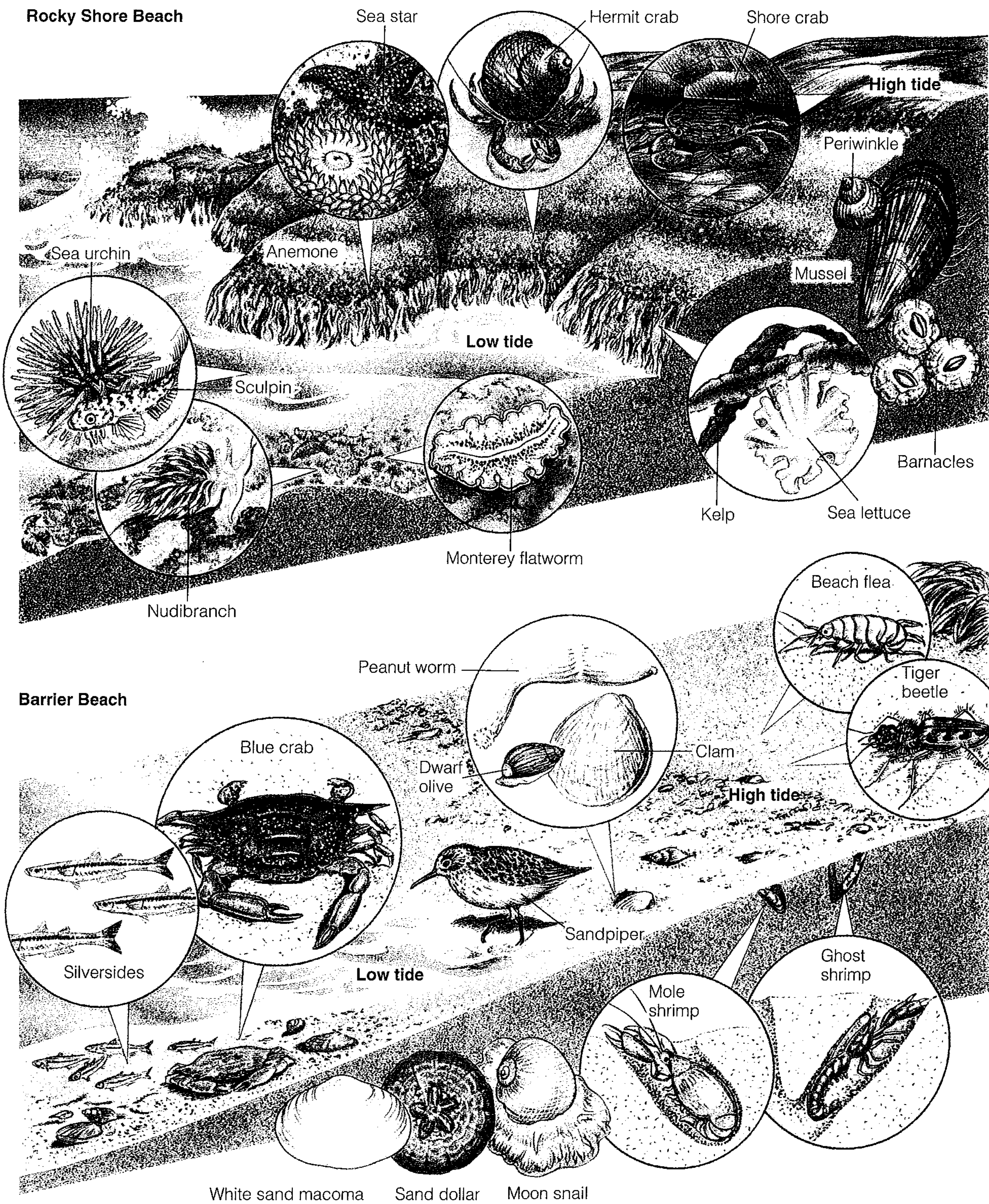


Figure 7-12 Living between the tides. Some organisms with specialized niches found in various zones on rocky shore beaches (top) and barrier or sandy beaches (bottom). Organisms are not drawn to scale.

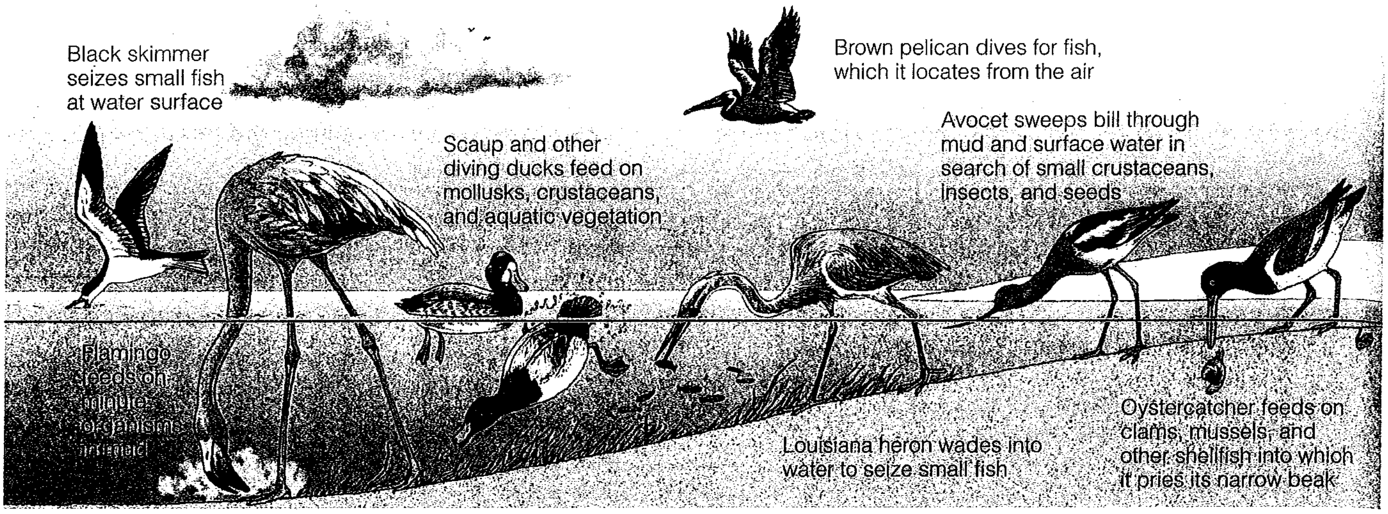


Figure 7-13 Specialized feeding niches of various bird species in a coastal wetland. Such resource partitioning reduces competition and allows sharing of limited resources.

What Are Barrier Islands? **Barrier islands** are long, thin, low offshore islands of sediment that generally run parallel to the shore. They are found along some coasts such as most of North America's Atlantic and Gulf coasts. These islands help protect the mainland, estuaries, and coastal wetlands by dispersing the energy of approaching storm waves.

Their low-lying beaches are constantly shifting, with gentle waves building them up and storms flattening and eroding them. Currents running parallel to the beaches constantly take sand from one area and deposit it in another. Sooner or later, many of the structures humans build on low-lying barrier islands (Figure 7-15), such as Atlantic City, New Jersey, and Miami Beach, Florida, are damaged or destroyed by flooding, severe beach erosion, or major storms (including hurricanes).

What Are Coral Reefs? Coral reefs (Figures 7-1 and 7-16, p. 154) form in clear, warm coastal waters of the tropics and subtropics (Figure 7-2). Collectively, they occupy only about 0.1% of the world's ocean area—amounting to an area about half the size of France. These beautiful natural wonders are among

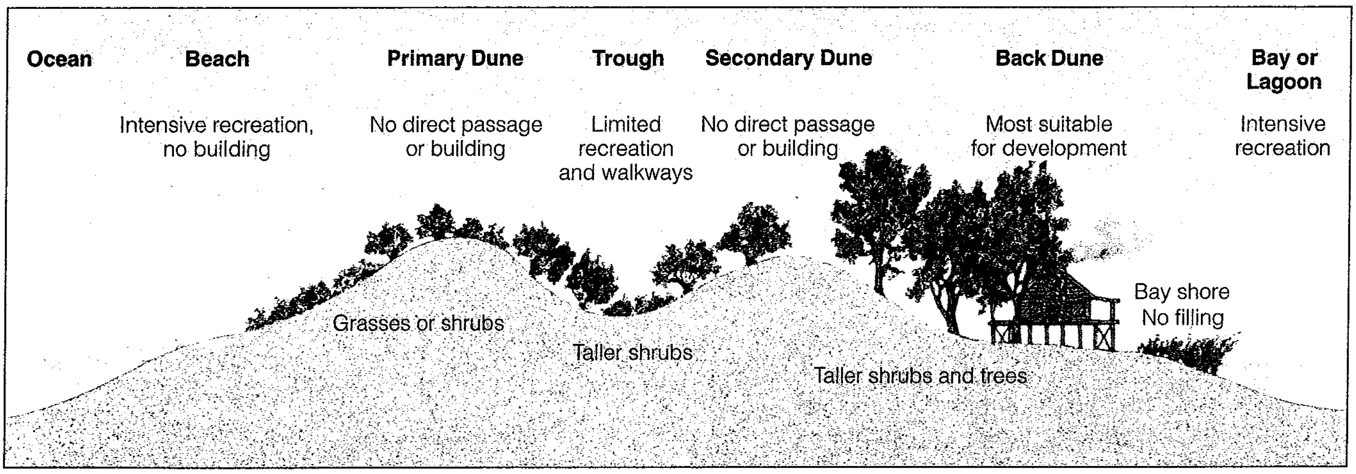
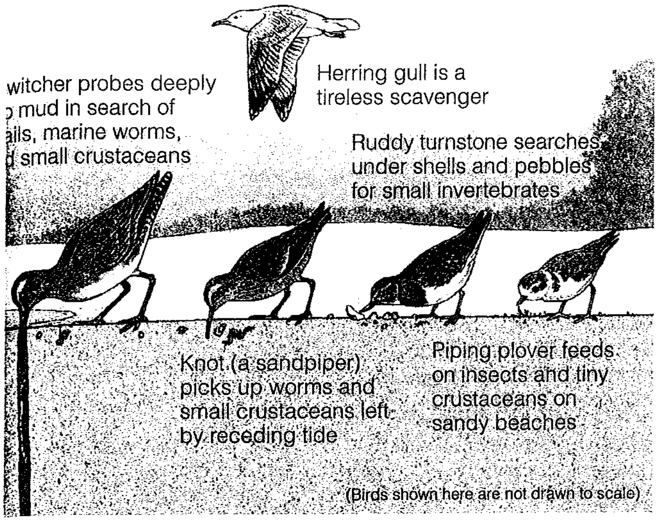


Figure 7-14 Primary and secondary dunes on gently sloping sandy beaches play an important role in protecting the land from erosion by the sea. The roots of various grasses that colonize the dunes help hold the sand in place. Ideally, **(1)** construction and development should be allowed only behind the second strip of dunes, and **(2)** walkways to the beach should be built over the dunes to keep them intact. This helps **(1)** preserve barrier beaches and **(2)** protect human structures from being damaged and washed away by wind, high tides, beach erosion, and flooding from storm surges. This type of protection is rare, however, because the short-term economic value of oceanfront land is considered much higher than its long-term ecological and economic values.



the world's oldest, most diverse, and productive ecosystems, and they are homes for about one-fourth of all marine species.

Coral reefs are also ecologically complex in terms of the many interactions among the diverse organisms that live there (Figure 7-16, p. 154). These organisms fall into three main groups: **(1)** attached organisms (such as corals, algae, and sponges) that give the reef its structure, **(2)** fishes, and **(3)** small organisms that bore into, attach to, or hide within a reef's many nooks and crannies.

Coral reefs are vulnerable to damage because they **(1)** grow slowly, **(2)** are disrupted easily, and **(3)** thrive only in clear, warm, and fairly shallow water of constant high salinity. Corals can live only in water with a temperature of 18–30°C (64–86°F), and coral bleaching (Figure 7-1, right) can be triggered by an increase of just 1°C (1.8°F) above the maximum.

Figure 7-15 A developed barrier island.

Thus the health and survival of coral reefs are closely connected to projected global warming caused by increases in atmospheric concentrations of gases such as CO_2. Rising temperatures in tropical oceans also can reduce the levels of calcium needed for reef growth.

The biodiversity of coral reefs can be reduced by natural disturbances such as severe storms, freshwater floods, and invasions of predatory fish. However, throughout their very long geologic history, coral reefs have been able to adapt to such natural environmental changes. Today the biggest threats to the biodiversity of many of the world's coral reefs come from human activities (Figure 7-17, p. 155). Scientists are concerned that these threats are occurring so rapidly (over decades) and over such a wide area that many of the world's coral systems may not have enough time to adapt.

Some 300 coral reefs in 65 countries are protected as reserves or parks, and another 600 have been recommended for protection. The *good news* is that protected coral reefs often can recover (Connections, p. 155). However, protecting reefs is difficult and expensive, and only half of the countries with coral reefs have set aside reserves that receive some protection from human activities.

What Biological Zones Are Found in the Open Sea? 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.** Based primarily on the penetration of sunlight, it is divided into three vertical zones (Figure 7-7):

- *Euphotic zone:* the lighted upper zone where **(1)** photosynthesis occurs mostly by phytoplankton, **(2)** nutrient levels are low (except around upwellings, Figure 6-13, p. 119), and **(3)** levels of dissolved oxygen are high (Figure 7-4). Large, fast-swimming predatory fish such as swordfish, sharks, and bluefin tuna populate this zone.
- *Bathyal zone:* dimly lit middle zone that does not contain photosynthesizing producers because of a lack of sunlight. Various types of zooplankton and smaller fish, many of which migrate to feed on the surface at night, populate this zone.
- *Abyssal zone:* dark lower zone that is **(1)** very cold, **(2)** has little dissolved oxygen (Figure 7-4), and **(3)** has enough nutrients on the ocean floor to support about 98% of the 250,000 identified species living in the ocean.

Dead and decaying organisms fall to the ocean floor to feed microscopic decomposers and scavengers such as crabs and sea urchins. Some of these organisms (such as many worms) are *deposit feeders,* which take mud into their guts and extract nutrients from it.

Others (such as oysters and mussels) are *filter feeders,* which pass water through or over their bodies and extract nutrients from it (Spotlight, p. 149). On portions of the dark, deep ocean floor near hydrothermal vents, scientists have recently found communities of organisms where specialized bacteria use chemosynthesis to produce their own food and food for other organisms feeding on them.

Average primary productivity and NPP per unit of area are quite low in the open sea (Figure 4-25, p. 81)

Figure 7-16 Some 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.

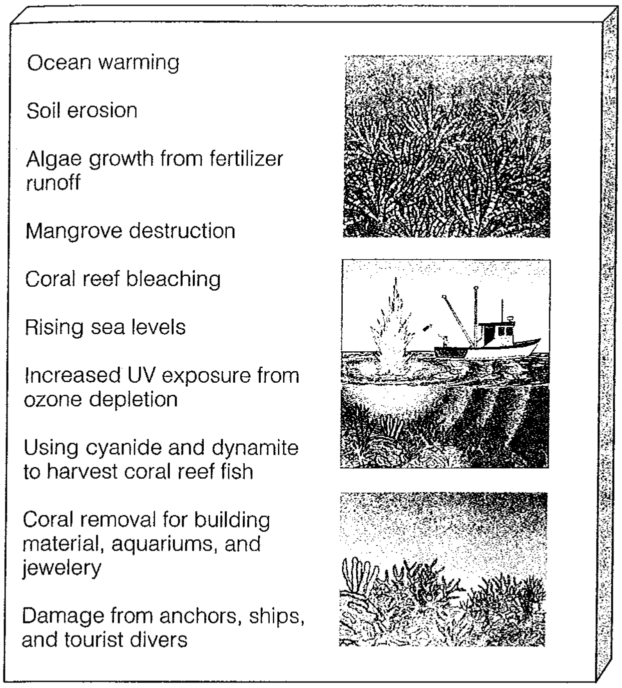


Figure 7-17 Major threats to coral reefs.

except at an occasional equatorial upwelling, where currents bring up nutrients from the ocean bottom. However, because the open sea covers so much of the earth's surface (Figure 7-5), it makes the largest contribution to the earth's overall NPP.

What Impacts Do Human Activities Have on Marine Systems? In their desire to live near the coast, people are destroying or degrading the resources that make coastal areas so enjoyable and economically and ecologically valuable. Currently, about 40% of the world's population live along coasts or within 100 kilometers (62 miles) of a coast. Some 13 of the world's 19 megacities with populations of 10 million or more people are in coastal zones. By 2030, at least 6.3 billion people—more than the current global population—are expected to live in or near coastal areas.

Here are some major impacts of human activities on marine systems:

- Salt marshes, mangrove forests, and sea-grass meadows—the sea's three great marine nurseries—are being lost and degraded at a high rate to make way for real estate developments, marinas, golf courses, and shrimp farms.
- Scientists estimate that half the world's original coastal wetlands and 53% of those in the lower 48 U.S. states (91% in California) have disappeared since 1800, mostly by being filled in for agriculture and coastal development. According to scientists, by 2080 half of the world's remaining coastal wetlands is likely to be lost to **(1)** agriculture, **(2)** urban development, and **(3)** rising sea levels from climate change.
- At least 35% of the world's original mangrove forests (Figures 7-2 and 7-9) have disappeared since 1980, mostly because of clearing for **(1)** coastal

Coral Partners May Enhance Reef Survival

CONNECTIONS

All of the news about coral reefs is not bad. In 1998, researchers found that in some cases coral bleaching (Figure 7-1, right)—in which coral reefs turn ghostly white—may not be as fatal to reefs as once thought.

Researchers have been puzzled because corals in shallow water in some areas might be healthy, whereas at a slightly greater depth they find extensive bleaching. Marine biologist Rob Rowan studied DNA extracted from coral at different depths and locations and identified up to three different algae species (which he labeled A, B, and C) in the same coral.

He also noticed a pattern in the distribution of these algae species. Two species, which he called A and B, preferred areas on coral with lots of light, and species C was adapted to lower light at greater depths. He hypothesized that coral with species A and B in shallow water may have some resistance to bleaching. In deeper and darker water, species C can grow on top of the corals.

Recent research also suggests that bleaching may allow some types of coral to switch to new algae species more adapted to the changed water conditions.

Additional research indicates that some types of coral which appear dead from bleaching may have a hidden reserve of algae that may eventually allow the coral to come back to life. But these researchers caution that we still have much to learn about the complex interactions between various types of algae and coral.

More *good news* is the growing evidence that coral reefs can recover when given a chance. When localities or nations have imposed restrictions on reef fishing or reduced inputs of nutrients and other pollutants, reefs have rebounded.

Critical Thinking

Does the research described here mean that we do not need to worry so much about protecting coral reefs? Explain.

development, **(2)** rice fields, and **(3)** aquaculture shrimp farms. The percentage of mangrove forest loss exceeds those for tropical rain forests and coral reefs. Much of the remaining mangroves are threatened. The clearing of mangroves also causes erosion that kills coral reefs by smothering the corals in plumes of soil.

- According to a World Wildlife Fund study, almost 70% of the world's beaches are eroding rapidly because of coastal developments and a rising sea level (caused mostly by global warming).
- Ocean bottom habitats are being degraded and destroyed by dredging operations and trawler boats, which drag huge nets weighted down with chains over ocean bottoms to harvest bottom fish and shellfish (Figure 7-18).
- According to a 2000 report from the Global Coral Reef Monitoring Network, **(1)** about 27% of the world's coral reefs have been severely damaged (up from 10% in 1992), **(2)** 11% have been destroyed, and **(3)** another 70% could be gone by 2050. In addition to the biodiversity losses, such a collapse would **(1)** sharply reduce fish harvests and **(2)** greatly increase storm damage on the coasts of tropical and warm temperate areas.

7-3 FRESHWATER LIFE ZONES

What Are Freshwater Life Zones? **Freshwater life zones** occur where water with a dissolved salt concentration of less than 1% by volume accumulates on or flows through the surfaces of terrestrial biomes. Examples are **(1)** *standing* (lentic) bodies of fresh water such as lakes, ponds, and inland wetlands and **(2)** *flowing* (lotic) systems such as streams and rivers. Although freshwater systems cover less than 1% of the earth's surface (Figure 7-2), they provide a number of important ecological and economic services (Figure 7-19).

Runoff from nearby land provides freshwater life zones with an almost constant input of organic material, inorganic nutrients, and pollutants. Thus these life zones are closely connected to nearby terrestrial biomes.

What Life Zones Are Found in Freshwater Lakes? **Lakes** are large natural bodies of standing fresh water formed when precipitation, runoff, or groundwater seepage fills depressions in the earth's surface. Causes of such depressions include **(1)** glaciation (the Great Lakes of North America), **(2)** crustal displacement (Lake Nyasa in East Africa), and **(3)** volcanic activity (Crater Lake in Oregon; see photo on p. iii). Rainfall, melting snow, and streams that drain the surrounding watershed feed lakes.

Because ponds (Figure 4-11, p. 72) are shallow, sunlight often penetrates to the bottom so ponds usually have only one zone. In contrast, lakes normally consist of four distinct zones that are defined by their depth and distance from shore (Figure 7-20, p. 158):

- *Littoral zone* ("LIT-tore-el"): consists of the shallow sunlit waters near the shore to the depth at which rooted plants stop growing. It has a high biological diversity.
- *Limnetic zone* ("limb-NET-ic"): the open, sunlit water surface layer away from the shore that extends to the depth penetrated by sunlight. As the main photosynthetic body of the lake, it produces the food and oxygen that support most of the lake's consumers.

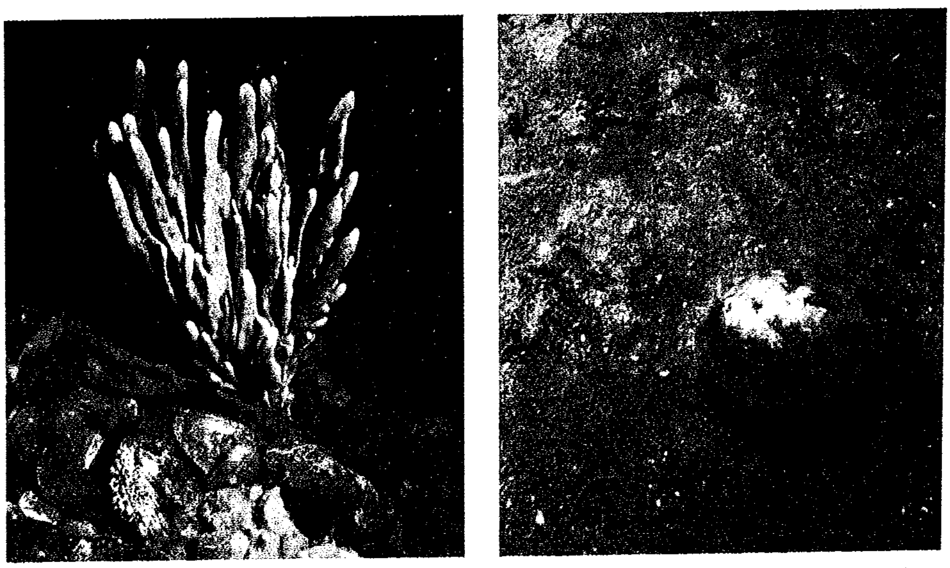


Figure 7-18 Area of ocean bottom before (left) and after (right) a trawler net scraped it like a gigantic plow. These ocean floor communities can take decades or centuries to recover. According to marine scientist Elliot Norse, "Bottom trawling is probably the largest human-caused disturbance to the biosphere." Trawler fishers disagree and claim that ocean bottom life recovers after trawling. (Peter J. Auster, National Undersea Research Center)

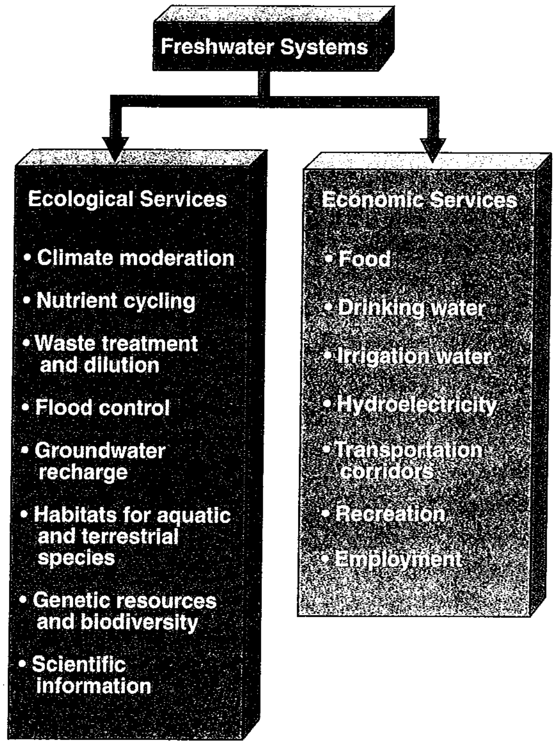


Figure 7-19 Major ecological and economic services provided by freshwater systems.

- *Profundal zone* ("pro-FUN-dahl"): the deep, open water where it is too dark for photosynthesis. Without sunlight and plants, oxygen levels are low. Fish adapted to its cooler and darker water are found in this zone.
- *Benthic zone* ("BEN-thick"): at the bottom of the lake. It is inhabited mostly by organisms that tolerate cool temperatures and low oxygen levels.

How Do Plant Nutrients Affect Lakes? 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 called an **oligotrophic** (poorly nourished) **lake** (Figure 7-21, left, p. 158). This type of lake is often deep, with steep banks. Because of its low NPP, such a lake usually has **(1)** crystal-clear blue or green water and **(2)** small populations of phytoplankton and fish (such as smallmouth bass and trout).

Over time, sediment washes into an oligotrophic lake, and plants grow and decompose to form bottom sediments. A lake with a large or excessive supply of nutrients (mostly nitrates and phosphates) needed by producers is called a **eutrophic** (well-nourished) **lake** (Figure 7-21, right, p. 158). Such lakes typically are shallow and have murky brown or green water with very poor visibility. Because of their high levels of nutrients, these lakes have a high NPP.

In warm months the bottom layer of a eutrophic lake often is depleted of dissolved oxygen. 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 and are called **mesotrophic lakes.**

What Seasonal Changes Occur in Temperate Lakes? Most substances become denser as they go from gaseous to liquid to solid physical states. Water does not follow this typical behavior; it is densest as a liquid at 4°C (39°F). In other words, solid ice at 0°C (32°F) is less dense than liquid water at 4°C (39°F), which is why ice floats on water.

This unusual property of water causes *thermal stratification* of deep lakes in temperate areas (Figure 7-22, p. 159). During the summer these lakes have the following three distinct layers characterized by different temperatures:

- *Epilimnion* ("ep-eh-LIM-knee-on"): an upper layer of warm water with high levels of dissolved oxygen.
- *Thermocline* ("THUR-moe-cline"): where the water temperature changes rapidly with depth and with moderate levels of dissolved oxygen.
- *Hypolimnion* ("high-poe-LIM-knee-on"): a lower layer of colder, denser water, usually with a lower concentration of dissolved oxygen because it is not exposed to the atmosphere. During the summer the thermocline acts as a barrier preventing the transfer of nutrients and dissolved oxygen between the epilimnion and hypolimnion.

In the fall, the surface water gradually cools, becomes denser, and sinks to the bottom when it cools to 4°C (39°F), and the thermocline disappears (Figure 7-22, top right). This mixing, or *fall overturn,* **(1)** brings nutrients from bottom sediments to the surface, **(2)** brings dissolved oxygen from the surface to the bottom, and **(3)** allows fish to live at various depths.

During the winter the colder temperatures cause the lake to separate into layers of different density (Figure 7-22, bottom left). In the spring, the lake's surface water reaches maximum density when it warms to 4°C (39°F) and sinks through and below the cooler, less dense water. Winds blowing across the lake's surface cause strong vertical currents that mix the surface and bottom water. This brings dissolved oxygen from the surface to the bottom and nutrients from the bottom to the surface. During this brief *spring overturn,* the temperature of the lake and dissolved oxygen levels are roughly the same at all depths (Figure 7-22, bottom right).

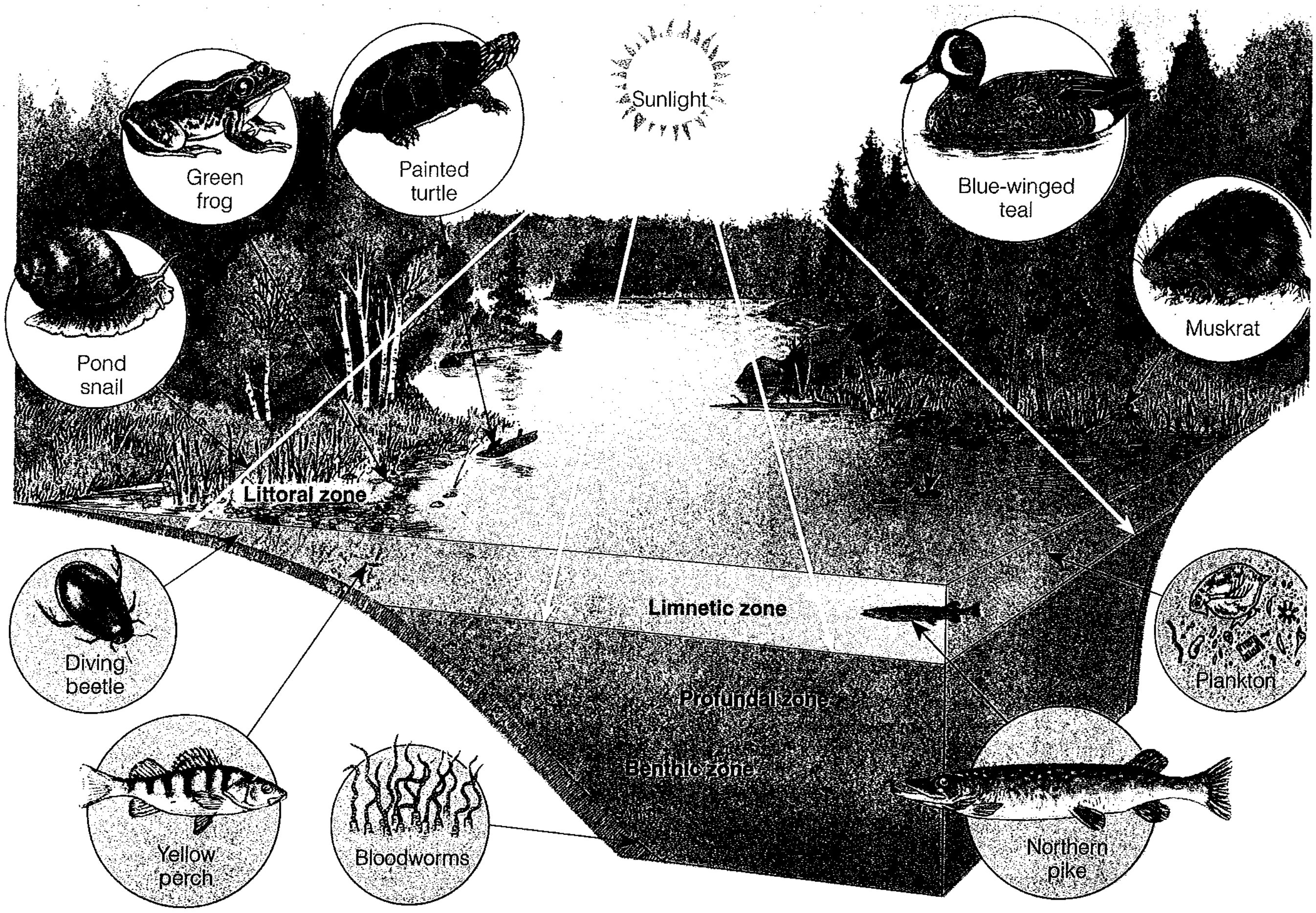


Figure 7-20 The distinct zones of life in a fairly deep temperate zone lake.

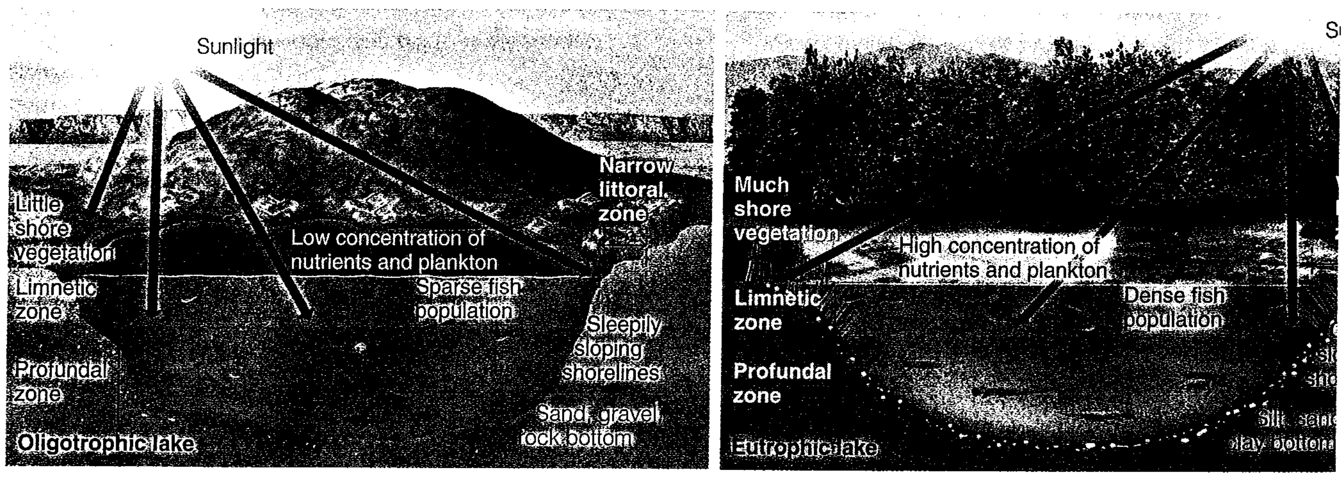


Figure 7-21 An *oligotrophic*, or nutrient-poor, lake (left) and a *eutrophic*, or nutrient-rich, lake (right). Mesotrophic lakes fall between these two extremes of nutrient enrichment. Nutrient inputs from human activities can accelerate eutrophication.

What Are the Major Characteristics of Freshwater Streams and Rivers? Precipitation that does not sink into the ground or evaporate is **surface water.** It becomes **runoff** when it flows into streams. The land area that delivers runoff, sediment, and dissolved substances to a stream is called a **watershed,** or **drainage basin.** Small streams join to form rivers, and rivers flow downhill to the ocean (Figures 7-2 and 7-23, p. 160) as part of the hydrologic cycle (Figure 4-27, p. 83).

In many areas, streams begin in mountainous or hilly areas that collect and release water falling to the earth's surface as rain or snow. The downward flow of surface water and groundwater from mountain highlands to the sea takes place in three different aquatic life zones with different environmental conditions: the **(1)** *source zone,* **(2)** *transition zone,* and **(3)** *floodplain zone* (Figure 7-23, p. 160).

In the first, narrow *source zone* (Figure 7-23, top), headwater or mountain highland streams of cold, clear water rush over waterfalls and rapids. As this turbulent water flows and tumbles downward, it dissolves large amounts of oxygen from the air so photosynthesis is a less important source of oxygen than it is in ponds and lakes. Here plants such as algae and mosses are attached to rocks and the zone is populated by cold-water fish (such as trout in some areas), which need lots of dissolved oxygen. Many fish and other animals in headwater streams have compact and flattened bodies that allow them to live under stones.

In the *transition zone* (Figure 7-23, middle), the headwater streams merge to form wider, deeper streams that flow down gentler slopes with fewer obstacles. The warmer water and other conditions in this zone support more producers (phytoplankton) and a variety of cool-water and warm-water fish species (such as black bass) with slightly lower oxygen requirements. Figure 7-24 (p. 161) shows some species and interactions in the transition zone of a river in a tropical forest.

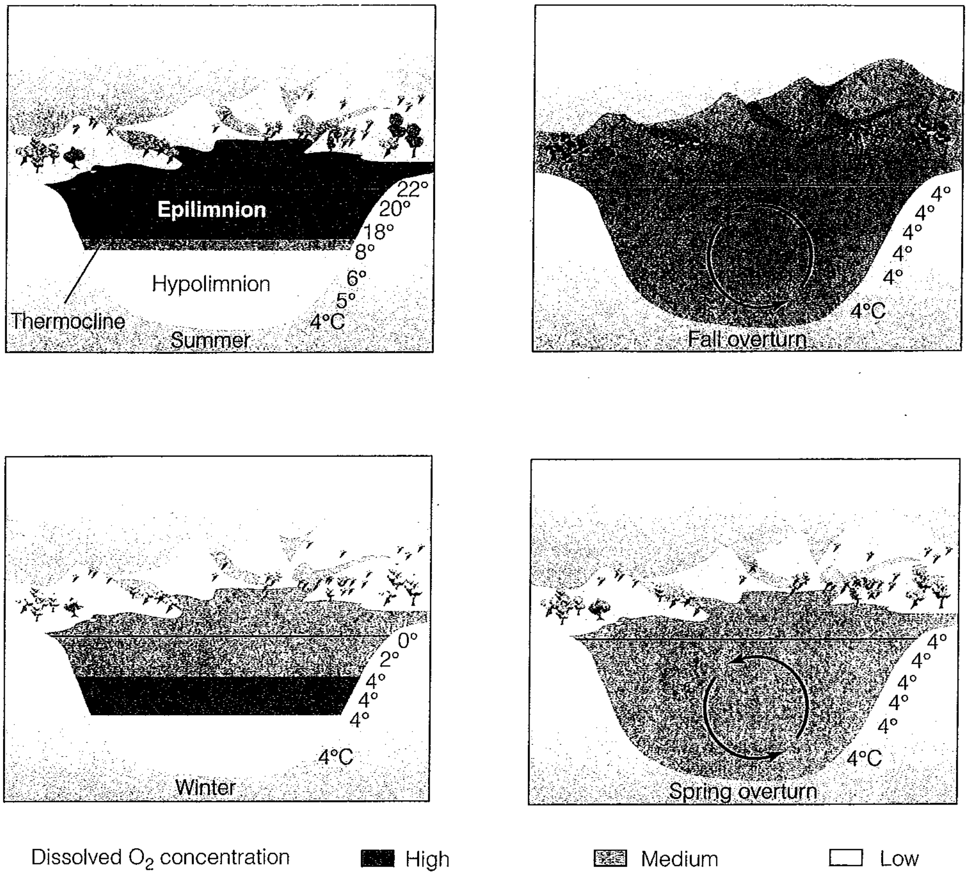


Figure 7-22 During the summer and winter, the water in deep temperate zone lakes becomes stratified into different temperature layers, which do not mix. Twice a year, in the fall and spring, the waters at all layers of these lakes mix in overturns that equalize the temperature at all depths. These overturns bring **(1)** oxygen from the surface water to the lake bottom and **(2)** nutrients from the lake bottom to the surface waters.

In the *floodplain zone* (Figure 7-23, bottom), streams join into wider and deeper rivers that meander across broad, flat valleys. Water in this zone usually has higher temperatures and less dissolved oxygen than water in the first two zones. These slow-moving rivers sometimes support fairly large populations of producers such as algae and cyanobacteria and rooted aquatic plants along the shores. Because of increased erosion and runoff over a larger area, water in this zone often is muddy and contains high concentrations of suspended particulate matter (silt). The main channels of these slow-moving, wide, and murky rivers support distinctive varieties of fish (carp and catfish), whereas their backwaters support species similar to those present in lakes. At its mouth, a river may divide into many channels as it flows through coastal wetlands and estuaries, where the river water mixes with ocean water (Figure 7-8).

As streams flow downhill, they become powerful shapers of land. Over millions of years the friction of

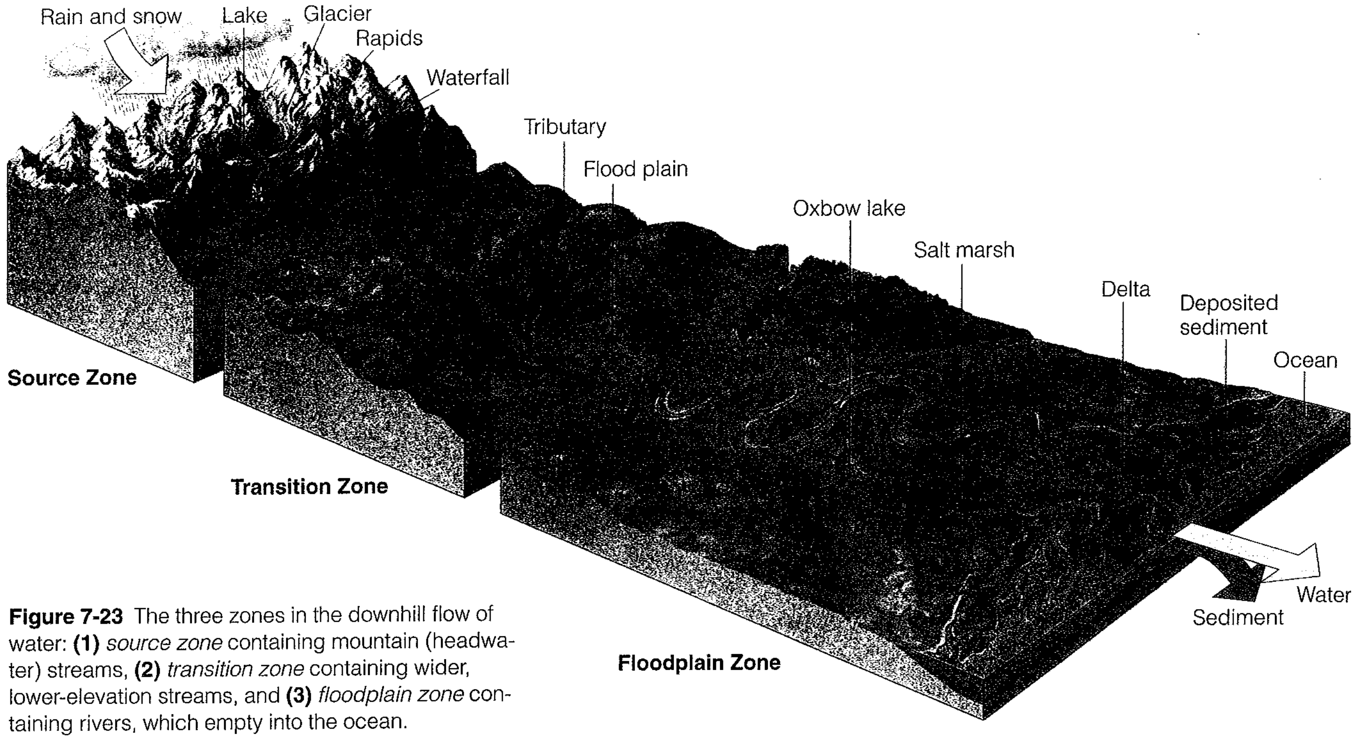


Figure 7-23 The three zones in the downhill flow of water: **(1)** *source zone* containing mountain (headwater) streams, **(2)** *transition zone* containing wider, lower-elevation streams, and **(3)** *floodplain zone* containing rivers, which empty into the ocean.

moving water levels mountains and cuts deep canyons, and the rock and soil the water removes are deposited as sediment in low-lying areas.

Streams are fairly open ecosystems that receive many of their nutrients from bordering land ecosystems. 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, the land around it.

What Are Freshwater Inland Wetlands? **Inland wetlands** are lands covered with fresh water all or part of the time (excluding lakes, reservoirs, and streams) and located away from coastal areas (Figure 7-25, p. 162). They include **(1)** *marshes* with few trees (Figure 7-25, bottom), **(2)** *swamps* dominated by trees and shrubs (Figure 7-25, middle), **(3)** *prairie potholes,* which are depressions carved out by glaciers (Figure 7-25, top), **(4)** *floodplains,* which receive excess water during heavy rains and floods (Figure 7-23, bottom), **(5)** *bogs* and *fens* that have waterlogged soils, which tend to accumulate peat, and may or may not have trees, and **(6)** *wet arctic tundra* in summer.

Some of these wetlands are covered with water year round. Others, called *seasonal wetlands,* usually are underwater or soggy for only a short time each year. They include prairie potholes (Figure 7-25, top), floodplain wetlands, and bottomland hardwood swamps. Some stay dry for years before being covered with water 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 really a wetland.

Inland wetlands need to be protected because of the important ecological and economic roles they play (Figure 7-19). For example, according to conservative estimates by the Audubon Society, inland wetlands in the United States provide **(1)** water quality protection worth at least $1.6 billion per year and **(2)** flood control worth $7.7–31 billion per year.

What Are the Impacts of Human Activities on Freshwater Systems? Here are some major impacts of human activities on freshwater systems:

- According to a 2000 study by the World Resources Institute, almost 60% of the world's 237 large rivers are strongly or moderately fragmented by dams, diversions, or canals. This alters and destroys wildlife habitats along rivers and in coastal deltas and estuaries by reducing water flow.
- Flood control levees and dikes built along rivers **(1)** alter and destroy aquatic habitats, **(2)** disconnect rivers from their floodplains, and **(3)** eliminate wetlands and backwaters that are important spawning grounds for fish.

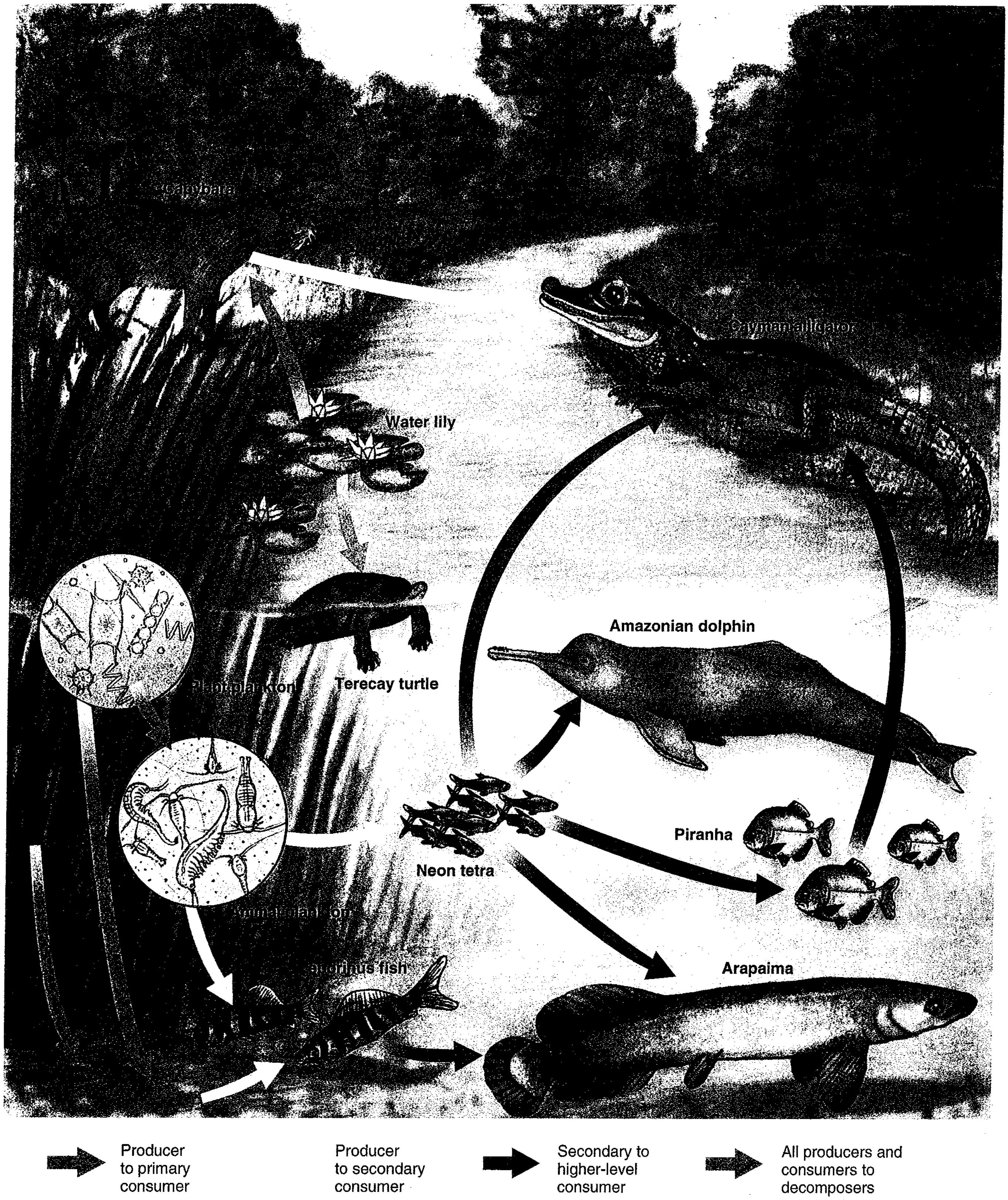


Figure 7-24 Some components and interactions in a river in a tropical forest. When these organisms die, decomposers break down their organic matter into minerals used by plants. Colored arrows indicate transfers of matter and energy between producers, primary consumers (herbivores), secondary (or higher-level) consumers, and decomposers. Organisms are not drawn to scale.

■ In the United States, 53% of the inland wetlands estimated to have existed in the lower 48 states during the 1600s have been drained or filled to grow crops (about 80% of wetland loss) or have been covered up with concrete, asphalt, and buildings. This has been an important factor in increased flood and drought damage in the United States. Many other countries have suffered similar losses.

7-4 SUSTAINABILITY OF AQUATIC LIFE ZONES

How Sustainable Are Aquatic Ecosystems? The *bad news* in terms of human impacts is that each stream, river, and lake reflects the sum of all that occurs in their watersheds. Also, many of the nutrients, wastes, and pollutants produced by human activities end up in the

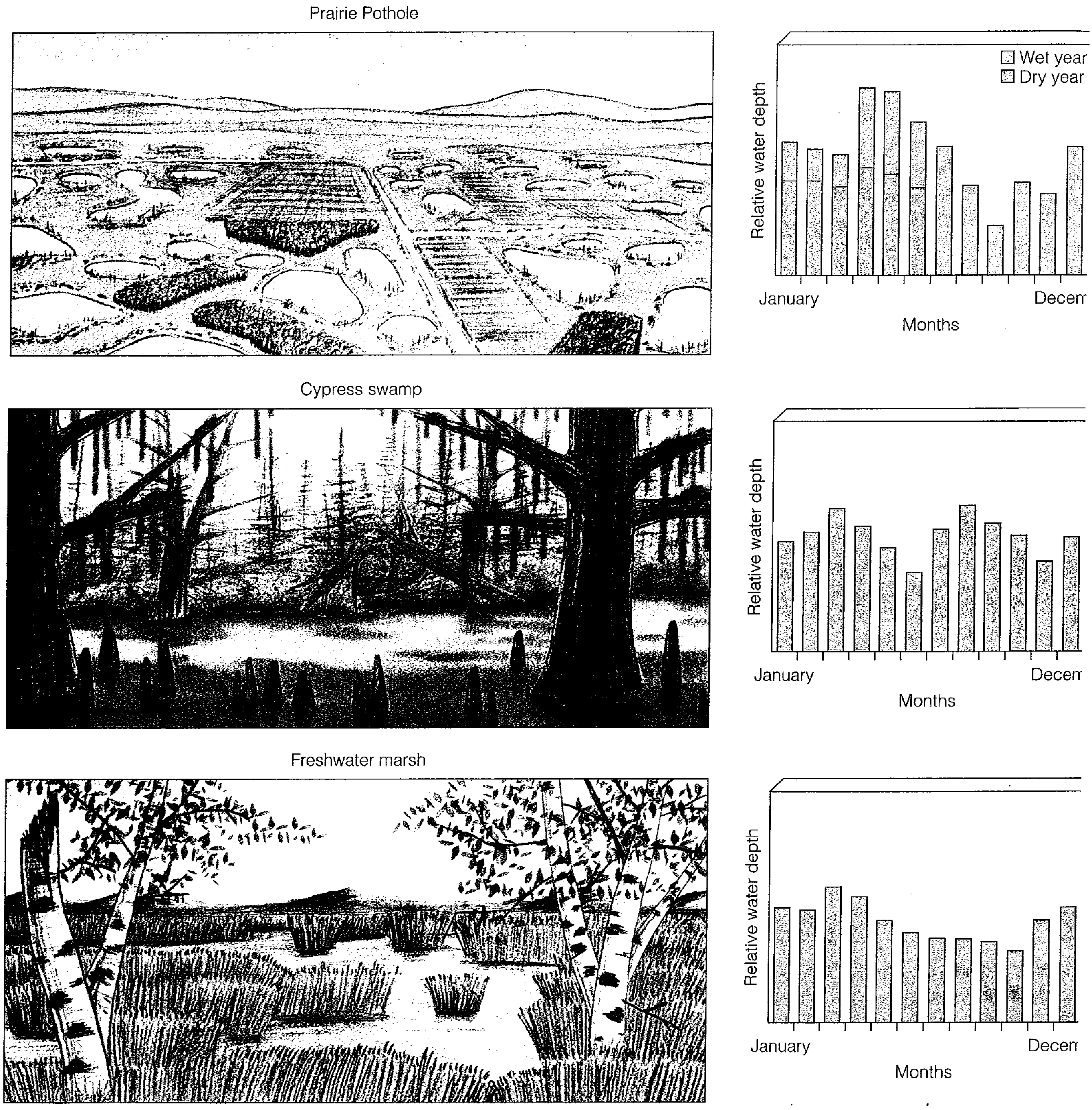


Figure 7-25 Inland wetlands are not always wet. The graphs show the fluctuating water levels of three types of inland wetlands. (Data from Jon A. Kusler, William J. Mitsch, and Joseph S. Larson, 1994)

ocean. Recent research also shows that many of the chemicals reaching aquatic systems come from the atmosphere.

The *good news* is that aquatic life zones are constantly renewed because **(1)** water is purified by natural hydrologic processes (Figure 4-27, p. 83), **(2)** nutrients cycle in and out, and **(3)** populations of biological organisms can be replenished, given sufficient opportunity and time. However, these life-sustaining processes work only if they are not **(1)** overloaded with pollutants and excessive nutrients and **(2)** overfished.

Scientists have made a start in understanding important aspects of the ecology of the aquatic systems discussed in this chapter and of terrestrial systems (see Chapter 6). One of the main lessons from such research is that in nature *everything is connected.* Most aquatic life zones are connected by flows of water and nutrients from one type to another. In addition, nutrients and pollutants flowing from the land and deposited from the atmosphere affect the ecological processes of aquatic systems.

According to scientists, we urgently need more research on how the world's terrestrial and aquatic systems work. With such information we will have a clearer picture of **(1)** the impacts of our activities on the earth's biodiversity and **(2)** what we can do to live more sustainably.

All at last returns to the sea—to Oceanus, the ocean river, like the ever-flowing stream of time, the beginning and the end.

RACHEL CARSON

REVIEW QUESTIONS

1. Define the boldfaced terms in this chapter.

2. What are *coral reefs* and *coral polyps?* How are coral reefs formed? List seven ecological and economic services that coral reefs provide. What is *coral bleaching,* and what are its main causes?

3. What are the two major types of aquatic life zones?

4. Distinguish among *phytoplankton, zooplankton, nekton, benthos,* and *decomposers* found in saltwater and freshwater life zones.

5. Describe major advantages and disadvantages of living in an aquatic environment.

6. List four major factors determining the types and numbers of organisms found in the surface, middle, and bottom layers of aquatic systems. How do the concentrations of carbon dioxide and dissolved oxygen vary in these three layers? What is the *euphotic zone?*

7. List the major ecological and economic services provided by the world's marine systems.

8. What is the *coastal zone?* Distinguish among *estuaries, coastal wetlands,* and *mangroves.* List three reasons why temperature and salinity vary widely in estuaries and coastal wetlands, and explain why they have such a high NPP.

9. What is the *intertidal zone?* Distinguish between *rocky shores* and *sandy beaches,* and describe the major types of aquatic life found in each. Why is it important to preserve the dunes on barrier beaches?

10. What are *barrier islands?* Why are they so attractive for human development, and why are human structures built there so vulnerable to destruction?

11. What are the three main groups of organisms found in coral reefs? List three reasons why coral reefs are vulnerable to damage. List 10 harmful impacts of human activities on coral reefs. Describe recent frontier research indicating that coral bleaching may not be as fatal to reefs as we once thought.

12. What is the *open sea,* and what are its three major zones? Why is the NPP per unit of area so low in the open sea?

13. List six major harmful human impacts on coastal zones.

14. What is a *freshwater life zone,* and what are the two major types of such zones?

15. List the major ecological and economic services provided by freshwater systems.

16. What is a *lake?* Distinguish among the *littoral, limnetic, profundal,* and *benthic zones* of a lake.

17. What are the three types of lakes, based on their nutrient content and primary productivity?

18. Describe the seasonal changes that can take place in deep lakes in northern temperate areas. What three layers are found in such lakes during the summer? What happens to these layers and to levels of dissolved oxygen and nutrients in such lakes during the fall, winter, and spring?

19. Distinguish among *surface water, runoff,* and a *watershed.* Describe the properties and general forms of life found in the three zones of a river as it flows from mountain highlands to the sea.

20. What are *inland wetlands?* List six examples of such wetlands. What are *seasonal inland wetlands?*

21. List three major harmful human impacts on freshwater systems.

22. Summarize *bad* and *good* news about the sustainability of aquatic systems.

23. Explain why a study of terrestrial and aquatic systems reinforces the basic ecological principle that *everything is connected.*

CRITICAL THINKING

1. List a limiting factor for each of the following: **(a)** the surface layer of a tropical lake, **(b)** the surface layer of the open sea, **(c)** an alpine stream, **(d)** a large, muddy river, **(e)** the bottom of a deep lake.

2. Why do terrestrial organisms evolve tolerances to broader temperature ranges than aquatic organisms? Why do aquatic plants tend to be very small (e.g., phytoplankton), whereas most terrestrial plants tend to be larger (e.g., trees) and have more specialized structures for growth (e.g., stems and leaves)? Why are some aquatic animals (especially marine mammals) extremely large compared with terrestrial animals?

3. How would you respond to someone who proposes that we use the deep portions of the world's oceans to deposit our radioactive and other hazardous wastes because the deep oceans are vast and are located far away from human habitats? Give reasons for your response.

4. What factors in your lifestyle contribute to the destruction and degradation of coastal and inland wetlands?

5. Someone tries to sell you several brightly colored pieces of dry coral. Explain in biological terms why this transaction is probably fraudulent.

6. Developers want to drain a large area of inland wetlands in your community and build a large housing development. List **(a)** the main arguments the developers would use to support this project and **(b)** the main arguments ecologists would use in opposing this project. If you were an elected city official, would you vote for or against this project? Can you come up with a compromise plan?

7. You are a defense attorney arguing in court for sparing an undeveloped old-growth tropical rain forest and a coral reef from severe degradation or destruction by development. Write your closing statement 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?

PROJECTS

1. Search for information about mangrove trees, using the Internet and library. Are the different species of mangrove trees closely related? What characteristics do they have in common? What characteristics do they have that make them a good place for fish to breed?

2. If possible, visit a nearby lake, pond, or reservoir. Would you classify it as oligotrophic, mesotrophic, or eutrophic? What are the primary factors contributing to its nutrient enrichment? Which of these factors are related to human activities?

3. Examine a topographic map for the area around a stream or lake near where you live to define the watershed for the stream. What human activities occur in the watershed? What influence, if any, do you expect these activities to have on the ecology of the stream or lake?

4. Use the library or the Internet to find bibliographic information about *Loren Eisley* and *Rachel Carson*, whose quotes appear at the beginning and end of this chapter.

5. Make a concept map of this chapter's major ideas, using the section heads and subheads and the key terms (in boldface). Look on the website for this book for information about making concept maps.

INTERNET STUDY RESOURCES AND RESOURCES FOR FURTHER READING AND RESEARCH

WWW.

The website for this book contains helpful study aids and many ideas for further reading and research. Log on to

http://www.info.brookscole.com/miller13

and click on the Chapter-by-Chapter area. Choose Chapter 7 and select a resource:

- Flash Cards allows you to test your mastery of the Terms and Concepts to Remember for this chapter.
- Tutorial Quizzes provides a multiple-choice practice quiz.
- Student Guide to InfoTrac will lead you to Critical Thinking Projects that use InfoTrac College Edition as a research tool.
- References lists the major books and articles consulted in writing this chapter.
- Hypercontents takes you to an extensive list of sites with news, research, and images related to individual sections of the chapter.

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or access InfoTrac through the website for this book. Try to find the following articles:

1. Taylor, P. 2001. Phantoms of the deep—What are stingrays doing in a freshwater Florida spring? The answer is found in these ocean creatures' unusual adaptations. *National Wildlife* (August–September). *Keywords:* "freshwater stingrays." In Florida's St. Johns River, there is a large population of what is usually considered a saltwater species: the Atlantic stingray. This article looks at the ways in which these fish make the transition from a saltwater to a freshwater environment.

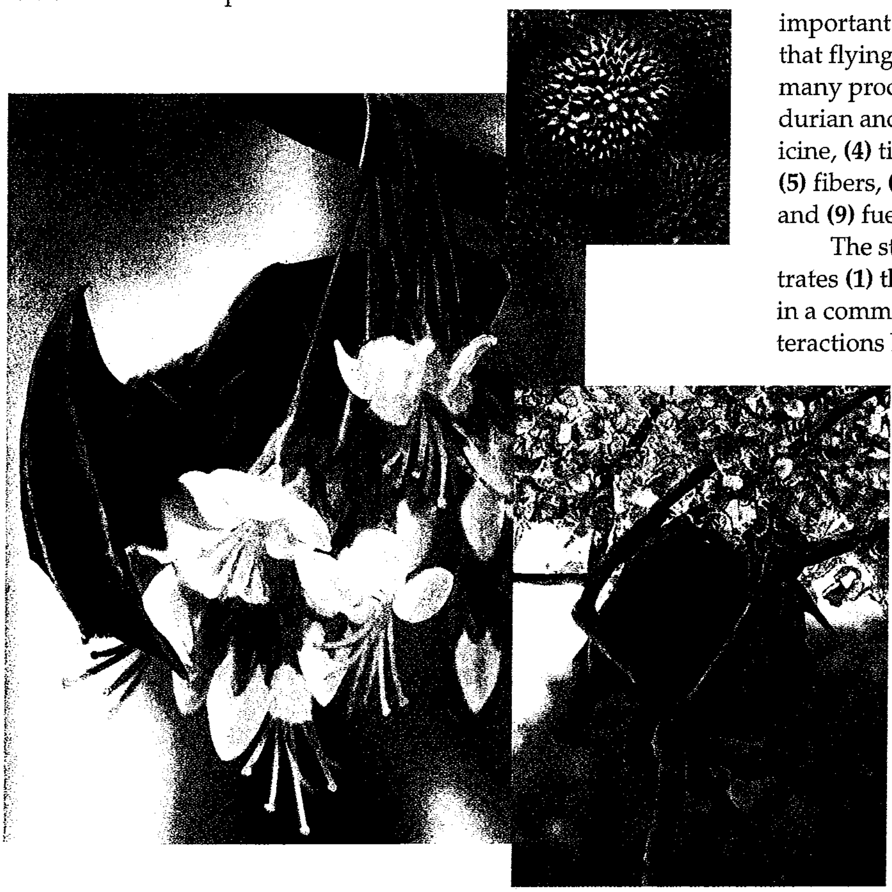
2. Valiela, I, J. L. Bowen, and J. K. York. 2001. Mangrove forests: One of the world's threatened major tropical environments. *BioScience* 51: 807. *Keywords:* "mangrove" and "deforestation." The loss of mangrove forests has not received the type of media attention that has characterized human activities in other ecosystems. However, the coastal mangrove forests of tropical and subtropical areas support a wide array of important ecological functions.

8 COMMUNITY ECOLOGY: STRUCTURE, SPECIES INTERACTIONS, SUCCESSION, AND SUSTAINABILITY

Flying Foxes: Keystone Species in Tropical Forests

The durian (Figure 8-1, top right) is one of the most prized fruits growing in Southeast Asian tropical forests. The odor of this football-sized fruit is so strong, it is illegal to have them on trains and in many hotel rooms in Southeast Asia. However, its custard-like flesh has been described as "exquisite," "sensual," "intoxicating," and "the world's finest fruit."

Durian fruits come from a wild tree that grows in the tropical rain forest. The tree depends on nectar- and pollen-feeding various species of bats called flying foxes (Figure 8-1, left and bottom right) to pollinate the flowers that hang high in the durian trees. Pollination by flying foxes is an example of *mutualism:* an interaction between two species in which both species benefit. Hundreds of tropical plant species depend entirely on various flying fox species for pollination and seed dispersal.



Many species of flying foxes are listed as *endangered,* and most populations are much smaller than historic numbers. One reason for these population declines is *deforestation.* Another is *hunting* of these bat species for their meat, which is sold in China and other parts of Asia. The bats also are viewed as pests and are killed to keep them from eating commercially grown fruits (even though these fruits are picked green). Flying foxes are easy to hunt because they tend to congregate in large numbers when they feed or sleep.

According to ecologists, flying foxes are *keystone species* in tropical forest ecosystems. They are important for **(1)** the plant species they pollinate, **(2)** the plant seeds they disperse in their droppings (which help maintain forest biodiversity and regenerate deforested areas), and **(3)** the many other species that depend on them.

Rain forest ecologists are concerned that the decline of flying fox populations could lead to a cascade of linked extinctions. Their decline also has important economic effects. Studies have shown that flying foxes are economically important for many products including **(1)** fruits (such as the durian and wild bananas), **(2)** other foods, **(3)** medicine, **(4)** timber (such as ebony and mahogany), **(5)** fibers, **(6)** dyes, **(7)** medicines, **(8)** animal fodder, and **(9)** fuel.

The story of flying foxes and durians illustrates **(1)** the unique role (niche) of each species in a community or ecosystem and **(2)** how interactions between species can affect ecosystem structure and function. This chapter discusses these topics and the subjects of *community structure, ecological succession,* and *ecosystem sustainability.*

Figure 8-1 Flying foxes (left and bottom right) are bats that play key ecological roles in tropical rain forests in Southeast Asia by pollinating (left) and spreading the seeds of durian trees that produce durians, a highly prized tropical fruit (top right).

What is this balance of nature that ecologists talk about?
STUART L. PIMM

This chapter addresses the following questions:

- What determines the number of species in a community?
- How can we classify species according to their roles?
- How do species interact with one another?
- How do communities and ecosystems change as environmental conditions change?
- Does high species diversity increase the stability of ecosystems?

8-1 COMMUNITY STRUCTURE: APPEARANCE AND SPECIES DIVERSITY

What Is Community Structure? One property of a community or ecosystem is the *structure* or *spatial distribution* of its individuals and populations. Ecologists usually describe the structure of a community or ecosystem in terms of four characteristics:

- *Physical appearance:* relative sizes, stratification, and distribution of its populations and species
- *Species diversity or richness:* the number of different species
- *Species abundance:* the number of individuals of each species
- *Niche structure:* the number of ecological niches (Section 5-3, p. 103), how they resemble or differ from each other, and how they interact (species interactions)

How Do Communities Differ in Physical Ap pearance and Population Distribution? Th types, relative sizes, and stratification of plants and ani mals vary in different terrestrial communities anc biomes (Figure 8-2). Marked differences are also appar ent in the physical structures of different types o aquatic life zones such as (1) oceans (Figure 7-7, p. 148) (2) rocky shores and sandy beaches (Figure 7-12, p. 151) (3) lakes (Figure 7-20, p. 158), (4) river systems (Fig ure 7-23, p. 160), and (5) inland wetlands (Figure 7-25 p. 162).

The physical structure within a particular type c community or ecosystem also can vary. A close look a most large terrestrial communities, ecosystems, an biomes reveals that they usually consist of a mosaic c *vegetation patches* of differing size. This leads to a comb nation of (1) fairly sharp edges or boundaries such a that between a forest and an open field and (2) wider an more diffuse *ecotones*, or transition zones, between on patch or community and another (Figure 4-10, p. 71).

Differences in the physical structure and physic properties (such as sunlight, temperature, wind, an humidity) at boundaries and in transition zone between two ecosystems (*ecotones*) are called **edg effects.** For example, the edge area between a fore and an open field may (1) be sunnier, warmer, and dri than the forest interior and (2) have a different comb nation of species than the forest and field interiors.

Popular wild game animals, such as pheasan and white-tailed deer, often are more plentiful in edg and ecotones between forests and fields. Wild gan managers sometimes create patches and edges increase populations of such species for sport hunter

However, increased edge area from habitat fra mentation (1) makes many species more vulnerable stresses such as predators and fire and (2) cr ates barriers that can prevent some speci from colonizing new areas and findi food and mates.

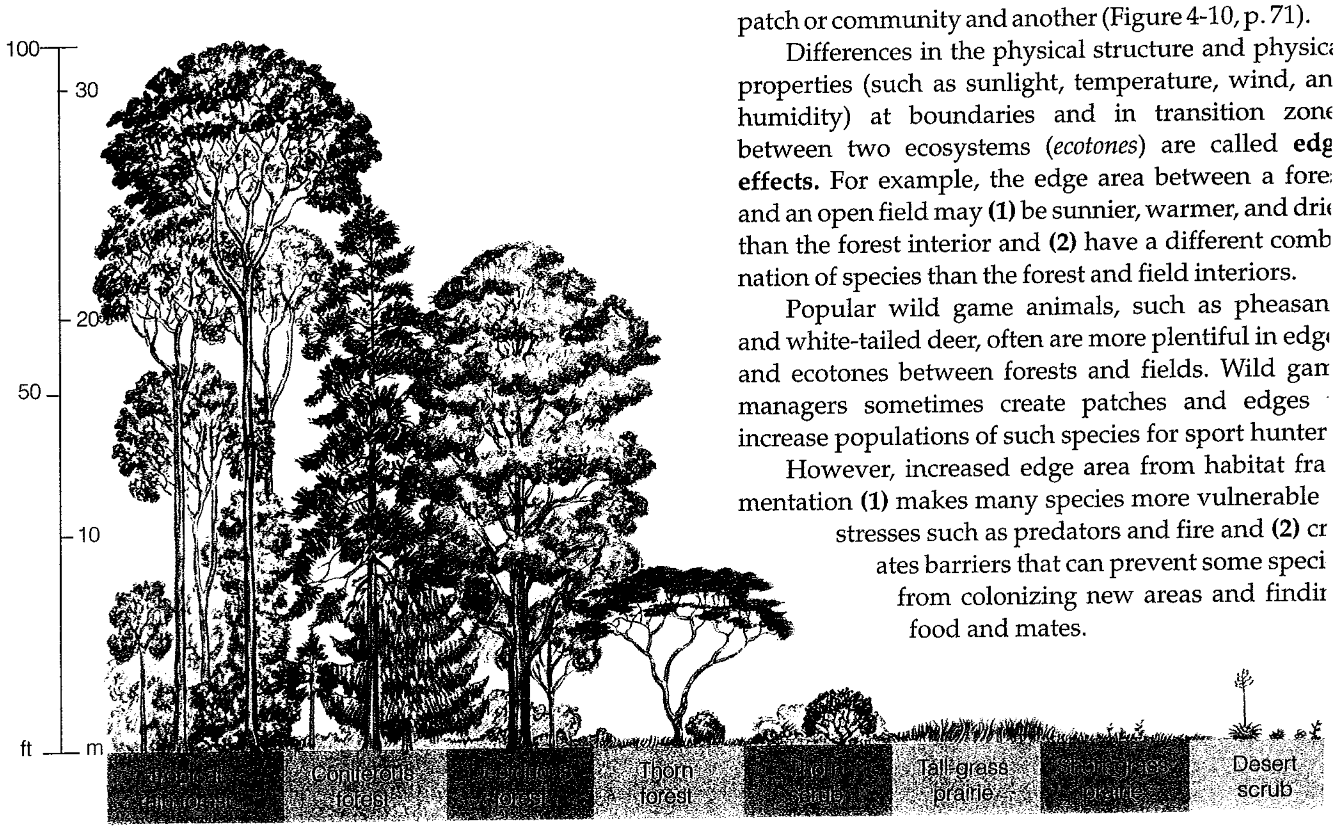


Figure 8-2 Generalized types, relative sizes, and stratification of plant species in various terrestrial communities or ecosystems.

Where Is Most of the World's Biodiversity Found? Studies indicate that the most species-rich environments are **(1)** tropical rain forests (Figure 6-35, p. 136), **(2)** coral reefs (Figure 7-1, p. 144, and Figure 7-16, p. 154), **(3)** the deep sea, and **(4)** large tropical lakes.

Communities such as a tropical rain forest or a coral reef with a large number of different species (high species diversity) generally have only a few members of each species (low species abundance).

During field investigations, ecologists have found that three major factors affect species diversity:

- *Latitude* (distance from the equator) in terrestrial communities. Research shows that for most groups of plants and animals, species diversity on continents decreases steadily with distance from the equator toward either pole (Figure 8-3 and Figure 6-22, right, p. 124). This *latitudinal species diversity gradient* leads to **(1)** the highest species diversity in tropical areas such as tropical rain forests (Figure 6-35, p. 136) and **(2)** the lowest in polar areas such as arctic tundra (Figure 6-32, p. 133). For example, the typical number of tree species per hectare (2.5 acres) is about 40–100 in a tropical forest, 10–30 in a temperate forest (Figure 6-38, p. 138), and 1–5 in a northern coniferous (taiga) forest (Figure 6-40, p. 140).
- *Depth* in aquatic systems. Research shows that in marine communities, species diversity increases from the surface to a depth of 2,000 meters (6,600 feet) and then begins to decline with depth (Figure 8-4) until the deep sea bottom is reached, where species diversity is very high.
- *Pollution* in aquatic systems. Research shows a decrease in species diversity and species abundance in aquatic systems as pollution increases and kills off or

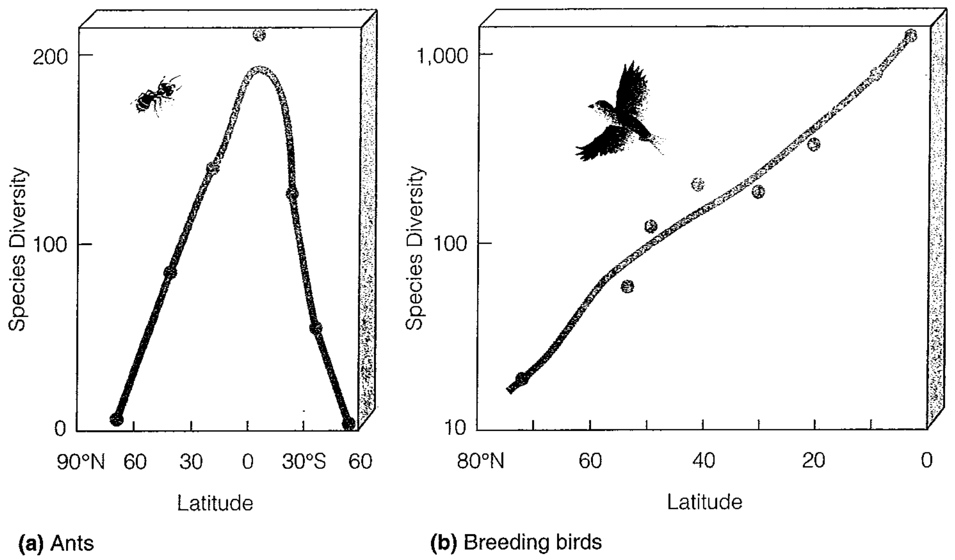


Figure 8-3 Changes in species diversity at different latitudes (distances from the equator) in terrestrial communities for **(a)** ants and **(b)** breeding birds of North and Central America. As a general rule, species diversity steadily declines as we go away from the equator toward either pole. (Adapted from Cecie Starr, *Biology: Concepts and Applications*, 4th ed. Brooks/Cole [Wadsworth] © 2000)

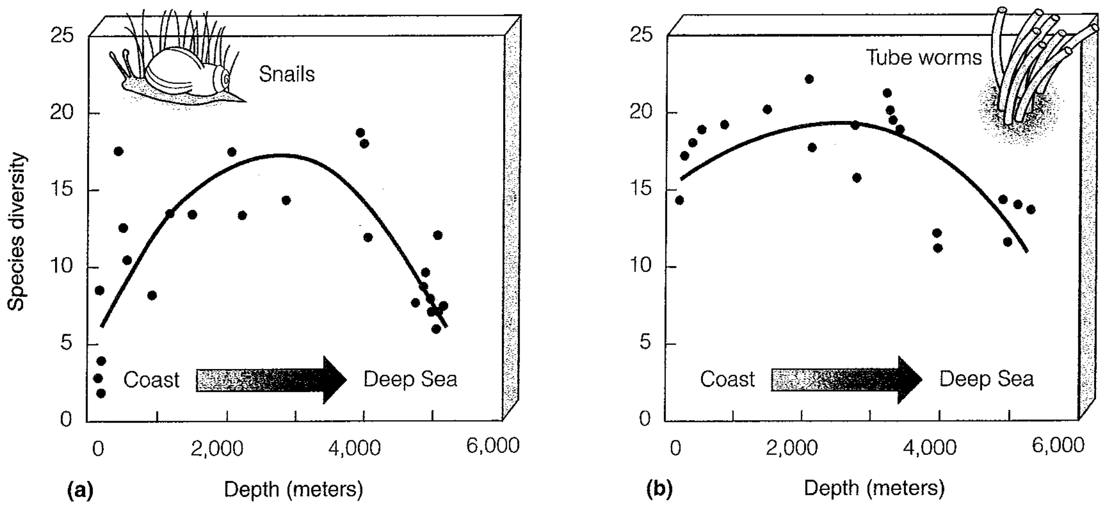


Figure 8-4 Changes in species diversity with depth in marine environments for **(a)** snails and **(b)** tube worms. As a general rule, species diversity in the ocean **(1)** increases from the surface to a depth of about 2,000 meters and **(2)** decreases until the sea bottom, where species diversity is usually high.

impairs the reproductivity of various aquatic species (Figure 8-5, p. 168).

In terrestrial communities, species diversity tends to increase with **(1)** increasing solar radiation, **(2)** increasing precipitation, **(3)** decreasing elevation (Figure 6-22, left, p. 124), and **(4)** pronounced seasonal variations.

What Determines the Number of Species on Islands? Two factors affecting the species diversity found in an isolated ecosystem such as an island are its *size* and *degree of isolation.* In the 1960s, Robert MacArthur and Edward O. Wilson began studying communities on islands to discover why large islands tend to have more species of a certain category (such as insects, birds, or ferns) than do small islands.

To explain these differences in species diversity with island size, MacArthur and Wilson proposed what is called the **species equilibrium model,** or the **theory of island biogeography.** According to this model, the number of species found on an island is determined by a balance between two factors: **(1)** the rate at which new species immigrate to the island and **(2)** the rate at which species become extinct on the island. The model predicts that at some point the rates of immigration and extinction will reach an equilibrium point (Figure 8-6a) that determines the island's average number of different species (species diversity).

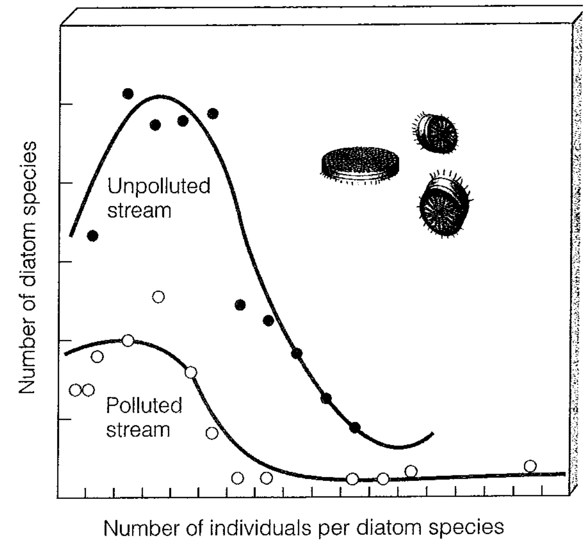


Figure 8-5 Changes in the species diversity and species abı dance of diatom species in an unpolluted stream and a pollut stream. Both species diversity and species abundance decrease with pollution.

The model also predicts that immigration a extinction rates (and thus species diversity) ε affected by two important features of the island: **(1)** *size* (Figure 8-6b) and **(2)** its distance from the near mainland (Figure 8-6c). According to the model,

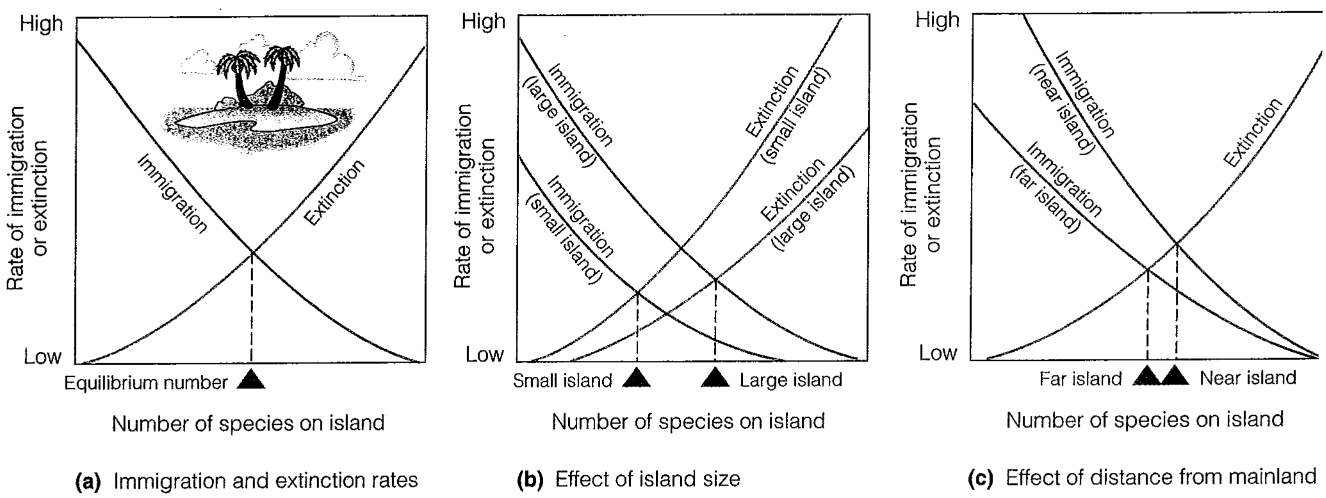


Figure 8-6 The *species equilibrium model* or *theory of island biogeography,* developed by Robert MacArthur and Edward O. Wilson. **(a)** The equilibrium number of species (blue triangle) on an island is determined by a balance between the immigration rate of new species and the extinction rate of species already on the island. **(b)** With time, large islands have a larger equilibrium number of species than smaller islands because of higher immigration rates and lower extinction rates on large islands. **(c)** Assuming equal extinction rates, an island near a mainland will have a larger equilibrium number of species than a more distant island because the immigration rate to a near island is higher than that to a more distant one.

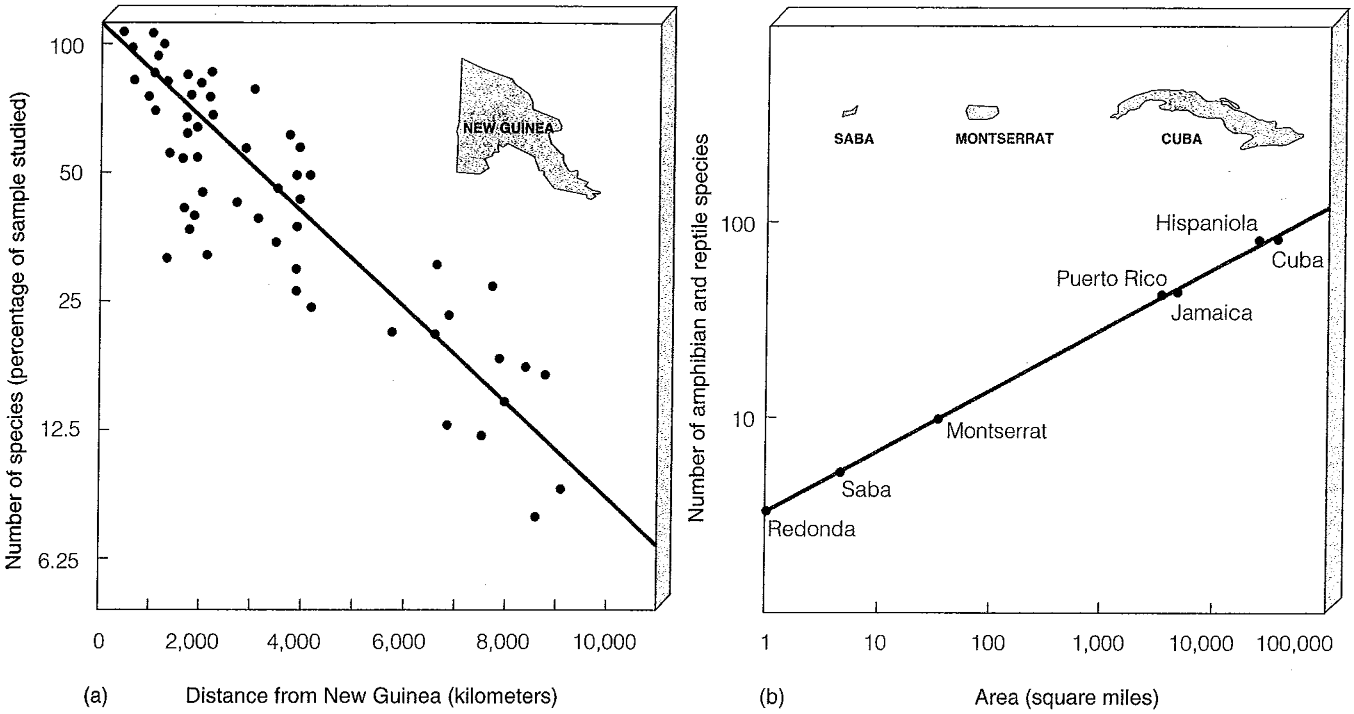


Figure 8-7 Research data supporting the theory of island biogeography with **(a)** the left graph showing that the species diversity of birds occupying lowland areas of South Pacific islands decreases with distance from New Guinea and **(b)** the right graph showing that species diversity increases with island size. (Used by permission from Cecie Starr, *Biology: Concepts and Applications*, 4th ed. Brooks/Cole [Wadsworth] © 2000)

small island tends to have a lower species diversity than a large one for two reasons: **(1)** a small island generally has a lower immigration rate because it is a smaller target for potential colonizers, and **(2)** a small island should have a higher extinction rate because it generally has fewer resources and less diverse habitats for colonizing species.

The model also predicts that an island's distance from a mainland source of new species is important in determining species diversity. For two islands of about equal size and other factors, the island closest to a mainland source of immigrant species will have the higher immigration rate and thus a higher species diversity (assuming that extinction rates on both islands are about the same).

A series of field experiments have tested and supported MacArthur and Wilson's original model or scientific hypothesis (Figure 8-7). As a result, biologists have elevated it to the status of an important and useful scientific theory, although it may apply to a limited number of cases over short periods of time. In recent years, it has also been applied to conservation efforts to protect wildlife on land in *habitat islands* such as national parks surrounded by a sea of developed and fragmented land.

8-2 GENERAL TYPES OF SPECIES

What Different Roles Do Various Species Play in Ecosystems? When examining ecosystems, ecologists often apply particular labels—such as *native, nonnative, indicator,* or *keystone*—to various species to clarify their ecological roles or niches (p. 103). Any given species may function as more than one of these four types in a particular ecosystem.

How Can Nonnative Species Cause Problems? Species that normally live and thrive in a particular ecosystem are known as **native species.** Others that migrate into an ecosystem or are deliberately or accidentally introduced into an ecosystem by humans are called **nonnative species, exotic species,** or **alien species.** Some of these introduced species (such as crops and game species for sport hunting) are beneficial to humans, but some thrive and crowd out native species.

From a human standpoint, introduction of some nonnative species can become a nightmare. In 1957, Brazil imported wild African bees to help increase honey production. Instead, these bees have displaced domestic honeybees and have reduced the honey supply.

Why Are Amphibians Vanishing?

CONNECTIONS

Amphibians (frogs, toads, and salamanders) first appeared about 350 million years ago. These cold-blooded creatures range in size from a frog that can sit on your thumb to a Japanese salamander that is about 1.5 meters (5 feet) long.

Since 1980, populations of hundreds of the world's estimated 5,280 amphibian species (including 2,700 frog and toad species) have been vanishing or declining in almost every part of the world, even in protected wildlife reserves and parks.

In some locales, frog deformities (such as extra legs and missing legs) are occurring in unusually high numbers. This information was discovered and published by schoolchildren in Henderson, Minnesota, who were catching frogs in a farm pond.

According to the World Conservation Union, 25% of all known amphibian species are extinct, endangered, or vulnerable. The Nature Conservancy estimates that 38% of the amphibian species in the United States are endangered.

Frogs are especially vulnerable to environmental disruption at various points in their life cycle (see figure, right). As tadpoles they live in water and eat plants, and as adults they live mostly on land and eat insects (which can expose them to pesticides). Their eggs have no protective shells to block ultraviolet radiation or pollution. As adults, they take in water and air through their thin, permeable skins that can readily absorb pollutants from water, air, or soil.

Although no single cause has been identified to explain the cause of amphibian declines, scientists have identified a number of contributing factors that can affect amphibians such as frogs at various points in their life cycle (see figure, right). They include the following:

- *Habitat loss and fragmentation*, especially because of **(1)** the draining and filling of inland wetlands, **(2)** deforestation, and **(3)** development.

- *Prolonged drought*, which dries up breeding pools so that few tadpoles survive. Dehydration can also weaken amphibians, making them more susceptible to fatal viruses, bacteria, fungi, and parasites.

- *Pollution.* Frog eggs, tadpoles, and adults (see figure, right) are very sensitive to many pollutants (especially pesticides). Exposure to such pollutants may harm their immune and endocrine systems, make them more vulnerable to bacterial infections and skin fungi, and cause an array of sexual abnormalities.

- *Increases in ultraviolet radiation* caused by reductions in stratospheric ozone. This can be especially harmful to young embryos (see figure, right) of amphibians found in shallow ponds.

- *Increased incidence of parasitism* by a flatworm (trematode), which may account for many frog deformities but not the worldwide decline of amphibians.

- *Overhunting*, especially in Asia and France, where frog legs are a delicacy.

- *Epidemic diseases* such as the chytrid fungus and iridoviruses. Pollution and other factors that weaken the immune systems of amphibians may make them more susceptible to these and other disease organisms.

- *Immigration or introduction of nonnative* **(1)** *predators and competitors* (such as fish) and **(2)** *disease organisms* such as the chytrid (which may have been introduced into Australia by imported tropical fish).

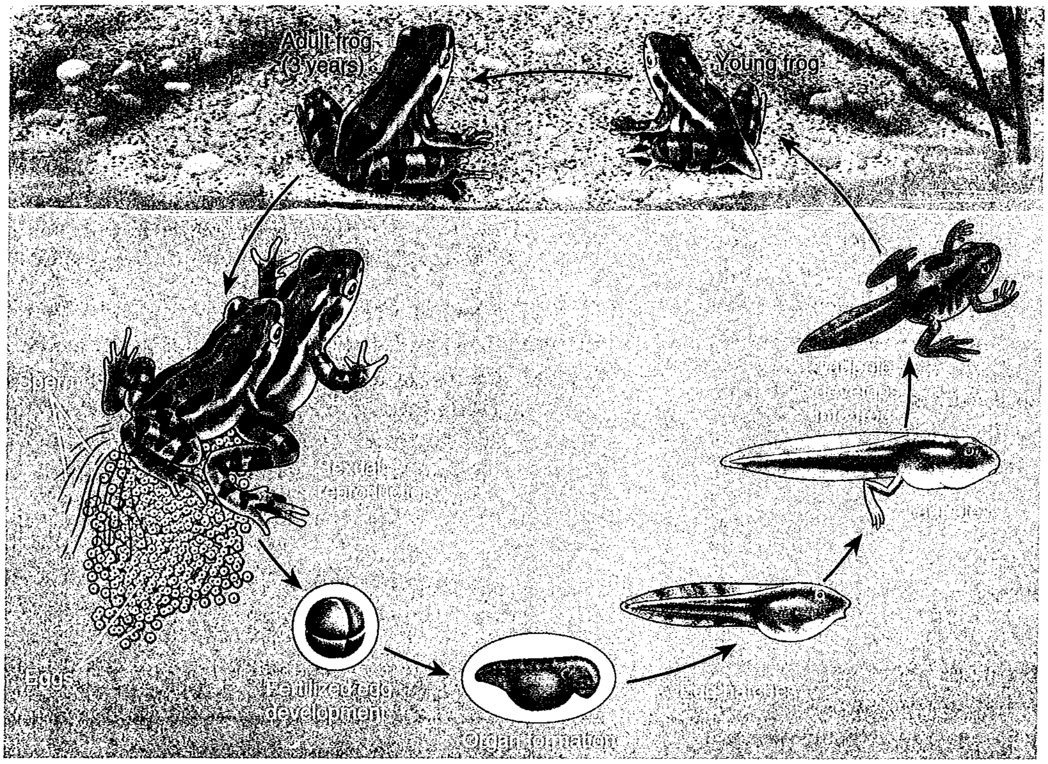
In most cases, the decline or disappearance of amphibian species probably is caused by a combination of such factors. Scientists are concerned about amphibians' decline for three reasons:

- It suggests that the world's environmental health is deteriorating rapidly because amphibians generally are **(1)** tough survivors and **(2)** sensitive biological indicators of changes in environmental conditions such as habitat loss and degradation, pollution, UV exposure, and climate change.

Since then, these nonnative bee species, popularly known as "killer bees," have moved northward into Central America. They have become established in Texas, Arizona, New Mexico, Puerto Rico, and California and are heading north at 240 kilometers (150 miles) per year. They should be stopped eventually by cold winters in the central United States unless they can adapt genetically to cold weather.

Although they are not the killer bees portrayed in some horror movies, these bees are aggressive and unpredictable. They have killed thousands of domesticated animals and an estimated 1,000 people in the western hemisphere. Fortunately, most people not allergic to bee stings can run away. Most of the people killed by these honeybees died because they fell down or became trapped and could not flee.

What Are Indicator Species? Species that serve as early warnings of damage to a community or an ecosystem are called **indicator species.** Birds are ex-



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

- Adult amphibians play important roles in the world's ecosystems. For example, amphibians eat more insects (including mosquitoes) than do birds. In some habitats, extinction of certain amphibian species could also result in extinction of other species, such as reptiles, birds, aquatic insects, fish, mammals, and other amphibians that feed on them or their larvae.

- From a human perspective, amphibians represent a genetic storehouse of pharmaceutical products waiting to be discovered. Hundreds of secretions from amphibian skin have been isolated, and some of these compounds are being used as painkillers and antibiotics and in treating burns and heart disease.

As possible indicator species, amphibians may be sending us an important message. They do not need us, but we and other species need them.

Critical Thinking

On an evolutionary time scale, all species eventually become extinct. Some people suggest that the widespread disappearance of amphibians is the result of natural responses to changing environmental conditions. Others contend that these losses are **(1)** caused mostly by human activities and **(2)** a warning of possible danger for our own species and other species. What is your position? Why?

cellent biological indicators because they are found almost everywhere and respond quickly to environmental change. Research indicates that a major factor in the current decline of some species of migratory, insect-eating songbirds in North America is habitat loss or fragmentation. The tropical forests of Latin America and the Caribbean that are winter habitats for such birds are disappearing rapidly. Their summer habitats in North America also are disappearing or are being fragmented into patches that make the birds more vulnerable to attack by predators and parasites.

The presence or absence of trout species in water at temperatures within their range of tolerance (Figure 4-14, p. 73) is an indicator of water quality because trout need clean water with high levels of dissolved oxygen. Some amphibians (frogs, toads, and salamanders), which live part of their lives in water and part on land, are also classified as indicator species (Connections, above).

What Are Keystone Species? The roles of some species in an ecosystem are much more important than their abundance or biomass suggests. Ecologists call such species **keystone species,** although this designation is controversial.* Such species play pivotal roles in the structure and function of an ecosystem because **(1)** their strong interactions with other species affect the health and survival of these species, and **(2)** they process material out of proportion to their numbers or biomass.

Critical roles of keystone species include **(1)** pollination of flowering plant species by bees, hummingbirds, bats (Figure 8-1), and other species, **(2)** dispersion of seeds by fruit-eating animals such as bats (Figure 8-1), with the undigested seeds scattered in their feces, **(3)** habitat modification, **(4)** predation by top carnivores that helps control the populations of various species, **(5)** improving the ability of plant species to obtain soil minerals and water, and **(6)** efficient recycling of animal wastes. Some species play more than one of these roles.

Beneficial *habitat modifications* by keystone species include the following:

- Elephants push over, break, or uproot trees, creating forest openings in the savanna grasslands and woodlands of Africa. This **(1)** promotes the growth of grasses and other forage plants that benefit smaller grazing species such as antelope and **(2)** accelerates nutrient cycling rates.
- Bats (p. 165) and birds regenerate deforested areas by depositing plant seeds in their droppings.
- Beaver dams can change a fast-moving stream into a pond or lake. This attracts fish (such as bluegill), muskrats, herons, and ducks that prefer deeper, slower-moving water, as well as woodpeckers that feed on dead trees emerging from the pond. However, by felling trees to build dams, beavers can also destroy large expanses of terrestrial forests.

Top predator keystone species exert a stabilizing effect on their ecosystems by feeding on and helping regulate the populations of certain species. Examples are the wolf, leopard, lion, alligator (Connections, p. 173), sea otter, and great white shark.

Have you thanked a *dung beetle* today? You should because these keystone species play a combination of vital roles in the ecosystems where they are found:

- They rapidly remove, bury, and recycle animal wastes (dung). Without them we would be up to our eyeballs in such waste, and many plants would be starved for nutrients.
- They establish new plants because the dung they bury contains seeds that have passed through the digestive tracts of fruit-eating animals.
- They churn and aerate the soil, making it more suitable for plant life.
- They reduce populations of microorganisms that spread disease to wild and domesticated animals (including humans) because the beetle larvae feed on parasitic worms and maggots that live in the dung.

The loss of a keystone species can lead to population crashes and extinctions of other species that depend on it for certain services, a ripple or domino effect that spreads throughout an ecosystem. According to biologist Edward O. Wilson, "The loss of a keystone species is like a drill accidentally striking a power line. It causes lights to go out all over."

*All species play some role in their ecosystems and thus are important. Whereas some scientists consider all species equally important, others consider certain species to be more important than others in helping maintain the structure and function of ecosystems of which they are a part.

8-3 SPECIES INTERACTIONS: COMPETITION AND PREDATION

How Do Species Interact? An Overview When different species in an ecosystem have activities or resource needs in common, they may interact with one another. Members of these species may **(1)** be harmed by, **(2)** benefit from, or **(3)** be unaffected by the interaction. Ecologists identify five basic types of interactions between species: **(1)** *interspecific competition,* **(2)** *predation,* **(3)** *parasitism,* **(4)** *mutualism,* and **(5)** *commensalism.*

How Do Members of the Same Species Compete for Resources? Competition between members of the *same* species for the same resources is called **intraspecific competition.** Intraspecific competition can be intense because members of a particular species compete directly for the same resources.

For example, some plants (especially in deserts) gain a competitive advantage by secreting chemicals that inhibit the growth of seedlings of their own and other species. Other plant species, such as dandelions, compete with other members of their species for living space and soil nutrients by dispersing their seeds to other sites by air (wind), water, or animals.

Another way members of the same species compete is through **territoriality,** in which organisms **(1)** patrol or mark an area around their home, nesting, or major feeding site and **(2)** defend it against members of their own species. Robins chase other robins away from their mating and nesting sites, and rhinos and lions use urine or scent to mark their breeding areas.

Why Should We Care About Alligators?

CONNECTIONS

The American alligator, North America's largest reptile, has no natural predators except humans. This species, which has been around for about 200 million years, 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 considered alligators to be useless and dangerous and hunted them for sport or out of hatred. Between 1950 and 1960, hunters wiped out 90% of the alligators in Louisiana, and by the 1960s, the alligator population in the Florida Everglades also was near extinction.

People who say "So what?" are overlooking the alligator's important ecological role or *niche* in subtropical wetland ecosystems. Alligators dig deep depressions, or gator holes, that **(1)** collect fresh water during dry spells, **(2)** serve as refuges for aquatic life, and **(3)** supply fresh water and food for many animals.

In addition, large alligator nesting mounds provide nesting and feeding sites for herons and egrets. Alligators also eat large numbers of gar (a predatory fish) and thus help maintain populations of game fish such as bass and bream.

As alligators move from gator holes to nesting mounds, they help keep areas of open water free of invading vegetation. Without these ecosystem services, freshwater ponds and shrubs and trees would fill in coastal wetlands in the alligator's habitat, and dozens of species would disappear.

Some ecologists classify the North American alligator as a *keystone species* because of these important ecological roles in helping maintain the structure and function of its natural ecosystems.

In 1967, the U.S. government placed the American alligator on the endangered species list. Protected from hunters, the alligator 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 sometimes are eaten by alligators.

In 1977, the U.S. Fish and Wildlife Service reclassified the American alligator from an *endangered* species to a *threatened* species in Florida, Louisiana, and Texas, where 90% of the animals live. In 1987, this reclassification was extended to seven other states.

Alligators now number perhaps 3 million, most in Florida and Louisiana. It is generally illegal to kill members of a threatened species, but limited kills by licensed hunters are allowed in some areas of Florida, Louisiana, and South Carolina to control the population. To biologists, the comeback of the American alligator from near premature extinction by overhunting is an important success story in wildlife conservation.

The increased demand for alligator meat and hides has created a booming business in alligator farms, especially in Florida. Such success reduces the need for illegal hunting of wild alligators.

Critical Thinking

Some home owners in Florida believe they should have the right to kill any alligator found on their property. Others argue this should not be allowed because **(1)** alligators are a threatened species, and **(2)** housing developments have invaded the habitats of alligators, not the other way around. What is your opinion on this issue? Explain.

A territory is essentially a set of resources a species needs for successful breeding. Factors contributing to a good territory are **(1)** an abundant food supply, **(2)** a good nesting site, **(3)** an absence or low population of predators, and **(4)** an absence of environmental factors that would reduce breeding success.

Territory size varies and is small for robins but large for species such as tigers. Two potential disadvantages of territoriality are **(1)** exclusion of many male members of a population from breeding and **(2)** large energy expenditure in defending the territory.

How Do Members of Different Species Compete for Resources? Competition between members of two or more *different* species for food, space, or any other limited resource is called **interspecific competition.**

As long as commonly used resources are abundant, different species can share them. This allows each species to come closer to occupying the *fundamental niche* it would occupy if there were no competition from other species.

However, most species face competition from other species for one or more limited resources (such as food, sunlight, water, soil nutrients, space, nesting sites, and good places to hide). Because of such *interspecific competition,* parts of the fundamental niches of different species overlap (Figure 5-7, p. 104). The more the niches of two species overlap, the more they compete with one another. With significant niche overlap, one of the competing species must **(1)** migrate to another area (if possible), **(2)** shift its feeding habits or behavior through natural selection and evolution (Section 5-2, p. 100), **(3)** suffer a sharp population decline, or **(4)** become extinct in that area.

Species compete with other species by:

- **Interference competition,** in which one species may limit another's access to some resource, regardless of its abundance, using the same types of methods found in intraspecific competition. For example, a territorial hummingbird species may defend patches of spring wildflowers from which it gets nectar by chasing away members of other hummingbird species. In desert and grassland habitats, many plants release chemicals into the soil. These chemicals prevent the growth of competing species or reduce the rates at which their seeds germinate.
- **Exploitation competition,** in which competing species have roughly equal access to a specific resource but differ in how fast or efficiently they exploit it. The species that can use the resource more quickly **(1)** gets more of the resource and **(2)** hampers the growth, reproduction, or survival of the other species.

Humans are in competition with other species for space, food, and other resources. As we convert more and more of the earth's land and aquatic resources and net primary productivity (Figure 4-26, p. 82) to our uses (Figure 1-5, p. 7, and Figure 1-8, p. 10), we deprive many other species of resources they need to survive.

What Is the Competitive Exclusion Principle? Sometimes one species eliminates another species in a particular area through competition for limited resources. In 1934, Russian ecologist G. F. Gause demonstrated this effect in a laboratory experiment. Two closely related species of single-celled, bac teria-eating *Paramecium* were grown, first separatel and then together in culture tubes (Figure 8-8).

The graph on the left of Figure 8-8 shows wha happened when both species were grown under ider tical conditions in separate containers with ample sup plies of food (bacteria). In this case, both species grev rapidly and established stable populations. Howeve the smaller *Paramecium aurelia* (red curve) grew faste than the larger *Paramecium caudatum* (green curve indicating that the former used the available food sup ply more efficiently than the latter. The graph on th right shows that when both species were grow together in a culture tube with a limited amount c bacteria, the smaller *Paramecium aurelia* (red curve outmultiplied and eliminated the larger *Parameciu caudatum* (green curve).

This research, which has been supported by var ous laboratory and field experiments using other an mal species, showed that two species needing th same resource cannot coexist indefinitely in an ecosys tem in which not enough of that resource is availabl to meet the needs of both species. In other words, th niches of two species cannot overlap completely c significantly for very long. This finding is called th **competitive exclusion principle.**

How Have Some Species Reduced or Avoide Competition? Over a time scale long enough fc evolution to occur, some species that compete for th same resources evolve adaptations that reduce c avoid competition or an overlap of their fundament niches (Figure 5-7, p. 104). One way this happens i through **resource partitioning,** the dividing up c scarce resources so that species with similar needs us them **(1)** at different times, **(2)** in different ways, c

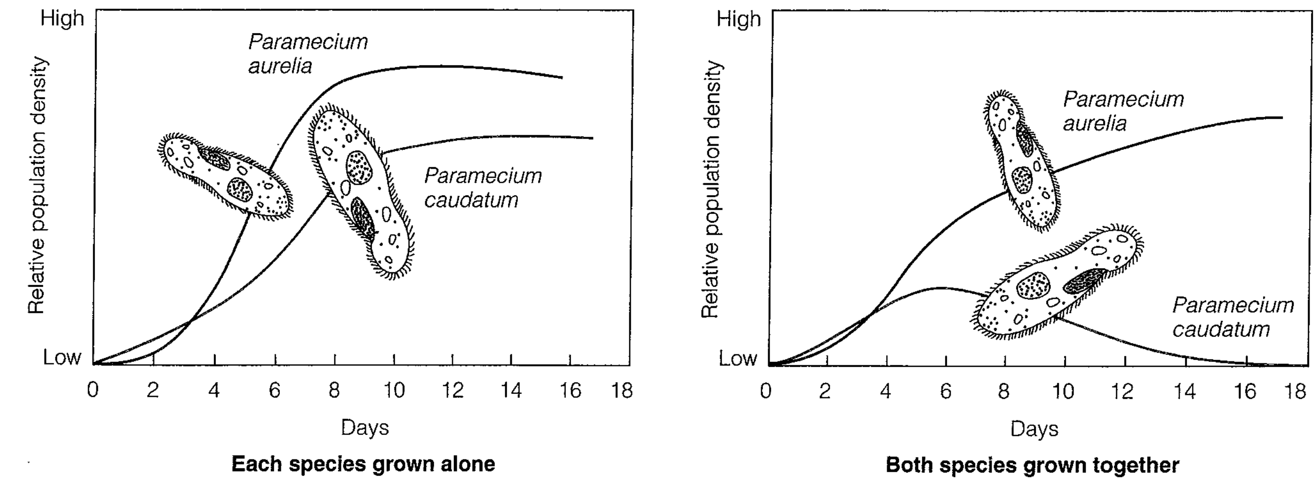


Figure 8-8 The results of G. F. Gause's classic laboratory experiment with two similar single-celled, bacteria-eating *Paramecium* species (which reproduce asexually). These data support the *competitive exclusion principle* that similar species cannot occupy the same ecological niche indefinitely.

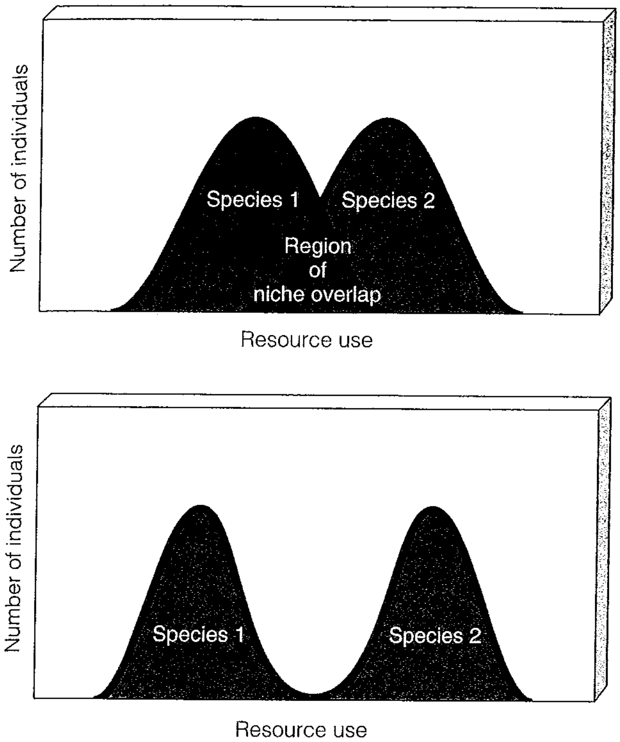


Figure 8-9 *Resource partitioning* and *niche specialization* as a result of competition between two species. The top diagram shows the overlapping niches of two competing species. The bottom diagram shows that through evolution the niches of the two species become separated and more specialized (narrower) so that they avoid competing for the same resources.

(3) in different places (Figure 7-13, p. 152). In effect, they evolve traits that allow them to share the wealth.

Each of the competing species occupies a *realized niche* that makes up only part of its *fundamental niche.* Thus through evolution the fairly broad niches of two competing species (Figure 8-9, top) become more specialized (Figure 8-9, bottom). Resource partitioning through niche specialization also occurs in the different layers of tropical rain forests (Figure 6-37, p. 137) and in coastal wetlands (Figure 7-13, p. 152).

Here are some other examples of resource partitioning. When lions and leopards live in the same area, 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. Some bird species feed on the ground, whereas others seek food in trees and shrubs.

Ecologist Robert H. MacArthur studied the feeding habits of five species of warblers (small insect-eating birds) that coexist in the forests of the northeastern United States and in the adjacent area of Canada. Although they appear to be competing for the same food resources, MacArthur found that the bird species reduce competition through resource partitioning by spending at least half their time hunting for insects in different parts of trees (Figure 8-10).

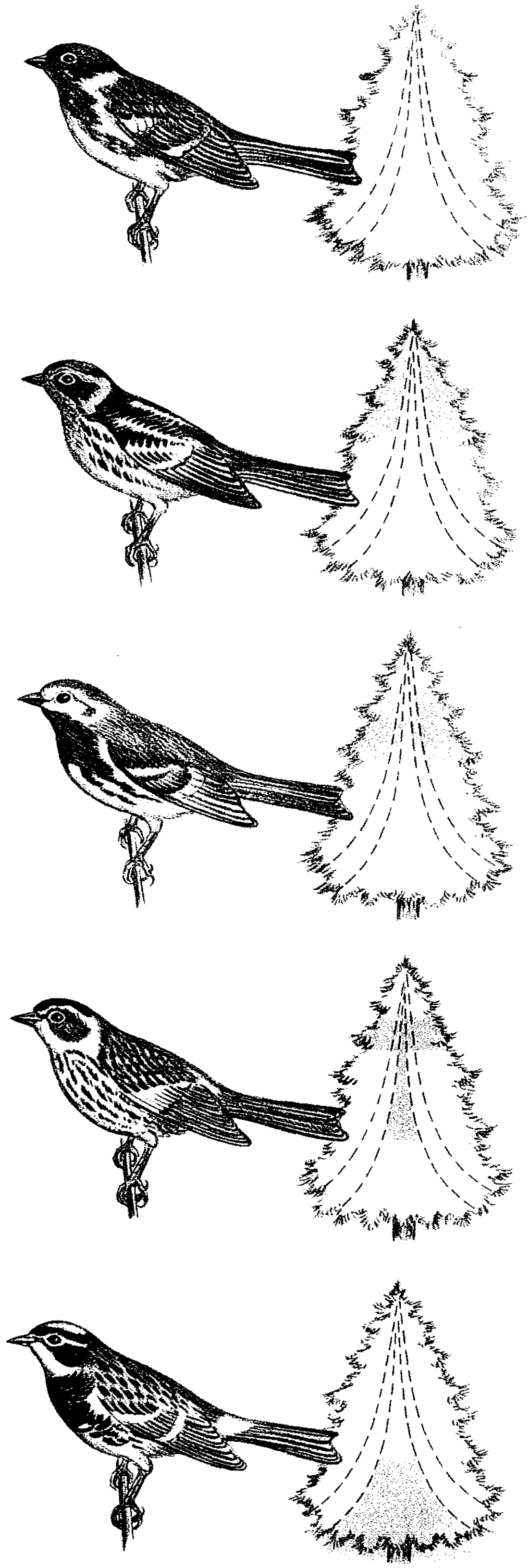


Figure 8-10 *Resource partitioning* of five species of common insect-eating warblers in the spruce forests of Maine. Each species minimizes competition with the others for food by **(1)** spending at least half its feeding time in a distinct portion (shaded areas) of the spruce trees, and **(2)** consuming somewhat different insect species. (After R. H. MacArthur, "Population Ecology of Some Warblers in Northeastern Coniferous Forests," *Ecology* 36 [1958]: 533–36)

CASE STUDY

Why Are Sharks Important Species?

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 is the whale shark, the world's largest fish, which can grow to 15 meters (50 feet) long and weigh as much as two full-grown African elephants.

Various shark species, feeding at the top of food webs, cull injured and sick animals from the ocean and thus play an important ecological role. Without such shark species, the oceans would be overcrowded with dead and dying fish.

Many people—influenced by movies (such as *Jaws*), popular novels, and widespread media coverage of a fairly small number of shark attacks per year—think of sharks as people-eating monsters. However, the three largest species—the whale shark, basking shark, and megamouth shark—are gentle giants that swim through the water with their mouths open, filtering out and swallowing huge quantities of *plankton* (small free-floating sea creatures).

Every year, members of a few species of shark—mostly great white, bull, tiger, gray reef, lemon, hammerhead, shortfin mako, and blue—typically injure about 100 people worldwide and kill between 5 and 15 people. Most attacks are by great white sharks, which feed on sea lions and other marine mammals and sometimes mistake divers and surfers for their usual prey.

Media coverage of shark attacks greatly distort the danger from sharks. You are 30 times more likely to be killed by lightning than by a shark. Each year **(1)** dogs inflict serious bites on many thousands more people than the 100 or so persons bitten by sharks, and **(2)** the number of people bitten by other people is more than 10 times the number of people bitten by sharks.

For every shark that injures a person, we kill at least 1 million sharks, for a total of 100 million sharks each year. Sharks are killed mostly for their fins, widely used in Asia as a soup ingredient and as a pharmaceutical cure-all and worth as much as $563 per kilogram ($256 per pound). In Hong Kong, a single bowl of shark fin soup can sell for as much as $100.

According to a 2001 study by Wild Aid, shark fins sold in restaurants throughout Asia and in Chinese communities in cities such as New York, San Francisco, and London contain dangerously high levels of toxic mercury. Consumption of high levels of mercury is especially threatening for pregnant women and their babies.

Sharks are also killed for their **(1)** livers, **(2)** meat (especially mako and thresher), **(3)** hides (a source of exotic, high-quality leather), and **(4)** jaws (especially great whites, whose jaws are worth thousands of dollars to collectors), or **(5)** just because we fear them. Some sharks (especially blue, mako, and oceanic whitetip) die when they are trapped as bycatch in nets or lines deployed to catch swordfish, tuna, shrimp, and other commercially important species.

Sharks also help save human lives. In addition to providing people with food, they are helping us learn how to fight cancer (which sharks almost never get), bacteria, and viruses. Their highly effective immune system is being studied because it allows wounds to heal without becoming infected.

Sharks have several natural traits that make them prone to population declines from overfishing. They **(1)** have only a few offspring (between 2 and 10) once every year or two, **(2)** take 10–24 years to reach sexual maturity and begin reproducing, and **(3)** have long gestation (pregnancy) periods, up to 24 months for some species.

Sharks are among the most vulnerable and least protected animals on the earth. Eight of the world's shark species, including great whites, sandtigers, and kitefins, are now considered critically endangered, endangered, or vulnerable to extinction. Of the 125 countries that commercially catch more than 100 million sharks per year, only four—Australia, Canada, New Zealand, and the United States—have implemented management plans for shark fisheries, and these plans are hard to enforce.

With more than 400 million years of evolution behind them, sharks have had a long time to get things right. Preserving their evolutionary genetic development begins with the knowledge that sharks do not need us, but we and other species need them.

Critical Thinking

After reading this information, has your attitude toward sharks changed? If so, how has it changed?

How Do Predator and Prey Species Interact? In **predation,** members of one species (the *predator*) feed directly on all or part of a living organism of another species (the *prey*). However, they do not live on or in the prey, and the prey may or may not die from the interaction.

In this interaction, the predator benefits and the individual prey is clearly harmed. Together, the two kinds of organisms, such as lions (the predator or hunter) and zebras (the prey or hunted), are said have a **predator–prey relationship,** as depicted in Fi; ures 4-11 (p. 72), 4-12 (p. 72), 4-18 (p. 77), and 4-19 (p. 78

At the individual level, members of the pre species are clearly harmed. However, at the populatic level, predation can benefit the prey species becau: predators such as tigers and some types of sharks ofte kill the sick, weak, and aged members (Case Stud above). Reducing the prey population **(1)** gives remai ing prey greater access to the available food supply and **(2)** can improve the genetic stock of the prey population, which enhances its chances of reproductive success and long-term survival.

Some people tend to view predators with contempt. When a hawk tries to capture and feed on a rabbit, some tend to root for the rabbit. Yet the hawk (like all predators) is merely trying to get enough food to feed itself and its young; in the process, it is playing an important ecological role in controlling rabbit populations.

How Do Predators Increase Their Chances of Getting a Meal? 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 being able to run fast; others, such as the American bald eagle, fly and have keen eyesight; still others, such as wolves and African lions, cooperate in capturing their prey by hunting in packs.

Other predators have characteristics or strategies that enable them to hide and ambush their prey. Examples include **(1)** praying mantises (Figure 4-1, right, p. 64) sitting in flowers of a similar color and ambushing visiting insects, **(2)** white ermines (a type of weasel) and snowy owls hunting in snow-covered areas, **(3)** the alligator snapping turtle lying camouflaged on its stream-bottom habitat and dangling its worm-shaped tongue to entice fish into its powerful jaws, and **(4)** people camouflaging themselves to hunt wild game and using traps to ambush wild game.

How Do Prey Defend Themselves Against or Avoid Predators? Species have various characteristics that enable them to avoid predators. They include **(1)** the ability to run, swim, or fly fast, **(2)** a highly developed sense of sight or smell that alerts them to the presence of predators, **(3)** protective shells (as on armadillos, which roll themselves up into an armor-plated ball, and turtles), **(4)** thick bark (giant sequoia), and **(5)** spines (porcupines) or thorns (cacti and rosebushes). Many lizards have brightly colored tails that break off when they are attacked, often giving them enough time to escape.

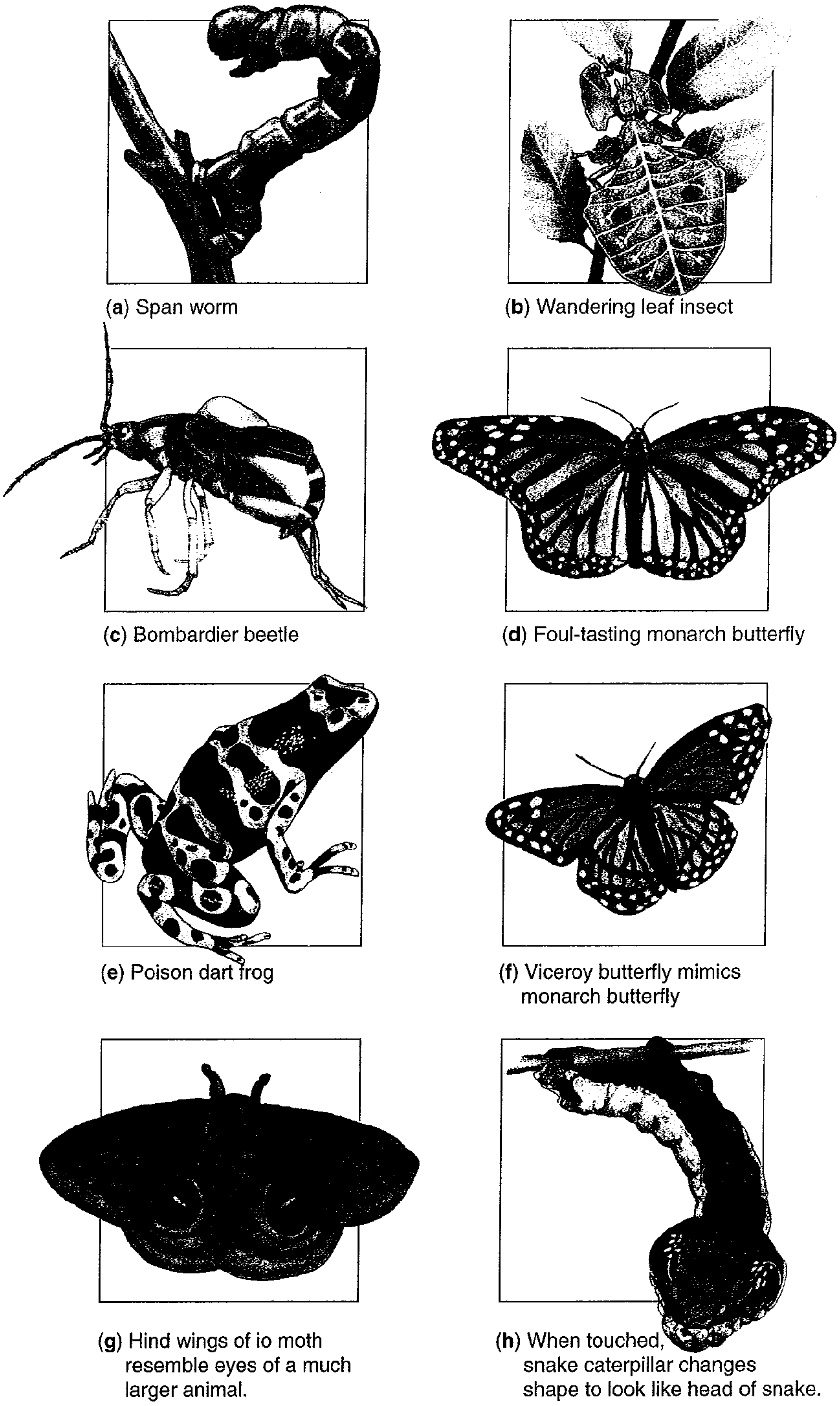


Figure 8-11 Some ways in which prey species avoid their predators by **(1)** *camouflage* (a and b), **(2)** *chemical warfare* (c and e), **(3)** *warning coloration* (d and e), **(4)** *mimicry* (f), **(5)** *deceptive looks* (g), and **(6)** *deceptive behavior* (h).

Other prey species use *camouflage* by having certain shapes or colors (Figure 8-11a) or the ability to change color (chameleons and cuttlefish). A leaf insect may be almost invisible against its background (Figure 8-11b), and an arctic hare in its white winter fur blends into the snow. Some insect species have evolved shapes that look like twigs (Figure 8-11a) or bird droppings on leaves.

Chemical warfare is another common strategy. Some prey species discourage predators with chemicals that are **(1)** poisonous (oleander plants), **(2)** irritating (bombardier beetles, Figure 8-11c), **(3)** foul smelling (skunks, skunk cabbages, and stinkbugs), or **(4)** bad tasting (buttercups and monarch butterflies, Figure 8-11d). Scientists have identified more than 10,000 defensive chemicals made by plants, including cocaine, caffeine, nicotine, cyanide, opium, strychnine, peyote, and rotenone (used as an insecticide).

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. Examples are **(1)** brilliantly colored poisonous frogs (Figure 8-11e) and red-, yellow-, and black-striped coral snakes and **(2)** foul-tasting monarch butterflies (Figure 8-11d) and grasshoppers. Other butterfly species, such as the nonpoisonous viceroy (Figure 8-11f), gain some protection by looking and acting like the poisonous monarch (Figure 8-11d), a protective device known as *mimicry.*

Some prey species use behavioral strategies to avoid predation. Some attempt to scare off predators by **(1)** puffing up (blowfish), **(2)** spreading their wings (peacocks), or **(3)** mimicking a predator (Figure 8-11h). To help fool or frighten would-be predators, some moths have wings that look likes the eyes of much larger animals (Figure 8-11g). Other prey gain some protection by living in large groups (schools of fish, herds of antelope, flocks of birds).

8-4 SYMBIOTIC SPECIES INTERACTIONS: PARASITISM, MUTUALISM, AND COMMENSALISM

What Is Symbiosis? **Symbiosis** is a relationship in which species live together in an intimate association. There are three types of symbiosis: *parasitism, mutualism,* and *commensalism.*

What Are Parasites, and Why Are They Important? **Parasitism** occurs when one species (the *parasite*) feeds on part of another organism (the *host*) by living on or in the host. In this symbiotic relationship, the parasite benefits and the host is harmed.

Parasitism can be viewed as a special form of predation. But unlike a conventional predator, a parasite **(1)** usually is smaller than its host (prey), **(2)** remains closely associated with, draws nourishment from, and may gradually weaken its host over time, and **(3)** rarely kills its host.

Tapeworms, disease-causing microorganisms (or pathogens), and other parasites live *inside* their hosts. Other parasites, such as ticks, fleas, mosquitoes, mistletoe plants, and fungi (that cause diseases such as athlete's foot), attach themselves to the *outside* of their hosts. Some parasites move from one host to another, as fleas and ticks do; others, such as tapeworms, spend their adult lives with a single host.

From the host's point of view, parasites are harmful, but parasites play important ecological roles. Collectively, the complex matrix of parasitic relationships in an ecosystem acts somewhat like glue that helps hold the species in an ecosystem together. Parasites also promote biodiversity by helping prevent some species from becoming too plentiful and eliminating other species through competition.

How Do Species Interact So That Both Species Benefit? In **mutualism,** two species involved in a symbiotic relationship interact in ways that benefit both. Such benefits include **(1)** having pollen and seeds dispersed for reproduction, **(2)** being supplied with food, or **(3)** receiving protection.

The *pollination* relationship between flowering plants and animals such as insects (Figure 4-1, left, p. 64), birds, and bats (p. 165) is one of the most common forms of mutualism. Examples of *nutritional mutualism* include the following:

- *Lichens,* hardy species that can grow on trees or barren rocks, consist of colorful photosynthetic algae and chlorophyll-lacking fungi living together. The fungi provide a home for the algae, and their bodies collect and hold moisture and mineral nutrients used by both species. The algae, through photosynthesis, provide sugars as food for themselves and the fungi.
- Plants in the legume family support root nodules, where *Rhizobium* bacteria convert atmospheric nitrogen into a form usable by the plants (Figure 4-29, p. 86), and the plants provide the bacteria with some simple sugars.
- One-celled algae called *zooxanthellae* that live in the tissues of the tiny animals called *polyps* that make up coral reefs (Figure 7-1, left, p. 144). The algae provide the polyps with color, food, and oxygen through photosynthesis, and the polyps provide a protected home for the algae.
- Vast armies of bacteria in the digestive systems of animals break down (digest) their food. The bacteria gain a safe home with a steady food supply; the animal gains more efficient access to a large source of energy.

Examples of mutualistic relationships involving *nutrition* and *protection* are as follows.

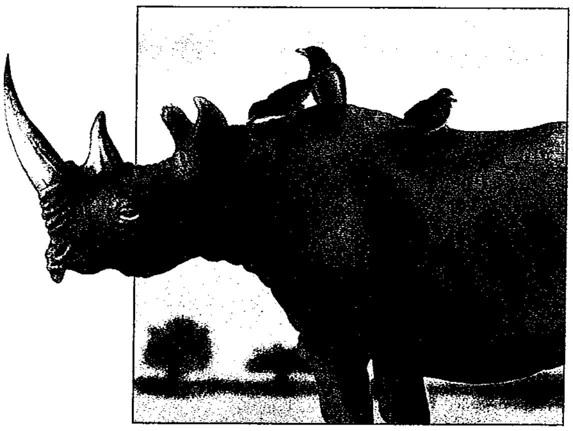
- Birds ride on the backs of large animals such as African buffalo, elephants, and rhinoceroses (Figure 8-12a). The birds remove and eat parasites from the animal's body and often make noises warning the animal when predators approach.

- Clownfish species live within sea anemones, whose tentacles sting and paralyze most fish that touch them (Figure 8-12b). The clownfish, which are not harmed by tentacles, gain protection from predators and feed on the detritus left from the meals of the anemones. The sea anemones benefit because the clownfish protect them from some of their predators.
- Minute fungi called mycorrhizae live on the roots of many plants (Figure 8-12c). The fungi get nutrition from a plant's roots and in turn benefit the plant by using their myriad networks of hairlike extensions to improve the plant's ability to extract nutrients and water from the soil.
- Our domesticated plants and animals rely on us for nutrition and protection. In return, we use them as sources of food and companionship and in some cases protection (guard dogs).

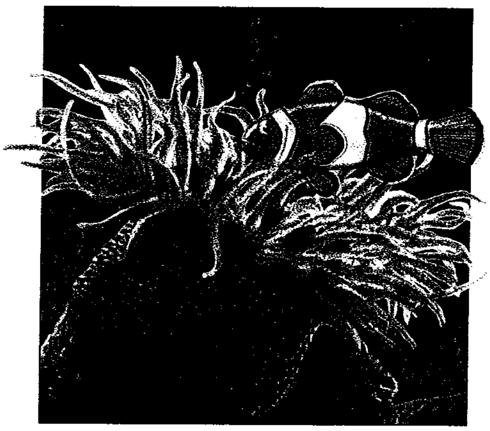
It is tempting to think of mutualism as an example of cooperation between species, but actually it involves each species benefiting by exploiting the other.

How Do Species Interact So That One Benefits But the Other Is Not Harmed? Commensalism is a symbiotic interaction that benefits one species but neither harms nor helps the other species much, if at all. Examples are as follows:

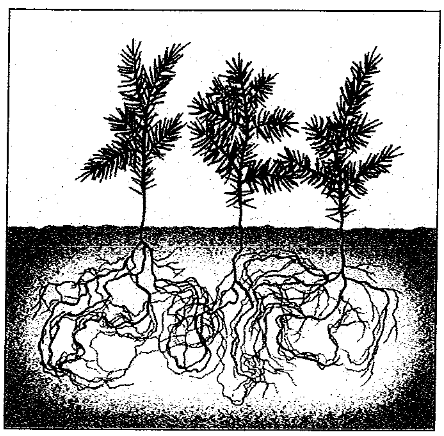
- A redwood sorrel, a small herb, benefits from growing in the shade of tall redwood trees, with no known negative effects on the redwood trees.
- Plants called *epiphytes* (such as some types of orchids and bromeliads) attach themselves to the trunks or branches of large trees (Figure 8-13, p. 180) in tropical and subtropical forests. These so-called air plants benefit by **(1)** having a solid base on which to grow and **(2)** living 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. This apparently does not harm the tree.
- Raccoons, opossums, and rats obtain food by robbing our garbage. This usually causes us no harm unless we have to pick up trash that scavenging animals have strewn around.



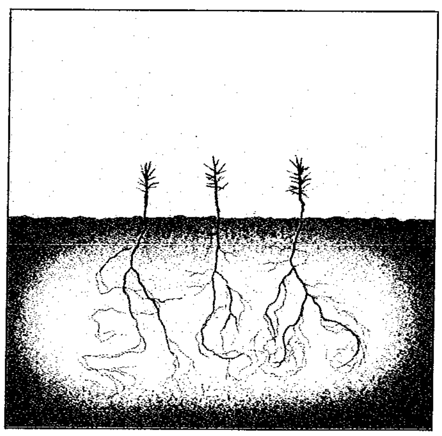
(a) Oxpeckers and black rhinoceros



(b) Clown fish and sea anemone



(c) Mycorrhizae fungi on juniper seedlings in normal soil



(d) Lack of mycorrhizae fungi on juniper seedlings in sterilized soil

Figure 8-12 Examples of *mutualism.* **(a)** Oxpeckers (or tickbirds) feed on and remove parasitic ticks that infest large thick-skinned animals such as a 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, and **(c)** beneficial effects of mycorrhizae fungi attached to roots of juniper seedlings on plant growth **(d)** compared to growth of such seedlings in sterilized soil without mycorrhizae fungi (right).

Figure 8-13 *Commensalism* between a white orchid (an epiphyte or air plant from the tropical forests of Latin America) that roots in the fork of a tree rather than the soil. In this interaction, the epiphytes gain access to water, nutrient debris, and sunlight; the tree apparently remains unharmed unless it contains a large number of epiphytes.

8-5 ECOLOGICAL SUCCESSION: COMMUNITIES IN TRANSITION

How Do Ecosystems Respond to Change? One characteristic of all communities and ecosystems is that their structures change constantly in response to changing environmental conditions. The gradual change in species composition of a given area is called **ecological succession.** During succession some species colonize an area and their populations become more numerous, whereas populations of other species decline and even disappear.

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 biotic communities on nearly lifeless ground.
- **Secondary succession,** the more common type, involves the reestablishment of biotic communities in an area where some type of biotic community is already present.

What Is Primary Succession? Establishing Life on Lifeless Ground Primary succession begins with an essentially lifeless area where there is no soil in a terrestrial ecosystem (Figure 8-14) or no bottom sediment in an aquatic ecosystem. Examples include **(1)** bare rock exposed by a retreating glacier or severe soil erosion, **(2)** newly cooled lava, **(3)** an abandoned highway or parking lot, or **(4)** a newly created shallow pond or reservoir.

Before a community of plants (producers), consumers, and decomposers can become established on land, there must be *soil:* a complex mixture of rock particles, decaying organic matter, air, water, and living organisms. Depending mostly on the climate, it takes natural processes several hundred to several thousand years to produce fertile soil.

Soil formation begins when hardy **pioneer species** attach themselves to inhospitable patches of bare rock. Examples are wind-dispersed lichens and mosses, which can withstand the lack

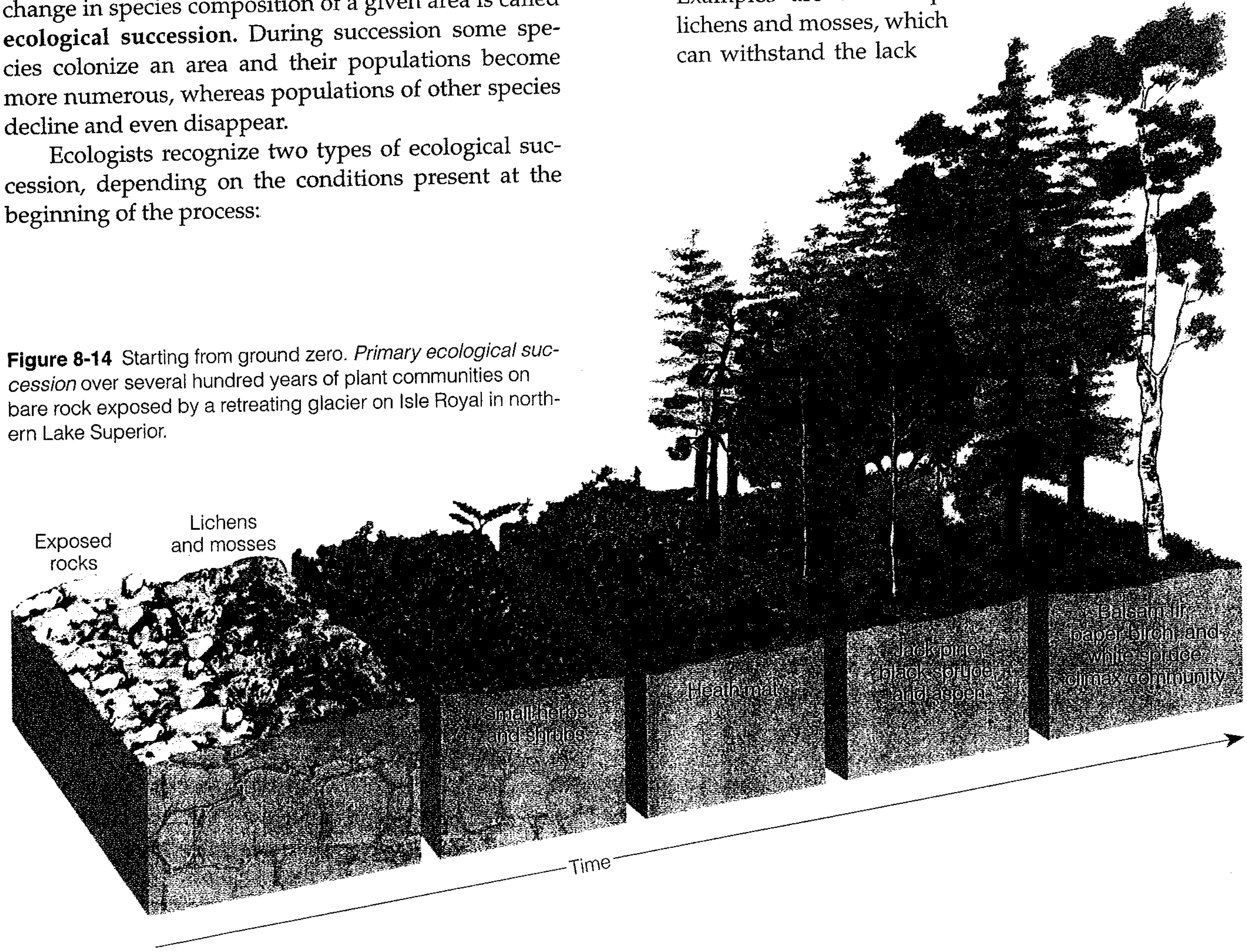


Figure 8-14 Starting from ground zero. *Primary ecological succession* over several hundred years of plant communities on bare rock exposed by a retreating glacier on Isle Royal in northern Lake Superior.

of moisture and soil nutrients and hot and cold temperature extremes found in such habitats.

These species start the soil formation process on patches of bare rock by **(1)** trapping wind-blown soil particles and tiny pieces of detritus, **(2)** producing tiny bits of organic matter, and **(3)** secreting mild acids that slowly fragment and break down the rock. This chemical breakdown (weathering) is hastened by physical weathering such as the fragmentation of rock when water freezes in cracks and expands.

As patches of soil build up and spread, eventually the community of lichens and mosses is replaced by a community of **(1)** small perennial grasses (plants that live for more than 2 years without having to reseed) and **(2)** herbs (ferns in tropical areas), whose seeds germinate after being blown in by the wind or carried there in the droppings of birds or on the coats of mammals.

These **early successional plant species** **(1)** grow close to the ground, **(2)** can establish large populations quickly under harsh conditions, and **(3)** have short lives. Some of their roots penetrate the rock and help break it up into more soil particles, and the decay of their wastes and dead bodies adds more nutrients to the soil.

After hundreds of years, the soil may be deep and fertile enough to store enough moisture and nutrients to support the growth of less hardy **midsuccessional plant species** of herbs, grasses, and low shrubs. Trees that need lots of sunlight and are adapted to the area's climate and soil usually replace these species.

As these tree species grow and create shade, they are replaced by **late successional plant species** (mostly trees) that can tolerate shade. Unless fire, flooding, severe erosion, tree cutting, climate change, or other natural or human processes disturb the area, what was once bare rock becomes a complex forest community (Figure 8-14).

What Is Secondary Succession? Secondary succession 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 **(1)** abandoned farmlands, **(2)** burned or cut forests, **(3)** heavily polluted streams, and **(4)** land that has been dammed or flooded. Because some soil or sediment is present, new vegetation usually can begin to germinate within a few weeks. Seeds can be present in soils, or they can be carried from nearby plants by wind or by birds and animals.

In the central (Piedmont) region of North Carolina, European settlers cleared the mature native oak and hickory forests and replanted the land with crops. Later they abandoned some of this farmland because of erosion and loss of soil nutrients. Figure 8-15 shows how such abandoned farmland has undergone secondary succession.

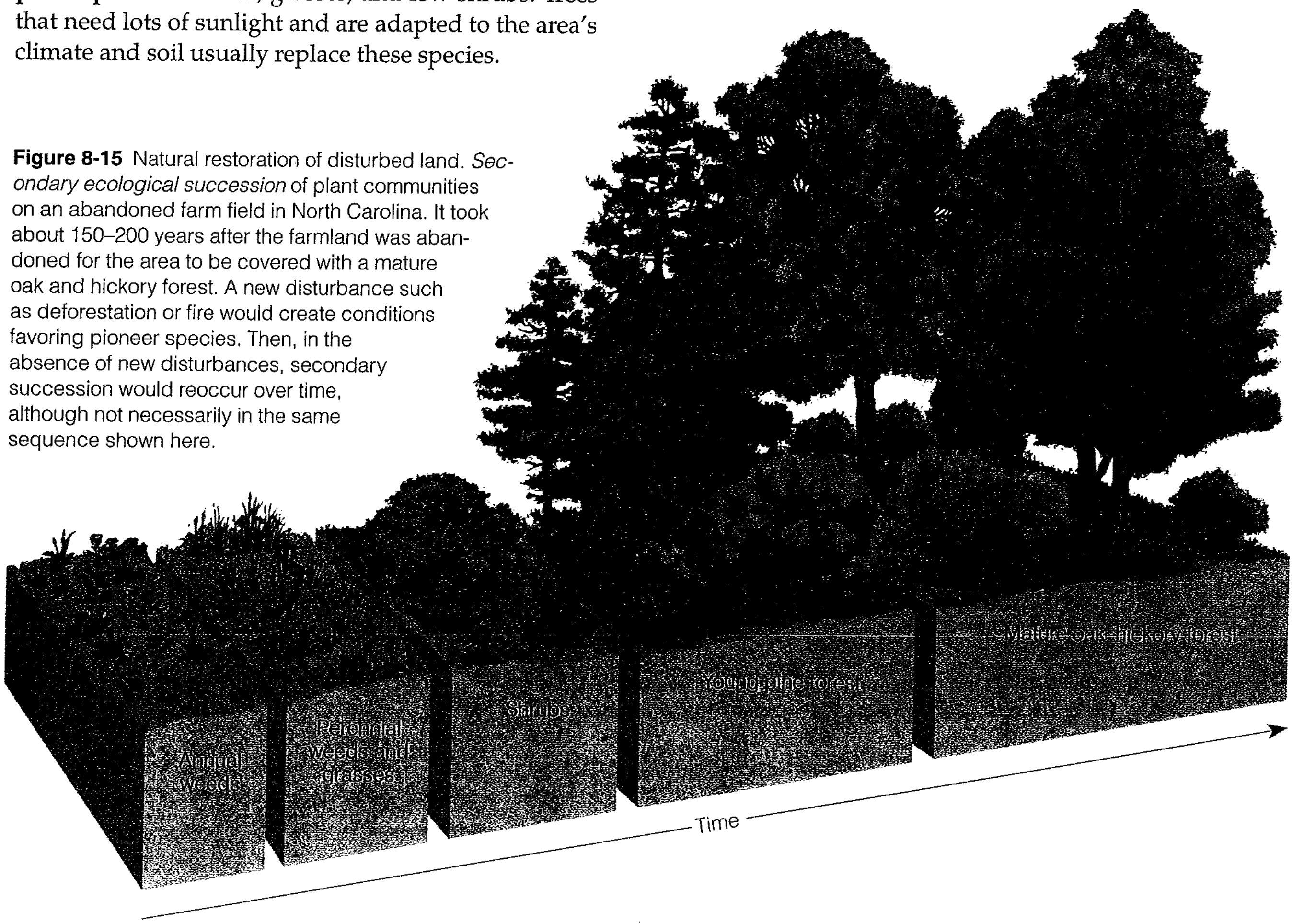


Figure 8-15 Natural restoration of disturbed land. *Secondary ecological succession* of plant communities on an abandoned farm field in North Carolina. It took about 150–200 years after the farmland was abandoned for the area to be covered with a mature oak and hickory forest. A new disturbance such as deforestation or fire would create conditions favoring pioneer species. Then, in the absence of new disturbances, secondary succession would reoccur over time, although not necessarily in the same sequence shown here.

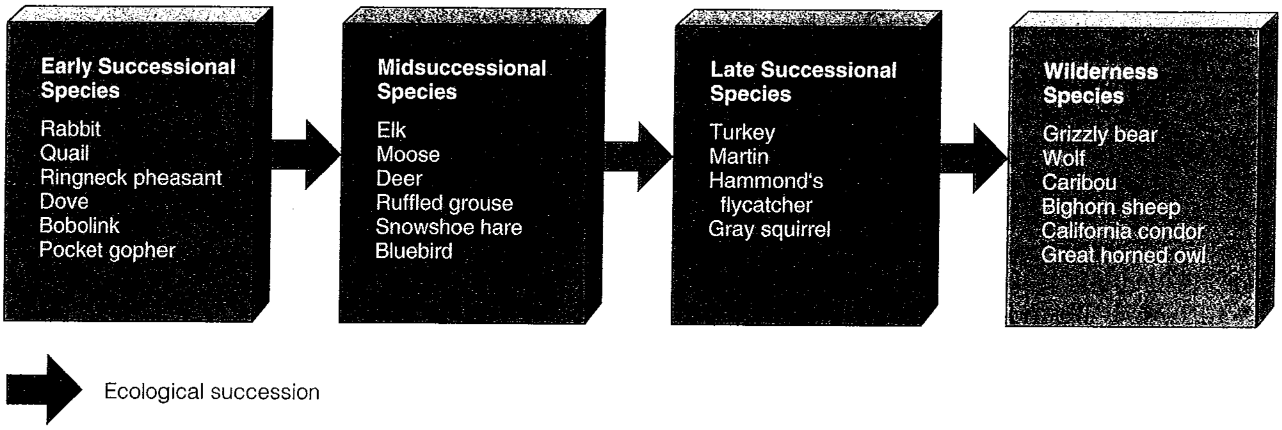


Figure 8-16 Examples of wildlife species typically found at different stages of ecological succession in areas of the United States with a temperate climate.

Descriptions of ecological succession usually focus on changes in vegetation. However, these changes in turn affect food and shelter for various types of animals. Thus, as succession proceeds, the numbers and types of animals and decomposers also change. Figure 8-16 shows some of the wildlife species likely to be found at various stages of secondary ecological succession in areas with a temperate climate.

Because primary and secondary succession involve changes in community structure, the various stages of succession have different patterns of **(1)** species diversity, **(2)** trophic structure, **(3)** niches, **(4)** nutrient cycling, and **(5)** energy flow and efficiency, as shown by the work of ecologists such as Eugene Odum (Table 8-1).

How Do Species Replace One Another in Ecological Succession? Ecologists have identified three factors that affect how and at what rate succession occurs.

Table 8-1 Ecosystem Characteristics at Immature and Mature Stages of Ecological Succession

Characteristic	Immature Ecosystem (Early Successional Stage)	Mature Ecosystem (Late Successional Stage)
Ecosystem Structure		
Plant size	Small	Large
Species diversity	Low	High
Trophic structure	Mostly producers, few decomposers	Mixture of producers, consumers, and decomposers
Ecological niches	Few, mostly generalized	Many, mostly specialized
Community organization (number of interconnecting links)	Low	High
Ecosystem Function		
Biomass	Low	High
Net primary productivity	High	Low
Food chains and webs	Simple, mostly plant → herbivore with few decomposers	Complex, dominated by decomposers
Efficiency of nutrient recycling	Low	High
Efficiency of energy use	Low	High

- *Facilitation,* in which one set of species makes an area suitable for species with different niche requirements. For example, as lichens and mosses gradually build up soil on a rock in primary succession, herbs and grasses can colonize the site. Similarly, plants such as legumes add nitrogen to the soil, making it more suitable for other plants found at later stages of succession.

- *Inhibition,* in which early species hinder the establishment and growth of other species. Inhibition often occurs when plants release toxic chemicals that reduce competition from other plants (interference competition). Succession then can proceed only when a fire, bulldozer, or other disturbance removes most of the inhibiting species.

- *Tolerance,* in which late successional plants are largely unaffected by plants at earlier stages of succession. Tolerance may explain why late successional plants can thrive in mature communities without eliminating some early successional and midsuccessional plants.

How Do Disturbances Affect Succession and Species Diversity? A **disturbance** is a change in environmental conditions that disrupts an ecosystem or community. Such disturbances can be catastrophic or gradual and caused by natural or human-caused changes (Table 8-2). At any time during primary or secondary succession, disturbances such as those listed in Table 8-2 can convert a particular stage of succession to an earlier stage.

Many people think of all environmental disturbances as harmful processes. Large catastrophic disturbances (Table 8-2) can devastate communities and ecosystems. However, many ecologists contend that in the long run some types of disturbances such as fires can be beneficial for the species diversity of some communities and ecosystems. Such disturbances create new conditions that can discourage or eliminate some species but encourage others by releasing nutrients and creating unfilled niches.

For example, when a large tree falls in a tropical forest, this local disturbance increases sunlight and

Table 8-2 Changes Affecting Ecosystems

Catastrophic*		Gradual*	
Natural	Drought	Natural	Climate change
	Flood		Immigration
	Fire		Adaption and evolution
	Volcanic eruption		Ecological succession
	Earthquake		Disease
	Hurricane or tornado		
	Landslide		
	Change in stream course		
	Disease		
Human-caused	Deforestation	Human-caused	Salinization and waterlogging of soils from irrigation
	Overgrazing		Soil compaction
	Plowing		Groundwater depletion
	Erosion		Water and air pollution
	Pesticide application		Loss and degradation of wildlife habitat
	Fire		"Pests" and predator elimination
	Mining		Introduction of nonnative species
	Toxic contamination		Overhunting and overfishing
	Urbanization		Toxic contamination
	Water and air pollution		Urbanization
	Loss and degradation of wildlife habitat		Excessive tourism

*Many changes can be either catastrophic or gradual.

nutrients for growth of plants in the understory. When a log hits a rock in an intertidal zone (Figure 7-12, top, p. 151), this **(1)** dislodges or kills many of the organisms that are growing on the rock and **(2)** provides space for colonization of new intertidal organisms.

According to the *intermediate disturbance hypothesis,* communities that experience fairly frequent but moderate disturbances have the greatest species diversity (Figure 8-17). Researchers hypothesize that in such communities, moderate disturbances are large enough to create openings for colonizing species in disturbed areas but mild and infrequent enough to allow the survival of some mature species in undisturbed areas. Some field experiments have supported this hypothesis.

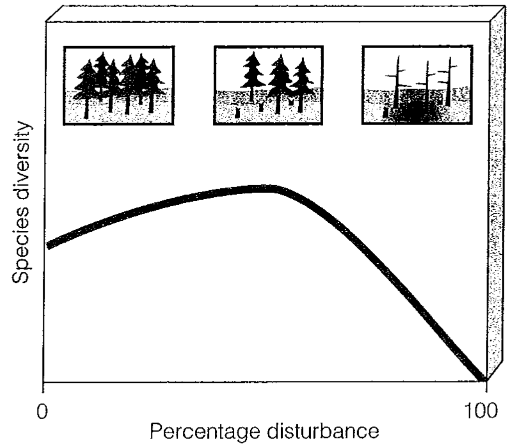


Figure 8-17 According to the *intermediate disturbance hypothesis*, moderate disturbances in communities promote greater species diversity than small or major disturbances.

How Predictable Is Succession, and Is Nature in Balance? We may be tempted to conclude that ecological succession is an orderly sequence in which each stage leads predictably to the next, more stable stage. According to this classic view, succession proceeds until an area is occupied by a generally predictable and stable type of *climax community* that is **(1)** dominated by a few long-lived plant species and **(2)** in balance with its environment. This equilibrium model of succession is what ecologists 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. When these ecologists look at a community or ecosystem, such as a young forest, they see continuous change, instability, and unpredictability instead of equilibrium, stability, and predictability.

Under the old *balance-of-nature* view, a large terrestrial community undergoing succession was viewed as eventually being covered with a predictable green blanket of climax vegetation. However, a close look at almost any ecosystem or community reveals that it consists of an ever-changing mosaic of vegetation patches at different stages of succession. These patches result from a variety of mostly unpredictable small and medium-sized disturbances (Figure 8-17).

This irregular quilt of vegetation increases the diversity of plant and animal life and provides sites where early successional species can gain a foothold. We can also observe a mosaic of shifting patches of plant and animal species in intertidal communities (Figure 7-12, p. 151) as a result of the random actions of waves.

Such research indicates that **(1)** *we cannot predict the course of a given succession or* **(2)** *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 to survive and gain reproductive advantages over other species by occupying as much of their fundamental niches as possible.

This change in the way we view what is happening in nature explains why a growing number of ecologists prefer terms such as *biotic change* instead of *succession* (which implies an ordered and predictable sequence of changes). Many ecologists have also replaced the term *climax community* with terms such as *mature community* or a mosaic of *vegetation patches* at different stages of succession. Ecologists do not consider nature totally chaotic and unpredictable, but they have lowered their expectations of being able to make accurate predictions about the course of succession.

8-6 ECOLOGICAL STABILITY AND SUSTAINABILITY

What Is Stability? All living systems, from single-celled organisms to the biosphere, contain complex networks of negative and positive feedback loops (p. 45) that interact to provide some degree of stability or sustainability over each system's expected life span.

This stability is maintained only by constant dynamic change in response to changing environmental conditions. For example, in a mature tropical rain forest, some trees die and others take their places. However, unless the forest is cut, burned, or otherwise destroyed, you will still recognize it as a tropical rain forest 50 or 100 years from now.

It is useful to distinguish among three aspects of stability or sustainability in living systems:

- **Inertia,** or **persistence:** the ability of a living system to resist being disturbed or altered
- **Constancy:** the ability of a living system such as a population to keep its numbers within the limits imposed by available resources
- **Resilience:** the ability of a living system to bounce back after an external disturbance that is not too drastic

Does Species Diversity Increase Ecosystem Stability? In the 1960s, most ecologists believed the greater the species diversity and the accompanying web of feeding and biotic interactions in an ecosystem, the greater its stability. According to this hypothesis, an ecosystem with a diversity of species and feeding paths has more ways to respond to most environmental stresses because it does not have "all its eggs in one basket." However, recent research has found exceptions to this intuitively appealing idea.

Because no ecosystem can function without some plants and decomposers, there is a minimum threshold of species diversity below which ecosystems cannot function.

Beyond this, it is difficult **(1)** to know whether simple ecosystems are less stable than complex ones or **(2)** to identify the threshold below which complex ecosystems fail. In part because some species play redundant roles (niches) in ecosystems, we do not know how many or which species can be eliminated before the entire ecosystem begins to lose stability or collapse.

Recent research by ecologist David Tilman and others indicates that **(1)** ecosystems with more species tend to have a higher net primary productivity and can be more resilient, but **(2)** the populations of individual species can fluctuate more widely in diverse ecosystems than in simpler ones. In 2002, biologists Margaret Palmer and Bradley Cardinale found that when several species of the caddisfly insect live together in a stream they get more food and are likely to be more productive than when a single caddisfly species lives in the same area.

Such studies support the idea that some level of biodiversity provides insurance against catastrophe, but how much biodiversity is needed in various ecosystems remains uncertain. For example, some recent research suggests that average annual net primary productivity of an ecosystem reaches a peak with 10–40 producer species. Many ecosystems contain more producer species than this, but it is difficult to distinguish among those that are essential and those that are not.

Part of the problem is that ecologists disagree on how to define *stability* and *diversity*. Does an ecosystem need both high inertia and high resilience to be considered stable? Evidence suggests that some ecosystems have one of these properties but not the other. For example, tropical rain forests have high species diversity and high inertia; that is, they are resistant to significant alteration or destruction. However, once a large tract of tropical forest is severely degraded, the ecosystem's resilience sometimes is 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 forest cover may so change the local or regional climate that forests can no longer be supported.

By contrast, grasslands **(1)** are much less diverse than most forests and **(2)** 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. A grassland can be destroyed only if **(1)** its roots are plowed up and something else is planted in its place, or **(2)** it is severely overgrazed by livestock or other herbivores.

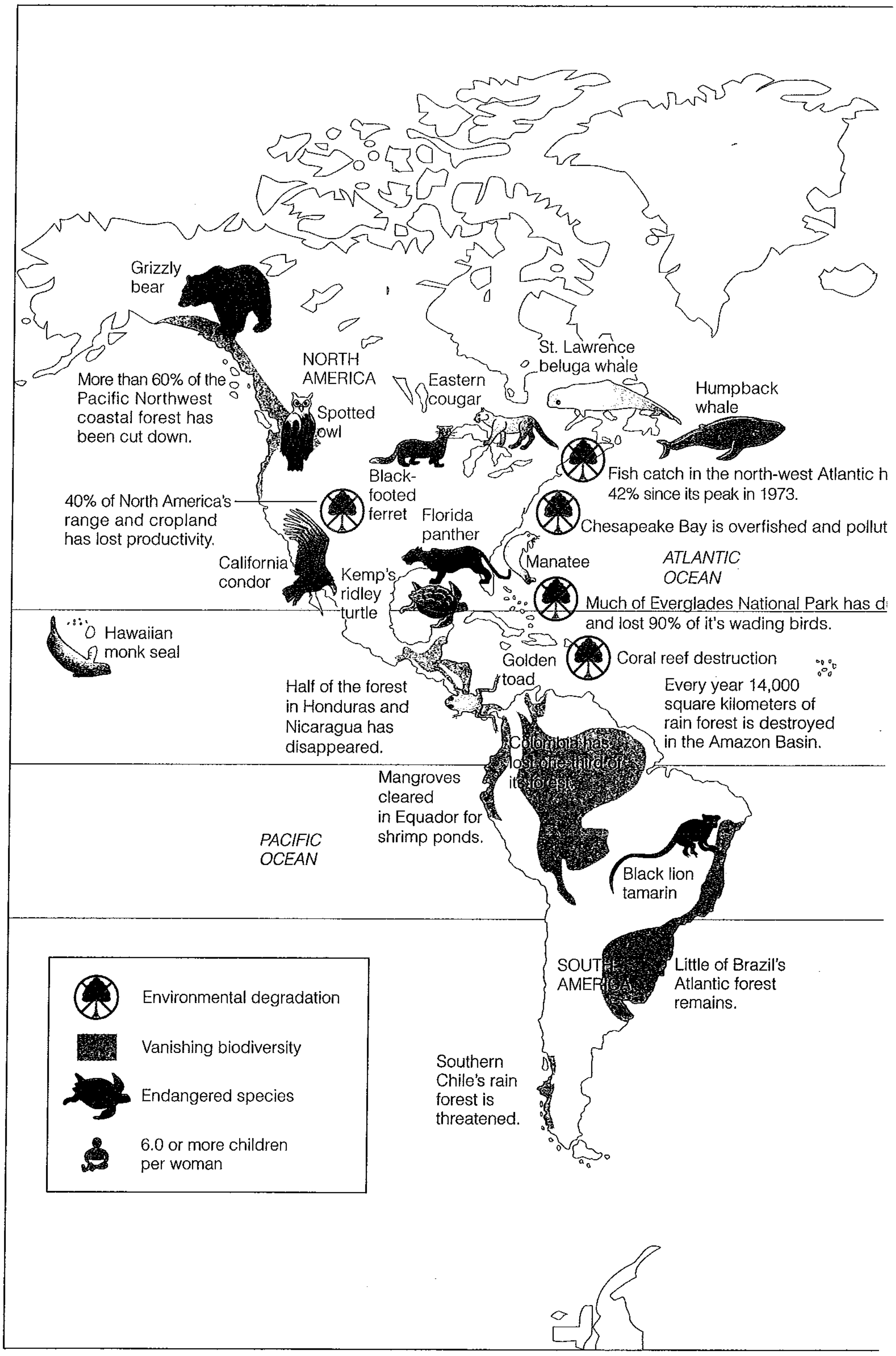
Another difficulty is that populations, communities, and ecosystems are rarely, if ever, at equilibrium (balance). Instead, nature is in a continuing state of disturbance, fluctuation, and change.

Why Should We Bother to Protect Natural Systems? The Precautionary Principle Some developers argue that if biodiversity does not necessarily lead to increased ecological stability and if nature is mostly unpredictable, there is no point in trying to preserve and manage old-growth forests and other ecosystems. They conclude that we should **(1)** cut down diverse old-growth forests, use the timber resources, and replace the forests with tree plantations (Figure 6-39, p. 139), **(2)** convert the world's grasslands to cropfields (Figure 6-31, p. 132), **(3)** drain and develop inland wetlands, **(4)** dump our toxic and radioactive wastes into the deep ocean, and **(5)** not worry about the premature extinction of species.

Ecologists and conservation biologists point to the overwhelming evidence that human disturbances (Figure 8-18, p. 186) are disrupting some of the ecosystem services (Figure 4-34, p. 92) that support and sustain all life and all economies. They contend that our ignorance about the effects of our actions means we need to use great caution in making potentially harmful changes to ecosystems.

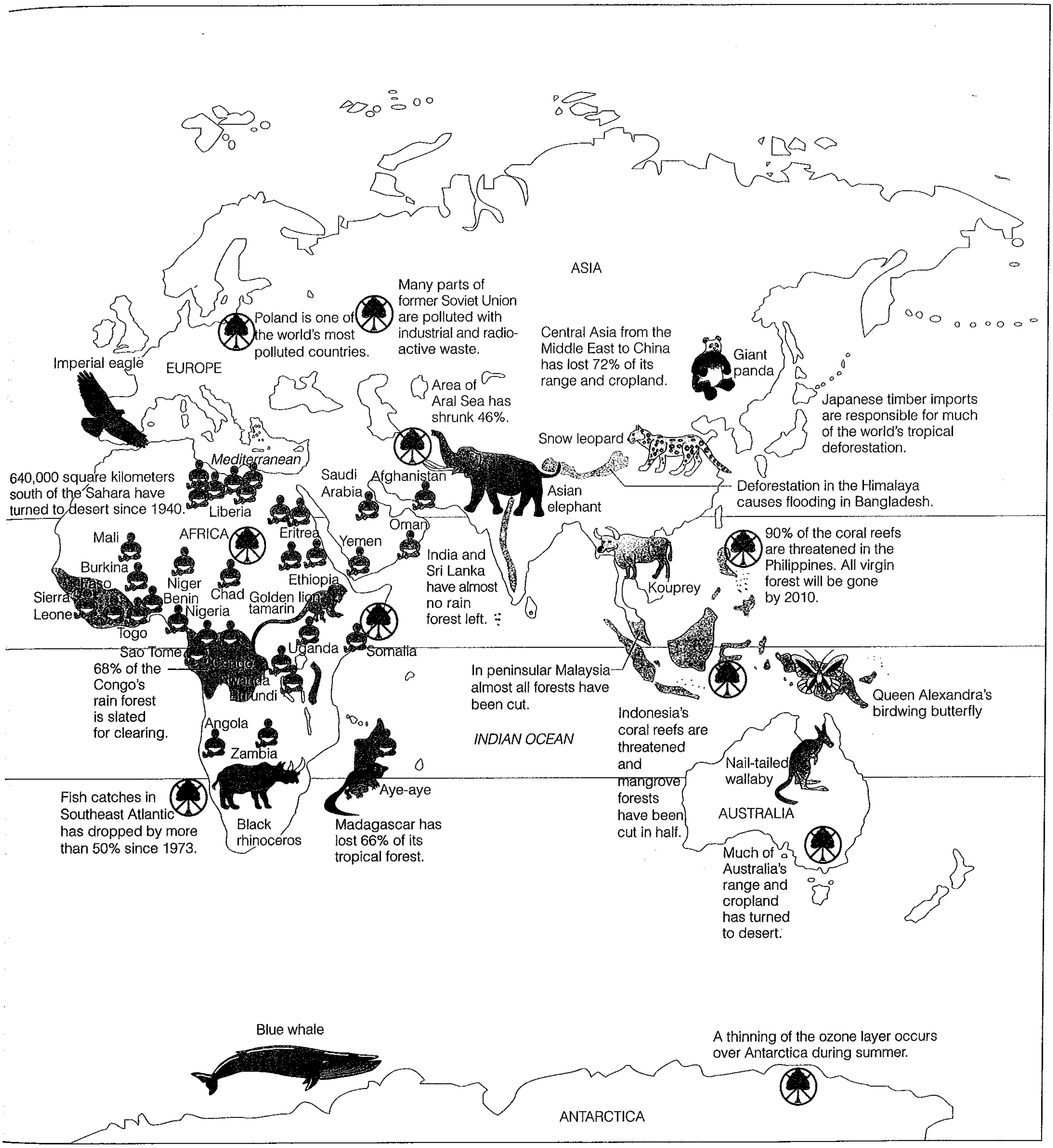
By analogy, we know that eating too much of certain types of foods and not getting enough exercise can greatly increase our chances of heart attacks, diabetes, and other disorders. But the exact connections between chemicals in these foods and between exercise and these health problems are largely unknown. Instead of using this uncertainty and unpredictability

Figure 8-18 Examples of how some of the earth's natural resources are being depleted and degraded at an accelerating rate as a result of the exponential growth of the human population and resource use by humankind. (Data from the World Conservation Union, World Wildlife Fund, Conservation International, United Nations, Population Reference Bureau, U.S. Fish and Wildlife Service, and Daniel Boivin)



as an excuse to continue overeating and not exercising, the wise course is to eat better and exercise more to help *prevent* potentially serious health problems.

This approach is based on the **precautionary principle:** When evidence indicates that an activity can harm human health or the environment, we should take precautionary measures to prevent harm even i some of the cause-and-effect relationships have no been fully established scientifically. It is based on the commonsense idea behind many adages such as "Bet ter safe than sorry," "Look before you leap," "First, do no harm," and "Slow down for speed bumps."



This commonsense idea has been used for more than 20 years as a formal principle of German law called the *Vorsorgeprinzip* principle ("forecaring" principle). Recently the precautionary principle has formed the basis of several international environmental treaties. One example is the global treaty developed by 122 countries in 2000 to ban or phase out 12 *persistent organic pollutants* (POPs).

In this chapter we have seen that interdependence and connectedness of species, communities, and ecosystems are essential features of life on the earth.

The old idea of a static landscape, like a single musical chord sounded forever, must be abandoned, for such a landscape never existed except in our imagination. Nature undisturbed by human influence seems more like a symphony whose harmonies arise from variation and change over every interval of time.

DANIEL B. BOTKIN

REVIEW QUESTIONS

1. Define the boldfaced terms in this chapter.

2. Describe the ecological and economic importance of flying foxes in tropical forests.

3. List four characteristics of the structure of a community or ecosystem. Distinguish between *species diversity* and *species abundance.*

4. Describe the types, relative sizes, and stratification of plants and animals in **(a)** a tropical rain forest, **(b)** an ocean, and **(c)** a lake.

5. Define and give an example of an *edge effect.* What are the advantages and disadvantages of edge effects?

6. What are the three most species-rich environments? How does species diversity vary with **(a)** latitude in terrestrial communities, **(b)** ocean depth, and **(c)** pollution in aquatic systems?

7. What two factors determine the species diversity found on an isolated ecosystem such as an island? What is the *theory of island biodiversity?* How do the size of an island and its distance from a mainland affect its species diversity?

8. Distinguish among *native, nonnative, indicator,* and *keystone* species, and give an example of each.

9. Why are birds good indicator species? Explain why amphibians are considered indicator species, and list reasons for declines in their populations.

10. Describe the keystone ecological roles of **(a)** flying foxes, **(b)** alligators, and **(c)** some shark species. What can happen in an ecosystem that loses a keystone species?

11. Distinguish between *intraspecific competition* and *interspecific competition,* and give an example of each. What is *territoriality?*

12. What are four options when the niches of two species competing in the same area overlap to a large degree? What is the *competitive exclusion principle?*

13. Distinguish between *interference competition* and *exploitation competition,* and give an example of each.

14. Define and give two examples of *resource partitioning.* How does it allow species to avoid overlap of their fundamental niches?

15. What is *predation?* Describe the *predator–prey relationship,* and give two examples of this type of species interaction.

16. Give two examples of how predators increase their chances of finding prey by **(a)** pursuit and **(b)** ambush.

17. List six ways (adaptations) used by prey to avoid their predators, and give an example of each type.

18. What is *symbiosis?* What are three types of symbioti interactions between species?

19. Define and give two examples of *parasitism,* and explain how it differs from predation. What is the ecolo ical importance of parasitism?

20. Define and give three examples of **(a)** *mutualism* anc **(b)** *commensalism.*

21. Distinguish between *primary succession* and *secondar succession.* Distinguish among *pioneer* (or *early successiona* *species, midsuccessional plant species,* and *late successional plant species.* Distinguish among *facilitation, inhibition,* an *tolerance* as factors that affect how and at what rate succe sion occurs.

22. Give three examples of environmental disturbances and explain how they can affect succession. How can some disturbances be beneficial to ecosystems? What is the *intermediate disturbance hypothesis?* Explain how occa sional fires can be beneficial to succession and species ir some types of ecosystems.

23. Explain why most ecologists contend that **(a)** the details of succession are not predictable and **(b)** no balance of nature exists.

24. Distinguish among *inertia, constancy,* and *resilience,* and explain how they help maintain stability in an ecosystem.

25. Does high species diversity always increase ecosystem stability? Explain.

26. What is the *precautionary principle,* and why do man scientists find it a useful strategy for dealing with some of the environmental problems we face?

CRITICAL THINKING

1. Why do deer hunters sometimes plant corn on strips of open land used for firebreaks or for telephone poles?

2. Why are **(a)** more species of trees per hectare usually found in tropical forests than in temperate forests and **(b)** more tube worm species found at intermediate ocea depths than in coastal areas and in the deep ocean?

3. 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 in th tropics?

4. What two factors determine the number of different species found on an island? Why is the species diversity of a large island usually higher than that on a smaller island?

5. What would you do if large numbers of cockroaches (Spotlight, p. 105) invaded your home? See whether you can come up with an ecological rather than a chemical (pesticide) approach to this problem.

6. How would you determine whether a particular species found in a given area is a keystone species?

7. Some butterfly species mimic other butterfly species that taste bad to predators such as birds (Figure 8-12f). Design an experiment to determine whether a particular mimic species of butterfly **(a)** tastes bad like its model (called *Müllerian mimicry* after Fritz Müller, who first recorded this phenomenon in 1878) or **(b)** does not taste bad but gains some protection by looking and acting like its bad-tasting model (called *Batesian mimicry* after Henry W. Bates, who first described this phenomenon in the 1860s).

8. Describe how evolution can affect predator–prey relationships.

9. 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)** if nature is largely unpredictable, why should we bother to preserve any natural systems, and **(c)** because there is no balance in nature and no stability in species diversity we should cut down diverse old-growth forests and replace them with tree plantations (Figure 6-39, p. 139)?

10. Suppose a hurricane blows down most of the trees in a forest. Timber company officials offer to salvage the fallen trees and plant a tree plantation to reduce the chances of fire and to improve the area's appearance, with an agreement that they can harvest the trees when they reach maturity and plant another tree plantation. Others argue that the damaged forest should be left alone because hurricanes and other natural events are part of nature, and the dead trees will serve as a source of nutrients for natural recovery through ecological succession. What do you think should be done, and why?

PROJECTS

1. Make field studies, consult research papers, and interview people to identify and evaluate **(a)** the effects of the deliberate introduction of a beneficial nonnative species into the area where you live and **(b)** the effects of the deliberate or accidental introduction of a harmful nonnative species into the area where you live.

2. Use the library or Internet to find and describe two species not discussed in this textbook that are engaged in **(a)** a commensalistic interaction, **(b)** a mutualistic interaction, and **(c)** a parasite–host relationship.

3. Visit a nearby natural area and identify examples of **(a)** territoriality, **(b)** interference competition, **(c)** exploitation competition, **(d)** mutualism, and **(e)** resource partitioning.

4. Use the library or Internet to identify the parasites likely to be found in your body.

5. Visit a nearby land area such as a partially cleared or burned forest or grassland or an abandoned cropfield and record signs of secondary ecological succession. Study the area carefully to see whether you can find patches that are at different stages of succession because of various disturbances.

6. Use the library or the Internet to find bibliographic information about *Stuart L. Pimm* and *Daniel B. Botkin,* whose quotes appear at the beginning and end of this chapter.

7. Make a concept map of this chapter's major ideas, using the section heads and subheads and the key terms (in boldface). Look on the website for this book for information about making concept maps.

INTERNET STUDY RESOURCES AND RESOURCES FOR FURTHER READING AND RESEARCH

The website for this book contains helpful study aids and many ideas for further reading and research. Log on to

www.info.brookscole.com/miller13

and click on the Chapter-by-Chapter area. Choose Chapter 8 and select a resource:

- Flash Cards allows you to test your mastery of the Terms and Concepts to Remember for this chapter.
- Tutorial Quizzes provides a multiple-choice practice quiz.
- Student Guide to InfoTrac will lead you to Critical Thinking Projects that use InfoTrac College Edition as a research tool.
- References lists the major books and articles consulted in writing this chapter.
- Hypercontents takes you to an extensive list of sites with news, research, and images related to individual sections of the chapter.

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http://www.infotrac-college.com

or access InfoTrac through the website for this book. Try to find the following articles:

1. Byers, J. E. 2000. Competition between two estuarine snails: Implications for invasions of exotic species. *Ecology* 81: 1225. *Keywords:* "competition" and "exotic species." The effects of exploitative competition between a native and an exotic species is examined to determine how competition influences the ability of exotic species to drive native species from a habitat.

2. Miller, L.A., and A. Surlykke. 2001. How some insects detect and avoid being eaten by bats: Tactics and countertactics of prey and predator. *BioScience* 51: 570. *Keywords:* "bats," "insects," and "tactics." Echolocating bats and their prey insects appear to be in an evolutionary relay race. This article describes in detail how these bats find the insects and how insects can avoid the bats.

9 POPULATION DYNAMICS, CARRYING CAPACITY, AND CONSERVATION BIOLOGY

Sea Otters: Are They Back from the Brink of Extinction?

Southern sea otters (Figure 9-1a) live in kelp forests (Figure 9-1c) in shallow waters along the Pacific coast from Baja Mexico up the California coast. These tool-using animals use stones to **(1)** pry shellfish off rocks underwater and **(2)** break open the shells while swimming on their backs and using their bellies as a table. Each day a sea otter consumes about 25% of its weight in sea urchins (Figure 9-1b), clams, mussels, crabs, abalone, and about 40 other species of bottom-dwelling organisms.

Before European settlers arrived, about 1 million southern sea otters lived along the Pacific coastline of North America. By the early 1900s, this species was almost extinct mostly because of **(1)** overhunting for their warm, beautiful fur and **(2)** removal by abalone fishers.

Biologists have learned that southern sea otters are *keystone species* (p. 172) that help keep sea urchins from depleting kelp forests in offshore waters from Alaska to southern California. Without significant predation by sea otters, sea urchin populations expand and consume much of the kelp, which in turn lowers the diversity of other plants and animals in kelp forest ecosystems.

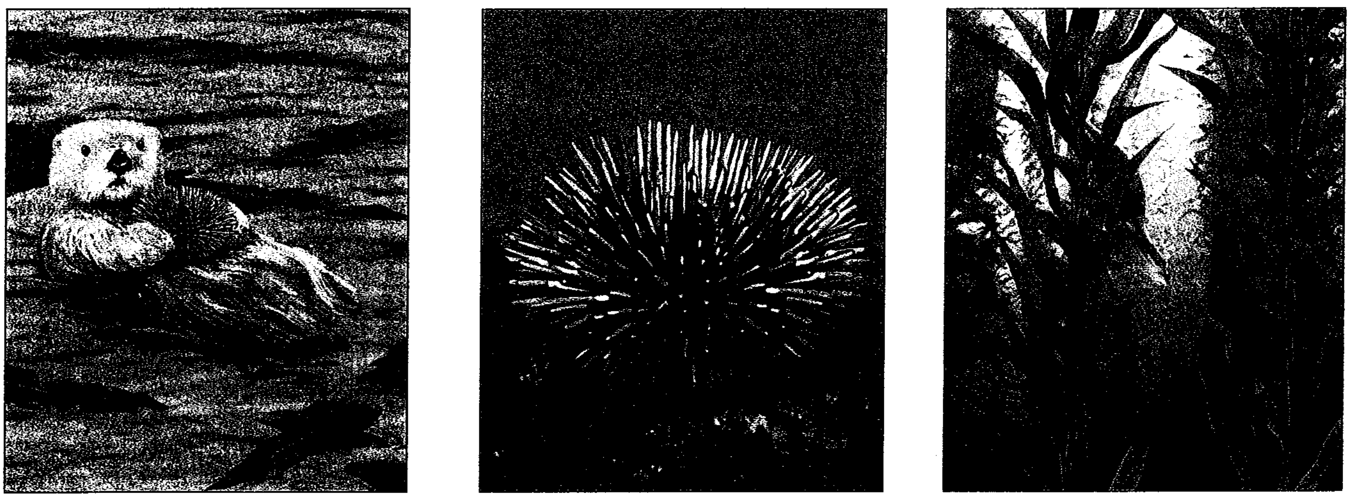
Preventing the loss of kelp forests has important ecological and economic benefits because they **(1)** provide essential habitats for a variety of species, **(2)** inhibit shore erosion, and **(3)** reduce the impact of storm waves on coastlines.

Since 1938, the population of southern sea otters has increased from about 300 to around 2,100. Wherever southern sea otters have returned or have been reintroduced, formerly deforested kelp areas recover within a few years and fish populations increase. This pleases biologists but upsets commercial fishers, who argue that sea otters consume too many abalone and compete with commercial fishing.

During the past few years, however, the southern sea otter population has been declining for unknown reasons. One possibility is increased pollution of coastal waters. Shellfish tend to concentrate toxins that are released into coastal waters. High levels of toxins may directly kill sea otters, and exposure to lower levels over long periods may reduce their resistance to disease and parasites.

Another possibility is increased predation of the otters by killer whales (orcas). Evidence indicates in some areas that they may consume southern sea otters when there is a decline in their normal prey of Stellar sea lions and harbor seals—whose numbers may have dropped because of overfishing of species they eat.

The dynamics of southern sea otter populations have helped us to better understand the ecological importance of this keystone species. *Population dynamics, conservation biology,* and *human impacts on natural ecosystems* are the subject of this chapter.



(a) (b) (c)

Figure 9-1 **(a)** A southern sea otter. **(b)** A sea urchin. **(c)** A kelp bed.

In looking at nature . . . never forget that every single organic being around us may be said to be striving to increase its numbers.

CHARLES DARWIN, 1859

This chapter addresses the following questions:

- How do populations change in size, density, and makeup in response to environmental stress?
- What is the role of predators in controlling population size?
- What different reproductive patterns enhance the survival of different species?
- What is conservation biology?
- What are the major impacts of human activities on populations, communities, and ecosystems?
- How can we live more sustainably?

9-1 POPULATION DYNAMICS AND CARRYING CAPACITY

What Are the Major Characteristics of a Population? Populations are dynamic and change in response to environmental stress or changes in environmental conditions. They change in **(1)** *size* (number of individuals), **(2)** *density* (number of individuals in a certain space), **(3)** *dispersion* (spatial pattern such as clumping, uniform dispersion, or random dispersion, depending mostly on resource availability, Figure 9-2), and **(4)** *age distribution* (proportion of individuals of each age in a population) These changes, called **population dynamics,** occur in response to **(1)** environmental stress (Table 8-2, p. 183) and **(2)** changes in environmental conditions.

What Limits Population Growth? Four variables—*births, deaths, immigration,* and *emigration*—govern changes in population size. A population gains individuals by birth and immigration and loses them by death and emigration:

Population change = (Births + Immigration) − (Deaths + Emigration)

These variables depend on changes in resource availability or on other environmental changes (Figure 9-3, p. 192).

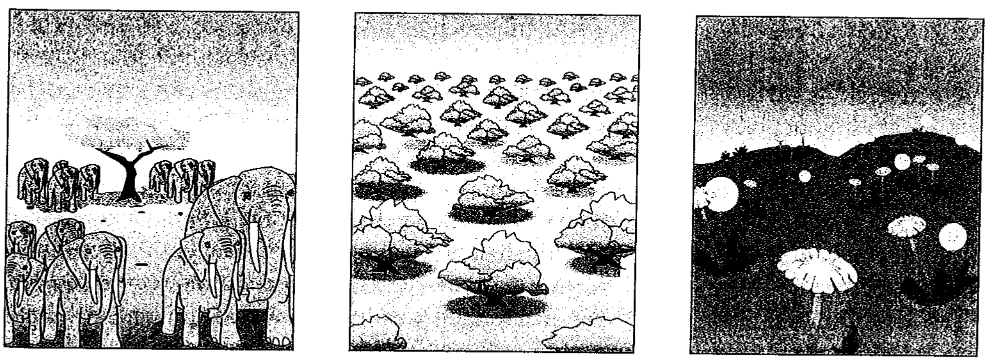
Populations vary in their capacity for growth, also known as the **biotic potential** of the population. The **intrinsic rate of increase (r)** is the rate at which a population would grow if it had unlimited resources. Generally, individuals in populations with a high intrinsic rate of increase **(1)** *reproduce early in life,* **(2)** *have short generation times* (the time between successive generations), **(3)** *can reproduce many times* (have a long reproductive life), and **(4)** *have many offspring each time they reproduce.*

Some species have an astounding biotic potential. For example, without any controls on its population growth, the ancestors of a single female housefly could total about 5.6 trillion flies within about 13 months, and within a few years there would be enough flies to cover the earth's entire surface.

However, this is not a realistic scenario because *no population can grow indefinitely.* In the real world, a rapidly growing population reaches some size limit imposed by a shortage of one or more limiting factors, such as light, water, space, or nutrients or too many competitors or predators. *There are always limits to population growth in nature.*

Environmental resistance consists of all the factors acting jointly to limit the growth of a population. The population size of a species in a given place and time is determined by the interplay between its biotic potential and environmental resistance (Figure 9-3, p. 192).

Together biotic potential and environmental resistance determine the **carrying capacity (K),** the number of individuals of a given species that can be sustained indefinitely in a given space (area or volume).



Clumped (elephants) | Uniform (creosote bush) | Random (dandelions)

Figure 9-2 Generalized *dispersion patterns* for individuals in a population throughout their habitat. The most common pattern is one in which members of a population exist in *clumps* throughout their habitat (left), mostly because resources usually are found in patches.

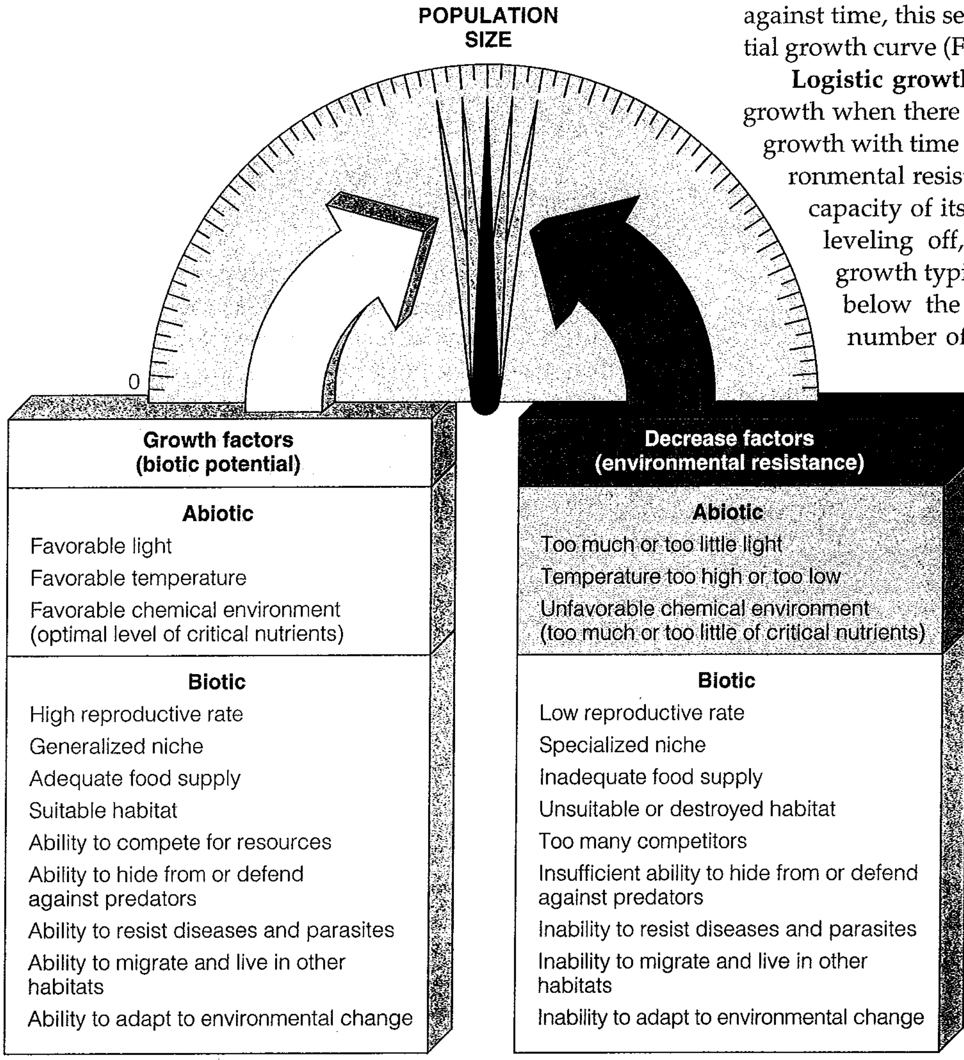


Figure 9-3 Factors that tend to increase or decrease the size of a population. Whether the size of a population grows, remains stable, or decreases depends on interactions between its growth factors (*biotic potential*) and decrease factors (*environmental resistance*).

The intrinsic rate of increase (r) of many species depends on having a certain minimum population size, called the **minimum viable population (MVP).** If a population declines below the MVP needed to support a breeding population, **(1)** certain individuals may not be able to locate mates, **(2)** genetically related individuals may interbreed and produce weak or malformed offspring, and **(3)** the genetic diversity may be too low to enable adaptation to new environmental conditions. Then the intrinsic rate of increase falls and extinction is likely.

What Is the Difference Between Exponential and Logistic Population Growth? A population that has few if any resource limitations grows exponentially. *Exponential growth* starts out slowly and then proceeds faster and faster as the population increases. If number of individuals is plotted against time, this sequence yields a *J*-shaped expone tial growth curve (Figure 9-4a).

Logistic growth involves exponential populati growth when there is a steady decrease in populati growth with time as the population encounters env ronmental resistance and approaches the carryi capacity of its environment and levels off. Aft leveling off, a population with this type growth typically fluctuates slightly above a below the carrying capacity. A plot of t number of individuals against time yields sigmoid, or *S*-shaped logis growth curve (Figure 9-4b). case of such growth involv the sheep population on t island of Tasmania, south Australia, in the early 19 century (Figure 9-5).

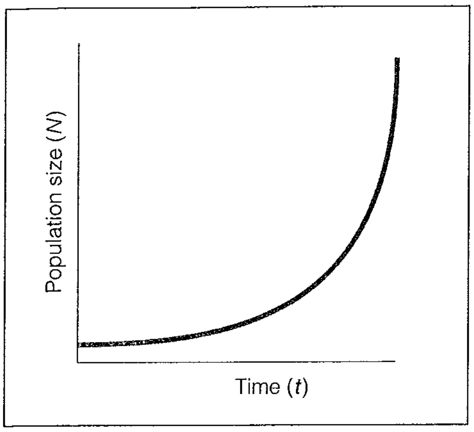
What Happens If the Po ulation Size Exceeds t Carrying Capacity? T populations of some species not make a smooth transiti from exponential growth logistic growth. Instead, suc population uses up its resour base and temporarily *ov shoots*, or exceeds, the carryi capacity of its environme This overshoot occurs becau of a *reproductive time lag*, t period needed for the birth ra to fall and the death rate to ri in response to resource ov consumption.

In such cases the popu tion suffers a *dieback*, or *cra* unless the excess individu switch to new resources or move to an area with mc favorable conditions. Such a crash occurred when rei deer were introduced onto a small island off the sou west coast of Alaska (Figure 9-6).

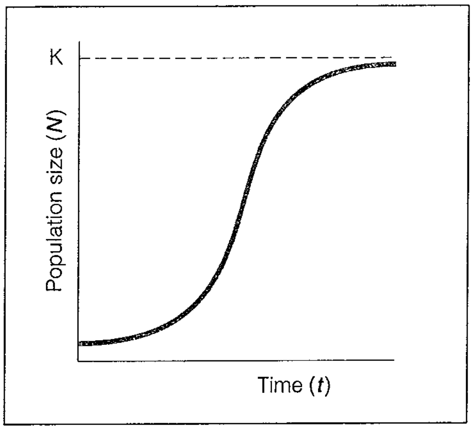
Carrying capacity is not a simple, fixed quant and is affected by many factors. Examples are **(1)** co petition within and between species, **(2)** immigrati and emigration, **(3)** natural and human-caused ca strophic events, and **(4)** seasonal fluctuations in t supply of food, water, hiding places, and nesting sit

Humans are not exempt from overshoot a dieback, as shown by the tragedy on Easter Isla (p. 40). Ireland also experienced a population cra after a fungus destroyed the potato crop in 18 About 1 million people died, and 3 million people em grated to other countries.

Technological, social, and other cultural chang (Section, 2-1, p. 22) have extended the earth's carryi



(a) Exponential Growth



(b) Logistic Growth

Figure 9-4 Theoretical population growth curves. **(a)** *Exponential growth*, in which the population's growth rate increases with time. Exponential growth occurs when resources are not limiting and a population can grow at its *intrinsic rate of increase* (r). Exponential growth of a population cannot continue forever because eventually some factor limits population growth. **(b)** *Logistic growth*, in which the growth rate decreases as the population gets larger. With time, the population size stabilizes at or near the *carrying capacity* (K) of its environment and results in a sigmoid (S-shaped) population growth curve.

capacity for the human species. We have increased food production and used large amounts of energy and matter resources to make normally uninhabitable areas of the earth habitable. However, there is growing concern about how long we will be able to keep doing this on a planet with **(1)** a finite size and resources and **(2)** a human population whose size (Figure 1-1, p. 2) and per capita resource use (Figure 1-11, p. 13) are growing exponentially.

How Does Population Density Affect Population Growth? *Density-independent population controls* affect a population's size regardless of its population density. Examples include **(1)** floods, **(2)** fires, **(3)** hurricanes, **(4)** unseasonable weather, **(5)** habitat destruction (such as clearing a forest of its trees or filling in a wetland), and **(6)** pesticide spraying. For example, a severe freeze in late spring can kill many individuals in a plant population, regardless of its density.

Some limiting factors have a greater effect as a population's density increases. Examples of such *density-dependent population controls* are **(1)** competition for resources, **(2)** predation, **(3)** parasitism, and **(4)** disease. As prey populations become denser, their members

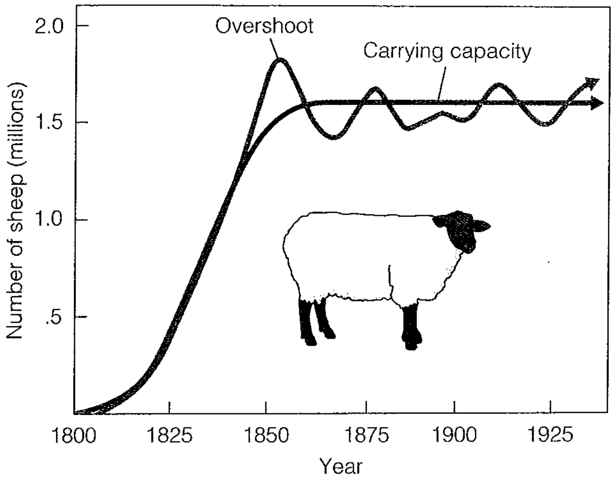


Figure 9-5 *Logistic growth* of a sheep population on the island of Tasmania between 1800 and 1925. After sheep were introduced in 1800, their population grew exponentially because of ample food. By 1855, they overshot the land's carrying capacity. Their numbers then stabilized and fluctuated around a carrying capacity of about 1.6 million sheep.

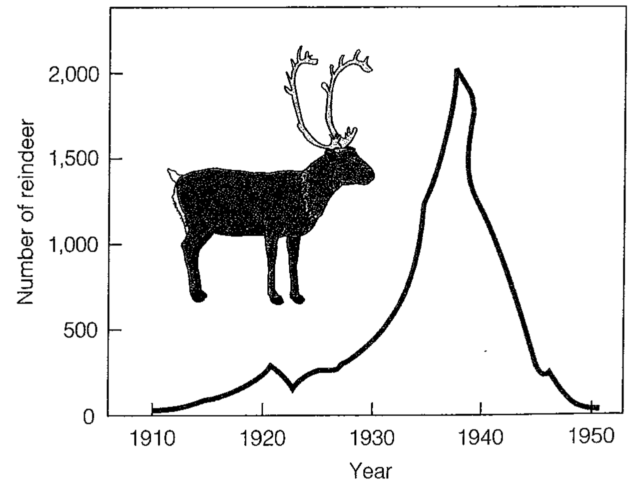


Figure 9-6 Exponential growth, overshoot, and population crash of reindeer introduced to a small island off the southwest coast of Alaska. When 26 reindeer (24 of them female) were introduced in 1910, lichens, mosses, and other food sources were plentiful. By 1935, the herd's population had soared to 2,000, overshooting the island's carrying capacity. This led to a population crash, with the herd plummeting to only 8 reindeer by 1950.

compete more for limited resources. Individuals in a dense population also are more likely to be infected by parasites or contagious disease organisms.

Infectious disease is a classic example of density-dependent population control. An example is the *bubonic plague,* which swept through Europe during the 14th century. The bacterium that causes this disease normally lives in rodents. It was transferred to humans by fleas that fed on infected rodents and then bit humans. The disease spread like wildfire through crowded cities, where sanitary conditions were poor and rats were abundant. At least 25 million people in European cities died from the disease.

Many health scientists are becoming increasingly alarmed about the possibility of new epidemics of common infectious diseases in crowded urban areas. The primary reason is that many common strains of disease-causing bacteria are becoming genetically resistant to most existing antibiotics through directional natural selection (Figure 5-6, left, p. 102).

What Kinds of Population Change Curves Do We Find in Nature? In nature we find four general types of *population fluctuations:* stable, irruptive, irregular, and cyclic (Figure 9-7). A species whose population size fluctuates slightly above and below its carrying capacity is said to have a fairly *stable* population size (Figures 9-5 and 9-7a). Such stability is characteristic of many species found in undisturbed tropical rain forests, where average temperature and rainfall varies little from year to year.

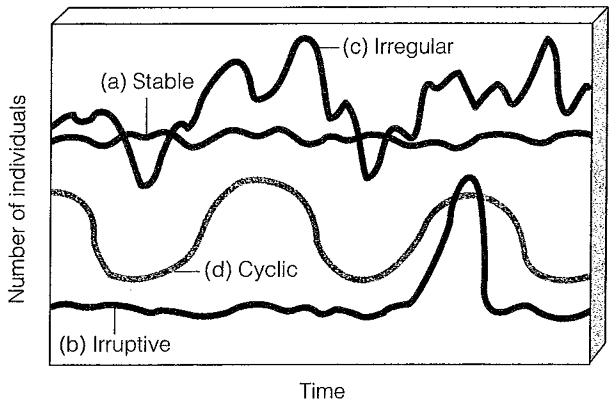


Figure 9-7 General types of simplified population change curves found in nature. **(a)** The population size of a species with a fairly *stable* population fluctuates slightly above and below its carrying capacity. **(b)** The populations of some species may occasionally explode, or *irrupt,* to a high peak and then crash to a more stable lower level. **(c)** The population sizes of some species change irregularly for mostly unknown reasons. **(d)** Other species undergo sharp increases in their numbers, followed by crashes over fairly regular time intervals. Predators sometimes are blamed, but the actual causes of such boom-and-bust cycles are poorly understood.

Some species, such as the raccoon and feral hous mouse, normally have a fairly stable population thɛ may occasionally explode, or *irrupt,* to a high peak an then crash to a more stable lower level or in some case to a very low level (Figures 9-6 and 9-7b). The populɛ tion explosion is caused by some factor that temporaı ily increases carrying capacity for the population, suc as **(1)** favorable weather, **(2)** more food, or **(3)** fewe predators.

Some populations exhibit what appears to b irregular *chaotic behavior* in their changes in populatio size, with no recurring pattern (Figure 9-7c). Some sc entists attribute such behavior to chaos in such sy tems. Other scientists contend that the behavior ma be caused by orderly, nonchaotic behavior whos details and interactions are still poorly understood.

The fourth type consists of *cyclic fluctuations* of pop ulation size over a regular time period (Figure 9-7d Examples are **(1)** lemmings, whose populations ris and fall every 3–4 years, and **(2)** grouse, lynx, and snow shoe hare, whose populations generally rise and fall o a 10-year cycle.

9-2 THE ROLE OF PREDATION IN CONTROLLING POPULATION SIZE

Do Predators Control Population Size? Th Lynx–Hare Cycle Some species that interact ɛ predator and prey undergo cyclic changes in the numbers, with sharp increases in their numbers fo lowed by seemingly periodic crashes (Figure 9-8).

For decades, predation has been the explanatio for the 10-year population cycles of the snowshoe haı and its predator, the Canadian lynx (Figure 9-8 According to this *top-down control* hypothesis, lyn preying on hares periodically reduce their populatioı The shortage of hares then reduces the lynx populɛ tion, which allows the hare population to build u again. At some point the lynx population increases t take advantage of the increased supply of hares, star ing the cycle again.

Some research has cast doubt on this appealin hypothesis because snowshoe hare populations hav been found to have similar 10-year boom-and-bu cycles on islands where lynx are absent. Researcheı now hypothesize that the periodic crashes in the haı population can also be influenced by the food suppl of the hares. Large numbers of hares can die whe they **(1)** consume food plants faster than they can b replenished (especially during winter) and **(2)** have decrease in the quantity and quality of their foo Once the hare population crashes, the plants recove and the hare population begins rising again in hare–plant cycle. If this *bottom-up control* hypothesis

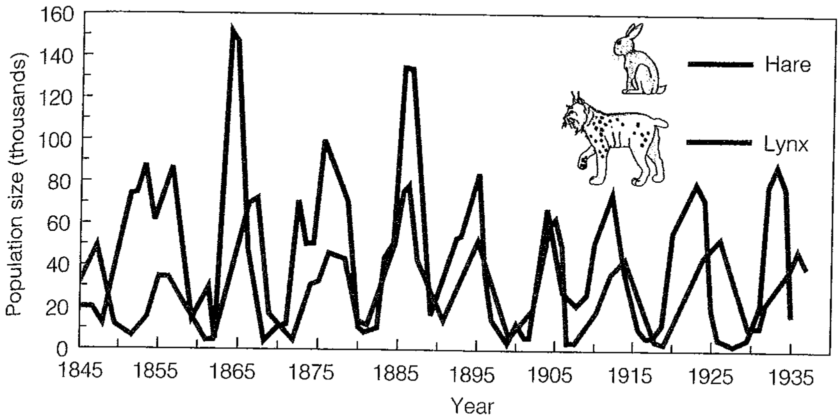


Figure 9-8 Population cycles for the snowshoe hare and Canadian lynx. At one time it was widely believed these curves provided circumstantial evidence that these predator and prey populations regulated one another. More recent research suggests that the periodic swings in the hare population are caused by a combination of **(1)** predation by lynx and other predators (*top-down population control*) and **(2)** changes in the availability of the food supply for hares with the rise and fall of the hare population helping determine the lynx population (*bottom-up population control*). (Data from D. A. MacLulich)

correct, instead of lynx controlling hare populations, the changing hare population size may be causing fluctuations in the lynx population.

These two hypotheses are not mutually exclusive. According to extensive research by Charles J. Krebs, the 10-year population cycle of snowshoe hares in boreal forests is caused by an interaction between predation (by lynx, coyotes, and other predators) and food supplies (especially in winter), with predation being the dominant process.

According to biologists, genuine cases of top-down control systems by predators exist in a number of ecosystems. Examples are **(1)** wolves controlling deer populations and moose populations (Case Study, p. 197), **(2)** large predatory fish controlling other fish populations in lakes, and **(3)** sharks (Case Study, p. 176) and alligators (Connections, p. 173) controlling some fish populations.

9-3 REPRODUCTIVE PATTERNS AND SURVIVAL

How Do Species Reproduce? Reproductive individuals in populations of all species engage in a struggle for genetic immortality by trying to have as many members of the next generation as possible carry their genes. Genes can be passed on to offspring by the following means:

- **Asexual reproduction,** in which all offspring are exact genetic copies (clones) of a single parent. This type of reproduction is common in single-celled species such as bacteria, in which the mother cell divides to produce two identical cells that are genetic clones or replicas of the mother cell.
- **Sexual reproduction,** in which organisms produce offspring by combining the gametes or sex cells (such as sperm and ovum) from both parents. This produces offspring that have combinations of traits (chromosomes) from each parent. About 97% of known organisms use sexual reproduction to perpetuate their species.

Sexual reproduction has several ecological costs and risks, which include the following:

- Females have to produce twice as many offspring to maintain the same number of young in the next generation as an asexually reproducing organism because males do not give birth.
- The chances of genetic errors and defects increase during the splitting and recombination of chromosomes.
- Mating entails costs such as **(1)** time-consuming courtship and mating rituals, **(2)** disease transmission, and **(3)** injury inflicted by males during mating.

So if sexual reproduction has so many costs and risks, why do 97% of the earth's organisms use it? Consider these two important advantages of sexual reproduction:

- It provides a greater genetic diversity in the offspring. Thus sexually reproducing organisms with "many different eggs in their genetic basket" have a greater chance of reproducing when environmental conditions change than does a brood of genetically identical clones with "only one type of egg in their genetic basket."
- Males can gather food for the female and the young and may protect and help train the young of some species. This is especially helpful for species such as mammals and birds that produce only a few young.

What Types of Reproductive Patterns Do Species Have? In 1967, Robert H. MacArthur and Edward O. Wilson suggested that species could be classified into two fundamental reproductive patterns, *r-selected* and *K-selected species,* on the basis of **(1)** their position on the sigmoid (S-shaped) population growth curve (Figure 9-9, p. 196) and **(2)** the characteristics of their reproductive patterns (Figure 9-10, p. 196).

What Are Opportunist or r-Selected Species? Species with a capacity for a high intrinsic rate of

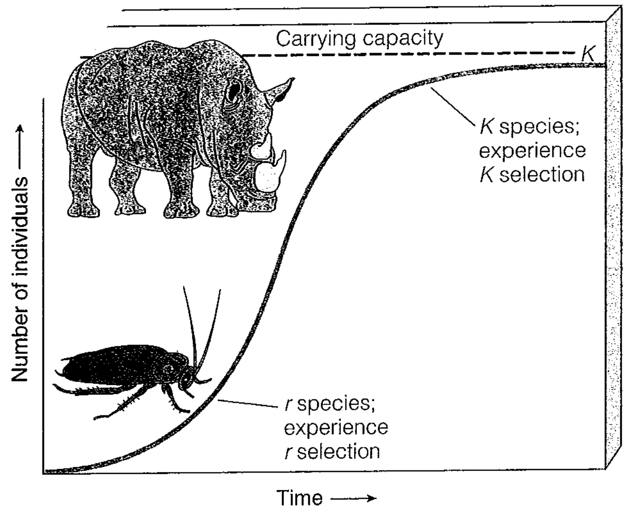


Figure 9-9 Positions of *r-selected* and *K-selected* species on the sigmoid (S-shaped) population growth curve.

increase (*r*) are called **r-selected species** (Figure 9-9 and Figure 9-10, left). Such species reproduce early and put most of their energy into reproduction. Examples are algae, bacteria, rodents, annual plants (such as dandelions), and most insects (p. 64).

These species **(1)** have many (usually small) offspring each time they reproduce, **(2)** reach reproductive age rapidly, **(3)** have short generation times, **(4)** give their offspring little or no parental care or protection to help them survive, and **(5)** are short lived (usually with a life span of less than a year). Species with this reproductive pattern overcome the massive loss of their offspring by producing so many unprotected young that a few will survive to reproduce many offspring to begin the cycle again.

Such species tend to be *opportunists.* They reproduce and disperse rapidly when conditions are favorable or when a disturbance (Table 8-2, p. 183) opens up a new habitat or niche for invasion, as in the early stages of ecological succession (Figures 8-14, p. 180 and 8-15, p. 181).

Changed environmental conditions from disturbances can allow opportunist species to gain a foothold. However, once established, their populations may crash because of **(1)** changing or unfavorable environmental conditions or **(2)** invasion by more competitive species. Therefore, most r-selected or opportunist species go through irregular and unstable boom-and-bust cycles in their population size. To survive, opportunists must continually invade new areas to compensate for being displaced by more competitive species.

What Are Competitor or K-Selected Species?

At the other extreme are *competitor,* or **K-selected species** (Figure 9-9 and Figure 9-10, right). These

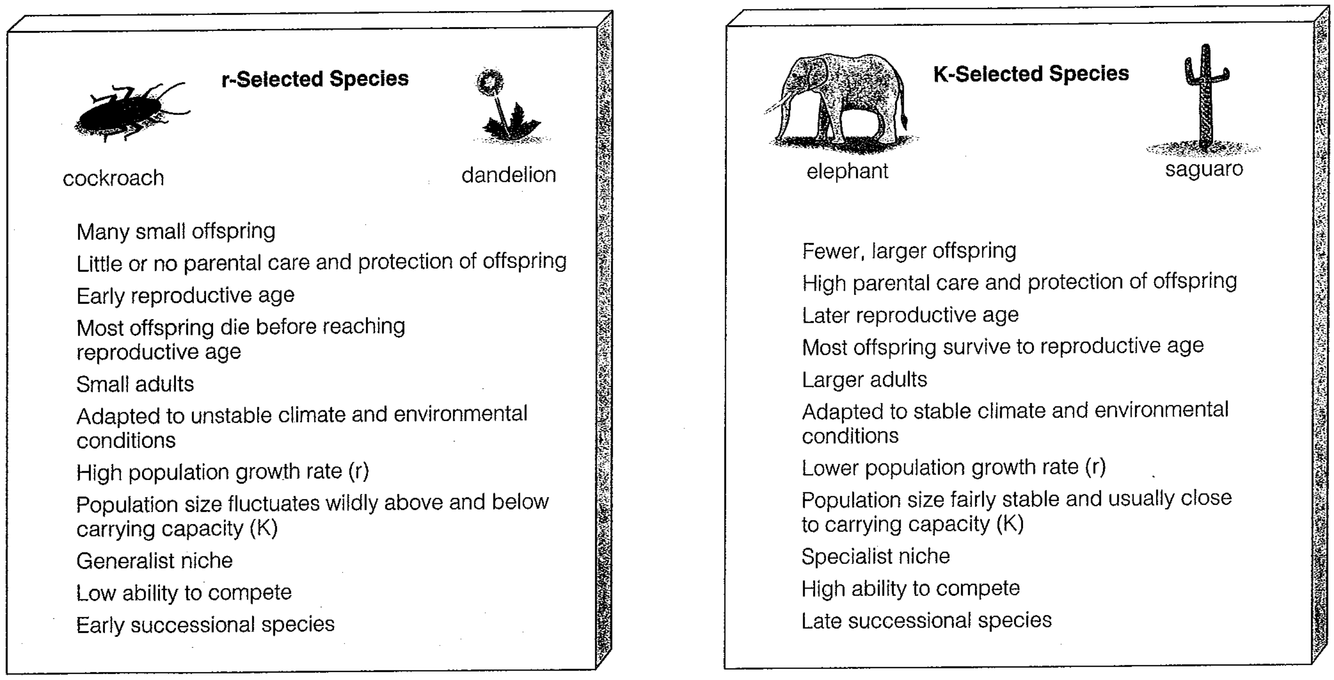


Figure 9-10 Generalized characteristics of *r-selected* or opportunist species and *K-selected* or competitor species. Many species have characteristics between these two extremes.

CASE STUDY

Wolf and Moose Interactions on Isle Royale

For decades, wildlife biologists have been studying the relationship between the moose and wolf populations on Isle Royale, an island in Lake Superior between Minnesota in the United States and Ontario in Canada (see figure).

In the early 1900s, a small herd of moose wandered across the frozen ice of Lake Superior to this island. With an abundance of food, the moose population exploded (see figure). In 1928, a wildlife biologist visiting the island successfully predicted that the large moose population would soon crash because the moose had stripped the island of most of its preferred food plants.

Sometime during the 1940s, timber wolves (probably a single pair) reached Isle Royale by traveling over the ice from the Canadian mainland during winter. They reproduced and slowly grew in numbers.

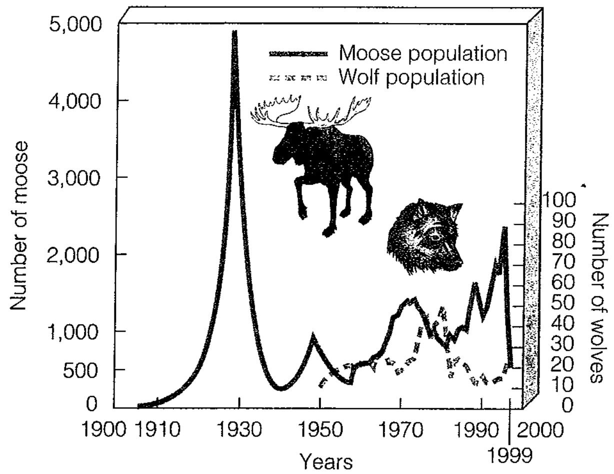
Since 1958, wildlife biologists have been tracking the populations of the two species (see figure). You might think that the wolves would have completely exterminated the moose, but instead the two species have been interacting in what appears to be an oscillating predator–prey cycle (see figure). If the wolves could drive the moose to extinction they probably would, but the moose are too formidable for this to happen.

Since 1980, the wolf population has declined from a high of about 50 and fluctuated between 12 and 25 individuals. Possible reasons for this decline are **(1)** a canine virus introduced to wolves by dogs and **(2)** a low reproduction rate because of a lack of genetic variability from inbreeding.

With the decline in wolves, the moose population rose sharply until 1995. Then it crashed from a combination of lack of food, poor reproduction, a severe winter, and a tick infestation. By 1999, the wolf population, with plenty of weakened prey, had grown to 25. If their population continues to grow, they may hold the moose numbers in check and allow damaged vegetation to recover and begin a new cycle of interactions.

Critical Thinking

What is the primary ecological lesson to be learned from the moose–wolf interaction on Isle Royale?



Changes in moose and wolf populations on Isle Royale, 1900–99. (Data from Rolf O. Peterson)

species **(1)** put fairly little energy into reproduction, **(2)** tend to reproduce late in life, **(3)** have few offspring with long generation times, and **(4)** put most of their energy into nurturing and protecting their young until they reach reproductive age.

Typically the offspring of such species **(1)** develop inside their mothers (where they are safe), **(2)** are fairly large, **(3)** mature slowly, and **(4)** are cared for and protected by one or both parents 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 (Figure 9-10, right).

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 9-4b and Figure 9-9). Examples are **(1)** most large mammals (such as elephants, whales, and humans), **(2)** birds of prey, and **(3)** large and long-lived plants (such as the saguaro cactus, oak trees, redwood trees, and most tropical rain forest trees). Many K-selected species, especially those with long generation times and low reproductive rates (such as elephants, rhinoceroses, and sharks, Case Study, p. 176), are prone to extinction.

Most competitor or K-selected species thrive best in ecosystems with fairly constant environmental conditions. In contrast, opportunists thrive in habitats that have experienced disturbances (Table 8-2, p. 183) such as a tree falling, a forest fire, or the clearing of a forest or grassland for raising crops.

Many organisms have reproductive patterns between the extremes of r-selected species and K-selected species, or they change from one extreme to the other under certain environmental conditions. In agriculture we raise both r-selected species (crops) and K-selected species (livestock).

The reproductive pattern of a species may give it a temporary advantage, but *the availability of suitable habitat for individuals of a population in a particular area is what determines its ultimate population size.* Regardless of how fast a species can reproduce, there can be no more dandelions than there is dandelion habitat and no more zebras than there is zebra habitat in a particular area.

What Are Survivorship Curves? Individuals of species with different reproductive strategies tend to have different *life expectancies.* One way to represent the age structure of a population is with a **survivorship curve,** which shows the number of survivors of each age group for a particular species. The three generalized types of survivorship curves (Figure 9-11) are

- *Late loss curves,* typical for K-selected species (such as elephants and humans) that produce few young and care for them until they reach reproductive age (thus reducing juvenile mortality).

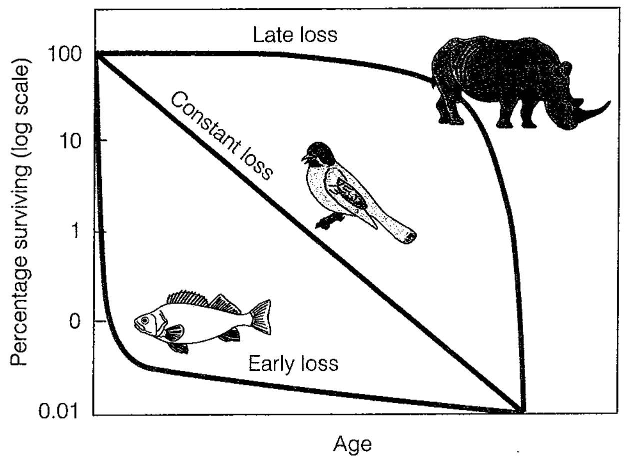


Figure 9-11 Three general *survivorship curves* for populations of different species, obtained by showing the percentages of the members of a population surviving at different ages. For a *late loss* population (such as elephants, rhinoceroses, and humans), there is typically high survivorship to a certain age, then high mortality. A *constant loss* population (such as many songbirds) shows a fairly constant death rate at all ages. For an *early loss* population (such as annual plants and many bony fish species), survivorship is low early in life. These generalized survivorship curves only approximate the behavior of species.

- *Early loss curves,* typical for r-selected species (such as most annual plants and most bony fish species) that have **(1)** many offspring, **(2)** high juvenile mortality, and **(3)** high survivorship once the surviving young reach a certain age and size.
- *Constant loss curves,* characteristic of species with intermediate reproductive patterns with a fairly constant rate of mortality in all age classes and thus a steadily declining survivorship curve. Examples include many types of songbirds, lizards, and small mammals that face a fairly constant threat from starvation, predation, and disease throughout their lives.

A *life table* shows the numbers of individuals at each age from a survivorship curve. It illustrates the projected life expectancy and probability of death for individuals at each age. Insurance companies use life tables of human populations in various countries or regions to determine policy costs for their customers. Because life tables show that women in the United States survive an average of 7 years longer than men, for example, a 65-year-old man normally pays more for life insurance than a 65-year-old woman.

9-4 CONSERVATION BIOLOGY: SUSTAINING WILDLIFE POPULATIONS

What Is Conservation Biology? Conservation biology is a multidisciplinary science, originated in the 1970s, that uses the best available science to take action to preserve species and ecosystems. Conservation biology seeks answers to three questions:

- *Which species are in danger of extinction?*
- *What is the status of the functioning of ecosystems, and what ecosystem services* (Figure 4-34, p. 92) *of value to humans and other species are we in danger of losing?*
- *What measures can we take to help sustain ecosystem functions and viable populations of wild species?*

These are challenging questions, and the answers require extensive field research. To understand the status of natural populations, we must **(1)** measure the current population size, **(2)** project how population size is likely to change with time, and **(3)** determine whether existing populations are likely to be sustainable.

Conservation biology rests on three underlying principles:

- Biodiversity is necessary to all life on earth and should not be reduced by human actions.
- Humans should not **(1)** cause or hasten the extinction of wildlife populations and species or **(2)** disrupt vital ecological processes.

- The best way to preserve earth's biodiversity and ecological functions is to protect intact ecosystems that provide sufficient habitat for sustaining natural populations of species.

Conservation biology is based on Aldo Leopold's ethical principle that something is right when it tends to maintain the earth's life-support systems for us and other species and wrong when it does not (Section 2-5, p. 36).

What Is Bioinformatics? Good conservation biology depends on good information. Increasingly, efforts of conservation biologists are focused on building computer databases that store useful information about biodiversity. Recently, a new discipline called *bioinformatics* has developed that **(1)** provides tools for storage and access to key biological information and **(2)** builds databases that contain the needed biological information.

9-5 HUMAN IMPACTS ON ECOSYSTEMS: LEARNING FROM NATURE

How Have Humans Modified Natural Ecosystems? To survive and support growing numbers of people, we have greatly increased the number and area of the earth's natural systems that we have modified, cultivated, built on, or degraded (Figure 1-5, p. 7). We have used technology to alter much of the rest of nature in the following ways:

- *Fragmenting and degrading habitat.*
- *Simplifying natural ecosystems.* When we plow grasslands and clear forests, we often replace their thousands of interrelated plant and animal species with one crop (Figure 6-31, p. 132) or one kind of tree (Figure 6-39, p. 139)—called *monocultures*—or with buildings, highways, and parking lots. Then we spend a lot of time, energy, and money trying to protect such monocultures from invasion by **(1)** opportunist species of plants (weeds), **(2)** pests (mostly insects, to which a monoculture crop is like an all-you-can-eat restaurant), and **(3)** pathogens (fungi, viruses, or bacteria that harm the plants we want to grow).
- *Using, wasting, or destroying an increasing percentage of the earth's net primary productivity that supports all consumer species (including humans)* (Figure 4-26, p. 82). This is the main reason we are crowding out or eliminating the habitats and food supplies of a growing number of species.
- *Strengthening some populations of pest species and disease-causing bacteria by* **(1)** *speeding up natural selection and* **(2)** *causing genetic resistance through overuse of pesticides and antibiotics* (Figure 5-6, left, p. 102).
- *Eliminating some predators.* Some ranchers want to eradicate bison or prairie dogs that compete with their sheep or cattle for grass. They also want to eliminate wolves, coyotes, eagles, and other predators that occasionally kill sheep. Big game hunters also push for elimination of predators that prey on game species.
- *Deliberately or accidentally introducing new or nonnative species,* some beneficial (such as most food crops) and some harmful to us and other species.
- *Overharvesting renewable resources.* Ranchers and nomadic herders sometimes allow livestock to overgraze grasslands until erosion converts these ecosystems to less productive semideserts or deserts. Farmers sometimes deplete soil nutrients by excessive crop growing. Fish species are overharvested. Illegal hunting (poaching) endangers wildlife species with economically valuable parts (such as elephant tusks, rhinoceros horns, and tiger skins).
- *Interfering with the normal chemical cycling and energy flows in ecosystems.* Soil nutrients can erode from monoculture crop fields, tree plantations, construction sites, and other simplified ecosystems and can overload and disrupt other ecosystems such as lakes and coastal ecosystems. Chemicals such as chlorofluorocarbons (CFCs) released into the atmosphere can increase the amount of harmful ultraviolet energy reaching the earth by reducing ozone levels in the stratosphere. Emissions of carbon dioxide and other greenhouse gases—from burning fossil fuels and from clearing and burning forests and grasslands—can trigger global climate change by altering energy flow through the atmosphere.

To survive we must exploit and modify parts of nature. But, we are beginning to understand that any human intrusion into nature has multiple effects, most of them unpredictable (p. 46 and Connections, p. 200).

The challenge is to **(1)** maintain a balance between simplified, human-altered ecosystems and the neighboring, more complex natural ecosystems on which we and other life-forms depend and **(2)** slow down the rates at which we are altering nature for our purposes. If we simplify and degrade too much of the planet to meet our needs and wants, what is at risk is not the earth but our own species.

Solutions: What Can We Learn from Nature About Living More Sustainably? Organisms, populations, and ecosystems are remarkably resilient when exposed to stresses (Table 8-2, p. 183) caused by natural or human-induced changes in environmental conditions. However, scientific research indicates that environmental stresses have harmful effects on organisms, populations, and ecosystems that can affect their environmental health and long-term sustainability (Figure 9-12, p. 200).

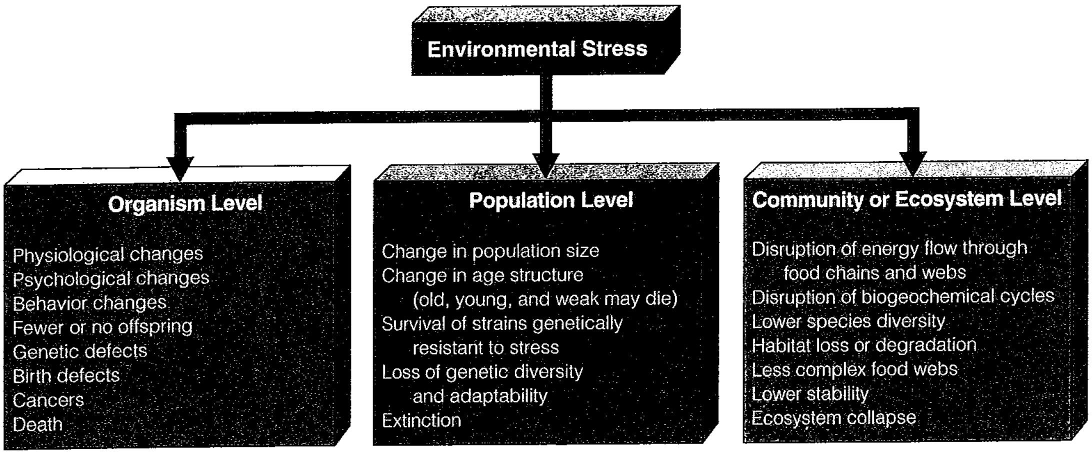


Figure 9-12 Some effects of environmental stress on organisms, populations, communities, and ecosystems.

Many biologists believe the best way for us to live more sustainably is to **(1)** learn about the processes and adaptations by which nature sustains itself (Solutions, p. 201) and **(2)** mimic these lessons from nature.

Biologists have used these lessons from nature to formulate several principles to guide us in our search for more sustainable lifestyles:

- ***Our lives, lifestyles, and economies are totally dependent on the sun and the earth.*** We need the earth, but the earth does not need us.
- ***Everything is connected to everything else.*** The primary goal of ecology is to discover which connections in nature are the strongest, most important, and most vulnerable to disruption.
- ***We can never do merely one thing.*** Any human intrusion into nature has mostly unpredictable side effects. When we alter nature, we should ask, "And then what?"
- ***We should reduce and minimize the damage we do to nature and help heal some of the ecological wounds we have inflicted.***
- ***We should use care, restraint, humility, and cooperation with nature as we alter the biosphere to meet our needs and wants.***

Using such guidelines, we can create a more ecologically and economically sustainable society that lives within its ecological means by **(1)** taking no more than we need, **(2)** using renewable resources no faster

Ecological Surprises

CONNECTIONS

Malaria once infected 9 out of 10 people in North Borneo, now known as Sabah. In 1955, the World Health Organization (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.

However, unexpected things began to happen. The dieldrin also killed other insects, including flies and cockroaches living in houses. The islanders applauded this turn of events, but then small lizards that also lived in the houses died after gorging themselves on dieldrin-contaminated insects.

Next, cats began dying after feeding on the lizards. Then, 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.

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 in thatched roofs.

Ultimately, this episode ended happily: both malaria and the unexpected effects of the spraying program were brought under control. Nevertheless, the chain of unforeseen events emphasizes the unpredictability of interfering with an ecosystem. It reminds us that when we intervene in nature, we need to ask, "And then what?"

Critical Thinking

Do you believe the beneficial effects of spraying pesticides on Sabah outweighed the resulting unexpected and harmful effects? Explain.

Principles of Sustainability: Learning from Nature

SOLUTIONS

Here are four basic ecological lessons or principles of sustainability derived from observing how nature works:

- ***Most ecosystems use renewable solar energy as their primary source of energy.*** Thus a sustainable society would be powered mostly by current sunlight, not ancient sunlight stored as polluting fossil fuels.
- ***Ecosystems replenish nutrients and dispose of wastes by recycling chemicals.*** There is almost no waste in nature because the waste outputs and decomposed remains of one organism are resource inputs for other organisms. Thus a sustainable society would emphasize **(1)** preventing and reducing waste and **(2)** recycling and reusing resources (Figure 3-21, p. 61).
- ***Biodiversity (1) helps maintain the sustainability and ecological functioning of ecosystems and (2) serves as a source of adaptations to changing environmental conditions.*** Thus a sustainable society emphasizes conserving biodiversity by protecting ecosystems and preventing the premature extinction of species.
- ***In nature there are always limits to population growth and resource consumption.*** The population size and growth rate of all species are controlled by their interactions with other species and with their nonliving environment, especially resource availability. Thus a sustainable society emphasizes reducing **(1)** births to control population growth and **(2)** resource consumption to prevent environmental overload and depletion of natural resources.

Critical Thinking

List two ways in which human activities violate each of these four principles of sustainability. In what ways does your lifestyle violate these principles? Would you be willing to change these practices? What beneficial and harmful effects would such changes have on your lifestyle?

than nature replaces them, **(3)** preserving biodiversity and human cultural diversity, and **(4)** not depleting natural capital (Figure 4-34, p. 92).

We cannot command nature except by obeying her.
Sir Francis Bacon

REVIEW QUESTIONS

1. Define the boldfaced terms in this chapter.

2. Explain how the populations of southern sea otters and kelp interact and why the southern sea otter is considered a keystone species.

3. What four factors affect population change?

4. Write an equation showing how population change is related to births, deaths, immigration, and emigration.

5. What is the *biotic potential* of a population? What are four characteristics of a population with a high *intrinsic rate of increase* (r)?

6. What are *environmental resistance* and *carrying capacity?* How do biotic potential and environmental resistance interact to determine carrying capacity? List four factors that can alter an area's carrying capacity. What is the *minimum viable population* size of a population?

7. Distinguish between *exponential* and *logistic growth* of a population, and give an example of each type.

8. How can a population overshoot its carrying capacity, and what are the consequences of doing this?

9. Distinguish between *density-dependent* and *density-independent factors* that affect a population's size, and give an example of each.

10. Distinguish among *stable, irruptive, irregular,* and *cyclic* forms of population change.

11. Distinguish between *top-down control* and *bottom-up control* of a population's size. Use these concepts to describe the effects of the predator–prey interactions between the snowshoe hare and the Canadian lynx on the population of each species.

12. Describe the predator–prey interactions between wolf and moose populations on Isle Royale. Is this a *top-down* or *bottom-up* form of population control?

13. Distinguish between *asexual reproduction* and *sexual reproduction.* What are the disadvantages and advantages of sexual reproduction?

14. List the characteristics of **(a)** *r-selected* or *opportunist species* and **(b)** *K-selected* or *competitor* species, and give two examples of each type. Under what environmental conditions are you most likely to find **(a)** r-selected species and **(b)** K-selected species?

15. What is a *survivorship curve,* and how is it used? List three general types of survivorship curves, and give an example of a species with each type.

16. What is *conservation biology?* What three questions does conservation biology try to answer? What are the three underlying principles of conservation biology? What is *bioinformatics,* and what is its importance?

17. List eight potentially harmful ways in which humans modify natural ecosystems.

18. List four *principles of sustainability* derived from observing how natural systems are sustained.

19. List five principles we could use to help us live more sustainably.

CRITICAL THINKING

1. Why do **(a)** biotic factors that regulate population growth tend to depend on population density and **(b)** abiotic factors that regulate population tend to be independent of population density?

2. What are the advantages and disadvantages of a species undergoing **(a)** exponential growth (Figure 9-4a) and **(b)** logistic growth (Figure 9-4b)?

3. Suppose that because of disease or genetic defects from inbreeding, the wolves on Isle Royale (Case Study, p. 197) die off. Should we **(a)** intervene and import new wolves to help control the moose population or **(b)** let the moose population grow until it exceeds its carrying capacity and suffers another population crash? Explain.

4. Why are pest species likely to be extreme r-selected species? Why are many endangered species likely to be extreme K-selected species?

5. Why is an animal that devotes most of its energy to reproduction likely to be small and weak?

6. Given current environmental conditions, if you had a choice would you rather be an r-strategist or a K-strategist? Explain your answer. What implications does your decision have for your current lifestyle?

7. Predict the type of survivorship curve you would expect given descriptions of the following organisms:
   a. This organism is an annual plant. It lives only 1 year. During that time, it sprouts, reaches maturity, produces many wind-dispersed seeds, and dies.
   b. This organism is a mammal. It reaches maturity after 10 years. It bears one young every 2 years. The parents and the rest of the herd protect the young.

8. Explain why a simplified ecosystem such as a cornfield usually is much more vulnerable to harm from insects and plant diseases than a more complex, natural ecosystem such as a grassland.

9. How has the human population generally been able to avoid environmental resistance factors that affect other populations? Is this likely to continue? Explain.

10. Explain why you agree or disagree with the five principles for living more sustainably listed on p. 200.

PROJECTS

1. Use the principles of sustainability derived from the scientific study of how nature sustains itself (Solutions, p. 201) to evaluate the sustainability of the following parts of human systems: **(a)** transportation, **(b)** cities, **(c)** agriculture, **(d)** manufacturing, **(e)** waste disposal, and **(f)** your own lifestyle. Compare your analysis with those made by other members of your class.

2. Use the library and Internet to choose one wild plant species and one animal species and analyze the factors that are likely to limit the populations of each species.

3. Use the library or the Internet to find bibliographic information about *Charles Darwin* and *Sir Francis Bacon,* whose quotes appear at the beginning and end of this chapter.

4. Make a concept map of this chapter's major ideas, using the section heads and subheads and the key terms (in boldface). Look on the website for this book for information about making concept maps.

INTERNET STUDY RESOURCES AND RESOURCES FOR FURTHER READING AND RESEARCH

The website for this book contains helpful study aids and many ideas for further reading and research. Log on to

www.info.brookscole.com/miller13

and click on the Chapter-by-Chapter area. Choose Chapter 9 and select a resource:

- Flash Cards allows you to test your mastery of the Terms and Concepts to Remember for this chapter.
- Tutorial Quizzes provides a multiple-choice practice quiz.
- Student Guide to InfoTrac will lead you to Critical Thinking Projects that use InfoTrac College Edition as a research tool.
- References lists the major books and articles consulted in writing this chapter.
- Hypercontents takes you to an extensive list of sites with news, research, and images related to individual sections of the chapter.

INFOTRAC COLLEGE EDITION

Improve your skills with InfoTrac College Edition, a searchable online database of articles from more than 700 periodicals. Log on to

http://www.infotrac-college.com

or access InfoTrac through the website for this book. Try to find the following articles:

1. Wangersky, R. 2000. Too many moose. *Canadian Geographic* 120: 44. *Keywords:* "Newfoundland," "moose," and "problems." Moose were introduced into Newfoundland where it is now thriving. But even though the introduction of moose has some benefits for humans, it is having significant adverse ecological impact.

2. Michigan Technological University. 2002. Longest-running predator-prey study in world links lack of wintry weather to changes in wolf, moose populations on Isle Royale in Lake Superior. *Ascribe Higher Education News Service* (March 12). *Keywords:* "predator-prey" and "Isle Royale." Most population-ecology books refer to the classic case of population regulation of moose and wolves on Isle Royale. This article indicates that other factors may also be affecting the populations of these animals.

10 GEOLOGY: PROCESSES, HAZARDS, AND SOILS

The Mount St. Helens Eruption

For 123 years the volcano at Mount St. Helens (Figure 10-1, top) in the Cascade Range near the Washington–Oregon border, had slumbered. On May 18, 1980, it erupted with an enormous explosive force (Figure 10-1, bottom), causing the worst volcanic disaster in U.S. history.

Devastation occurred in three semicircular zones reaching out about 44 kilometers (27 miles) to the north of the volcano:

- In the *blast zone* or *tree-removal zone,* extending about 13 kilometers (8 miles), everything was obliterated or carried away.
- In the *tree-down zone,* extending 30 kilometers (19 miles) beyond the blast zone, a wave of ash-laden air blew the trees down like matchsticks.
- In the *seared zone,* 1–2 kilometers (0.6–1.2 miles) further out, trees were left standing but were scorched brown.

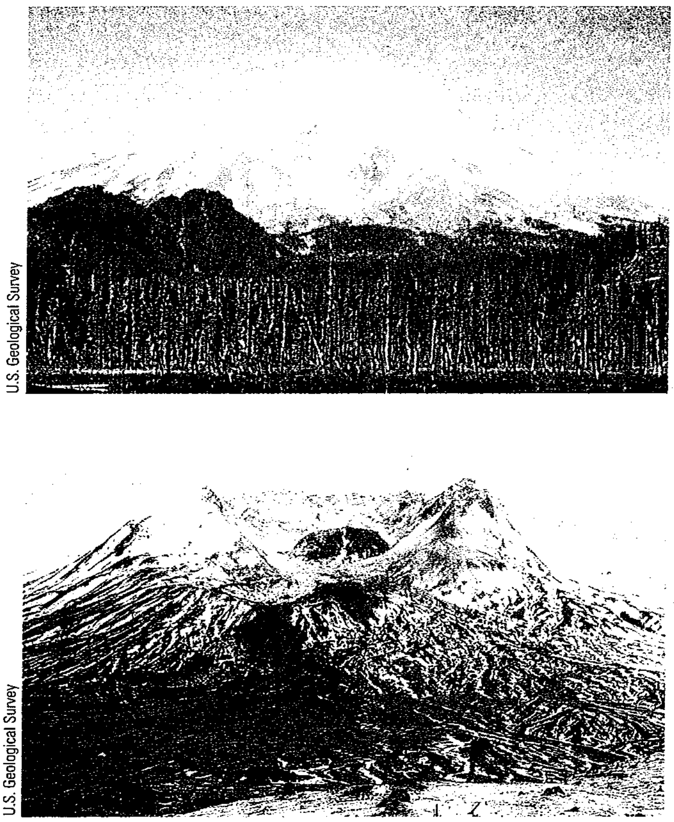


Figure 10-1 Mount St. Helens, a composite volcano in Washington, near the Oregon border, before (top), and shortly after (bottom), its major eruption in May 1980.

The explosion also threw ash more than 7 kilometers (4 miles) up into the atmosphere, high enough to be injected into global atmospheric circulation patterns. Several hours after the blast, ash-darkened sky triggered automatic streetlights during the morning in Yakima and Spokane, Washington. Within two weeks the ash cloud had traveled around the globe and eventually circled the planet several times before settling to the ground.

Fifty-seven people died in the eruption, and several hundred cabins and homes were destroyed or severely damaged. Tens of thousands of hectares of forest were obliterated, along with campgrounds and bridges. An estimated 7,000 big game animals (bear, deer, elk, and mountain lions) died, as did millions of smaller animals and birds and some 11 million fish.

Salmon hatcheries were damaged, and crops (including alfalfa, apples, potatoes, and wheat) were lost. Many people living in the area lost their jobs.

On the positive side, trace elements from ash that were added to the soil may eventually benefit agriculture. Increased tourism to the area to view the destruction also brought new jobs and income.

By 1990, biologists were surprised at how fast various forms of life had begun colonizing many of the most devastated areas. This rapid recovery taught biologists important and often surprising lessons about nature's ability to recover from what seems to be devastation.

We live on a dynamic planet. Energy from the sun and from the earth's interior, coupled with the erosive power of flowing water, have created continents, mountains, valleys, plains, and ocean basins in an ongoing process that continues to change the landscape. **Geology** is the science devoted to the study of these dynamic processes. Geologists study and analyze rocks and the features and processes of the earth's interior and surface. Some of these processes lead to geologic hazards such as earthquakes and volcanic eruptions (Figure 10-1), and others produce the renewable soil and nonrenewable mineral resources and energy resources that support life and economies.

Civilization exists by geological consent, subject to change without notice.

WILL DURANT

This chapter addresses the following questions:

- What major geologic processes occur within the earth and on its surface?
- What are rocks, and how are they recycled by the rock cycle?
- What are the hazards from earthquakes and volcanic eruptions?
- What are soils, and how are they formed?
- What is soil erosion, and how can it be reduced?

10-1 GEOLOGIC PROCESSES

What Is the Earth's Structure? As the primitive earth cooled over eons, its interior separated into three major concentric zones, which geologists identify as the *core*, the *mantle*, and the *crust* (Figure 4-6, p. 68, and Figure 10-2). What we know about the earth's interior comes mostly from indirect evidence: **(1)** density measurements, **(2)** seismic (earthquake) wave studies, **(3)** measurements of heat flow from the interior, **(4)** lava analyses, and **(5)** research on meteorite composition.

The earth's innermost zone, the **core** (Figure 10-2), is very hot and has a solid inner part, surrounded by a liquid core of molten material. A thick, solid zone called the **mantle** surrounds the earth's core (Figure 10-2). Most of the mantle is solid rock, but under its rigid outermost part is a zone of very hot, partly melted rock that flows like soft plastic. This plastic region of the mantle is called the *asthenosphere.*

The outermost and thinnest zone of the earth is called the **crust** (Figure 10-2). It consists of **(1)** the *continental crust,* which underlies the continents (including the continental shelves extending into the oceans, Figure 10-3 and Figure 7-7, p. 148), and **(2)** the *oceanic crust,* which underlies the ocean basins and covers 71% of the earth's surface (Figure 10-3).

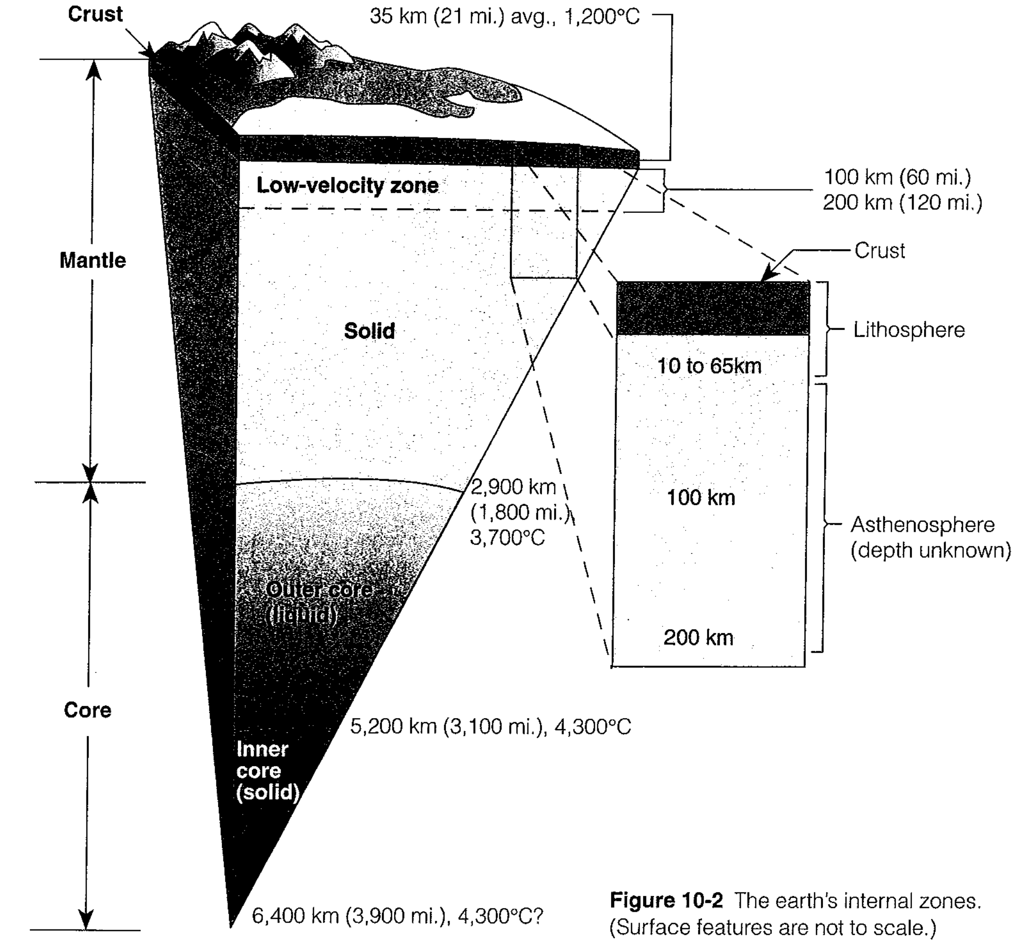


Figure 10-2 The earth's internal zones. (Surface features are not to scale.)

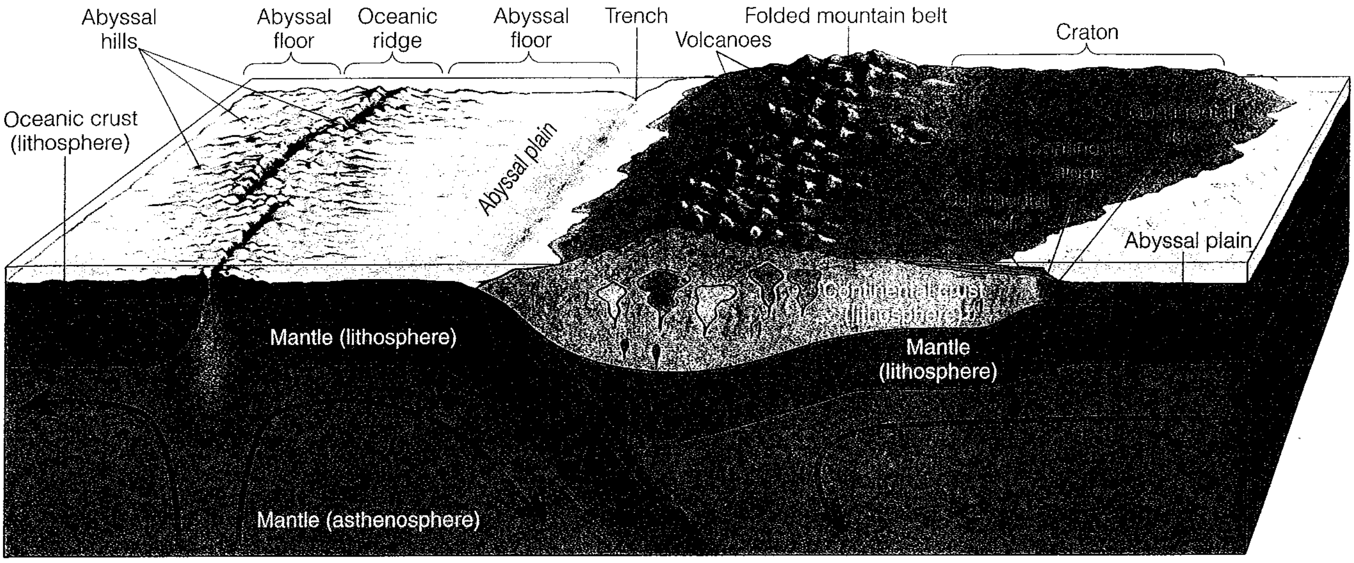


Figure 10-3 Major features of the earth's crust and upper mantle. The *lithosphere,* composed of the crust and outermost mantle, is rigid and brittle. The *asthenosphere,* a zone in the mantle, can be deformed by heat and pressure.

10-2 INTERNAL AND EXTERNAL EARTH PROCESSES

What Geologic Processes Occur Within the Earth's Interior? We tend to think of the earth's crust, mantle, and core as fairly static. However, they are constantly changed by geologic processes taking place within the earth and on the earth's surface, most over thousands to millions of years (Figure 10-4, p. 206).

Geologic changes originating from the earth's interior are called *internal processes;* generally they build up the planet's surface. Heat from the earth's interior provides the energy for these processes (Figure 10-4, p. 206), but gravity also plays a role.

Residual heat from the earth's formation is still being given off as the inner core cools and as the outer core cools and solidifies. Continued decay of radioactive elements in the crust, especially the continental crust, adds to the heat flow from within.

This heat from the earth's core causes much of the mantle to deform and flow slowly like heated plastic (in the same way that a red-hot iron horseshoe behaves plastically). Measurements of heat flow within the earth suggest that two kinds of movement occur in the mantle's asthenosphere:

- *Convection cells,* in which large volumes of heated rock move (Figure 10-4), following a pattern resembling convection in the atmosphere (Figure 6-10, p. 117) or a pot of boiling water (Figure 3-11, left, p. 53)
- *Mantle plumes,* in which mantle rock flows slowly upward in a column (Figure 10-4, p. 206), like smoke from a chimney on a cold, calm morning. When the moving rock reaches the top of the plume, it moves out in a radial pattern, as if it were flowing up an umbrella through the handle and then spreading out in all directions from the tip of the umbrella to the rim.

What Is Plate Tectonics? Both convection currents and mantle plumes move upward as the heated material is displaced by denser, cooler material sinking under the influence of gravity (Figure 10-4). These flows of energy and heated material in the mantle convection cells cause movement of rigid plates, called **tectonic plates** (Figure 10-4 and Figure 10-5b, p. 207). These plates are about 100 kilometers (60 miles) thick. They are composed of the continental and oceanic crust and the rigid, outermost part of the mantle (above the asthenosphere), a combination called the **lithosphere** (Figure 10-3).

These plates move constantly, supported by the slowly flowing asthenosphere like large pieces of ice floating on the surface of a lake. Some plates move faster than others do, but a typical speed is about the rate at which fingernails grow.

The theory explaining the movements of the plates and the processes that occur at their boundaries is called **plate tectonics.** The concept, which became widely accepted by geologists in the 1960s, was developed from an earlier idea called *continental drift.* Throughout the earth's history, continents have split

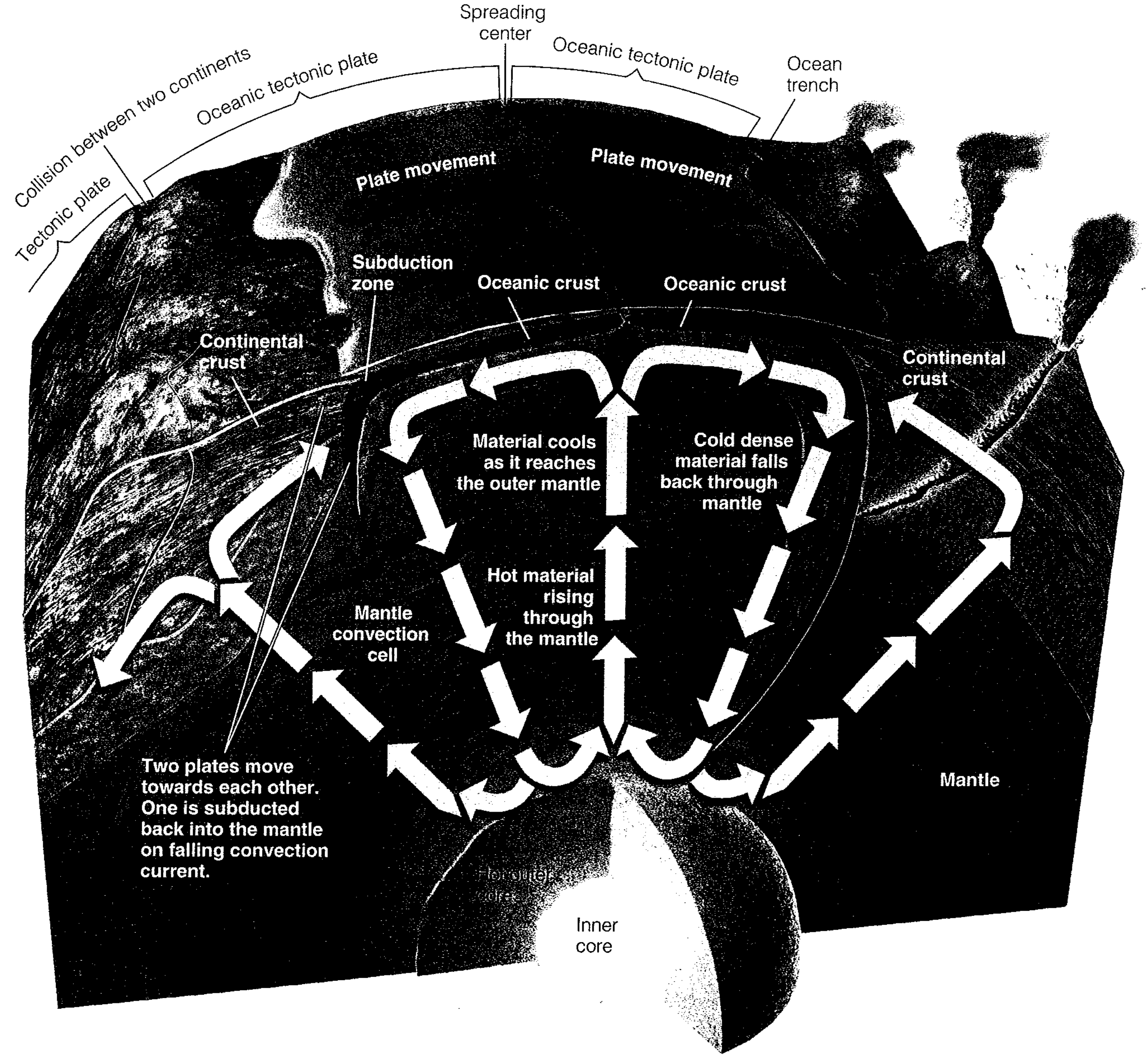


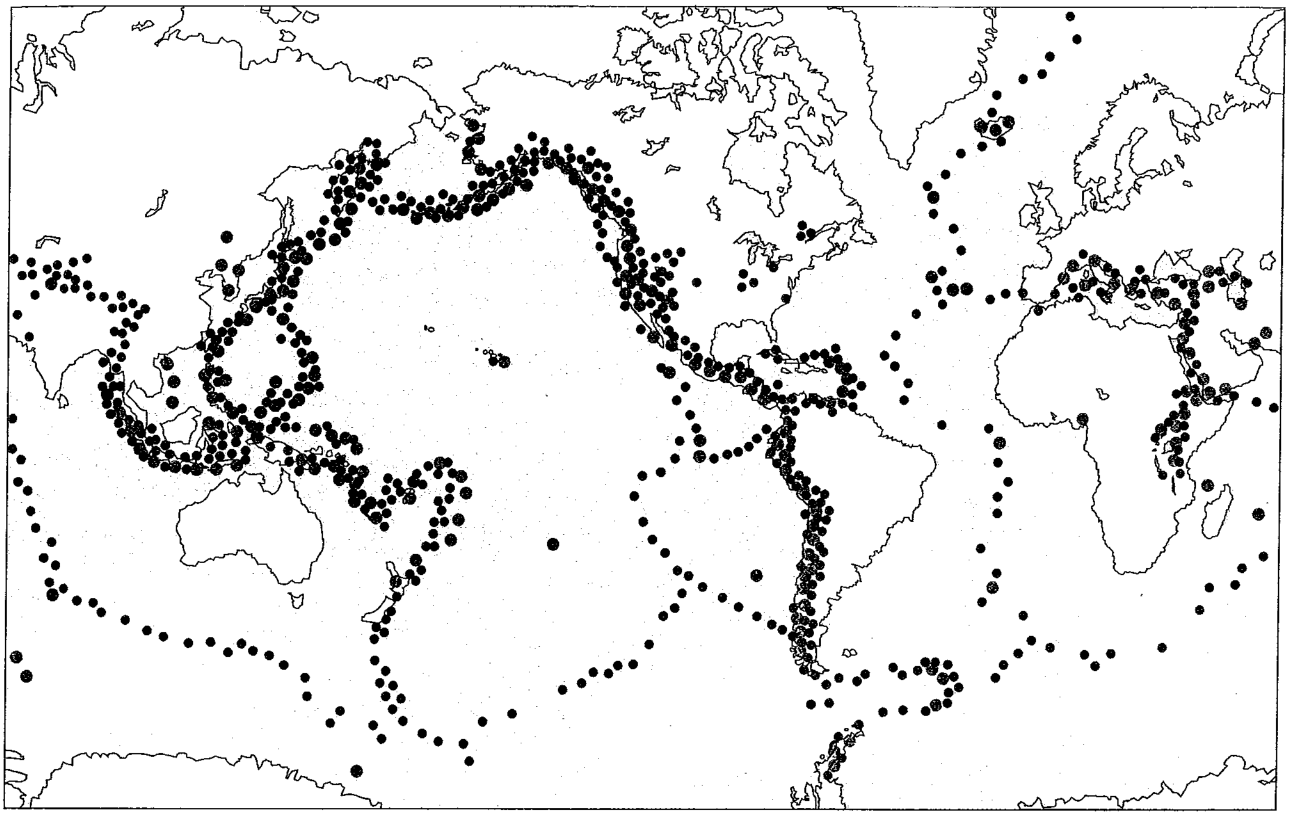
Figure 10-4 The earth's crust is made up of a series of rigid plates, called *tectonic plates*, which move around in response to forces in the mantle.

and joined as plates have drifted thousands of kilometers back and forth across the planet's surface (Figure 5-9, p. 106).

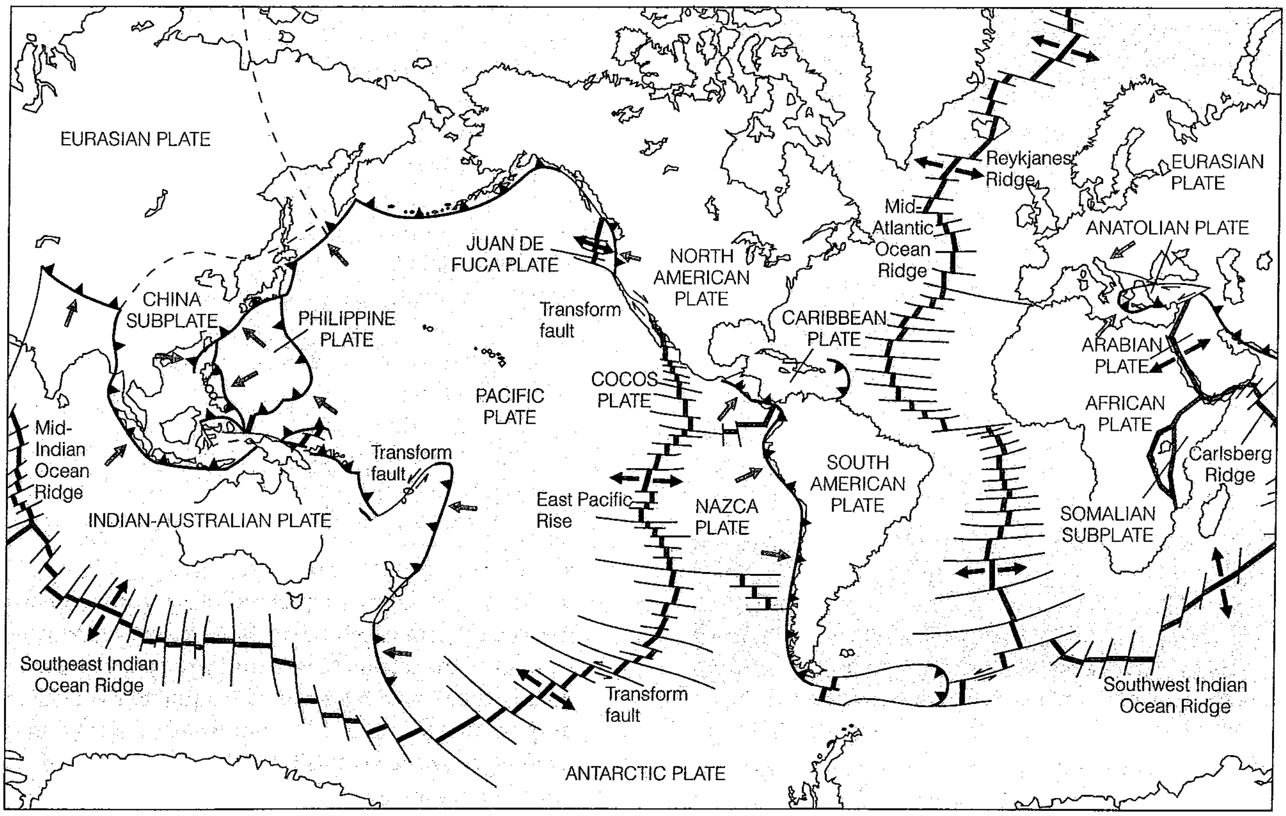
Plate motion produces mountains (including volcanoes), the oceanic ridge system, trenches, and other features of the earth's surface (Figure 10-3). Natural hazards such as volcanoes and earthquakes are likely to be found at plate boundaries (Figure 10-5a), and plate movements and interactions concentrate many of the minerals we extract and use.

The theory of plate tectonics also helps explain how certain patterns of biological evolution occurred. By reconstructing the course of continental drift over millions of years (Figure 5-9, p. 106), we can trace how life-forms migrated from one area to another when continents that are now far apart were still joined together. As the continents separated, populations became geographically and reproductively isolated, and speciation occurred (Figure 5-8, p. 105).

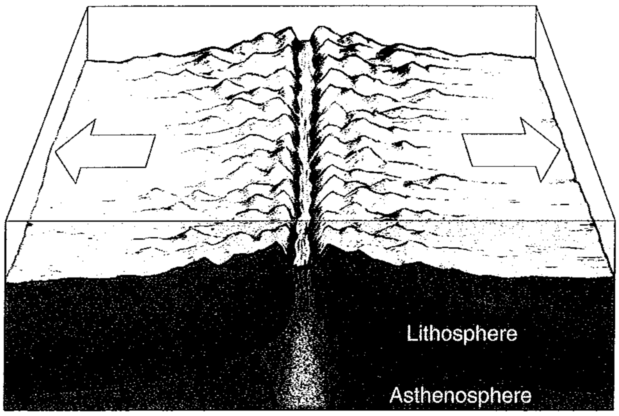
Figure 10-5 (facing page) Earthquake and volcano sites are distributed mostly in bands along the planet's surface **(a).** These bands correspond to the patterns for the types of lithospheric plate boundaries **(b)** shown in Figure 10-6 (p. 208).



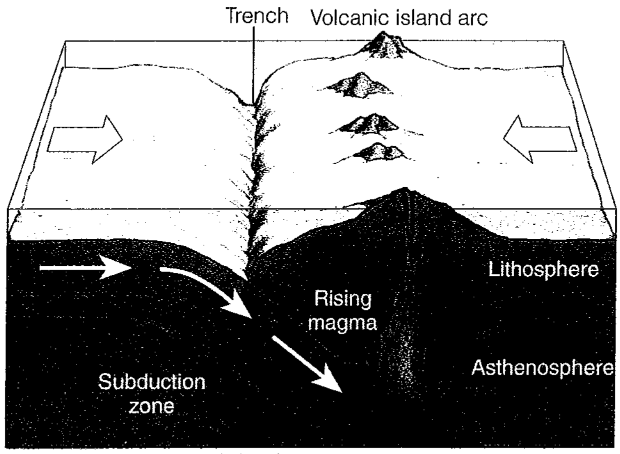
(a) ● Volcanoes • Earthquakes



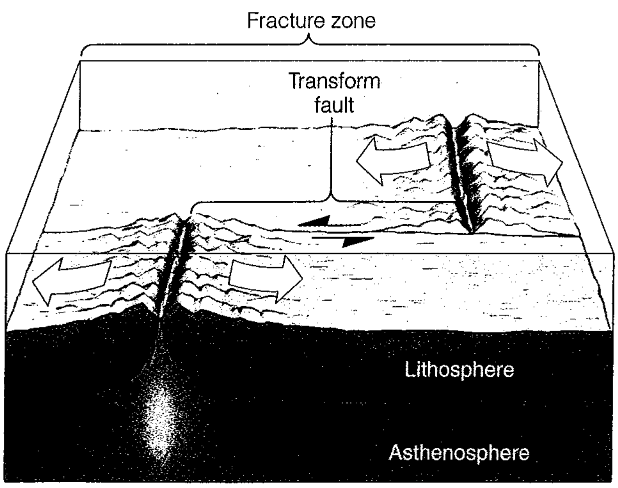
(b) Convergent plate boundaries; Plate motion at convergent plate boundaries; Divergent (/) and transform fault (⇌) boundaries; Plate motion at divergent plate boundaries



Oceanic ridge at a divergent plate boundary



Trench and volcanic island arc at a convergent plate boundary



Transform fault connecting two divergent plate boundaries

Figure 10-6 Types of boundaries between the earth's lithospheric plates. All three boundary types occur both in oceans and on continents.

What Types of Boundaries Occur Between the Earth's Plates? Lithospheric plates have three types of boundaries (Figure 10-6):

- **Divergent plate boundaries,** where the plates move apart in opposite directions (Figure 10-4 and Figure 10-6, top)
- **Convergent plate boundaries,** where the plates are pushed together by internal forces (Figures 10-5b and 10-6, middle). At most convergent plate boundaries, oceanic lithosphere is carried downward (subducted) under the island arc or the continent at a **subduction zone.** A *trench* ordinarily forms at the boundary between the two converging plates (Figure 10-6, middle). Stresses in the plate undergoing subduction cause earthquakes at convergent plate boundaries.
- **Transform faults,** which occur where plates slide past one another along a fracture (fault) in the lithosphere (Figure 10-6, bottom). Most transform faults are on the ocean floor (Figure 10-5b).

What Geologic Processes Occur on the Earth's Surface? Erosion and Weathering Geological changes based directly or indirectly on energy from the sun and on gravity (rather than on heat in the earth's interior) are called *external processes.* Whereas internal processes generally build up the earth's surface, external processes tend to wear it down and produce a variety of landforms and environments formed by the buildup of eroded sediment (Figure 10-7).

A major external process is **erosion:** the process by which material is **(1)** dissolved, loosened, or worn away from one part of the earth's surface and **(2)** deposited in other places. Streams, the most important agent of erosion, operate everywhere on the earth except in the polar regions (Figure 7-2, p. 145). They produce valleys and canyons, and may form deltas where streams flow into lakes and oceans (Figure 7-23, p. 160). Some erosion is caused when wind blows particles of soil from one area to another (Figure 6-1, p. 110). Human activities, particularly those that destroy vegetation, accelerate erosion.

Weathering caused by mechanical or chemical processes usually produces loosened material that can be eroded. There are two types of weathering processes:

- *Mechanical weathering,* in which a large rock mass is broken into smaller fragments of the original material, similar to the results you would get by using a hammer to break a rock into small fragments. The most important agent of mechanical weathering is *frost wedging,* in which water **(1)** collects in pores and cracks of rock, **(2)** expands upon freezing, and **(3)** splits off pieces of the rock.

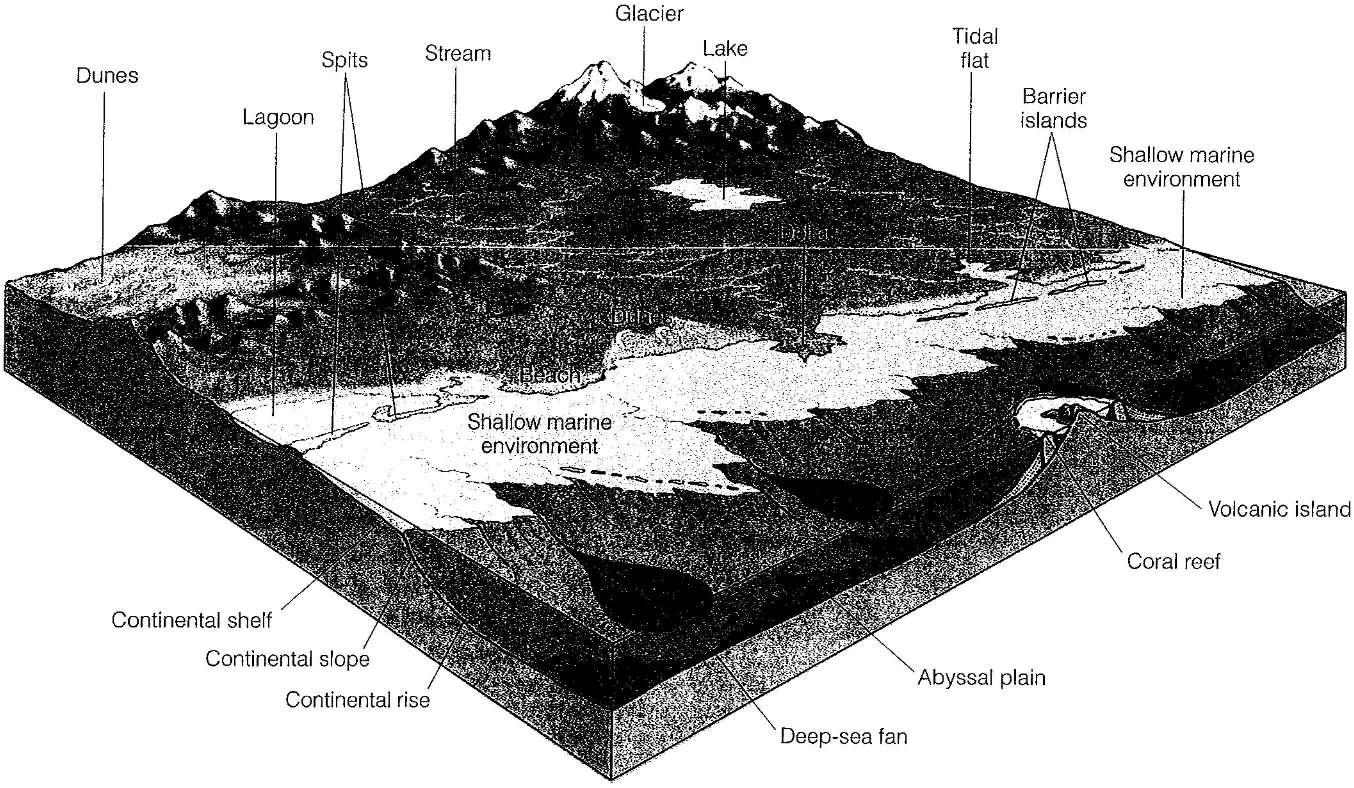


Figure 10-7 The variety of landforms and sedimentary environments depicted here result mainly from *external processes.* They are powered primarily by solar energy (as it drives the hydrologic cycle and wind) and gravity, with some assistance from organisms such as reef-building corals.

- *Chemical weathering,* in which one or more chemical reactions decompose a mass of rock. Most chemical weathering involves a reaction of rock material with oxygen, carbon dioxide, and moisture in the atmosphere and the ground.

10-3 MINERALS, ROCKS, AND THE ROCK CYCLE

What Are Minerals and Rocks? The earth's crust, still forming in various places, is composed of minerals and rocks. It is the source of almost all the nonrenewable resources we use: fossil fuels, metallic minerals, and nonmetallic minerals (Figure 1-6, p. 9). It is also the source of soil and of the elements that make up our bodies and those of other living organisms.

A **mineral** is an element or inorganic compound that occurs naturally and is solid. Some minerals consist of a single element, such as gold, silver, diamond (carbon), and sulfur. However, most of the more than 2,000 identified minerals occur as inorganic compounds formed by various combinations of elements. Examples are salt, mica, and quartz.

Rock is any material that makes up a large, natural, continuous 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, but most rocks consist of two or more minerals.

What Are the Three Major Rock Types? Based on the way it forms, rock is placed in three broad classes:

- **Igneous rock** formed below or on the earth's surface when molten rock material (magma) **(1)** wells up from the earth's upper mantle or deep crust, **(2)** cools, and **(3)** hardens into rock. Examples are **(1)** granite (formed underground) and **(2)** lava rock (formed above ground when molten lava cools and hardens). 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 nonfuel mineral resources.
- **Sedimentary rock** formed from sediment when preexisting rocks are **(1)** weathered and eroded into small pieces, **(2)** transported from their sources, and **(3)** deposited in a body of surface water. Examples are **(1)** sandstone and shale formed from pressure created

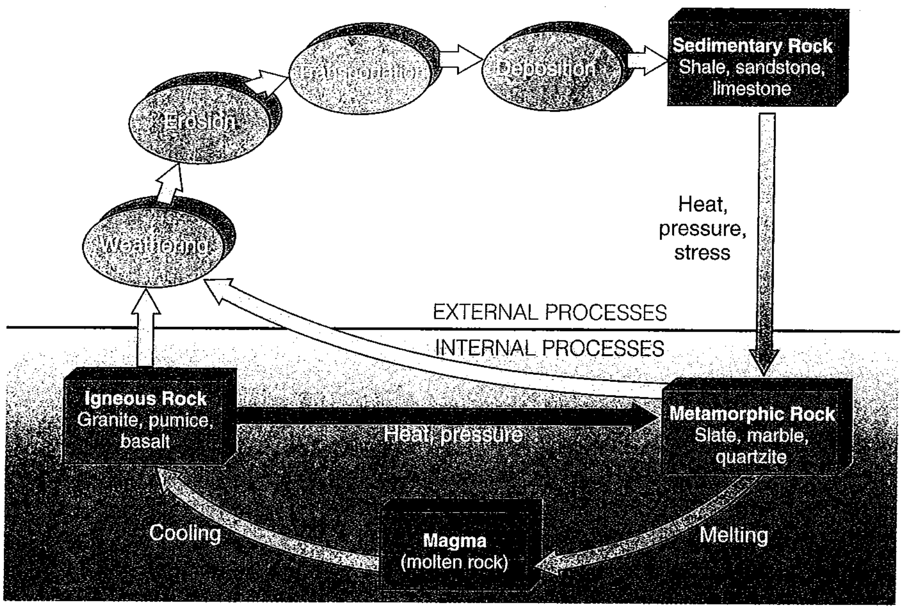


Figure 10-8 The *rock cycle*, the slowest of the earth's cyclic processes. The earth's materials are recycled over millions of years by three processes: *melting, erosion,* and *metamorphism,* which produce *igneous, sedimentary,* and *metamorphic* rocks. Rock of any of the three classes can be converted to rock of either of the other two classes (or can even be recycled within its own class).

by deposited layers of sediment, **(2)** dolomite and limestone formed from the compacted shells, skeletons, and other remains of dead organisms, and **(3)** lignite and bituminous coal derived from plant remains.

- **Metamorphic rock** produced when a preexisting rock is subjected to **(1)** high temperatures (which may cause it to melt partially), **(2)** high pressures, **(3)** chemically active fluids, or **(4)** a combination of these agents. Examples are anthracite (a form of coal), slate, and marble.

What Is the Rock Cycle? Rocks are constantly exposed to various physical and chemical conditions that can change them over time. The interaction of processes that change rocks from one type to another is called the **rock cycle** (Figure 10-8).

The slowest of the earth's cyclic processes, the rock cycle recycles material over millions of years. It concentrates the planet's nonrenewable mineral resources on which we depend.

10-4 NATURAL HAZARDS: EARTHQUAKES AND VOLCANIC ERUPTIONS

What Are Earthquakes? 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 10-6, bottom. The faulting or a later abrupt movement on an existing fault causes an **earthquake.**

An earthquake has certain features and effects (Figure 10-9). When the stressed parts of the earth suddenly fracture or shift, energy is released as shock waves, which move outward from the earthquake's focus like ripples in a pool of water. The *focus* of an earthquake is the point of initial movement, and the *epicenter* is the point on the surface directly above the focus (Figure 10-9).

One way to measure the severity of an earthquake is by its *magnitude* on a modified version of the Richter scale. 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). Using this approach, seismologists rate earthquakes as **(1)** *insignificant* (less than 4.0 on the Richter scale), **(2)** *minor* (4.0–4.9), **(3)** *damaging* (5.0–5.9), **(4)** *destructive* (6.0–6.9), **(5)** *major* (7.0–7.9), and **(6)** *great* (over 8.0). Each unit on the Richter scale represents an amplitude that is 10 times greater than the next smaller unit. Thus a magnitude 5.0 earthquake is 10 times greater than a magnitude 4.0, and a magnitude 6.0 quake is 100 times greater than a magnitude 4.0 quake.

Earthquakes often have *aftershocks* that gradually decrease in frequency over a period of up to several

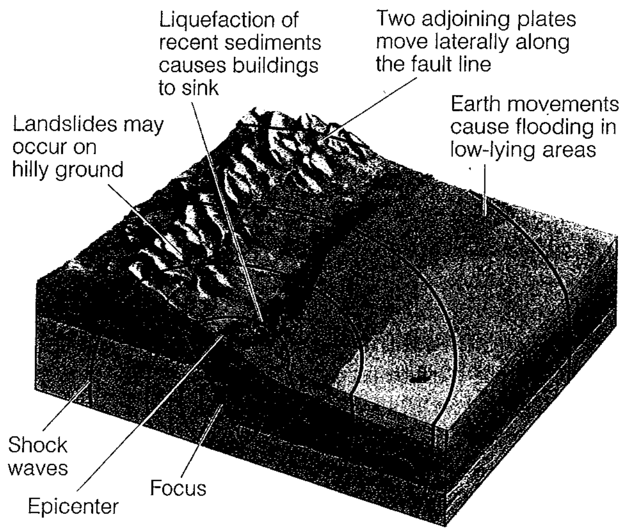


Figure 10-9 Major features and effects of an *earthquake.*

months, and some have *foreshocks* 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.

Secondary effects of earthquakes include rock slides, urban fires, and flooding caused by subsidence (sinking) of land. Coastal areas also can be severely damaged by large earthquake-generated water waves, called *tsunamis* (misnamed "tidal waves," even though they have nothing to do with tides) that travel as fast as 950 kilometers (590 miles) per hour.

Solutions: How Can We Reduce Earthquake Hazards? We can reduce loss of life and property from earthquakes by **(1)** examining historical records and making geologic measurements to locate active fault zones, **(2)** making maps showing high-risk areas (Figure 10-10), **(3)** establishing building codes that regulate the placement and design of buildings in areas of high risk, and **(4)** trying to predict when and where earthquakes will occur.

Engineers know how to make homes, large buildings, bridges, and freeways more earthquake resistant. But this can be expensive, especially if existing structures must be reinforced.

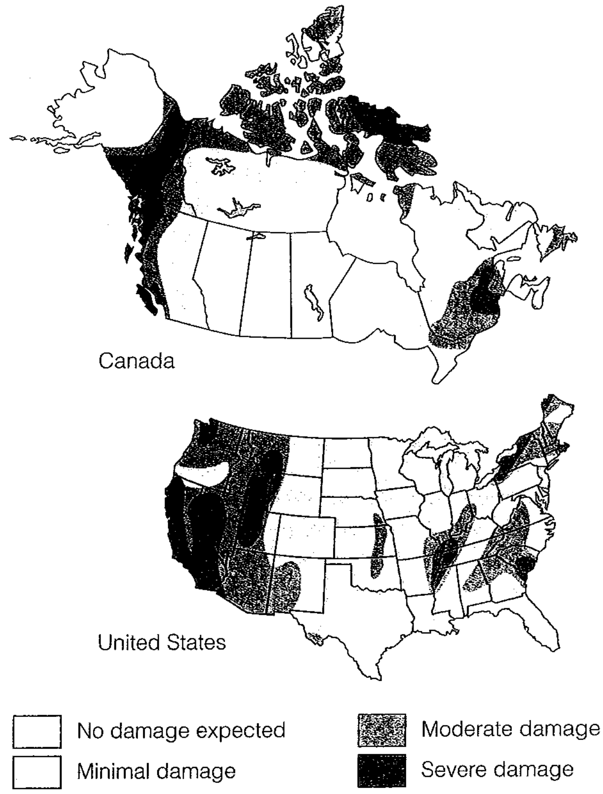


Figure 10-10 Expected damage from earthquakes in Canada and the contiguous United States. This map is based on earthquake records. (Data from U.S. Geological Survey)

What Are Volcanoes? An active **volcano** occurs where magma (molten rock) reaches the earth's surface through a central vent or a long crack (fissure; Figure 10-11). Volcanic activity can release **(1)** *ejecta* (debris ranging from large chunks of lava rock to ash that may be glowing hot), **(2)** liquid lava, and **(3)** 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 (Figure 10-5a). Some volcanoes, such as those at Mount St. Helens in Washington (which erupted in 1980; Figure 10-1) and Mount Pinatubo in the Philippines (which erupted in 1991), have a steep, flaring cone shape. They usually erupt explosively and eject large quantities of gases and particulate matter (soot and mineral ash) high into the troposphere.

Most of the particles of soot and ash soon fall back to the earth's surface. However, gases such as sulfur dioxide remain in the atmosphere and are converted to tiny droplets of sulfuric acid, many of which stay above the clouds and may not be washed out by rain for up to 3 years.

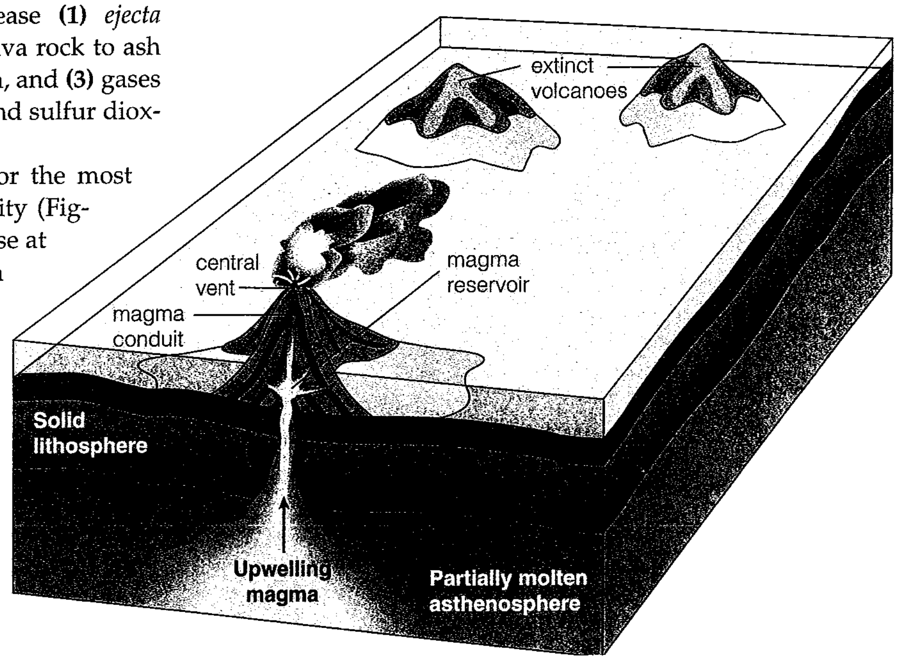


Figure 10-11 A *volcano* erupts when molten magma in the partially molten asthenosphere rises in a plume through the lithosphere to erupt on the surface as lava that can spill over or be ejected into the atmosphere. Chains of islands can be created by the action of volcanoes that then become inactive.

These tiny droplets reflect some of the sun's energy and can cool the atmosphere by as much as 0.5°C (1°F) for 1–4 years.

Other volcanic eruptions at divergent boundaries (e.g., in Iceland) and ocean islands (e.g., the Hawaiian Islands) usually erupt more quietly. They involve primarily lava flows, which can cover roads and villages and ignite brush, trees, and homes.

Between 1985 and 1999, nearly 561,000 people died prematurely from natural catastrophes such as floods, earthquakes, volcanic eruptions, and windstorms. About 30%, or 169,000, of these deaths resulted from earthquakes and volcanic eruptions.

We tend to think negatively of volcanic activity, but it also provides some benefits. One is outstanding scenery in the form of majestic mountains, some lakes (such as Crater Lake in Oregon; see photo on the title page of this book), and other landforms. Perhaps the most important benefit of volcanism is the highly fertile soils produced by the weathering of lava.

Solutions: How Can We Reduce Volcano Hazards? We can reduce the loss of human life and sometimes property from volcanic eruptions by **(1)** land-use planning, **(2)** better prediction of volcanic eruptions and **(3)** effective evacuation plans. The eruptive history of a volcano or volcanic center can provide some indication of where the risks are.

Scientists are also studying phenomena that precede an eruption such as **(1)** tilting or swelling of the cone, **(2)** changes in magnetic and thermal properties of the volcano, **(3)** changes in gas composition, and **(4)** increased seismic activity.

10-5 SOIL RESOURCES: FORMATION AND TYPES

What Major Layers Are Found in Mature Soils? **Soil** is a complex mixture of eroded rock mineral nutrients, decaying organic matter, water, air

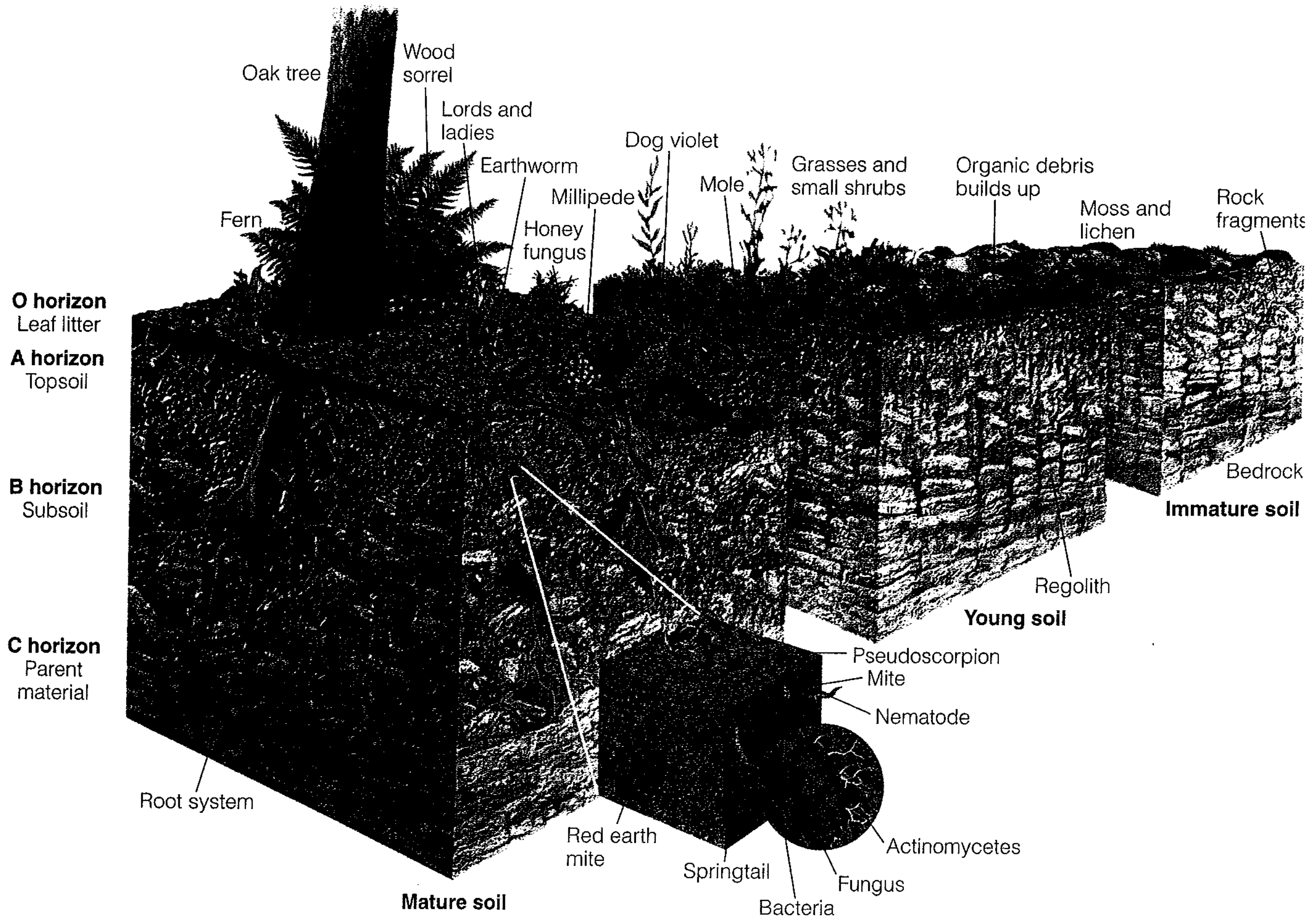


Figure 10-12 Soil formation and generalized soil profile. Horizons, or layers, vary in number, composition, and thickness, depending on the type of soil. (From Derek Elsom, *Earth*, 1992. Copyright © 1992 by Marshall Editions Developments Limited. New York: Macmillan. Used by permission)

and billions of living organisms, most of them microscopic decomposers (Figure 10-12). Although soil is a renewable resource, it is produced very slowly by the (1) weathering of rock, (2) deposit of sediments by erosion, and (3) decomposition of organic matter in dead organisms.

Mature soils are arranged in a series of zones called **soil horizons,** each with a distinct texture and composition that varies with different types of soils. A cross-sectional view of the horizons in a soil is called a **soil profile.** Most mature soils have at least three of the possible horizons (Figure 10-12).

The top layer, the *surface litter layer,* or *O horizon,* consists mostly of (1) freshly fallen and partially decomposed leaves, (2) twigs, (3) animal waste, (4) fungi, and (5) other organic materials. Normally, it is brown or black. The *topsoil layer,* or *A horizon,* is a porous mixture of (1) partially decomposed organic matter, called **humus,** and (2) some inorganic mineral particles. It is usually darker and looser than deeper layers. A fertile soil that produces high crop yields has a thick topsoil layer with lots of humus. This helps topsoil hold water and nutrients taken up by plant roots. Thus the thin mantle of productive topsoil found over much of the earth's terrestrial surface is the foundation of civilization.

The roots of most plants and most of a soil's organic matter are concentrated in these two upper layers. As long as vegetation anchors these layers, soil stores water and releases it in a nourishing trickle instead of a devastating flood.

The two top layers of most well-developed soils teem with bacteria, fungi, earthworms, and small insects that interact in complex food webs (Figure 10-13). Bacteria and other decomposer microorganisms found by the billions in every handful of topsoil recycle the nutrients we and other land organisms need

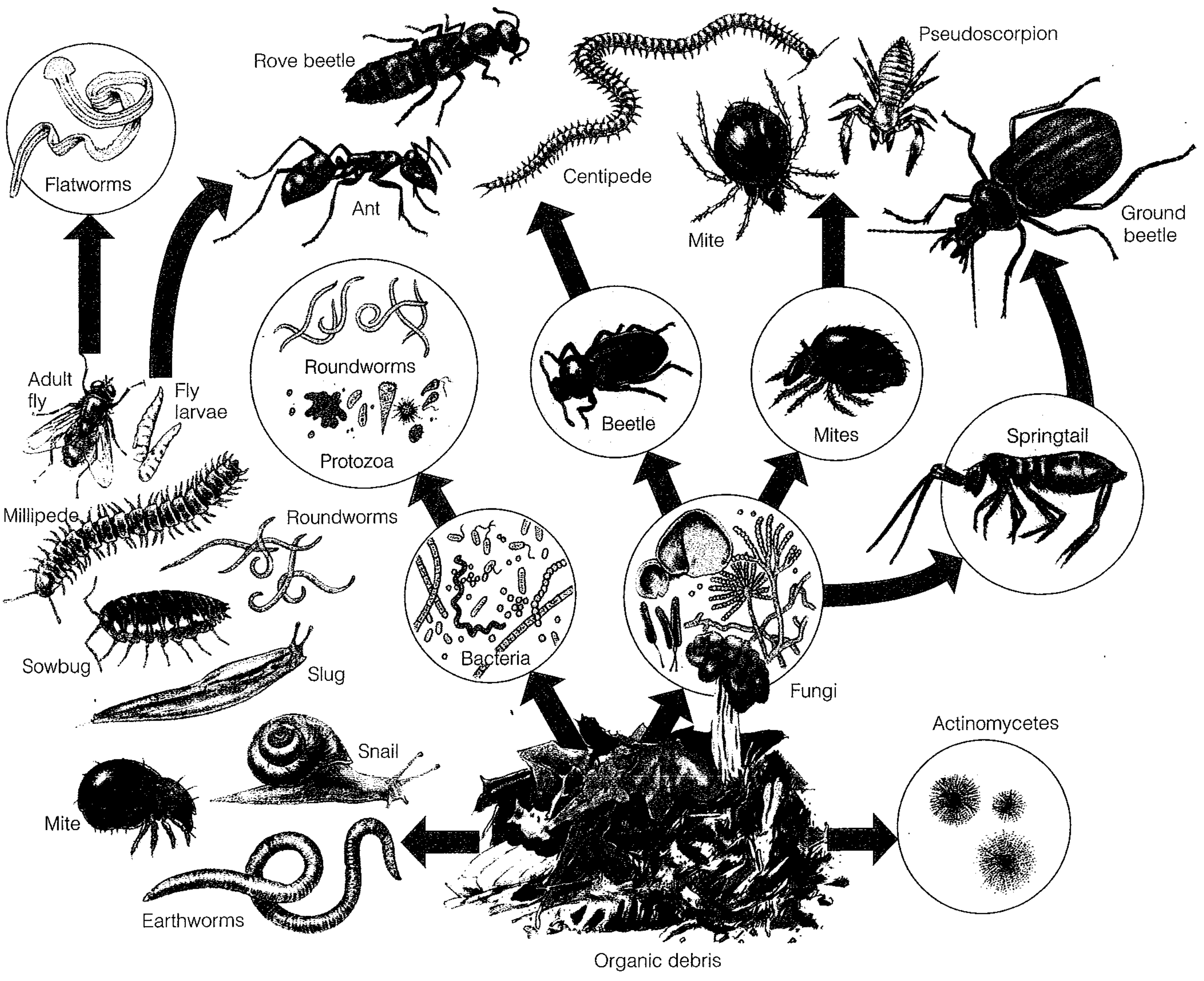


Figure 10-13 Greatly simplified food web of living organisms found in soil.

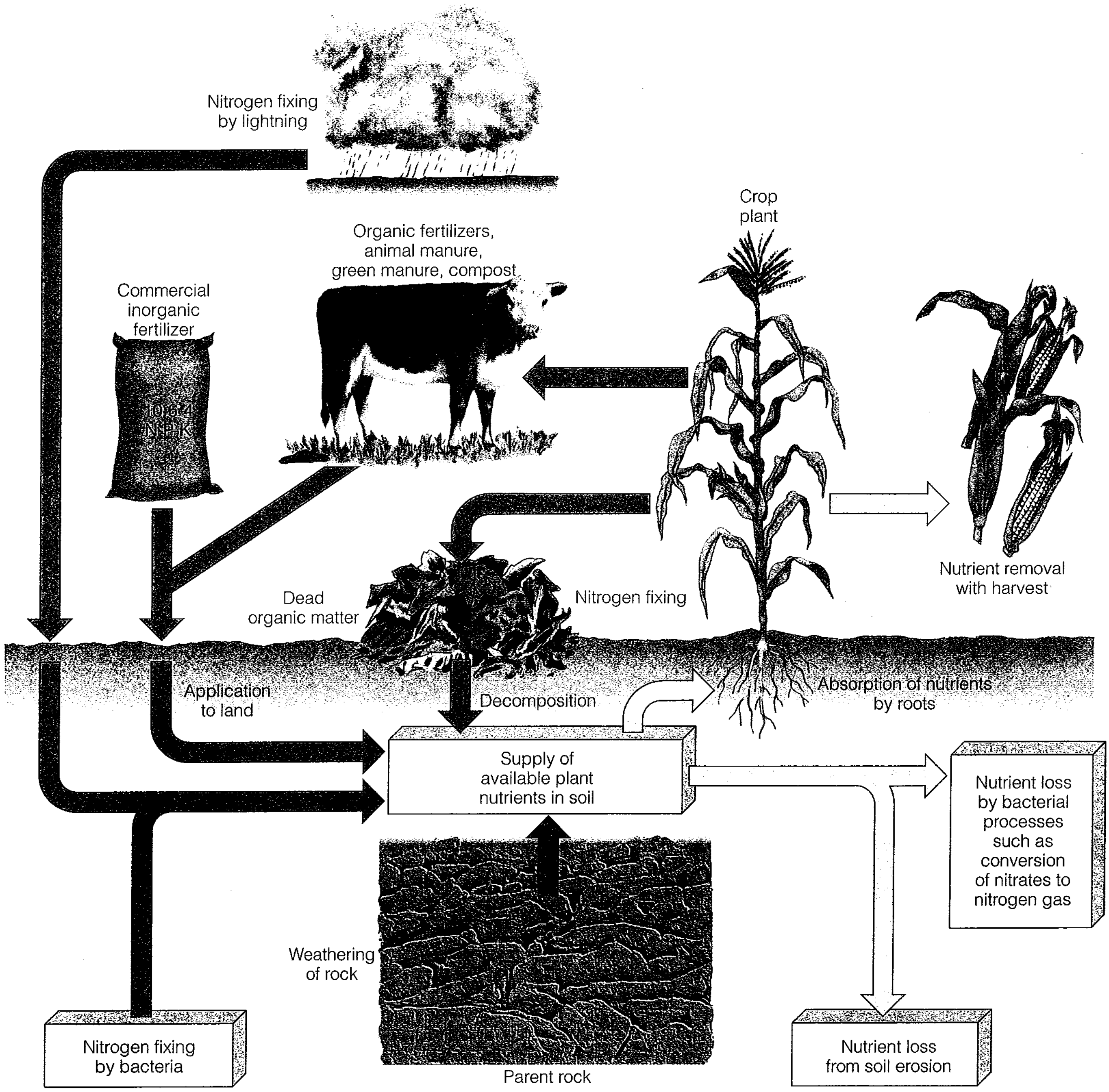


Figure 10-14 Pathways of plant nutrients in soils.

(Figure 10-14). They break down some 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.

The color of its topsoil tells us a lot about a soil's usefulness for growing crops. For example, dark brown or black topsoil is nitrogen-rich and high in organic matter. Gray, bright yellow, or red topsoils are low in organic matter and need nitrogen enrichment to support most crops.

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. The C horizon lies on a base of unweathered parent rock called *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 need oxygen for cellular respiration.

Some of the precipitation that reaches the soil percolates through the soil layers and occupies many of the soil's open spaces or pores. This downward movement of water through soil is called **infiltration.** As the water seeps down, it dissolves various soil compo-

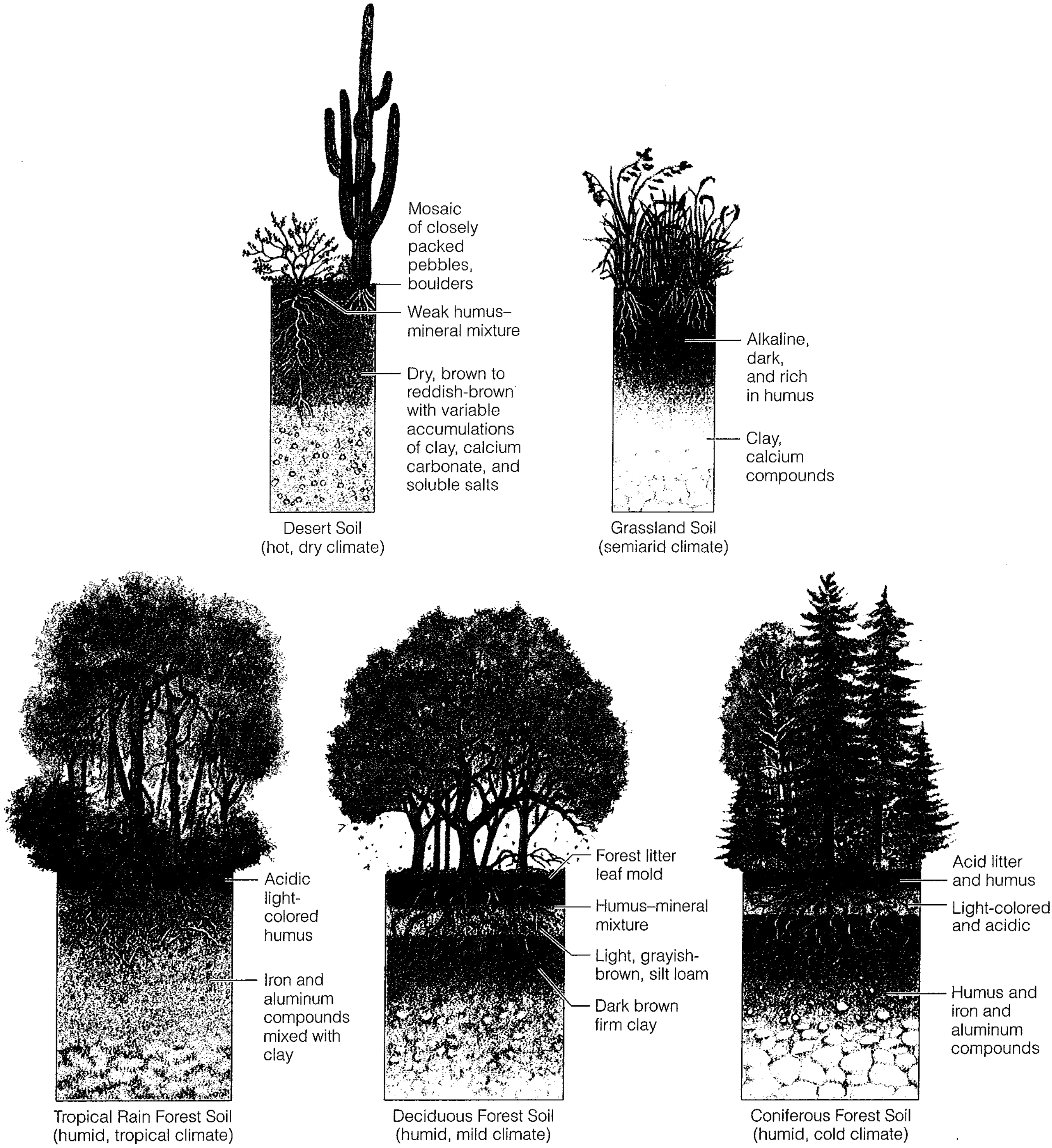


Figure 10-15 Soil profiles of the principal soil types typically found in five different biomes.

nents in upper layers and carries them to lower layers in a process called **leaching.**

Five important soil types, each with a distinct profile, are shown in Figure 10-15. Most of the world's crops are grown on soils exposed when grasslands (Figure 6-31, p. 132) and deciduous forests are cleared.

How Do Soils Differ in Texture, Porosity, and Acidity? Soils vary in their content of **(1)** *clay* (very fine particles), **(2)** *silt* (fine particles), **(3)** *sand* (medium-size particles), and **(4)** *gravel* (coarse to very coarse particles). The relative amounts of the different sizes and types of mineral particles determine **soil texture,** as depicted in Figure 10-16 (p. 216). Soils with roughly equal mixtures of clay, sand, silt, and humus are called **loams.**

To get an idea of a soil's texture, take a small amount of topsoil, moisten it, and rub it between your

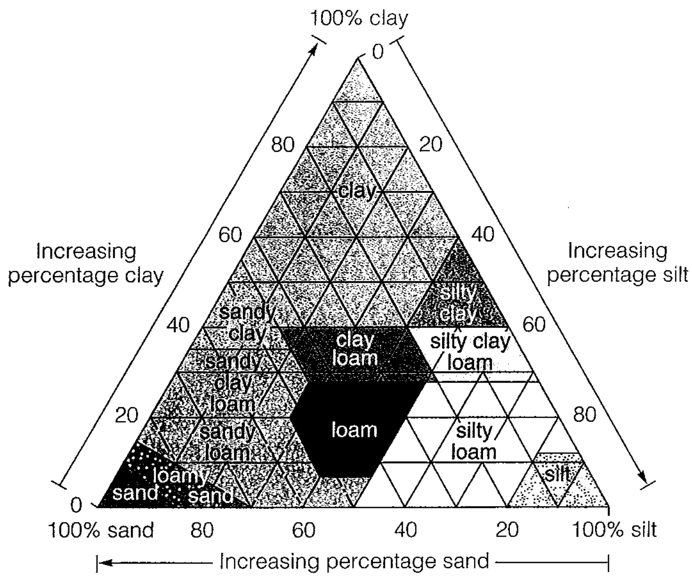


Figure 10-16 *Soil texture* depends on the proportions of clay, silt, and sand particles in the soil. Soil texture affects *soil porosity,* the average number and spacing of pores in a given volume of soil. Loams—roughly equal mixtures of clay, sand, silt, and humus—are the best soils for growing most crops. (Data from Natural Resources Conservation Service)

fingers and thumb. A gritty feel means it contains a lot of sand. A sticky feel means a high clay content, and you should be able to roll it into a clump. Silt-laden soil feels smooth, like flour. A loam topsoil, best suited for plant growth, has a texture between these extremes—a crumbly, spongy feeling—with many of its particles clumped loosely together.

Soil texture helps determine **soil porosity,** a measure of the volume of pores or spaces per volume of soil and of the average distances between those spaces. Fine particles are needed for water retention and coarse ones for air spaces. A porous soil has many pores and can hold more water and air than a less porous soil. The average size of the spaces or pores in a soil determines **soil permeability:** the rate at which water and air move from upper to lower soil layers. Soil porosity is also influenced by **soil structure:** the ways in which soil particles are organized and clumped together (Figure 10-17). Table 10-1 compares the main physical and chemical properties of sand, clay, silt, and loam soils.

Loams are the best soils for growing most crops because they hold lots of water, but not too tightly for plant roots to absorb. Sandy soils are easy to work, but water flows rapidly through them (Figure 10-17, left). They are useful for growing irrigated crops or those with low water needs, such as peanuts and strawberries.

The particles in clay soils are very small and easily compacted. When these soils get wet, they form large, dense clumps, which is why wet clay can be molded into bricks and pottery. Clay soils are more porous and have a greater water-holding capacity than sandy soils, but the pore spaces are so small that these soils have a low permeability (Figure 10-17, right). Because little water can infiltrate to lower levels, the upper layers can easily become too waterlogged for growing most crops.

The acidity or alkalinity of a soil, as measured by its pH (Figure 3-5, p. 49), influences the uptake of soil nutrients by plants. When soils are too acidic, the acids can be partially neutralized by an alkaline substance such as lime. Because lime speeds up the decomposition of organic matter in the soil, however, manure or another organic fertilizer should be added to maintain soil fertility.

In dry regions such as much of the western and southwestern United States, rain does not leach away calcium and other alkaline compounds, so soils in such areas may be too alkaline (pH above 7.5) for some crops. Adding sulfur, which is gradually converted into sulfuric acid by soil bacteria, reduces soil alkalinity.

10-6 SOIL EROSION AND DEGRADATION

What Causes Soil Erosion? Soil erosion is the movement of soil components, especially surface litter and topsoil (Figure 10-12), from one place to another. It results in the buildup of sediments and sedimentary

Table 10-1 Properties of Soils with Different Textures

Soil Texture	Nutrient-Holding Capacity	Water Infiltration Capacity	Water-Holding Capacity	Aeration	Workability
Clay	Good	Poor	Good	Poor	Poor
Silt	Medium	Medium	Medium	Medium	Medium
Sand	Poor	Good	Poor	Good	Good
Loam	Medium	Medium	Medium	Medium	Medium

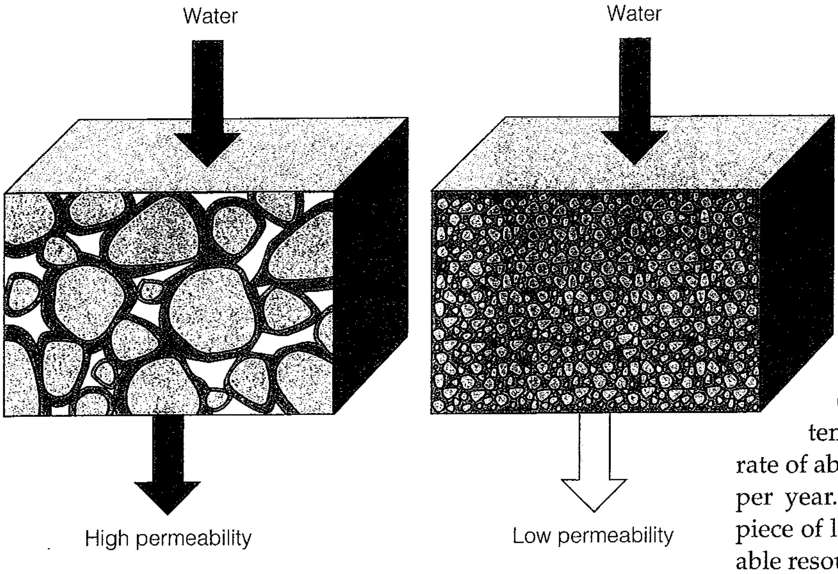


Figure 10-17 The size, shape, and degree of clumping of soil particles determine the number and volume of spaces for air and water within a soil. Soils with more pore spaces (left) contain more air and are more permeable to water flows than soils with fewer pores (right).

rock on land and in bodies of water (Figure 10-7). The two main agents of erosion are *flowing water* and *wind.* Some soil erosion is natural, and some is caused by human activities. In undisturbed vegetated ecosystems, the roots of plants help anchor the soil, and usually soil is not lost faster than it forms.

Farming, logging, construction, overgrazing by livestock, off-road vehicles, deliberate burning of vegetation, and other activities that destroy plant cover leave soil vulnerable to erosion. Such human activities can speed up erosion and destroy in a few decades what nature took hundreds to thousands of years to produce.

Moving water causes most soil erosion. Soil scientists distinguish among three types of water erosion:

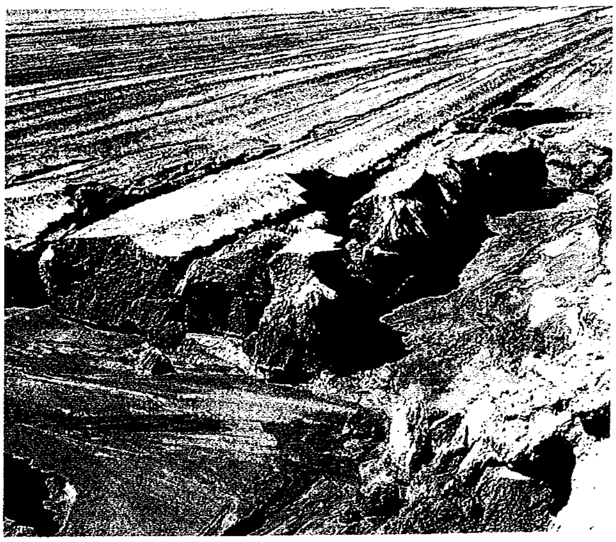
- *Sheet erosion* occurs when surface water moves down a slope or across a field in a wide flow and peels off fairly uniform sheets or layers of soil. Because the topsoil disappears evenly, sheet erosion may not be noticeable until much damage has been done.
- *Rill erosion* (Figure 10-18) occurs when surface water forms fast-flowing rivulets that cut small channels in the soil.
- *Gully erosion* (Figure 10-18) occurs when rivulets of fast-flowing water join together and with each succeeding rain cut the channels wider and deeper until they become ditches or gullies. Gully erosion usually happens on steep slopes where all or most vegetation has been removed.

The two major harmful effects of soil erosion are **(1)** loss of soil fertility and its ability to hold water and **(2)** runoff of sediment that pollutes water, kills fish and shellfish, and clogs irrigation ditches, boat channels, reservoirs, and lakes.

Soil, especially topsoil, is classified as a renewable resource because natural processes regenerate it. However, in tropical and temperate areas it takes 200–1,000 years (depending on climate and soil type) for 2.54 centimeters (1 inch) of new topsoil to form. In tropical and temperate areas soil is renewed at an average rate of about 1 metric ton of topsoil per hectare of land per year. If topsoil erodes faster than it forms on a piece of land, its soil eventually becomes a nonrenewable resource.

How Serious Is Global Soil Erosion? Several studies document the seriousness of soil erosion:

- A 1992 joint survey by the United Nations (UN) Environment Programme and the World Resources Institute estimated that **(1)** topsoil is eroding faster than it forms on about 38% of the world's cropland (Figure 10-19, p. 218) and **(2)** 17% of the world's land (two-thirds of it in Asia and Africa) was degraded to some extent by soil erosion.
- In Northwest China, a combination of overplowing and overgrazing is causing massive wind erosion of topsoil. The resulting huge dust plumes of eroded soil **(1)** blot out the sun and reduce visibility in China's northeastern cities and **(2)** reduce visibility and



Natural Resources Conservation Service

Figure 10-18 Rill and gully erosion of vital topsoil from irrigated cropland in Arizona.

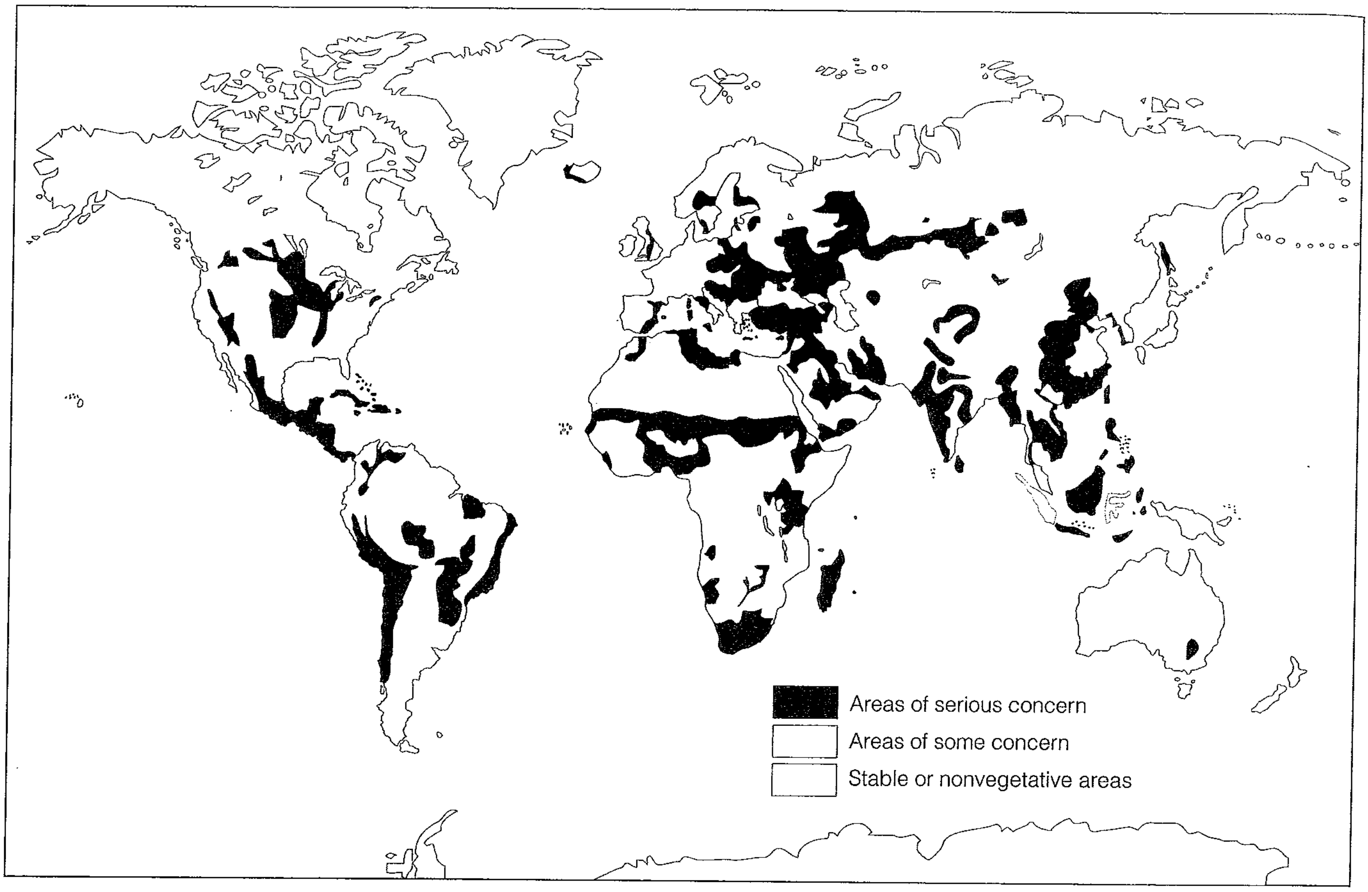


Figure 10-19 Global soil erosion. (Data from UN Environment Programme and the World Resources Institute)

increase air pollution in Japan, the Korea Peninsula, and the northwestern United States (p. 110)

- According to a 2000 study by the Consultative Group on International Agricultural Research, **(1)** nearly 40% of the world's land (75% in Central America) used for agriculture is seriously degraded by erosion, salt buildup (salinization), and waterlogging, and **(2)** soil degradation has reduced food production on about 16% of the world's cropland.

The situation is worsening as many poor farmers in some developing countries plow up marginal (easily erodible) lands to survive. Soil erosion has a number of harmful economic and ecological effects. They include **(1)** loss of soil organic matter and vital plant nutrients, **(2)** reduced ability to store water for use by crops, **(3)** increased use of costly fertilizer to maintain soil fertility, **(4)** increased water runoff on eroded mountain slopes that can flood agricultural land and dwellings in the valleys below, **(5)** increased buildup of soil sediment in navigable waterways and coastal areas that reduces ship navigation, decreases fish production, and harms many other forms of aquatic life, and **(6)** increased input of sediment into reservoirs that shortens their useful life. Any evaluation of the harm caused by soil erosion should include these effects—not just the effect of topsoil loss on crop productivity.

According to ecologist and agricultural expert David Pimentel,

> *One reason that soil erosion is not a high priority for many governments and farmers is that it usually occurs so slowly that its cumulative effects may take decades to become apparent. For example, the loss of 1 millimeter (0.04 inch) of soil is so small that it goes undetected. But over a 25-year period the loss would be 25 millimeters (1 inch), which would take about 500 years to replace by natural processes.*

There is no doubt that as agriculture has spread over the past 100 years topsoil has been lost faster than it is created in many areas and the total loss of topsoil is increasing. However, some analysts and the FAO contend that

- There is insufficient data on soil erosion to draw firm conclusions about its effect on crop productivity.
- Much of the eroded topsoil does not go far and is deposited further down a slope, valley, or plain. In some places, the loss in crop yields in one area could be offset by increased yields elsewhere.

▪ Incomplete studies suggest that the annual loss in crop productivity is only about 0.3% per year—much less than the world's 1–2% annual increase in crop productivity. However, some soil scientists point out that this global average **(1)** masks much higher rates of soil erosion in heavily farmed areas and **(2)** does not include the other harmful ecological effects of soil erosion. When such effects are included, some soil scientists and ecologists estimate that soil erosion causes a 15–30% reduction in crop productivity in some areas.

How Serious Is Soil Erosion in the United States? According to the National Resources Conservation Service, about one-third of the nation's original prime topsoil has been washed or blown into streams, lakes, and oceans, mostly as a result of overcultivation, overgrazing, and deforestation (Case Study, below).

According to the U.S. Department of Agriculture (USDA), soil on cultivated land in the United States is eroding about 16 times faster than it can form. Erosion rates are even higher in heavily farmed regions. An

The Dust Bowl

CASE STUDY

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.

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 (Figure 10-15, top right). Plowing the prairie tore up these roots, and the agricultural crops the 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 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.

Such a drought occurred between 1926 and 1934. In the 1930s, dust clouds created by hot, dry windstorms darkened the sky at midday in some areas; 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. Journalists gave the Great Plains a new name: the *Dust Bowl* (see figure).

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 as thousands of displaced farm families from Oklahoma, Texas, Kansas, and Colorado 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.

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.

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.

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 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.

Climate researchers see signs of a returning Dust Bowl period because of a megadrought that lasts 2 to 4 decades. By examining tree rings, archeological finds, lake sediments, and sand dunes, scientists have found that prolonged megadroughts generally hit twice a century as part of a complex drought cycle. They also found that smaller 2-year droughts strike every 20 years or so. If the earth warms as projected, the region could become even drier, and farming in some areas might have to be abandoned.

Critical Thinking

1. Do you think Americans learned a lesson about protecting soil as a result of the Dust Bowl in the 1930s? Explain.

2. Recent scientific studies and news reports indicate that a massive dust bowl is now forming in northern China. What do you believe are the three most important things for Chinese officials to do to help ward off this threat to China's food production?

example is the Great Plains, which has lost one-third or more of its topsoil in the 150 years since it was first plowed. Some of the country's most productive agricultural lands, such as those in Iowa, have lost about half their topsoil.

Because of soil conservation efforts, the USDA estimates that soil erosion in the United States decreased by about 40% between 1985 and 1997. Using these data, USDA researchers estimate that soil erosion cost the United States about $30 billion in 1997, an average loss of $3.4 million per hour.

Critics such as Pierre Crosson say these estimates of soil erosion and damages from such erosion are exaggerated and based on inexact models instead of field measurements of soil loss and sedimentation rates in nearby bodies of water. However, other soil scientists point out that current estimates by models and a few on-site measurements do not include all the ecological effects of soil erosion.

What Is Desertification, and How Serious Is This Problem? In **desertification,** the productive potential of arid or semiarid land falls by 10% or more because of a combination of **(1)** natural climate change that causes prolonged drought and **(2)** human activities that reduce or degrade topsoil. The process can be **(1)** *moderate* (with a 10–25% drop in productivity), **(2)** *severe* (with a 25–50% drop), or **(3)** *very severe* (with a drop of 50% or more, usually creating huge gullies and sand dunes). Desertification is a serious and growing problem in many parts of the world (Figure 10-20).

Desertification is a complex process that involves multiple natural and human-related causes and that proceeds at varying rates in different climates. It results mainly from a combination of prolonged drought and unsustainable human activities. Figure 10-21 summarizes the major causes and consequences of desertification.

An estimated 8.1 million square kilometers (3.1 million square miles)—an area the size of Brazil and 12 times the size of Texas—have become desertified in the past 50 years. According to a 1999 UN conference on desertification, **(1)** about 40% of the world's land and

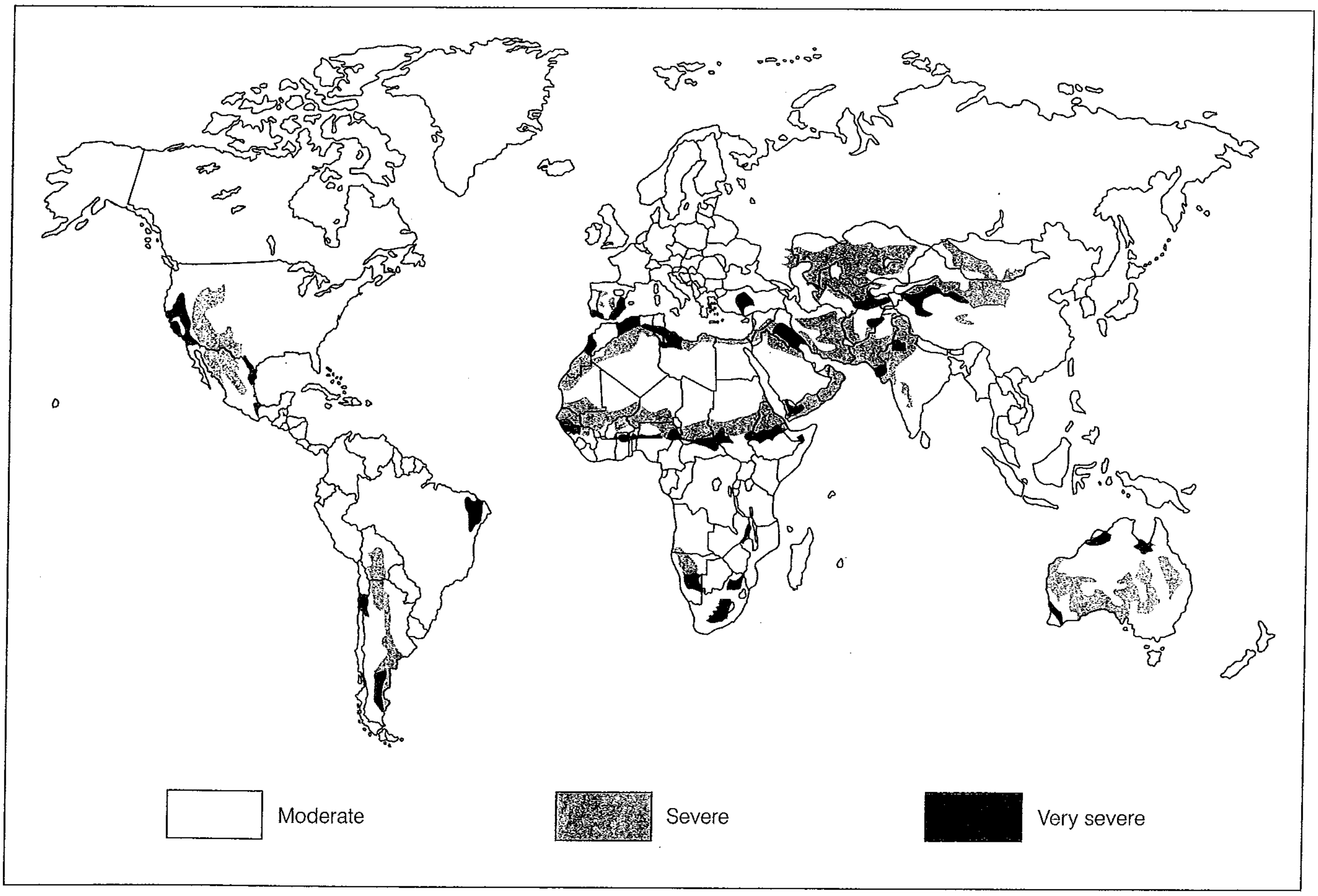


Figure 10-20 *Desertification* of arid and semiarid lands. (Data from UN Environmental Programme and Harold E. Drengue)

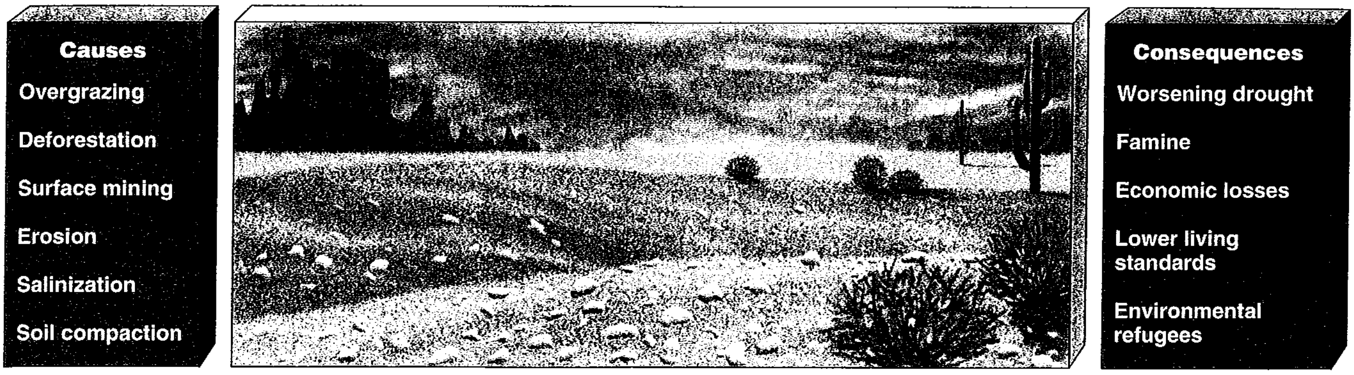


Figure 10-21 Causes and consequences of desertification. Natural climate change also plays a role in desertification.

70% of all drylands is suffering from the effects of desertification, and **(2)** each year about 150,000 square kilometers (58,000 square miles)—an area larger than Greece—becomes desertified. This threatens the livelihoods of at least 135 million people in 100 countries and causes economic losses estimated at $42 billion per year.

Desertification can feed on itself through positive feedback. Changes in the reflectivity of the land surface because of widespread desertification can change local climates in ways that increase drought and thus the area of land affected by desertification.

Here are the most effective ways to slow desertification:

- Reduce **(1)** overgrazing, **(2)** deforestation, and **(3)** destructive forms of planting, irrigation, and mining.
- Plant trees and grasses that will **(1)** anchor the soil, **(2)** hold water, and **(3)** help reduce the threat of global warming by increasing uptake of carbon dioxide from the atmosphere.

How Do Excess Salts and Water Degrade Soils? Some *good news* is that the approximately 17% of the world's cropland that is irrigated produces almost 40% of the world's food. Irrigated land can produce crop yields two to three times greater than those from rain watering.

But irrigation also has a downside. Most irrigation water is a dilute solution of various salts, picked up as the water flows over or through soil and rocks. Small quantities of these salts are essential nutrients for plants, but they are toxic in large amounts.

Irrigation water not absorbed into the soil evaporates, leaving behind a thin crust of dissolved salts (such as sodium chloride) in the topsoil. This accumulation of salts is called **salinization** (Figure 10-22), which **(1)** stunts crop growth, **(2)** lowers crop yields, and **(3)** eventually kills plants and ruins the land (Figure 10-23, p. 222).

According to a 1995 study, severe salinization has reduced yields on 21% of the world's irrigated cropland, and another 30% has been moderately salinized. The most severe salinization occurs in Asia, especially in China, India, and Pakistan.

In the United States, salinization affects 23% of all irrigated cropland. However, the proportion is much higher in some heavily irrigated western states, including **(1)** 66% of the irrigated land in the lower

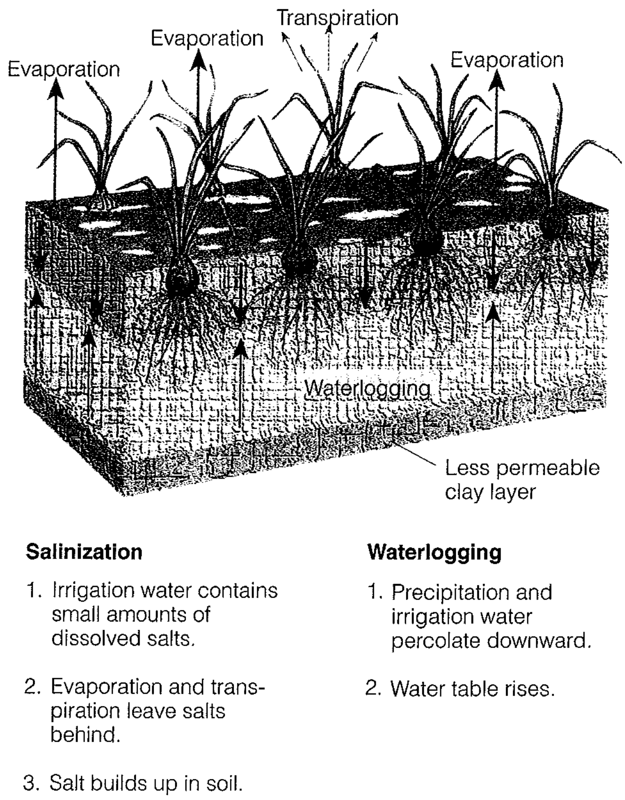
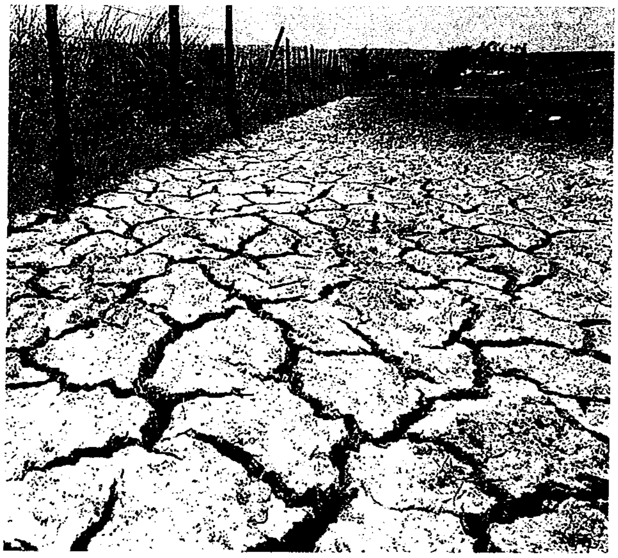


Figure 10-22 *Salinization* and *waterlogging* of soil on irrigated land without adequate drainage lead to decreased crop yields.



Natural Resource Conservation Service

Figure 10-23 Severe *salinization.* Because of high evaporation, poor drainage, and severe salinization, white alkaline salts have displaced crops that once grew on this heavily irrigated land in Colorado.

Colorado Basin and **(2)** 35% of such land in California. Figure 10-24 summarizes solutions for preventing and dealing with soil salinization.

Another problem with irrigation is **waterlogging** (Figure 10-22). Farmers often apply large amounts of irrigation water to leach salts deeper into the soil. Without adequate drainage, however, water accumulates underground and gradually raises the water table. Saline water then envelops the deep roots of plants, lowering their productivity and killing them after prolonged exposure. At least one-tenth of all irrigated land worldwide suffers from waterlogging, and the problem is getting worse.

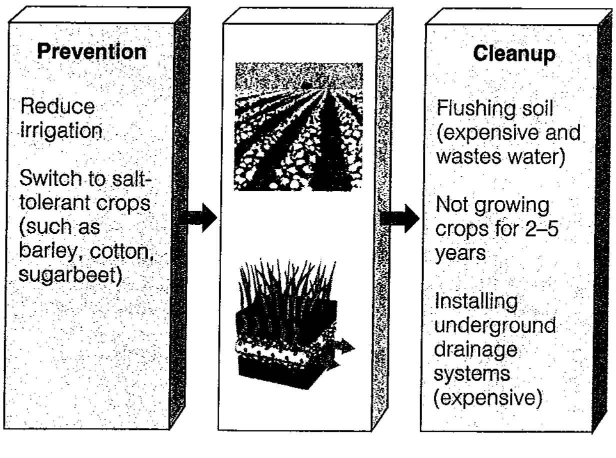


Figure 10-24 *Solutions:* methods for preventing and cleaning up soil salinization.

10-7 SOLUTIONS: SOIL CONSERVATION

How Can Conservation Tillage Reduce Soil Erosion? **Soil conservation** involves reducing soil erosion and restoring soil fertility. For hundreds of years, farmers have used various methods to reduce soil erosion, mostly by keeping the soil covered with vegetation.

In **conventional-tillage farming,** farmers plow the land and then break up and smooth the soil to make a planting surface. In areas such as the midwestern United States, harsh winters prevent plowing just before the spring growing season. Thus crop fields often are plowed in the fall. This leaves the soil bare during the winter and early spring and makes it vulnerable to erosion.

To reduce erosion, many U.S. farmers are using **conservation-tillage farming** (either *minimum-tillage* or *no-till farming*). The idea is to disturb the soil as little as possible while planting crops. With *minimum-tillage farming,* special tillers break up and loosen the subsurface soil without turning over the topsoil, previous crop residues, and any cover vegetation. In *no-till farming,* special planting machines inject seeds, fertilizers, and weed killers (herbicides) into slits made in the unplowed soil. Figure 10-25 lists the advantages and disadvantages of conservation tillage.

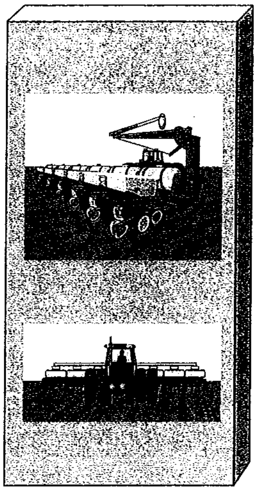
By 2001, conservation tillage was used on about 45% of U.S. cropland. In Indiana, the Nature Conservancy is giving farmers money to buy no-till equipment in exchange for a promise to use conservation tillage for at least 3 years. The USDA estimates that using conservation tillage on 80% of U.S. cropland would reduce soil erosion by at least half. Conservation tillage is used in Brazil, Argentina, Canada, and Paraguay and beginning to be embraced by more farmers worldwide.

Solutions: What Other Methods Can Reduce Soil Erosion? Farmers have developed a number of other ways to reduce soil erosion (Figure 10-26, p. 224). They include the following:

- **Terracing,** which can reduce soil erosion on steep slopes by converting the land into a series of broad, nearly level terraces that run across the land contour (Figure 10-26a). This **(1)** retains water for crops at each level and **(2)** reduces soil erosion by controlling runoff. Although most poor farmers know the risk of not terracing, many have too little time and too few workers to build terraces; they must plant crops without terracing hillsides or starve.
- **Contour farming,** which involves plowing and planting crops in rows across the contour of gently sloped land (Figure 10-26b). Each row acts as a small dam to help hold soil and to slow water runoff.

Advantages

- Reduces erosion
- Saves fuel
- Cuts costs
- Holds more soil water
- Reduces soil compaction
- Allows several crops per season
- Does not reduce crop yields
- Reduces CO_2 release from soil



Disadvantages

- Can increase herbicide use for some crops
- Leaves stalks that can harbor crop pests and fungal diseases and increase pesticide use
- Requires investment in expensive equipment

Figure 10-25 Advantages and disadvantages of using *conservation tillage.*

- **Strip cropping,** which involves planting alternating strips of **(1)** a row crop (such as corn) and **(2)** another crop (such as a grass or a grass and legume mixture) that completely covers the soil (Figure 10-26b, p. 224). The cover crop strips **(1)** trap soil that erodes from the row crop, **(2)** catch and reduce water runoff, and **(3)** help prevent the spread of pests and plant diseases. Planting strips of nitrogen-fixing legumes (such as soybeans or alfalfa) helps restore soil fertility.
- **Alley cropping** or **agroforestry,** in which several crops are planted together in strips or alleys between trees and shrubs that can provide fruit or fuelwood (Figure 10-26c, p. 224). The trees or shrubs **(1)** provide shade (which reduces water loss by evaporation), **(2)** help retain and slowly release soil moisture, and **(3)** can provide fruit, fuelwood, and trimmings that can be used as mulch (green manure) for the crops and as fodder for livestock.

CASE STUDY

Slowing Soil Erosion in the United States

Of the world's major food-producing countries, only the United States is sharply reducing some of its soil losses through conservation tillage and government-sponsored soil conservation programs.

The 1985 Farm Act established a strategy for reducing soil erosion in the United States. In the first phase of this program, farmers are given a subsidy for taking highly erodible land out of production and replanting it with soil-saving grass or trees for 10–15 years. By 2001, approximately 15 million hectares (37 million acres), roughly one-tenth of U.S. cropland, were in this Conservation Reserve Program (CRP).

The land in such a *conservation reserve* cannot be farmed, grazed, or cut for hay. Farmers who violate their contracts must pay back all subsidies plus interest.

According to the U.S. Department of Agriculture, since 1985 this program has cut soil losses on cropland in the United States by about 65%—a shining example of *good news*—and could eventually cut such losses as much as 80%. In 1996, Congress reauthorized the CRP until 2002. If lawmakers continue to support this program, it could eventually cut such soil losses as much as 80%.

The second phase of the program required all farmers with highly erodible land to develop government-approved 5-year soil conservation plans for their entire farms by the end of 1990. A third provision of the Farm Act authorizes the government to forgive all or part of farmers' debts to the Farmers Home Administration if they agree not to farm highly erodible cropland or wetlands for 50 years. The farmers must plant trees or grass on this land or restore it to wetland.

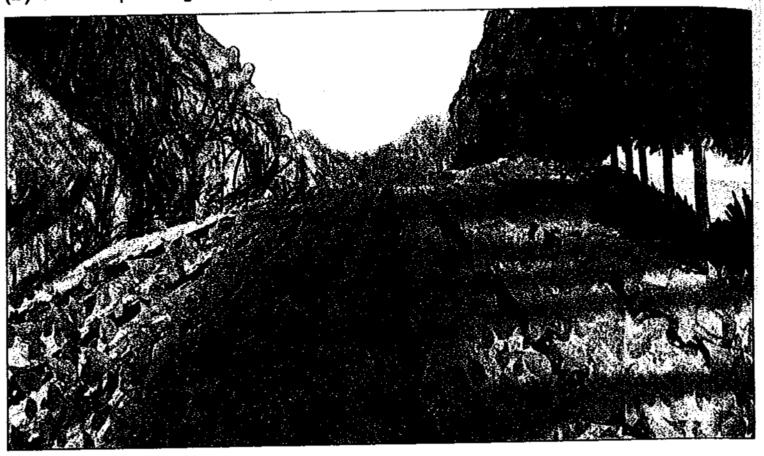
The 1985 Farm Act made the United States the first major food-producing country to make soil conservation a national priority. Even though these efforts to slow soil erosion are an important step, effective soil conservation is practiced on only about half of all U.S. agricultural land and on less than half of the country's most erodible cropland.

Critical Thinking

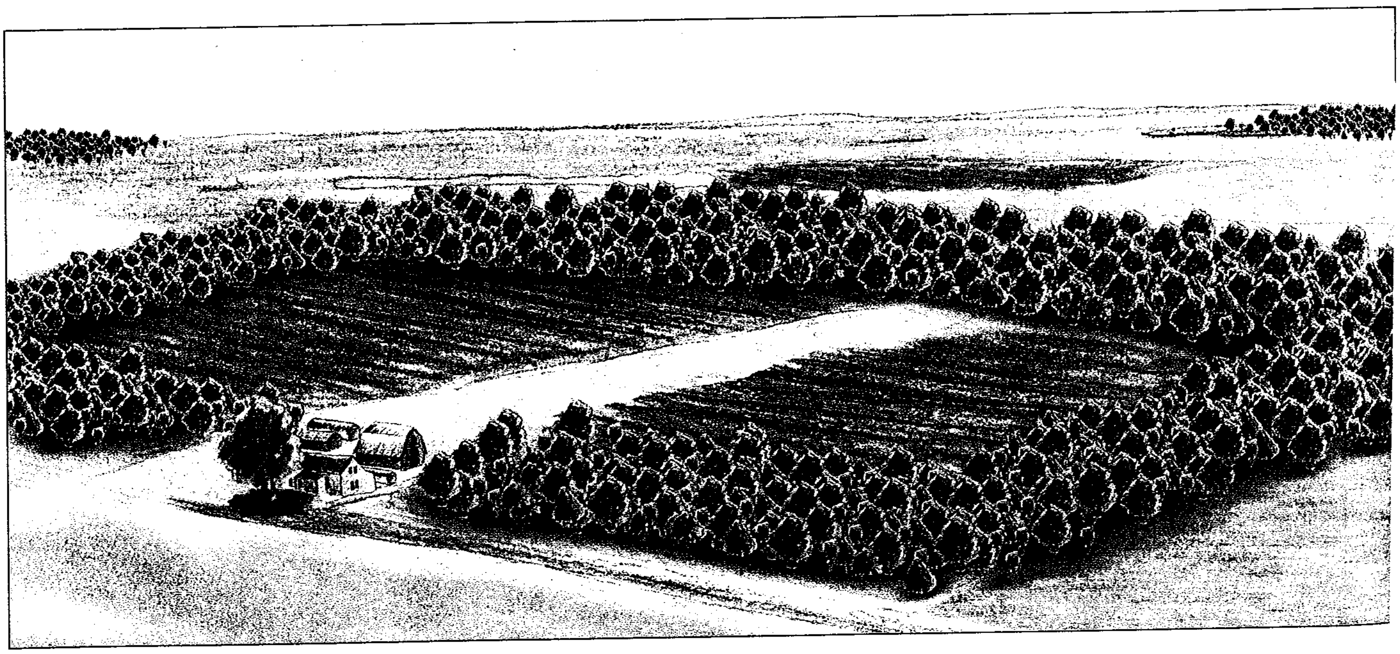
Do you believe U.S. tax dollars should be used to pay farmers for taking highly erodible land out of production? Explain. What are the alternatives?

(a) Terracing

(b) Contour planting and strip cropping



(c) Alley cropping



(d) Windbreaks

Figure 10-26 In addition to conservation tillage, soil conservation methods include **(a)** terracing, **(b)** contour planting and strip cropping, **(c)** alley cropping, and **(d)** windbreaks.

- Establishing **windbreaks,** or **shelterbelts,** of trees (Figure 10-26d) to **(1)** reduce wind erosion, **(2)** help retain soil moisture, **(3)** supply some wood for fuel, and **(4)** provide habitats for birds, pest-eating and pollinating insects, and other animals.
- **Gully reclamation,** which involves restoring severely eroded bare land by **(1)** planting fast-growing shrubs, vines, and trees to stabilize the soil, **(2)** building small dams at the bottoms of gullies to collect silt and gradually fill in the channels, and **(3)** building channels to divert water from the gully.
- Using *land classification* to identify easily erodible (marginal) land that should be neither planted in crops nor cleared of vegetation. In the United States, the National Resources Conservation Service has set up a classification system to identify types of land that are suitable or unsuitable for cultivation. Such efforts and recent farm legislation have helped reduce soil erosion in the United States (Case Study, p. 223).

How Can We Maintain and Restore Soil Fertility? Fertilizers partially restore plant nutrients lost by erosion, crop harvesting, and leaching. Farmers can use **(1) organic fertilizer** from plant and animal materials or **(2) commercial inorganic fertilizer** produced from various minerals.

Types of *organic fertilizer* include the following:

- **Animal manure:** the dung and urine of cattle, horses, poultry, and other farm animals. It improves **(1)** soil structure, **(2)** adds organic nitrogen, and **(3)** stimulates beneficial soil bacteria and fungi. However, its use in the United States has decreased because of **(1)** replacement of most mixed animal-raising and crop-farming operations with separate operations for growing crops and raising animals, **(2)** the high costs of transporting animal manure from feedlots near urban areas to distant rural crop-growing areas, and **(3)** the use of tractors and other motorized farm machinery to replace horses and other draft animals that added manure to the soil. Researchers at the U.S. Department of Agriculture are evaluating the use of phosphorus-rich ash produced from burning poultry wastes to produce electricity as an organic fertilizer.
- **Green manure:** fresh or growing green vegetation plowed into the soil to increase the organic matter and humus available to the next crop.
- **Compost:** a sweet-smelling, dark-brown, humus-like material that is rich in organic matter and soil nutrients. It is produced when microorganisms (mostly fungi and aerobic bacteria) in soil break down organic matter such as leaves, food wastes, paper, and wood in the presence of oxygen. Compost is a rich natural fertilizer and soil conditioner that **(1)** aerates soil, **(2)** improves its ability to retain water and nutrients, **(3)** helps prevent erosion, and **(4)** prevents nutrients from being wasted by being dumped in landfills.
- **Spores of mushrooms, puffballs, and truffles:** Rapidly growing and spreading mycorrhizae fungi (Figure 8-12c, p. 179) in the spores attach to plant roots and help them **(1)** take in moisture and nutrients from the soil and **(2)** make plants more disease resistant. Unlike typical fertilizers that farmers must apply every few weeks, one application of mushroom fungi lasts all year and costs just pennies per plant.

Crops such as corn, tobacco, and cotton can deplete the topsoil of nutrients (especially nitrogen) if planted on the same land several years in a row (Figure 10-14). One way to reduce such losses is **crop rotation.** Farmers plant areas or strips with nutrient-depleting crops one year. In 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 **(1)** reduces erosion by keeping the soil covered with vegetation and **(2)** helps reduce crop losses to insects by presenting them with a changing target.

Can Inorganic Fertilizers Save the Soil? Today, many farmers (especially in developed countries) rely on *commercial inorganic fertilizers* containing **(1)** nitrogen (as ammonium ions, nitrate ions, or urea), **(2)** phosphorus (as phosphate ions), and **(3)** potassium (as potassium ions). Other plant nutrients may also be present in low or trace amounts.

Inorganic commercial fertilizers are easily transported, stored, and applied. Worldwide, their use increased about nine-fold between 1950 and 1989 but has leveled off since then. The good news is that the additional food these fertilizers help produce feeds one of every three people in the world; without them, world food output would drop an estimated 40%.

Commercial inorganic fertilizers have some disadvantages, however. These include **(1)** not adding humus to the soil, **(2)** reducing the soil's content of organic matter and thus its ability to hold water (unless animal manure and green manure are also added to the soil), **(3)** lowering the oxygen content of soil and keeping fertilizer from being taken up as efficiently, **(4)** typically supplying only 2 or 3 of the 20 or so nutrients needed by plants, **(5)** requiring large amounts of energy for their production, transport, and application, and **(6)** releasing nitrous oxide (N_2O), a greenhouse gas that can enhance global warming, from the soil.

The widespread use of commercial inorganic fertilizers, especially on sloped land near streams and lakes, also causes water pollution as nitrate (NO_3^-) and phosphate (PO_4^{3-}) fertilizer nutrients are washed into nearby bodies of water. The resulting plant nutrient enrichment (cultural eutrophication) causes algae blooms that use up oxygen dissolved in the water, thereby killing fish. Rainwater seeping through the soil can also leach nitrates in commercial fertilizers into groundwater. Drinking water drawn from wells containing high levels of nitrate ions can be toxic, especially for infants, and cause bladder cancer.

According to soil scientists, responsibility for reducing soil erosion should not be limited to farmers. Timber cutting, overgrazing, mining, and urban development that are carried out without proper regard for soil conservation also cause soil erosion. See the website material for this chapter for what you can do to reduce soil erosion.

The challenge is to arrest the excessive loss of topsoil on all land everywhere, reducing it to below the level of new soil formation. The world cannot afford this loss of natural capital. If we cannot preserve the foundation of civilization, we cannot preserve civilization itself.

LESTER R. BROWN

REVIEW QUESTIONS

1. Define all boldfaced terms in this chapter.

2. Describe the harmful and beneficial effects of the Mount St. Helens volcanic eruption in the United States in 1980.

3. What are the main characteristics of the earth's *core, mantle,* and *crust?*

4. What are *tectonic plates?* What is the *lithosphere?* What is the *theory of plate tectonics,* and how is it important to physical and biological processes on the earth?

5. What are the three different types of boundaries between the earth's lithospheric plates?

6. What is *erosion,* and what are its two major causes?

7. Distinguish between a *mineral* and a *rock.* Distinguish among *igneous, sedimentary,* and *metamorphic rock,* and give two examples of each type.

8. Describe the *rock cycle,* and explain its importance.

9. What is an *earthquake,* and what are its major harmful effects? List ways to reduce the hazards from earthquakes.

10. What is a *volcanic eruption?* What are some of the hazards and benefits of volcanic eruptions? List ways to reduce the hazards from volcanic eruptions.

11. What is *soil?* Distinguish between a *soil horizon* and a *soil profile.*

12. What is *humus,* and what is its importance? What does the color of topsoil tell you about its usefulness as a soil for growing crops?

13. Distinguish between *soil infiltration* and *leaching.* Distinguish among *soil texture, soil porosity,* and *soil permeability.*

14. What are *loams,* and why are they the best soils for growing most crops?

15. What is *soil erosion,* and what are its major natural and human-related causes? Describe three types of soil erosion.

16. What are the major harmful effects of soil erosion?

17. How serious is soil erosion **(a)** globally and **(b)** in the United States?

18. Describe the *Dust Bowl* event in the United States. Describe how the U.S. government is reducing soil erosion.

19. What is *desertification?* How serious is this problem? What are its major causes and consequences? How can we slow desertification?

20. Distinguish between *salinization* and *waterlogging* of soils. How serious are these problems? List five ways to reduce the threat of soil salinization.

21. What is *soil conservation?* Distinguish between *conventional-tillage farming* and *conservation-tillage farming.* What are the advantages and disadvantages of conservation-tillage farming?

22. Distinguish among *terracing, contour farming, strip cropping, alley cropping, windbreaks, gully reclamation,* and *land classification* as methods for reducing soil erosion.

23. Distinguish between *organic fertilizer* and *commercial inorganic fertilizer,* and list the advantages of each approach for maintaining or restoring soil fertility. Discuss using *animal manure, green manure, compost,* and *mushroom spores* as methods for fertilizing soil. What is *crop rotation,* and why is it useful in helping maintain soil fertility?

24. List the advantages and disadvantages of using commercial inorganic fertilizers to maintain and restore soil fertility.

CRITICAL THINKING

1. List some ways, positive and negative, in which **(a)** the external earth processes of weathering and erosion and **(b)** plate tectonics are important to you.

2. Explain what would happen if **(a)** plate tectonics stopped and **(b)** erosion and weathering stopped. If you could, would you eliminate either group of processes? Explain.

3. Imagine you are an igneous rock. Act as a reporter and send in a written report on what you experience as you move through various parts of the rock cycle (Figure 10-8, p. 210). Repeat this experience, assuming in turn you are a sedimentary rock and then a metamorphic rock.

4. In the area where you live, are you more likely to experience an earthquake or a volcanic eruption? What can you do to escape or reduce the harm if such a disaster strikes? What actions can you take when it occurs?

5. How does your lifestyle directly or indirectly contribute to soil erosion?

6. Some analysts contend that average soil erosion rates around the world are low and the soil erosion problem can be solved easily with improved agricultural technology such as no-till cultivation and increased use of commercial inorganic fertilizers. Do you agree or disagree with this position? Explain.

7. Why should everyone, not just farmers, be concerned about soil conservation?

8. What are the main advantages and disadvantages of using commercial inorganic fertilizers to restore or increase soil fertility? Why should both inorganic and organic fertilizers be used?

9. Congratulations! You are in charge of the world. What are the three most important features of your policy to reduce soil erosion?

PROJECTS

1. Write a brief scenario describing the sequence of consequences to us and to other forms of life if the rock cycle stopped functioning.

2. Use the library or the Internet to find out where earthquakes and volcanic eruptions have occurred during the past 30 years, and then stick small flags on a map of the world or place dots on Figure 10-5a (p. 207). Compare their locations with the plate boundaries shown in Figure 10-5b.

3. Conduct a survey of soil erosion and soil conservation in and around your community on cropland, construction sites, mining sites, grazing land, and deforested land. Use these data to develop a plan for reducing soil erosion in your community.

4. Use the library or the Internet to find bibliographic information about *Will Durant* and *Lester R. Brown*, whose quotes appear at the beginning and end of this chapter.

5. Make a concept map of this chapter's major ideas using the section heads and subheads and the key terms (in boldface). Look on the website for this book for information about making concept maps.

INTERNET STUDY RESOURCES AND RESOURCES FOR FURTHER READING AND RESEARCH

The website for this book contains helpful study aids and many ideas for further reading and research. Log on to

www.info.brookscole.com/miller13

and click on the Chapter-by-Chapter area. Choose Chapter 10 and select a resource:

- Flash Cards allows you to test your mastery of the Terms and Concepts to Remember for this chapter.
- Tutorial Quizzes provides a multiple-choice practice quiz.
- Student Guide to InfoTrac will lead you to Critical Thinking Projects that use InfoTrac College Edition as a research tool.
- References lists the major books and articles consulted in writing this chapter.
- Hypercontents takes you to an extensive list of sites with news, research, and images related to individual sections of the chapter.

INFOTRAC COLLEGE EDITION

Improve your skills with InfoTrac College Edition, a searchable online database of articles from more than 700 periodicals. Log on to

http://www.infotrac-college.com

or access InfoTrac through the website for this book. Try to find the following articles:

1. Pearce, F. 2002. On shaky ground. *Geographical* 74: 32. *Keywords:* "Peru," "earthquake," and "aftermath." Damaging earthquakes are a way of life in Peru. However, not all the damage is caused by the shaking of the earth. Now developers are displacing people after areas are considered unsafe for habitation.

2. Sparks, D. L. 2000. Soil as an endangered ecosystem. (brief article) *BioScience* 50 : 947. *Keywords:* "endangered ecosystem" and "soil." This article explores several issues related to soil erosion and ecosystem damage.

11 RISK, TOXICOLOGY, AND HUMAN HEALTH

The Big Killer

What is roughly the diameter of a 30-caliber bullet, can be bought almost anywhere, is highly addictive, and kills about 11,000 people every day, 460 per hour, or 1 person every 8 seconds? It is a cigarette. *Cigarette smoking is the single most preventable major cause of death and suffering among adults.*

According to the World Health Organization (WHO) between 1950 and 2000, tobacco helped kill 60 million people. WHO estimates that each year tobacco contributes to the premature deaths of at least 4 million people from 25 illnesses including **(1)** heart disease, **(2)** lung cancer, **(3)** other cancers, **(4)** bronchitis, **(5)** emphysema, and **(6)** stroke. The annual death toll from smoking-related diseases is projected to reach 10 million by 2030 (70% of them in developing countries)—an average of about 27,400 preventable deaths per day or 1 death every 3 seconds.

According to a 2002 study by the Centers for Disease Control and Prevention, smoking prematurely kills about 440,000 Americans per year, an average of 1,205 deaths per day (Figure 11-1). This death toll is roughly equivalent to three fully loaded jumbo (400-passenger) jets crashing accidentally every day with no survivors. Smoking causes more deaths each year in the United States than do all illegal drugs, alcohol (the second most harmful legal drug after nicotine), accidents, suicide, and homicide combined (Figure 11-1).

According to a 1998 study, secondhand smoke (inhaled by nonsmokers) causes 30,000–60,000 premature deaths per year in the United States. Each year, parental smoking prematurely kills an estimated 6,000 children and causes 5.4 million serious child ailments in the United States.

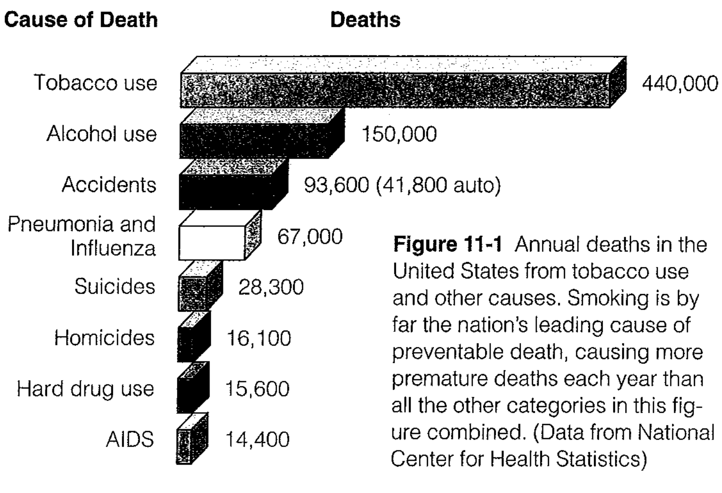


Figure 11-1 Annual deaths in the United States from tobacco use and other causes. Smoking is by far the nation's leading cause of preventable death, causing more premature deaths each year than all the other categories in this figure combined. (Data from National Center for Health Statistics)

The overwhelming consensus in the scientific community is that the nicotine (and probably the acetaldehyde) inhaled in tobacco smoke is highly addictive. Only 1 in 10 people who try to quit smoking succeed, about the same relapse rate as for recovering alcoholics and those addicted to heroin or crack cocaine. A British government study showed that adolescents who smoke more than one cigarette have an 85% chance of becoming smokers. According to a 1999 World Bank study, each day some 80,000–100,000 young people become regular long-term smokers, primarily in developing countries, where 73% of the world's smokers live.

According to a 2002 study by the Centers for Disease Control and Prevention, smoking costs the United States about $158 billion a year for **(1)** medical bills, **(2)** increased insurance costs, **(3)** disability, **(4)** lost earnings and productivity because of illness, and **(5)** property damage from smoking-caused fires. This is an average of $7 per pack of cigarettes sold in the United States.

Many health experts urge that a $3–5 federal tax be added to the price of a pack of cigarettes in the United States. Such a tax would mean that the users of cigarettes (and other tobacco products), not the rest of society, would pay a much greater share of the health, economic, and social costs associated with their smoking: a *user-pays* approach. WHO and the World Bank estimate that a 10% global tax on cigarettes would cause 40 million smokers to quit and would prevent the premature deaths of 10 million people alive today.

Other suggestions for reducing the death toll and health effects of smoking in the United States include **(1)** banning all cigarette advertising, **(2)** prohibiting the sale of cigarettes and other tobacco products to anyone under 21 (with strict penalties for violators), **(3)** banning all cigarette vending machines, **(4)** classifying nicotine as an addictive and dangerous drug (and placing its use in tobacco or other products under the jurisdiction of the Food and Drug Administration), **(5)** eliminating all federal subsidies and tax breaks to U.S. tobacco farmers and tobacco companies, and **(6)** using cigarette tax income to finance an aggressive antitobacco advertising and education program.

The dose makes the poison.

PARACELSUS, 1540

This chapter addresses the following questions:

- What types of hazards do people face?
- What is toxicology, and how do scientists measure toxicity?
- What chemical hazards do people face, and how can they be measured?
- What types of disease (biological hazards) threaten people in developing countries and developed countries?
- How can risks be estimated, managed, and reduced?

11-1 RISK, PROBABILITY, AND HAZARDS

What Is Risk? **Risk** is the possibility of suffering harm from a hazard that can cause injury, disease, economic loss, or environmental damage. Risk is expressed in terms of **probability:** a mathematical statement about how likely it is that some event or effect will occur. In these terms, *risk* is defined as the probability of exposure times the probability of harm (Risk = Exposure × Harm).

Probability often is stated in terms such as "The lifetime probability of developing cancer from exposure to a certain chemical is 1 in 1 million." This means that 1 of every 1 million people exposed to the chemical at a specified average daily dosage will develop cancer over a typical lifetime (usually considered 70 years).

How Are Risks Assessed and Managed? **Risk assessment** involves **(1)** identifying a real or potential hazard ("What is the hazard?"), **(2)** determining the probability of its occurrence ("How likely is the event?"), and **(3)** assessing the severity of its health, environmental, economic, and social impact ("How much damage is it likely to cause?" (Figure 11-2, left).

This is a complex, difficult, and controversial process. For example, assessing the risk of exposure to a toxic chemical involves estimating **(1)** the number of people or other organisms exposed, **(2)** the level and duration of exposure, and **(3)** other possible contributing factors such as age, health, sex, personal habits, and interactions with other chemicals.

After a risk has been assessed, the next step is **risk management,** in which people make decisions about **(1)** how serious it is compared to other risks (*comparative risk analysis*), **(2)** how much (if at all) the risk should be reduced, **(3)** how such risk reduction can be accomplished, and **(4)** how much money should be devoted to reducing the risk to an acceptable level

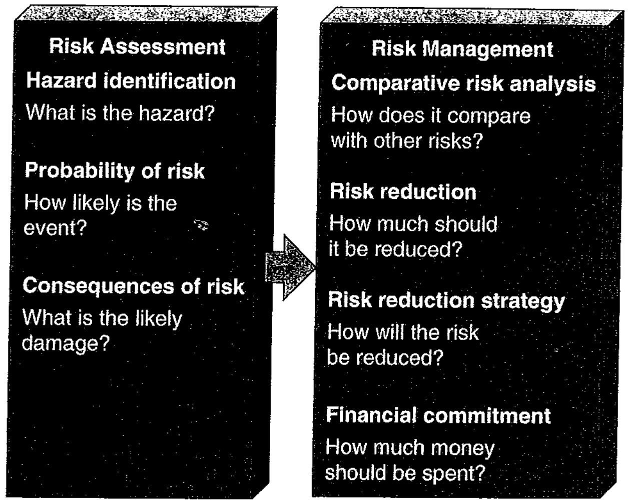


Figure 11-2 *Risk assessment* and *risk management.* These are important, difficult, and controversial processes.

(Figure 11-2, right). This is even more difficult and controversial than risk assessment because of **(1)** a lack of information and **(2)** the economic, health, and political implications of such decisions.

What Are the Major Types of Hazards? The various kinds of hazards we face can be categorized as follows:

- *Cultural hazards* such as unsafe working conditions, smoking (p. 228), poor diet, drugs, drinking, driving, criminal assault, unsafe sex, and poverty.
- *Chemical hazards* from harmful chemicals in the air, water, soil, and food. The bodies of most human beings contain small amounts of about 500 synthetic organic chemicals—whose health effects are mostly unknown—that did not exist in 1920.
- *Physical hazards* such as ionizing radiation (p. 57), fire, earthquake (p. 210), volcanic eruption (p. 211), flood, tornadoes (p. 113), and hurricanes (p. 113).
- *Biological hazards* from pathogens (bacteria, viruses, and parasites), pollen and other allergens, and animals such as bees and poisonous snakes.

According to a 1998 study by Cornell University scientist David Pimentel, *environmental factors* such as malnutrition, smoking, cooking fires, skin cancer, exposures to pesticides and other hazardous chemicals, and air and water pollution contribute to about 40% of the world's annual deaths.

11-2 TOXICOLOGY

What Determines Whether a Chemical Is Harmful? Dose and Response **Toxicity** measures how harmful a substance is. Whether a chemical (or other agent such as ionizing radiation) is harmful depends on several factors. One is the **dose,** the amount of a potentially harmful substance that a person has ingested, inhaled, or absorbed through the skin. Whether a chemical is harmful depends on **(1)** the size of the dose over a certain period of time, **(2)** how often an exposure occurs, **(3)** who is exposed (adult or child, for example), **(4)** how well the body's detoxification systems (liver, lungs, and kidneys) work, and **(5)** genetic makeup that determines an individual's sensitivity to a particular toxin (Figure 11-3).

This genetic variation in individual responses to exposure to various toxins raises a difficult ethical, political, and economic question. When regulating levels of a toxin in the environment, should the allowed level be set to protect **(1)** the most sensitive individuals (at great cost) or **(2)** the average person?

A substance's harm can also be affected by

- *Solubility. Water-soluble toxins* (which are often inorganic compounds) can move throughout the environment and get into water supplies. *Oil- or fat-soluble toxins* (which are usually organic compounds) can accumulate in body tissues and cells.
- *Persistence.* Many chemicals, such as chlorofluorocarbons (CFCs), chlorinated hydrocarbons, and plastics, are used widely because of their persistence or resistance to breakdown. However, this persistence also means they can have long-lasting effects on the health of wildlife and people.
- **Bioaccumulation,** in which some molecules are absorbed and stored in specific organs or tissues at levels higher than normally would be expected.
- **Biomagnification,** in which the levels of some toxins in the environment are magnified as they pass

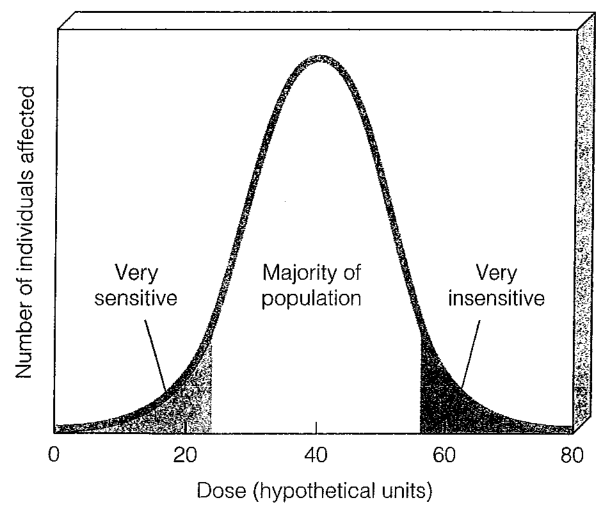


Figure 11-3 Typical variations in sensitivity to a toxic chemical within a population, mostly because of differences in genetic makeup. Some individuals in a population are very sensitive to small doses of a toxin (left), and others are very insensitive (right). Most people fall between these two extremes (middle).

through food chains and webs (Figure 11-4). Examples of chemicals that can be biomagnified include long-lived, fat-soluble organic compounds such as **(1)** the pesticide DDT, **(2)** PCBs (oily chemicals used in electrical transformers), and **(3)** some radioactive isotopes (such as strontium-90; Table 3-2, p. 56). Stored in body fat, such chemicals can be passed along to offspring during gestation or egg laying and as mothers nurse their young.

- *Chemical interactions* that can decrease or multiply the harmful effects of a toxin. An *antagonistic interaction* can reduce the harmful response. For example, vitamins E and A apparently interact to reduce the body's response to some carcinogens. A *synergistic interaction* (p. 46) multiplies harmful effects. For example, workers exposed to asbestos increase their chances of getting lung cancer 20-fold. However, asbestos workers who also smoke have a 400-fold increase in lung cancer rates.

The type and amount of health damage that result 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; it can range from dizziness or a rash to death. A *chronic effect* is a permanent or long-lasting consequence (kidney or liver damage, for example) of exposure to a harmful substance.

Should We Be Concerned About Trace Levels of Toxic Chemicals in the Environment and in Our Bodies? The answer is that it depends on the chemical and its concentration. The detection of trace amounts of a chemical in air, water, or food does not necessarily mean it is there at a level harmful to most people or to wildlife.

A basic concept of toxicology is that *any synthetic or natural chemical (even water) can be harmful if ingested in a large enough quantity.* 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 (ethanol) would kill most people.

The critical question is how much exposure to a particular toxic chemical causes a harmful response. This is the meaning of the quote by German scientist Paracelsus about the dose making the poison (found at the top of p. 229 in this chapter).

Most chemicals have some safe, or *threshold level,* of exposure below which their harmful effects are insignificant because

- The human body has mechanisms for breaking down (usually by enzymes found in the liver), diluting, or excreting small amounts of most toxins to keep them from reaching harmful levels.
- Individual cells have enzymes that can repair damage to DNA and protein molecules.

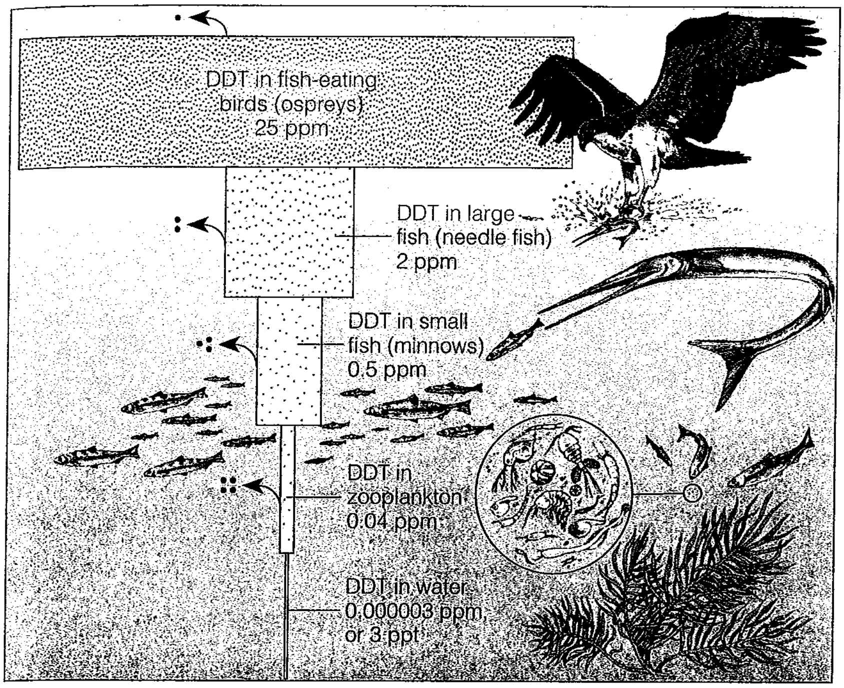


Figure 11-4 *Bioaccumulation* and *biomagnification.* DDT is a fat-soluble chemical that can accumulate in the fatty tissues of animals. In a food chain or food web, the accumulated concentrations of DDT can be biologically magnified in the bodies of animals at each higher trophic level. This diagram shows that 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 New York. If each phytoplankton organism in such a food chain takes up from the water and retains one unit of DDT, a small fish eating thousands of zooplankton (which feed on the phytoplankton) will store thousands of units of DDT in its fatty tissue. Then 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. Dots represent DDT, and arrows show small losses of DDT through respiration and excretion.

- Cells in some parts of the body (such as the skin and linings of the gastrointestinal tract, lungs, and blood vessels) reproduce fast enough to replace damaged cells. However, such high rates of cell reproduction can sometimes be altered by exposure to ionizing radiation and certain chemicals so that cell growth accelerates and creates a nonmalignant or malignant (cancerous) tumor.

Some people 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. For example, the average person is far more likely to be killed by aflatoxin in peanut butter than by lightning or a shark. However, the chance of dying from eating several spoonfuls of peanut butter a day is quite small.

In addition, the ability of chemists to detect increasingly small amounts of potentially toxic chemicals in air, water, and food can give the false impression that dangers from toxic chemicals are increasing. In 1980, chemists could routinely detect concentrations of substances in parts per million (ppm) (Table 3-1, p. 55). By 1990, chemists could detect parts per billion (ppb), and today they can detect concentrations of parts per trillion (ppt) and in some cases parts per quadrillion (ppq).

What Is a Poison? Legally, a **poison** is a chemical that has an LD_{50} of 50 milligrams or less per kilogram of body weight. The **LD_{50}** is the **median lethal dose:** the amount of a chemical received in one dose that kills exactly 50% of the animals (usually rats and mice) in a test population, within a 14-day period (Figure 11-5). Until recently 50–200 rodents were needed for each LD_{50}, but new procedures require only 8–15 rodents per test.

Chemicals vary widely in their toxicity (Table 11-1, p. 232). Some poisons can cause serious harm or death after a single acute exposure at very low dosages. Others cause such harm only at such huge dosages that it is nearly impossible to get enough into the body. Most chemicals fall between these two extremes.

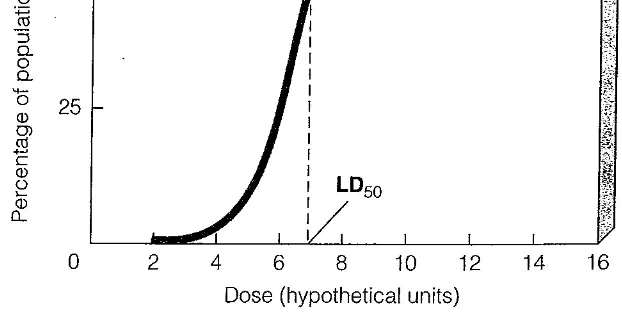


Figure 11-5 Hypothetical *dose-response curve* showing determination of the LD_{50}, the dosage of a specific chemical that kills 50% of the animals in a test group.

Table 11-1 Toxicity Ratings and Average Lethal Doses for Humans

Toxicity Rating	LD_{50} (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 that are liquids at room temperature when given to a 70.4-kilogram (155-pound) human

How Are Case Reports and Epidemiological Studies Used to Estimate Toxicity? Two methods scientists use to get information about the harmful effects of chemicals on human health are

- *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 poisonings, drug overdoses, homicides, or suicide attempts. Most case reports are not a reliable source for determining toxicity because the actual dosage and the exposed person's health status often are not known. However, such reports can provide clues about environmental hazards and suggest the need for laboratory investigations.
- *Epidemiological studies* in which the health of people exposed to a particular toxic agent (the *experimental group*) is compared with the health of another group of statistically similar people not exposed to the agent (the *control group*). The goal is to determine whether the statistical association (if any) between a exposure to a toxic chemical and a health problem is strong, moderate, or weak. Such studies are limited because **(1)** too few people have been exposed to high enough levels of many toxic agents to detect statistically significant differences, **(2)** conclusively linking an observed effect with exposure to a particular chemical is very difficult because people are exposed to many different toxic agents throughout their lives, and **(3)** they cannot be used to evaluate hazards from new technologies or chemicals to which people have not been exposed.

How Are Laboratory Experiments Used to Estimate Toxicity? The most widely used method for determining acute toxicity and chronic toxicity is to expose a population of live laboratory animals (especially mice and rats) to measured doses of a specific substance under controlled conditions. Animal tests take 2–5 years and cost $200,000 to $2 million per substance tested.

Animal welfare groups want to limit or ban use of test animals or ensure that experimental animals are treated in the most humane manner possible. More humane methods for carrying out toxicity tests include using **(1)** bacteria, **(2)** cell and tissue cultures, and **(3)** chicken egg membranes. In 1999, scientists developed a cheaper and much more sensitive way to determine toxicity by almost continuous measurement of changes in the electrical properties of individual animal cells. The United States, Japan, and most European countries are gradually replacing older LD_{50} methods with these newer procedures.

These alternatives can greatly decrease the use of animals for testing toxicity. However, scientists point out that some animal testing is needed because the alternative methods cannot adequately mimic the complex biochemical interactions of a live animal.

Acute toxicity tests are run to develop a **dose-response curve,** which shows the effects of various dosages of a toxic agent on a group of test organisms (Figure 11-6). Such tests are *controlled experiments* in which the effects of the chemical on a *test group* are compared with the responses of a *control group* of organisms not exposed to the chemical. Care is taken to ensure that organisms in each group are **(1)** as identical

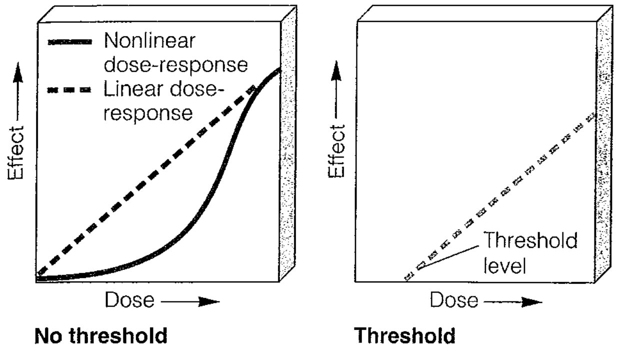


Figure 11-6 Hypothetical *dose-response curves.* The linear and nonlinear curves in the left graph show that exposure to any dosage of a chemical or ionizing radiation has a harmful effect that increases with the dosage. The curve on the right shows that a harmful effect occurs only when the dosage exceeds a certain *threshold level.* Which of these models applies to various harmful agents is very uncertain because of the difficulty in estimating the response to very low dosages. (Adapted from Chiras, *Environmental Science*, 5th ed., p. 352, fig. 19.12. Copyright © 1998 by Wadsworth)

as possible in age, health status, and genetic makeup and **(2)** exposed to the same environmental conditions.

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, the results of high-dose exposures usually are extrapolated to low-dose levels using mathematical models. Then the low-dose results on the test organisms are extrapolated to humans to estimate LD_{50} values for acute toxicity (Table 11-1).

According to the *nonthreshold dose-response model* (Figure 11-6, left), any dosage of a toxic chemical or ionizing radiation causes harm that increases with the dosage. Many chemicals that cause birth defects or cancers show this kind of response.

With the *threshold dose-response model* (Figure 11-6, 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. To be on the safe side, the nonthreshold dose-response model often is assumed.

Some scientists challenge the validity of extrapolating data from test animals to humans because human physiology and metabolism often are different from those of the test animals. Also, different species of test animals can react differently to the same toxin because of differences in body size, physiology, metabolism, and toxin sensitivity (Figure 11-3). Other scientists counter that such tests and models work fairly well (especially for revealing cancer risks) when the correct experimental animal is chosen or when a chemical is toxic to several different test animal species.

How Valid Are Estimates of Toxicity? As we have seen, all methods for estimating toxicity levels and risks have serious limitations. However, they are all we have. To take this uncertainty into account and minimize harm, standards for allowed exposure to toxic substances and ionizing radiation typically are set at levels 1/100 or even 1/1,000 of the estimated harmful levels.

Despite their many limitations, carefully conducted and evaluated toxicity studies are important sources of information for understanding dose-response effects and estimating and setting exposure standards. However, citizens, lawmakers, and regulatory officials must recognize the huge uncertainties and guesswork involved in all such studies.

11-3 CHEMICAL HAZARDS

What Are Toxic and Hazardous Chemicals? **Toxic chemicals** generally are defined as substances that are fatal to more than 50% of test animals (LD_{50}) at given concentrations. **Hazardous chemicals** cause harm by **(1)** being flammable or explosive, **(2)** irritating or damaging the skin or lungs (strong acidic or alkaline substances such as oven cleaners), **(3)** interfering with or preventing oxygen uptake and distribution (asphyxiants such as carbon monoxide and hydrogen sulfide), or **(4)** inducing allergic reactions of the immune system (allergens).

What Are Mutagens? **Mutagens** are agents, such as chemicals and ionizing radiation, that cause random *mutations,* or changes, in the DNA molecules found in cells. Mutations in a sperm or egg cell can be passed on to future generations and cause diseases such as **(1)** bipolar disorder, **(2)** cystic fibrosis, **(3)** hemophilia, **(4)** sickle-cell anemia, **(5)** Down syndrome, and **(6)** some types of cancer. Mutations in other cells are not inherited but may cause harmful effects.

Most mutations are harmless, probably because all organisms have biochemical repair mechanisms that can correct mistakes or changes in the DNA code. In addition, some mutations play a vital role in microevolution (p. 100).

What Are Teratogens? **Teratogens** are chemicals, radiation, or viruses that cause birth defects while the human embryo is growing and developing during pregnancy, especially during the first 3 months. Chemicals known to cause birth defects in laboratory animals include **(1)** PCBs, **(2)** thalidomide, **(3)** steroid hormones, and **(4)** heavy metals such as arsenic, cadmium, lead, and mercury.

What Are Carcinogens? **Carcinogens** are chemicals, radiation, or viruses that cause or promote the growth of a malignant (cancerous) tumor, in which certain cells multiply uncontrollably. Many cancerous tumors spread by **metastasis** when 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.

According to the WHO, environmental and lifestyle factors play a key role in causing or promoting up to 80% of all cancers. Major sources of carcinogens are **(1)** cigarette smoke (30–40% of cancers), **(2)** diet (20–30%), **(3)** occupational exposure (5–15%), and **(4)** environmental pollutants (1–10%). Inherited genetic factors and certain viruses cause about 10–20% of all cancers.

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 (p. 228), drinking, eating, and other lifestyle habits today could lead to some form of cancer before they reach age 50.

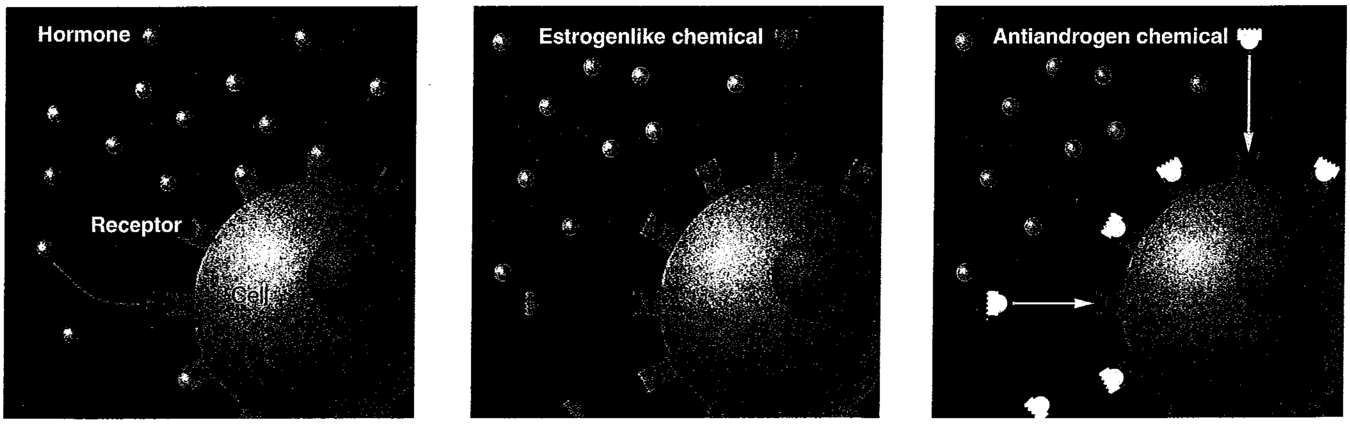
How Can Chemicals Harm the Immune, Nervous, and Endocrine Systems? Since the 1970s, a growing body of research on wildlife and laboratory animals and epidemiological studies of humans has indicated that long-term (often low-level) exposure to various toxic chemicals in the environment can disrupt the body's immune, nervous, and endocrine systems.

The *immune system* consists of specialized cells and tissues that protect the body against disease and harmful substances by forming antibodies that make invading agents harmless. Viruses such as the human immunodeficiency virus (HIV), ionizing radiation, malnutrition, and some synthetic chemicals (including several widely used pesticides) can weaken the human immune system. This can leave the body vulnerable to attacks by **(1)** allergens, **(2)** infectious bacteria, **(3)** viruses, and **(4)** protozoans. Recent studies of laboratory animals and wildlife as well as epidemiological studies of humans (especially in developing countries) have linked immune system suppression to several widely used pesticides.

Synthetic chemicals in the environment threaten the human *nervous system* (brain, spinal cord, and peripheral nerves). Many poisons are *neurotoxins*, which attack nerve cells (neurons). Examples are **(1)** chlorinated hydrocarbons (DDT, PCBs, dioxins), **(2)** organophosphate pesticides, **(3)** formaldehyde, **(4)** various compounds of arsenic, mercury, lead, and cadmium, and **(5)** widely used industrial solvents such as trichloroethylene (TCE), toluene, and xylene.

The *endocrine system* is a complex network of glands that release small amounts of *hormones* into the bloodstream. In humans and other animals, these chemicals control body functions such as **(1)** sexual reproduction, **(2)** growth, **(3)** development, and behavior.

Each type of hormone has a specific molecular shape that allows it to attach only to certain cell receptors (Figure 11-7, left). Once bonded together, the hormone and its receptor molecule move to the cell's



Normal Hormone Process | **Hormone Mimic** | **Hormone Blocker**

Figure 11-7 Hormones are molecules that act as messengers in the endocrine system to regulate various bodily processes, including reproduction, growth, and development. Each type of hormone has a unique molecular shape that allows it to attach to specially shaped receptors on the surface of or inside cells and transmit its chemical message (left). Molecules of certain pesticides and other synthetic chemicals have shapes similar to those of natural hormones and can affect the endocrine system in people and various other animals. These molecules are called *hormonally active agents* (HAAs). Some HAAs, sometimes called *hormone mimics*, disrupt the endocrine system by attaching to estrogen receptor molecules (center). Other HAAs, sometimes called *hormone blockers*, prevent natural hormones such as androgens (male sex hormones) from attaching to their receptors (right). Some pollutants called *thyroid disrupters* may disrupt hormones released by thyroid glands and cause growth and weight disorders and brain and behavioral disorders.

Are Hormonally Active Agents a Health Threat?

CONNECTIONS

Over the last 25 years, experts from a number of disciplines have been piecing together **(1)** field studies on wildlife, **(2)** studies on laboratory animals, and **(3)** epidemiological studies of human populations. This analysis suggests that a variety of human-made chemicals can act as *hormone* or *endocrine disrupters*, known as *hormonally active agents (HAAs)*. So far more than 60 endocrine disrupters have been identified, and the list of HAAs could reach several hundred.

Some, called *hormone mimics*, are estrogenlike chemicals that disrupt the endocrine system by attaching to estrogen receptor molecules (Figure 11-7, center).

Others, called *hormone blockers*, disrupt the endocrine system by preventing natural hormones such as androgens (male sex hormones) from attaching to their receptors (Figure 11-7, right). There is also growing concern about pollutants that can act as *thyroid disrupters* and cause growth, weight, brain, and behavioral disorders.

Most natural hormones are broken down or excreted. However, many synthetic hormone impostors are stable fat-soluble compounds whose concentrations can be biomagnified as they move through food chains and webs (Figure 11-4). Thus they can pose a special threat to humans and other carnivores dining at the top of food webs.

Numerous wildlife and laboratory studies reveal various possible effects of estrogen mimics and hormone blockers (HAAs). Here are a few of many examples:

- Ranch minks that were fed Lake Michigan fish contaminated with endocrine disrupters such as DDT and PCBs failed to reproduce.
- Exposure to PCBs has reduced penis size in some test animals and in 118 boys born to women who were exposed to a PCB spill in Taiwan in 1979.
- Female shell fish (dog whelks) and snails exposed to tributyl tin (TBT) grew male sex organs. TBT has been widely used since the 1960s in marine paints to prevent the growth of barnacles and other crustaceans on the bottoms of ships and boats.
- A 1999 study by Michigan State University zoologists found that female rats exposed to PCBs were reluctant to mate, raising the possibility that such contaminants could cause low sex drives in women.
- In 1973, estrogen mimics called PBBs accidentally got into cattle feed in Michigan, and from there into beef. Pregnant women who ate the beef (and whose breast milk had high levels of PBBs) had sons with undersized penises and malformed testicles.
- The past 50 years have seen dramatic increases in testicular and prostate cancer in humans almost everywhere.

In 1999, the U.S. National Academy of Sciences released a report based on a 4-year review of the scientific literature on hormone disrupters (HAAs). The panel concluded that far too little is known about the effects of such chemicals to come to a definitive conclusion about their effects on humans.

Scientists on this panel called for greatly increased research to **(1)** verify current frontier science findings and **(2)** determine whether low levels of most hormone-disrupting chemicals in the environment pose a threat to the human population. However, the report also concluded that at present the 75,000 or more industrial chemicals in commercial use cannot be tested to determine whether they are hormone disrupters because the necessary tests do not exist.

Some health scientists believe we should begin sharply reducing the use of potential hormone disrupters now because they meet the two requirements of the *precautionary principle:* great scientific uncertainty and a reasonable suspicion of harm (p. 236).

Other researchers disagree. They point out that **(1)** the hormonal effects of synthetic hormone imposters are much weaker than those of naturally occurring hormones and **(2)** current levels of exposure to such chemicals are not high enough to pose any real danger to humans.

Critical Thinking

1. Do you consider the possible threat from hormone disrupters a problem that could affect you or any child you might have? Explain.

2. Do you believe the precautionary approach should be used to deal with this problem while more definitive research is carried out over the next two decades? Explain. What harmful effects could using this approach have on the economy and on your lifestyle? Do these potentially harmful effects outweigh the benefits of continuing to use HAAs? Explain.

nucleus to execute the chemical message carried by the hormone. There is concern that human exposure to low levels of synthetic chemicals, known as *hormonally active agents* (HAAs), can mimic and disrupt the effects of natural hormones (Connections, above).

Why Do We Know So Little About the Harmful Effects of Chemicals? According to risk assessment expert Joseph V. Rodricks, "Toxicologists know a great deal about a few chemicals, a little about many, and next to nothing about most." The U.S. National

Academy of Sciences estimates that only about **(1)** 10% of at least 75,000 chemicals in commercial use have been thoroughly screened for toxicity, and **(2)** 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 damage to the nervous, endocrine, and immune systems.

Each year manufacturers introduce about 1,000 new synthetic chemicals into the marketplace, with little knowledge about their potentially harmful effects. Currently, federal and state governments do not regulate about 99.5% of the commercially used chemicals in the United States. There are three major reasons for this lack of information and regulation:

- Under existing laws, most chemicals are considered innocent until proven guilty.
- Not enough funds, personnel, facilities, and test animals are available to provide such information for more than a small fraction of the many chemicals we encounter in our daily lives.
- Analyzing the combined effects of multiple exposures to various chemicals and the possible interactions of such chemicals is too difficult and expensive. For example, just studying the possible different three-chemical interactions of the 500 most widely used industrial chemicals would take 20.7 million experiments—a physical and financial impossibility.

What Is the Precautionary Approach? Because of the difficulty and expense of getting information about the harmful effects of chemicals, an increasing number of scientists and health officials are pushing for much greater emphasis on *pollution prevention.* This strategy greatly reduces **(1)** the need for statistically uncertain and controversial toxicity studies and exposure standards and **(2)** the risk posed by exposure to potentially hazardous chemicals and products and their possible but poorly understood multiple interactions.

This approach is based on the **precautionary principle.** According to this concept, when we are uncertain about potentially serious harm from chemicals or technologies, decision makers should act to prevent harm to humans and the environment. The principle is based on familiar axioms: "Look before you leap," "better safe than sorry," and "an ounce of prevention is worth a pound of cure."

Under this approach, those proposing to introduce a new chemical or technology would bear the burden of establishing its safety. In other words, new chemicals and technologies would be assumed guilty until proven innocent. Manufacturers and businesses contend that doing this would make it too expensive and almost impossible to introduce any new chemical or technology.

11-4 BIOLOGICAL HAZARDS: DISEASE IN DEVELOPED AND DEVELOPING COUNTRIES

What Are Nontransmissible Diseases? A **nontransmissible disease** is not caused by living organisms and does not spread from one person to another. Examples are **(1)** cardiovascular (heart and blood vessel) disorders, **(2)** most cancers, **(3)** diabetes, **(4)** asthma, **(5)** emphysema, and **(6)** malnutrition. Such diseases typically have multiple (and often unknown) causes and tend to develop slowly and progressively. The world's population is growing and getting older. Thus, the incidence of and deaths from many nontransmissible diseases (especially cardiovascular disorders and cancers) are expected to increase.

What Are Transmissible Diseases? A **transmissible disease** is caused by a living organism (such as a bacterium, virus, protozoa, or parasite) and can be spread from one person to another (Figure 11-8). These infectious agents, called *pathogens,* are spread by air, water, food, body fluids, some insects, and other nonhuman carriers called *vectors.*

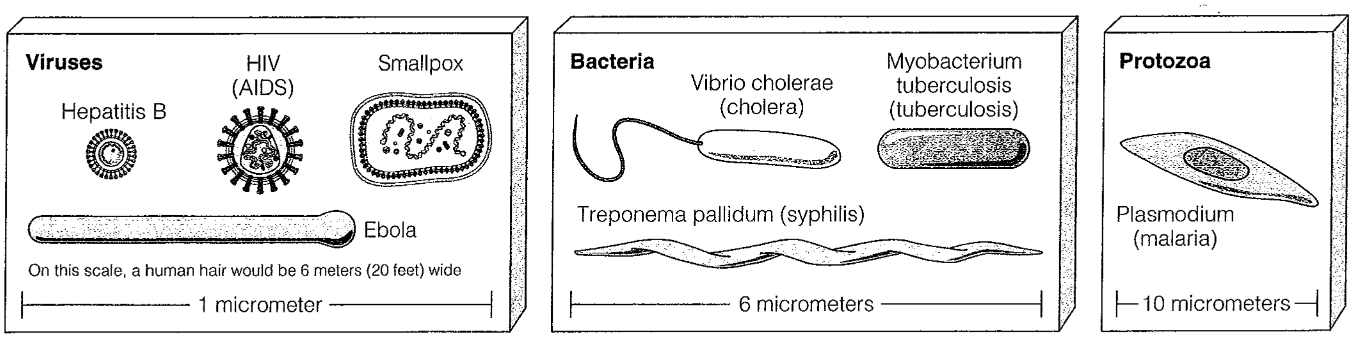


Figure 11-8 Examples of *pathogens* or agents that can cause transmissible diseases. A micrometer is one-millionth of a meter.

Typically, a *bacterium* is a one-celled microorganism capable of replicating itself by simple cell division. A *virus* is a microscopic, noncellular infectious agent. Its DNA or RNA contains instructions for making more viruses, but it has no apparatus to do so. To replicate, a virus must invade a host cell and take over the cell's DNA to create a factory for producing more viruses (Figure 11-9).

Antibiotics have greatly reduced the incidence of infectious disease caused by bacteria. However, their widespread use and misuse have increased the genetic resistance of many disease-causing bacteria, which can reproduce rapidly (Spotlight, p. 238).

Some *great news* is that since 1900, and especially since 1950, we have greatly reduced the incidence of infectious diseases and the death rates from such diseases. Some *bad news* is that worldwide, infectious diseases cause about one of every four deaths each year—mostly in developing countries.

According to the WHO, the world's seven deadliest infectious diseases are **(1)** *acute respiratory infections,* mostly pneumonia and flu (caused by bacteria and viruses and killing about 3.9 million people per year, about 2.5 million of them children under age 5), **(2)** *acquired immune deficiency syndrome* (AIDS, a viral disease, killing about 3 million people per year, most of them young adults), **(3)** *diarrheal diseases* (caused by bacteria and viruses, killing about 2.1 million per year, 1.9 million of them children under age 5), **(4)** *tuberculosis* (TB, a bacterial disease, with 1.6 million deaths per year; Case Study, p. 241), **(5)** *malaria* (caused by parasitic protozoa, with 1.1 million annual dealths, about 700,000 of them children under age 5), **(6)** *hepatitis B* (a viral disease, killing 1 million people per year) and **(7)** *measles* (a viral disease, which kills about 800,000 people annually, most of them in children under age 5).

As a country industrializes, it usually makes an *epidemiological transition.* The infectious diseases of childhood become less important, and the chronic diseases of adulthood (heart disease and stroke, cancer, and respiratory conditions) become more important in causing mortality. In 1999, for example, infectious and parasitic diseases were responsible for 43% of all deaths in developing countries but only 1% in developed countries.

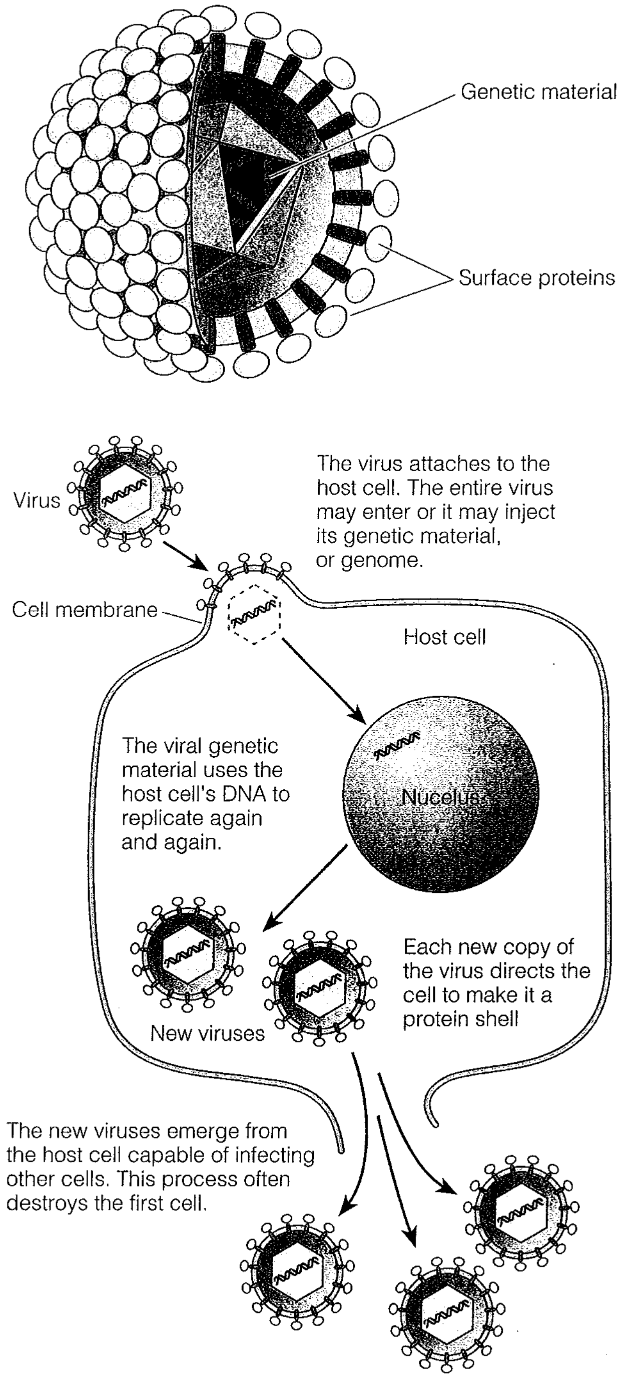


Figure 11-9 How a virus reproduces. (American Medical Association)

How Rapidly Are Viral Diseases Spreading? Viral diseases include **(1)** *influenza* or *flu* (transmitted by the body fluids or airborne emissions of an infected person), **(2)** *Ebola* (transmitted by the blood or other body fluids of an infected person), **(3)** *West Nile virus* (transmitted by the bite of a common mosquito that became infected by feeding on birds that carry the virus), **(4)** *rabies* (transmitted by dogs, coyotes, raccoons, skunks, and bats), and **(5)** *AIDS* (transmitted by unsafe sex, sharing of needles by drug users, infected mothers to offspring before or during birth, and exposure to infected blood). Viruses, like bacteria, can genetically adapt rapidly to different conditions.

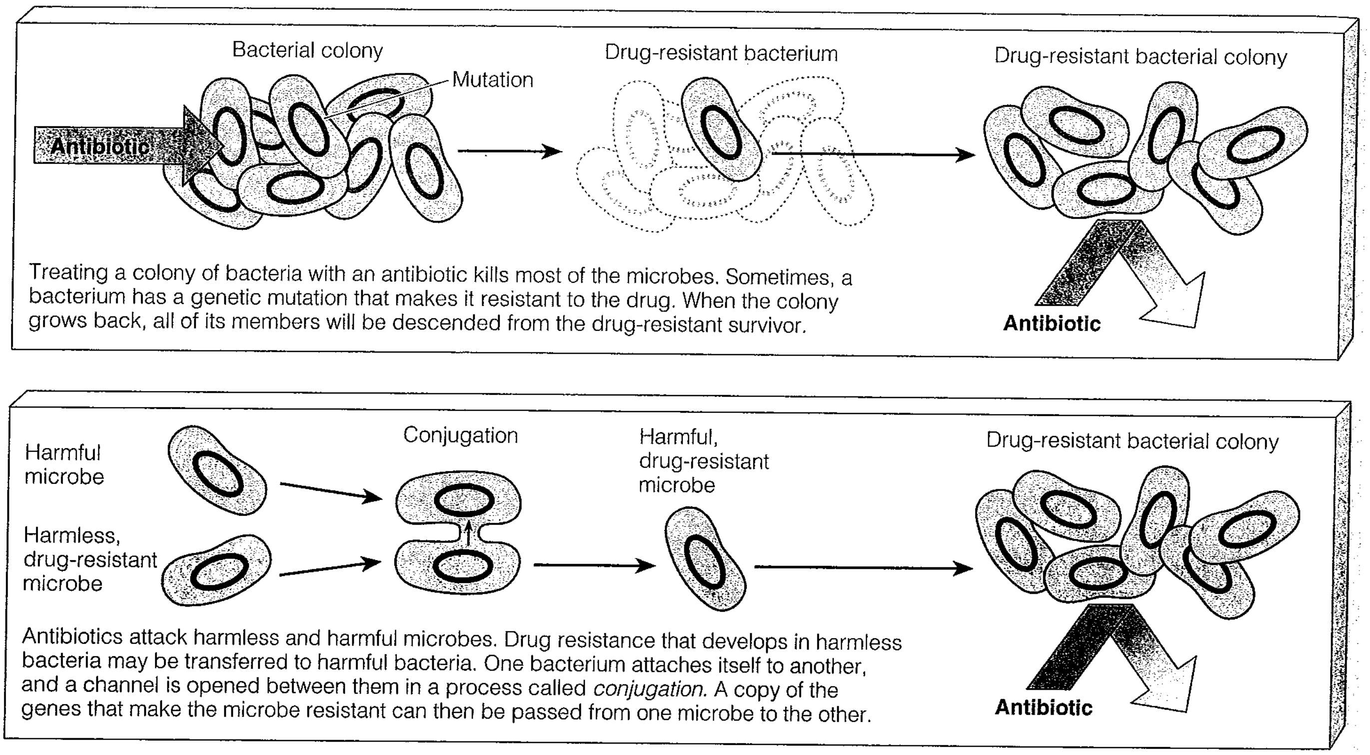
We are exposed to news reports about the emergence of new viral diseases such those caused by Ebola

SPOTLIGHT: Are We Losing Ground In Our War Against Infectious Bacteria?

Growing evidence indicates we may be falling behind our war against infectious bacterial diseases because bacteria are among the earth's ultimate survivors. When a colony of bacteria is dosed with an antibiotic such as penicillin, most of the bacteria are killed.

However, a few have mutant genes that make them immune to the drug (see figure, below, top). Through natural selection (Figure 5-6, left, p. 102), a single mutant can pass such traits on to most of its offspring, which can amount to 16,777,216 in only 24 hours.

Even worse, bacteria can become genetically resistant to antibiotics they have never been exposed to. When a resistant and a nonresistant bacterium touch one another (say, on a hospital bedsheet or in a human stomach), they can exchange a small loop of DNA called a plasmid, thereby transferring genetic resistance



Treating a colony of bacteria with an antibiotic kills most of the microbes. Sometimes, a bacterium has a genetic mutation that makes it resistant to the drug. When the colony grows back, all of its members will be descended from the drug-resistant survivor.

Antibiotics attack harmless and harmful microbes. Drug resistance that develops in harmless bacteria may be transferred to harmful bacteria. One bacterium attaches itself to another, and a channel is opened between them in a process called *conjugation.* A copy of the genes that make the microbe resistant can then be passed from one microbe to the other.

Development of genetic resistance in strains of bacteria exposed to repeated doses of antibiotics.

viruses (Figure 11-8) and the West Nile virus. Heath officials are concerned about such diseases but point out that they cause relatively few deaths.

They also point out that the greatest virus health threat to humans is the emergence of new, very virulent strains of influenza. Flu viruses move through the air and are highly contagious. During 1918 and 1919, a flu epidemic infected more than half the world's population and killed 20–30 million people (including about 500,000 in the United States). Today, flu kills about 1 million people per year (20,000 of them in the United States).

Sex can be dangerous to one's health. According to the U. S. Centers for Disease Control, **(1)** about 65 million Americans (23% of the population) are walking around with a *sexually transmitted disease* (STD), and **(2)** each year STDs infect about 15.3 million Americans. According to a 1998 report by the American Social Health Association, at least one in every three sexually active people in the United States will contract an STD by age 24. Some of these diseases can cause infertility in men and women. Others can cause warts and genital cancers or, in the case of HIV, death. Worldwide, about 333 million adults are infected with an STD (excluding HIV) each year.

Globally, the spread of *acquired immune deficiency syndrome (AIDS),* caused by the human immunodeficiency virus (HIV), is a growing threat. The virus itself from one organism to another (see figure, left, bottom).

The incredible genetic adaptability of bacteria is one reason the world faces a potentially serious rise in the incidence of some infectious bacterial diseases once controlled by antibiotics. Other factors also play a key role, including **(1)** spread of bacteria (some beneficial and some harmful) around the globe by human travel and the trade of goods, **(2)** overuse of antibiotics by doctors, often at the insistence of their patients (with a 2000 study by Richard Wenzel and Michael Edward suggesting that at least half of all antibiotics used to treat humans are prescribed unnecessarily), **(3)** failure of many patients to take all of their prescribed antibiotics, which promotes bacterial resistance, **(4)** availability of antibiotics in many countries without prescriptions, **(5)** overuse of pesticides, which increases populations of pesticide-resistant insects and other carriers of bacterial diseases, and **(6)** widespread use of antibiotics in the livestock and dairy industries to control disease in livestock animals and to promote animal growth.

The result of these factors acting together is that every major disease-causing bacterium now has strains that resist at least one of the roughly 160 antibiotics we use to treat bacterial infections. In 1998, health officials were alarmed to learn of the existence of a strain of bubonic plague in Madagascar that is resistant to multiple antibiotics.

In 2000, officials at the U.S. Centers for Disease Control and Prevention estimated that **(1)** about 2.2 million people (most with a weakened immune system) a year get sick, and **(2)** at least 88,000 die from infectious diseases they pick up in U.S. hospitals, nursing homes, or home health-care settings. Most of these infections are caused by **(1)** contaminated catheters, intravenous lines, and breathing tubes and **(2)** failure of doctors and other health-care personnel to carefully wash their hands with water or alcohol-based antimicrobial hand rubs and frequently change their latex gloves. Patients and their loved ones can reduce such infections by asking any doctor or health-care worker coming into their room, "Did you wash your hands?" or "Did you change your gloves?"

The widespread use of antibiotics to increase the growth rate of about 80% of the livestock animals raised each year in the United States, mainly cattle, pigs, and poultry, is a controversial issue. According to a 2000 study by Margaret Mellon and other researchers, about 84% of all antibiotics in the United States are used mostly as feed additives to boost livestock production. Resistant strains of infectious diseases that develop in livestock animals can spread to humans through contact with infected animals or water and through food chains.

The European Union, the World Health Organization, the American Public Health Association, and the U.S. Centers for Disease Control and Prevention all favor the immediate phaseout of all antibiotics used to promote growth in livestock animals that are the same as or closely related to antibiotics used in humans. Several European countries have imposed such bans, and since 1986 Sweden has banned all use of antibiotics for growth promotion in livestock.

Critical Thinking

1. What role, if any, have you played in the increase in genetic resistance of bacteria to widely used antibiotics? List three ways to reduce this threat.

2. Do you believe the use of the same antibiotics to treat human illness and to fatten livestock should be banned in the United States (or the country where you live)? Explain. Would you favor using small amounts of such antibiotics to treat disease in livestock?

is not deadly, but it kills immune cells and leaves the body defenseless against infectious bacteria and other viruses.

According to the WHO, by the end of 2001 some 40 million people worldwide (two-thirds of them in sub-Saharan Africa were infected with HIV (Figure 11-10, p. 240). During 2001, 5.4 million people (80% of them in Africa and Asia) were newly infected with HIV—an average of almost 15,300 new infections per day. In seven sub-Saharan African countries 20% or more of adults are infected with HIV.

Within about 7–10 years, at least half of those with HIV develop AIDS. This long incubation period means that infected people often spread the virus for several years without knowing they are infected. So far, no cure for AIDS exists, although drugs may help some infected people live longer (if they can afford the treatment, which can cost up to $15,000 per year).

According to the United Nations, by the end of 2001 about 24.8 million people (420,000 in the United States), had died of AIDS-related diseases. Most of these deaths occurred in developing countries (80% of them in sub-Saharan Africa).

During the last two decades, people in eight African countries have lost more than 10 years in their expected life span. In two African countries, Zimbabwe (where 33% of adults are HIV positive) and Botswana (with 39% of adults infected with HIV),

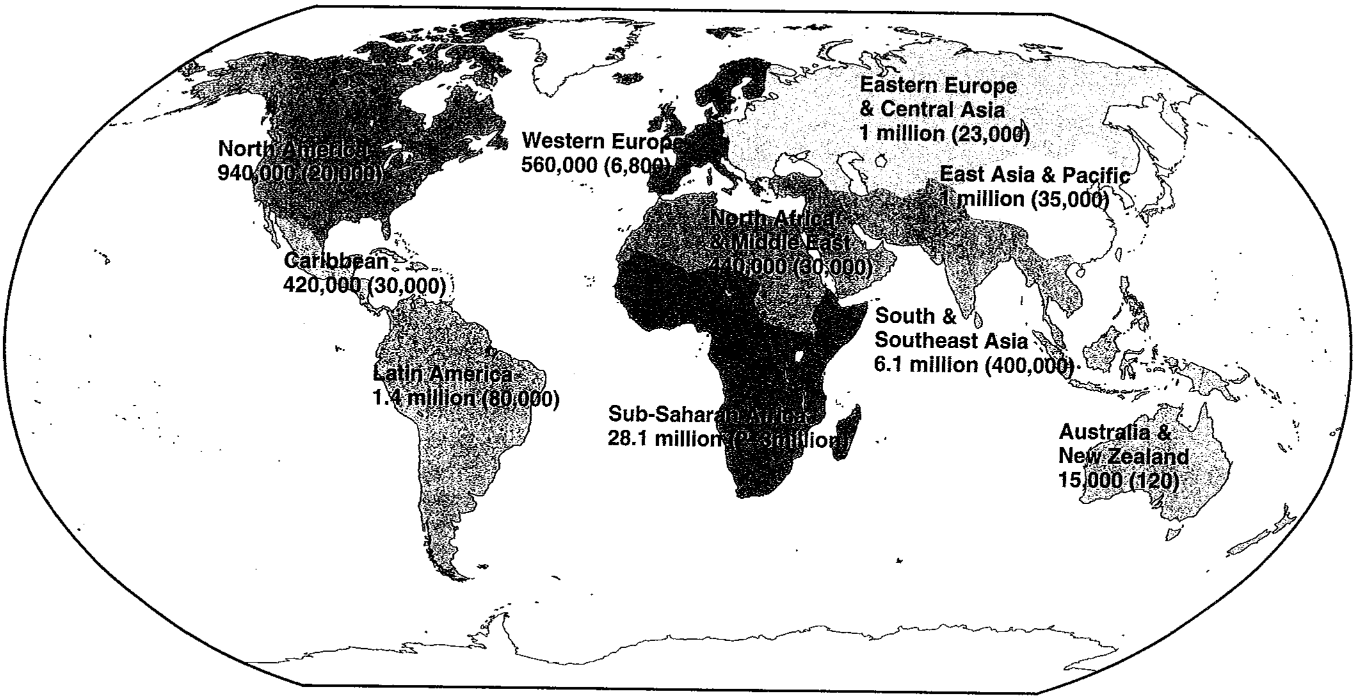


Figure 11-10 Distribution of the 40 million people infected with HIV in 2001. Numbers in parentheses give the number of deaths from AIDS in 2001. (Data from United Nations)

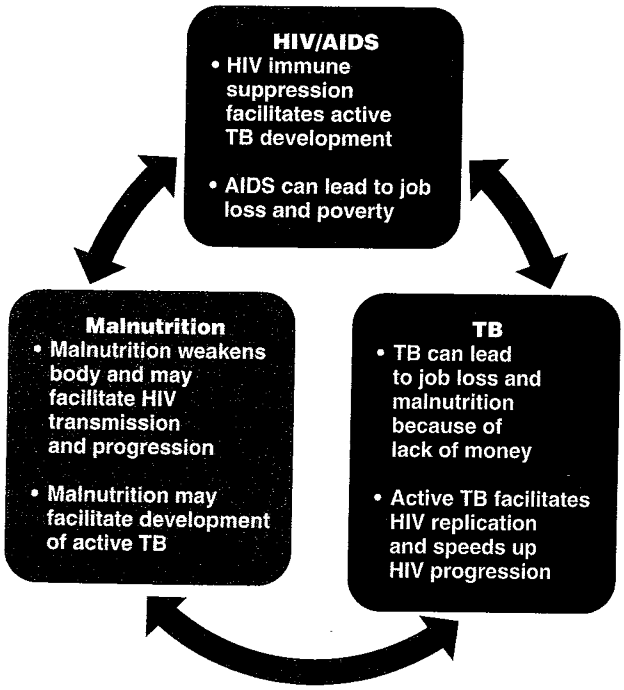


Figure 11-11 Synergistic interactions among HIV/AIDS, TB, and hunger/malnutrition. (Data from Daniel W. Fitzgerald and Patrice Joseph)

average life expectancy has dropped by more than 30 years since 1980. Because of AIDS the populations of 35 African countries were projected to have a 10% drop between 2000 and 2015. Between 2001 and 2020, 69 million people are expected to die of AIDS—equivalent to a loss of one-fourth the current U. S. population and more than all people currently living in the United Kingdom.

HIV/AIDS and TB problems among the poor are made worse by synergistic interactions between HIV/AIDS, TB, and hunger/malnutrition (Figure 11-11). According to a 2001 WHO report, up to 50% of the people infected with HIV/AIDS can expect to develop TB. Testing in a number of developing countries shows that up to 70% of TB patients are infected with HIV.

How Are Viral Diseases Treated? Once a viral infection starts, it is much harder to fight than infections by bacteria and protozoans. Only a few antiviral drugs exist because most drugs that will kill a virus also harm the cells of its host. Treating viral infections (such as colds, flu, and most mild coughs and sore throats) with antibiotics is useless and increases genetic resistance in disease-causing bacteria (Spotlight, p. 238).

Medicine's only effective weapons against viruses are *vaccines* that stimulate the body's immune system to produce antibodies to ward off viral infections.

CASE STUDY: The Global Tuberculosis Epidemic

Since 1990, one of the world's most underreported stories has been the rapid spread of tuberculosis (TB). According to the World Health Organization, this highly infectious bacterial disease kills about 1.6 million people and infects about 8 million people per year (see figure).

The bacterium causing TB infection moves from person to person, mainly in airborne droplets produced by coughing, sneezing, singing, or even talking. About one of every three people in the world is infected with the TB bacillus.

During their lifetime about 5–10% of these people will become sick or infectious with active TB, especially when their immune system is weakened. Left untreated, each person with active TB will infect 10–15 other people. Many infected people do not appear to be sick, and about half of them do not know they are infected. As a result, this serious health problem has been called a *silent global epidemic.*

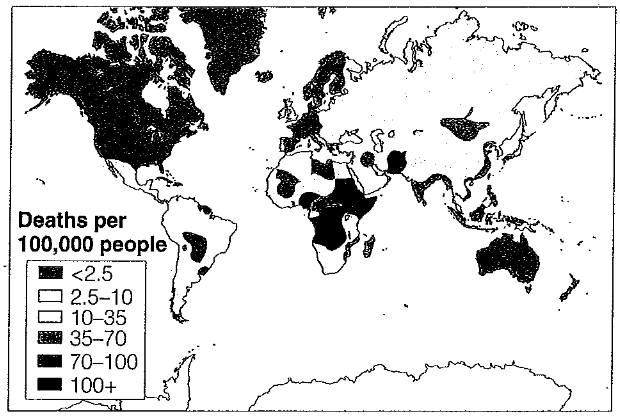
Major reasons for the recent increase in TB are **(1)** poor TB screening and control programs (especially in developing countries, where about 95% of the new cases occur), **(2)** development of strains of the tuberculosis bacterium that are genetically resistant to almost all effective antibiotics (typically leading to mortality rates of more than 50%), **(3)** population growth and increased urbanization (which increase contacts between people), **(4)** poverty, and **(5)** the spread of AIDS (Figures 11-10 and 11-11), which greatly weakens the immune system and allows TB bacteria to multiply.

Slowing the spread of the disease involves early identification and treatment of people with active TB, usually those with a chronic cough. Treatment with a combination of four inexpensive drugs can cure 90% of those with active TB. However, to be successful 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. This allows the disease to recur in a hard-to-treat form. It then spreads to other people, and drug-resistant strains of TB bacteria develop.

According to the World Health Organization, a worldwide campaign to help control TB would cost about $360 million to help save at least 20 million lives during the next decade.

Critical Thinking

Before you read this report, were you aware of the serious global TB epidemic, primarily in developing countries? Why do you think this important story has gotten so little media attention compared to other diseases that cause many fewer deaths per year?



The current global tuberculosis epidemic. This easily transmitted disease is spreading rapidly and now kills about 1.6 million people a year, mostly in developing countries. (Data from World Health Organization)

Immunization with vaccines has helped reduce the spread of viral diseases such as **(1)** smallpox, **(2)** polio, **(3)** rabies, **(4)** influenza, **(5)** measles, and **(6)** hepatitis B (Solutions, p. 242).

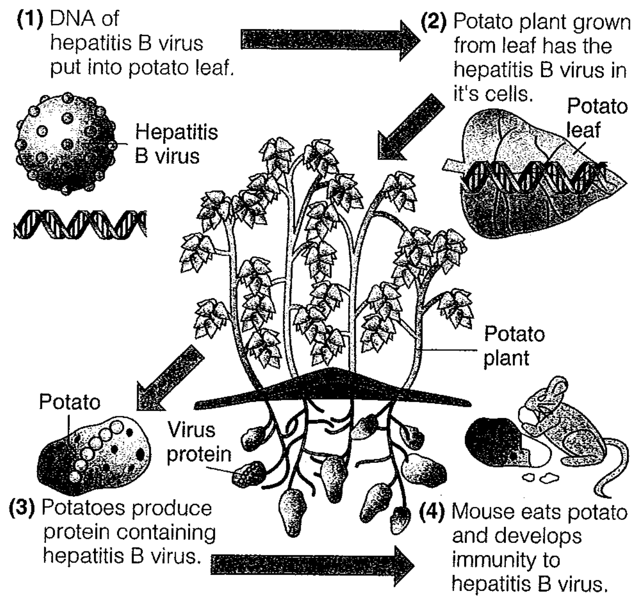
Connections: What Factors Can Affect the Spread of Transmissible Diseases? Outbreaks of infectious diseases often occur because of a change in the physical, social, or biological environment of disease reservoirs, carrier vectors, or exposure to new host populations. Important factors include the following:

- *Increased international air travel.*
- *Migration to urban areas,* which increases the probability of infection from diseases such as TB (Case Study, above), cholera, and STDs.

Producing an Edible Hepatitis B Vaccine

SOLUTIONS

Worldwide, about 300 million people (most in developing countries, with China having the world's highest infection rate) are infected with liver-damaging hepatitis B. Each year about 1 million people die from this disease and about 1 million new infections occur.



Using genetic engineering to produce food crops that contain a vaccine for hepatitis B.

A vaccine for hepatitis B has been developed from bioengineered yeast. But it **(1)** costs about $100 per person, **(2)** requires three shots over a 6-month period, and **(3)** must be refrigerated continuously before use. This makes it impractical to carry out mass immunizations for hepatitis B in developing countries.

Researchers are developing a much cheaper and easily administered vaccine by inserting DNA extracted from the hepatitis B virus into the cells of leaves of plants such as potatoes (see figure). Mice eating raw potatoes from the plant developed immunity to hepatitis B. Researchers hope to introduce the vaccine into bananas, which might cost as little as 5¢ per dose to produce.

Critical Thinking

What might be some disadvantages of introducing hepatitis B vaccine into the genes of food plants? Do you believe the advantages of using this vaccine in food outweigh its disadvantages? Explain.

- *Migration to uninhabited rural areas and deforestation in tropical developing countries,* which can expose people to new diseases and disease vectors such as malaria, sleeping sickness, and yellow fever.
- *Migration to suburbs in developed countries.* For example, as more people have moved to wooded suburbs in the eastern United States, they have come into greater contact with ticks infested with bacteria that cause Lyme disease, which causes fever, lethargy, and (sometimes) long-lasting arthritis.
- *Hunger and malnutrition,* which increase the number of children killed by infectious diseases such as measles and diarrhea.
- *Increased rice cultivation* in flooded fields and paddies, which creates ideal breeding grounds for mosquitoes and other insects that transmit diseases to humans.
- *Global warming,* which is leading to the spread of tropical infectious diseases such as malaria, yellow fever, and dengue fever (called "breakbone fever" by those who experience the excruciating pain it causes in joints) to temperate areas.
- *High winds or hurricanes,* which can transfer infectious organisms and carriers of disease (such as insects) from tropical to temperate areas.
- *Accidental introduction of insect vectors.* The Asian tiger mosquito is a vector for dengue fever, yellow fever, and other viruses. In 1985, it was brought accidentally to the United States inside used tires shipped from Asia. Since then, this mosquito species has spread from Texas to at least 21 other states.
- *Deliberate introduction of pathogens as an act of bioterrorism.* This occurred in 2001 when strains of potentially fatal anthrax bacteria were introduced into the United States, mostly through deliberately contaminated letters and packages.
- *Flooding,* which **(1)** often contaminates water supplies with raw sewage and **(2)** creates areas of stand-

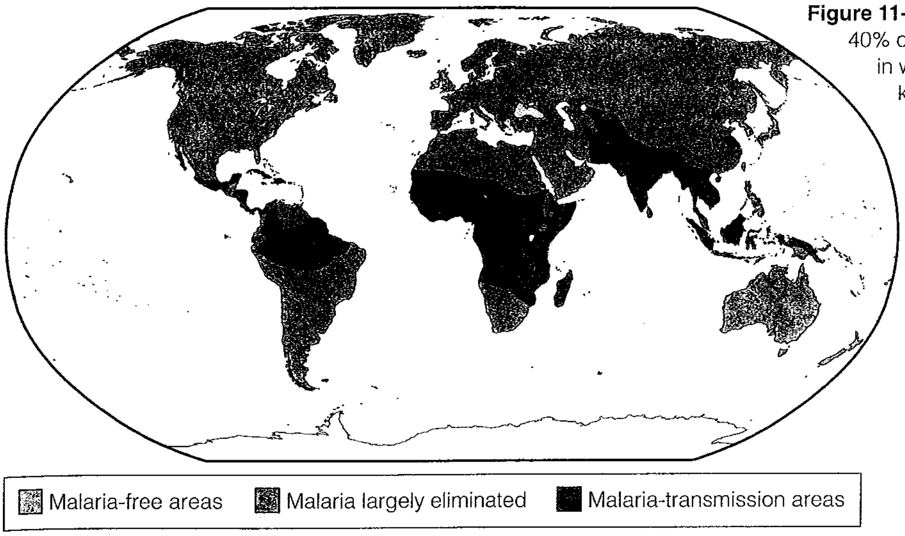


Figure 11-12 Worldwide distribution of *malaria.* About 40% of the world's current population lives in areas in which malaria is present, with the disease killing at least 1.1 million people a year. In some African countries, 80% of the children are infected with the malaria parasite. (Data from the World Health Organization)

ing water and moist soil that are ideal breeding grounds for mosquitoes and other insects that spread infectious diseases.

Case Study: Malaria, a Protozoal Disease

About 40% of the world's people live in tropical and subtropical regions where malaria is present (Figure 11-12). Currently, an estimated 300–500 million people are infected with malaria parasites worldwide, and 270–500 million new cases are reported each year.

Malaria's symptoms come and go and include **(1)** fever and chills, **(2)** anemia, **(3)** an enlarged spleen, **(4)** severe abdominal pain and headaches, **(5)** extreme weakness, and **(6)** greater susceptibility to other diseases. The disease kills about 1.1 million people each year, about 700,000 of them children under age 5.

Malaria is caused by four protozoa species of the genus *Plasmodium* (Figure 11.8). Most cases of the disease are transmitted when an uninfected female of any one of 60 *Anopheles* mosquito species **(1)** bites an infected person, **(2)** ingests blood that contains the parasite, and **(3)** later bites an uninfected person (Figure 11-13). When this happens, *Plasmodium* parasites **(1)** move out of the mosquito and into the human's bloodstream, **(2)** multiply in the liver, and **(3)** enter blood cells to continue multiplying. Malaria also can 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 **(1)** draining swamplands and marshes, **(2)** spraying breeding areas with insecticides,

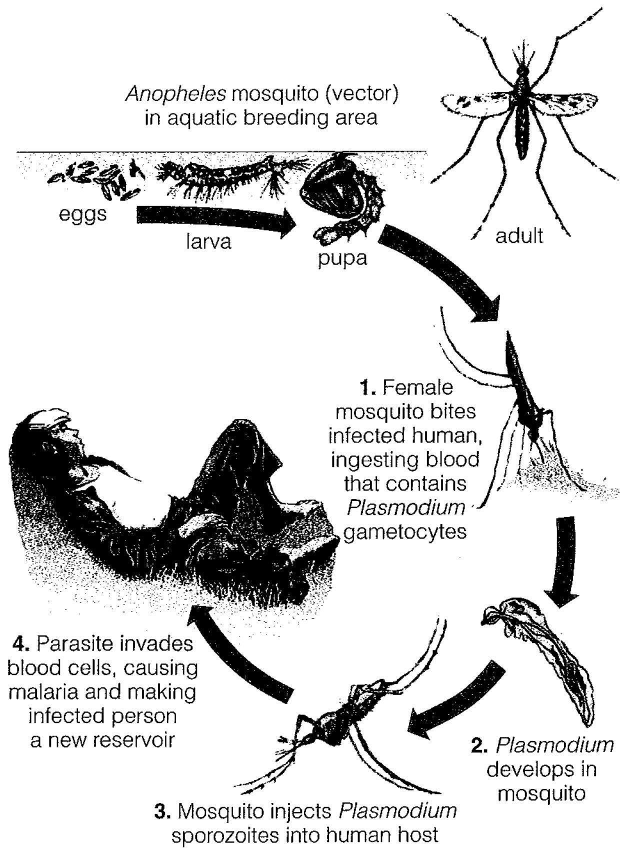


Figure 11-13 The life cycle of malaria. This life cycle of *Plasmodium* circulates from mosquito to human and back to mosquito. Although various mosquito species carry diseases (such as malaria, yellow fever, encephalitis, and dengue fever to humans and heartworm to dogs), mosquitoes also play important ecological roles. Their eggs are a major food source for fish, various insects, and frogs and other amphibians, and adult mosquitoes are an important source of food for bats, spiders, and many insect and bird species.

Improving Health Care in Developing Countries

SOLUTIONS

With adequate funding, the health of people in developing countries and the poor in developed countries can be improved dramatically, quickly, and cheaply by providing the following forms of mostly preventive health care:

- Better nutrition, prenatal care, and birth assistance for pregnant women.
- Better nutrition for children.
- Greatly improved postnatal care (including promotion of breast-feeding, except for mothers infected with HIV) to reduce infant mortality. Breast-fed babies get natural immunity to many diseases from antibodies in their mothers' milk.
- Immunization against the world's five largest preventable infectious diseases: tetanus, measles, diphtheria, typhoid fever, and polio. Some good news is that since 1971, the percentage of children in developing countries immunized against these diseases has increased from 10% to 84%, saving about 10 million lives a year.
- Oral rehydration therapy for victims of diarrheal diseases, which cause about one-fourth of all deaths of children under age 5. A simple solution of boiled water, salt, and sugar or rice, at a cost of only a few cents per person, can prevent death from dehydration.
- Careful and selective use of antibiotics for infections (Spotlight, p. 238).
- Clean drinking water and sanitation facilities for the one-third of the world's population that lacks them. In 2001, the WHO began promoting a simple, do-it-yourself technique that uses sunlight to disinfect water. The process is simple: **(1)** fill a transparent plastic bottle with contaminated water and **(2)** lay it horizontally on a flat black surface (which absorbs more heat and kills more pathogens). The heat and ultraviolet rays of the sun kill most illness-causing microorganisms in polluted water. This method is especially useful in tropical countries where sunlight is intense.

According to the WHO, extending such primary health care to all the world's people would cost an additional $10 billion per year, about 4% of what the world spends every year on cigarettes or devotes every 4 days to military spending. The cost of this primary health-care program is about $1 per child. In 2002, Bill and Melinda Gates created a fund of more than $24 billion to help fight diseases that affect the world's poorest people.

Critical Thinking

1. Do you believe developed countries should foot at least half the bill for implementing such proposals? What economic and environmental benefits would this provide for developed countries?

2. How many dollars per year of your taxes would you be willing to spend for such a preventive health program in developing countries?

and **(3)** using drugs to kill the parasites in the bloodstream. Since 1970, malaria has come roaring back. Most species of the malaria-carrying *Anopheles* mosquito have become genetically resistant to most insecticides. Worse, the *Plasmodium* parasites have become genetically resistant to common antimalarial drugs. According to the United Nations, since the 1980s, death rates from malaria among African children have tripled, due mostly to the drug-resistant strains of mosquitoes and overly used antimalarial drugs.

Researchers are working to develop new antimalarial drugs (such as artemisinins derived from the Chinese herbal remedy quihaosu), vaccines, and biological controls for *Anopheles* mosquitoes. However, such approaches receive too little funding and have proved more difficult than originally thought. Researchers also are studying the feasibility of altering the genetic makeup of mosquitoes so they cannot carry and transmit the parasite to humans.

According to health experts, prevention is the best approach to slowing the spread of malaria. Methods include **(1)** increasing water flow in irrigation systems to prevent mosquito larvae from developing (an expensive and wasteful use of water), **(2)** using mosquito nets dipped in a nontoxic insecticide (permethrin) in windows and doors of homes, **(3)** cultivating fish that feed on mosquito larvae (biological control), **(4)** clearing vegetation around houses, **(5)** planting trees that soak up water in low-lying marsh areas where mosquitoes thrive (a method that can degrade or destroy ecologically important wetlands), **(6)** using zinc and vitamin A supplements to boost children's resistance to malaria, and **(7)** greatly increased public education. In 1998, the World Bank, the WHO, and several other organizations launched the Roll Back Malaria program to help reduce the mortality rate from malaria.

How Can We Reduce the Incidence of Infectious Diseases? Figure 11-14 lists measures that health scientists and public health officials suggest for preventing or reducing the incidence of infectious dis-

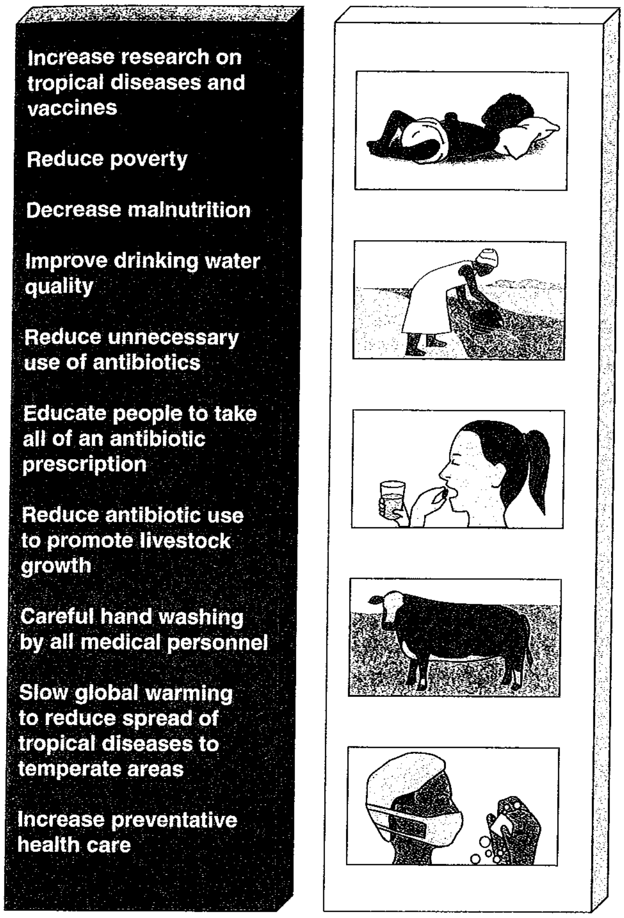


Figure 11-14 *Solutions:* ways to prevent or reduce the incidence of infectious diseases.

eases that affect humanity (especially in developing countries). They also call for increased emphasis on preventive health care in developing countries (Solutions, p. 244).

The WHO estimates that only 2% of the world's global research and development funds are devoted to infectious diseases in developing countries, even though more people worldwide suffer and die from these diseases than from all others combined. Indeed, according to a 2000 study by the International Federation of Red Cross, an estimated 150 million people have died from tuberculosis, malaria, and AIDS since 1945, compared to 23 million in wars.

The *good news* is that **(1)** the global death rate from infectious diseases has decreased by about 66% between 1970 and 2000 and is projected to continue dropping and **(2)** the average life expectancy of people in developed and developing countries is more than twice what it was a hundred years ago.

The *bad news* is that death rates from infectious diseases in developing countries are still unacceptably high. This situation could be greatly reduced by devoting **(1)** much more of the world's global research and development funds to infectious diseases in developing countries, and **(2)** more funds and efforts to preventive health care in such countries (Solutions, p. 244)

11-5 RISK ANALYSIS

How Can We Estimate Risks? Risk analysis involves **(1)** identifying hazards and evaluating their associated risks (*risk assessment,* Figure 11-2, left), **(2)** ranking risks (*comparative risk analysis*), **(3)** determining options and making decisions about reducing or eliminating risks (*risk management,* Figure 11-2, right), and **(4)** informing decision makers and the public about risks (*risk communication*).

Statistical probabilities based on past experience, animal testing and other tests, and epidemiological studies 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.

The left side of Figure 11-15 (p. 246) illustrates *comparative risk analysis,* summarizing the greatest ecological and health risks identified by a panel of scientists acting as advisers to the U.S. Environmental Protection Agency. Note the difference between the comparison of relative risk by scientists (Figure 11-15, left) and the general public (Figure 11-15, right). These differences result largely from failure of professional risk evaluators to educate the public about the nature of risks and their relative importance. Some risk experts contend that much of our risk education is based on often misleading media reports on the latest risk scare (based mainly on frontier science, p. 44) that do not put such risks in perspective.

Once a risk assessment has been completed, decision makers must decide what level of risk is acceptable. Figure 11-16 (p. 247) shows four methods used to determine the acceptability of a risk. The most widely used method is *benefit–cost analysis,* which attempts to determine whether the estimated short- and long-term benefits of using a particular technology or chemical outweigh the estimated short- and long-term risks or costs.

What Are the Greatest Risks People Face? 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 11-17, p. 247) and reduced life span, *the greatest risk by far is poverty* (Figure 11-18, p. 248).

Figure 11-15 *Comparative risk analysis* of the most serious ecological and health problems according to scientists acting as advisers to the U.S. Environmental Protection Agency (left column). Risks in each of these categories are not listed in rank order. The right side of this figure represents polls showing how U.S. citizens rank the ecological and health risks they perceive as the most serious. Why do you think there is such a great difference between the ranking by risk experts and by the general public? (Data from Science Advisory Board, *Reducing Risks*, Washington, D.C.: Environmental Protection Agency, 1990)

Scientists (Not in rank order in each category)	**Citizens** (In rank order in each category)
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	**High-Risk Problems** • Hazardous waste sites • Industrial water pollution • Occupational exposure to chemicals • Oil spills • Stratospheric ozone depletion • Nuclear power-plant accidents • Industrial accidents releasing pollutants • Radioactive wastes • Air pollution from factories • Leaking underground tanks
Medium-Risk Ecological Problems • Acid deposition • Pesticides • Airborne toxic chemicals • Toxic chemicals, nutrients, and sediment in surface waters	**Medium-Risk Problems** • Coastal water contamination • Solid waste and litter • Pesticide risks to farm workers • Water pollution from sewage plants
Low-Risk Ecological Problems • Oil spills • Groundwater pollution • Radioactive isotopes • Acid runoff to surface waters • Thermal pollution	**Low-Risk Problems** • Air pollution from vehicles • Pesticide residues in foods • Global climate change • Drinking water contamination

After the health risks associated with poverty, the greatest risks of premature death are mostly the result of voluntary choices people make about their lifestyles (Figures 11-1 and 11-18, p. 248).

By far the best ways to reduce one's risk of premature death and serious health risks are to **(1)** not smoke, **(2)** avoid excess sunlight (which ages skin and causes skin cancer), **(3)** not drink alcohol or drink only in moderation (no more than two drinks in a single day), **(4)** reduce consumption of foods containing cholesterol and saturated fats, **(5)** eat a variety of fruits and vegetables, **(6)** exercise regularly, **(7)** lose excess weight, and **(8)** for those who can afford a car, drive as safely as possible in a vehicle with the best available safety equipment.

However, we have little or no control over some factors that can influence our vulnerability to some risks. For example, we cannot control **(1)** our gender, **(2)** the genes we inherited from our parents, and **(3)** our social and psychological environment during early childhood.

How Can We Estimate Risks for Technological Systems? 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. The overall reliability of any technological system (expressed as a percentage) is the product of two factors:

$$\text{System reliability (\%)} = \text{Technology reliability} \times \text{Human reliability}$$

With careful design, quality control, maintenance, and monitoring, a highly complex system such as a nuclear power plant or space shuttle can achieve a high degree of technology reliability. However, human reliability usually is much lower than technology reliability and is almost impossible to predict: To err is human.

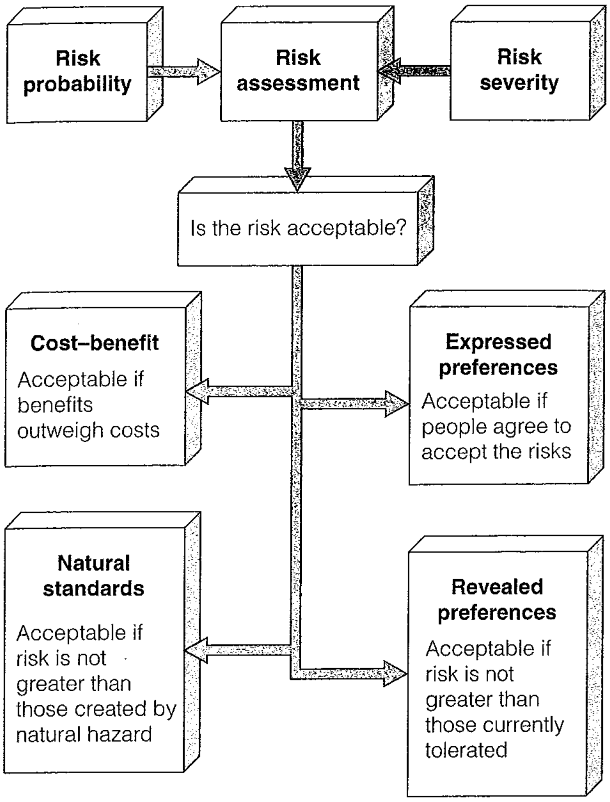


Figure 11-16 Methods for determining the acceptability of a risk after a risk assessment has been made. Cost–benefit analysis is the most widely used method. (Adapted from Chiras, *Environmental Science*, 5th ed., p. 351. Copyright © 1998 by Wadsworth)

Suppose the technology reliability of a nuclear power plant is 95% (0.95) and human reliability is 75% (0.75). Then the overall system reliability is 71% ($0.95 \times 0.75 = 0.71 = 71\%$). Even if we could make the technology 100% reliable (1.0), the overall system reliability would still be only 75% ($1.0 \times 0.75 = 0.75 = 75\%$). The crucial dependence of even the most carefully designed systems on unpredictable human reliability helps explain essentially "impossible" tragedies such as the **(1)** Chernobyl nuclear power plant accident and **(2)** explosion of the space shuttle *Challenger.*

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 technical side. However, **(1)** chance events such as a lightning bolt can knock out an automatic control system, **(2)** no machine or computer program can completely replace human judgment, **(3)** the parts in any automated control system are manufactured, assembled, tested, certified, and maintained by fallible human beings, and **(4)** computer software programs used to monitor and control complex

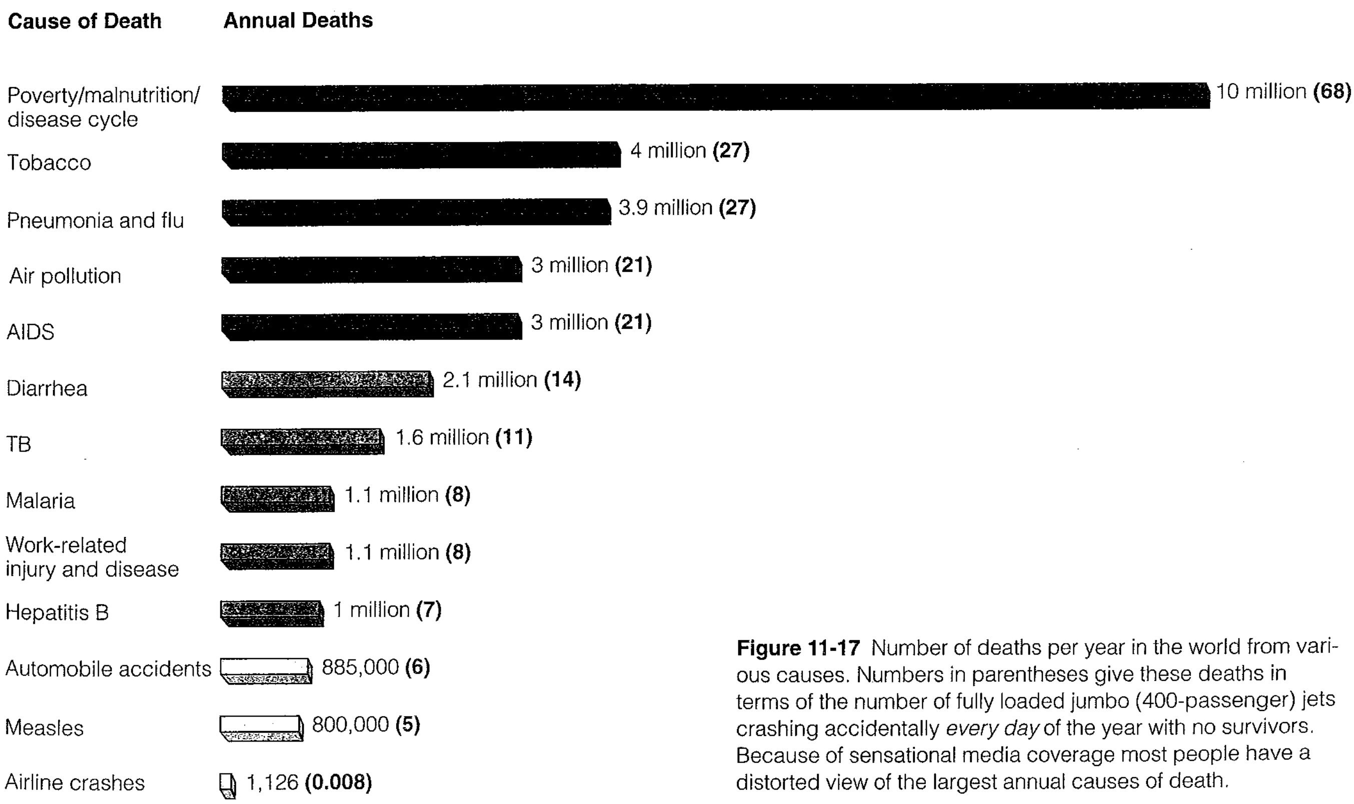


Figure 11-17 Number of deaths per year in the world from various causes. Numbers in parentheses give these deaths in terms of the number of fully loaded jumbo (400-passenger) jets crashing accidentally *every day* of the year with no survivors. Because of sensational media coverage most people have a distorted view of the largest annual causes of death.

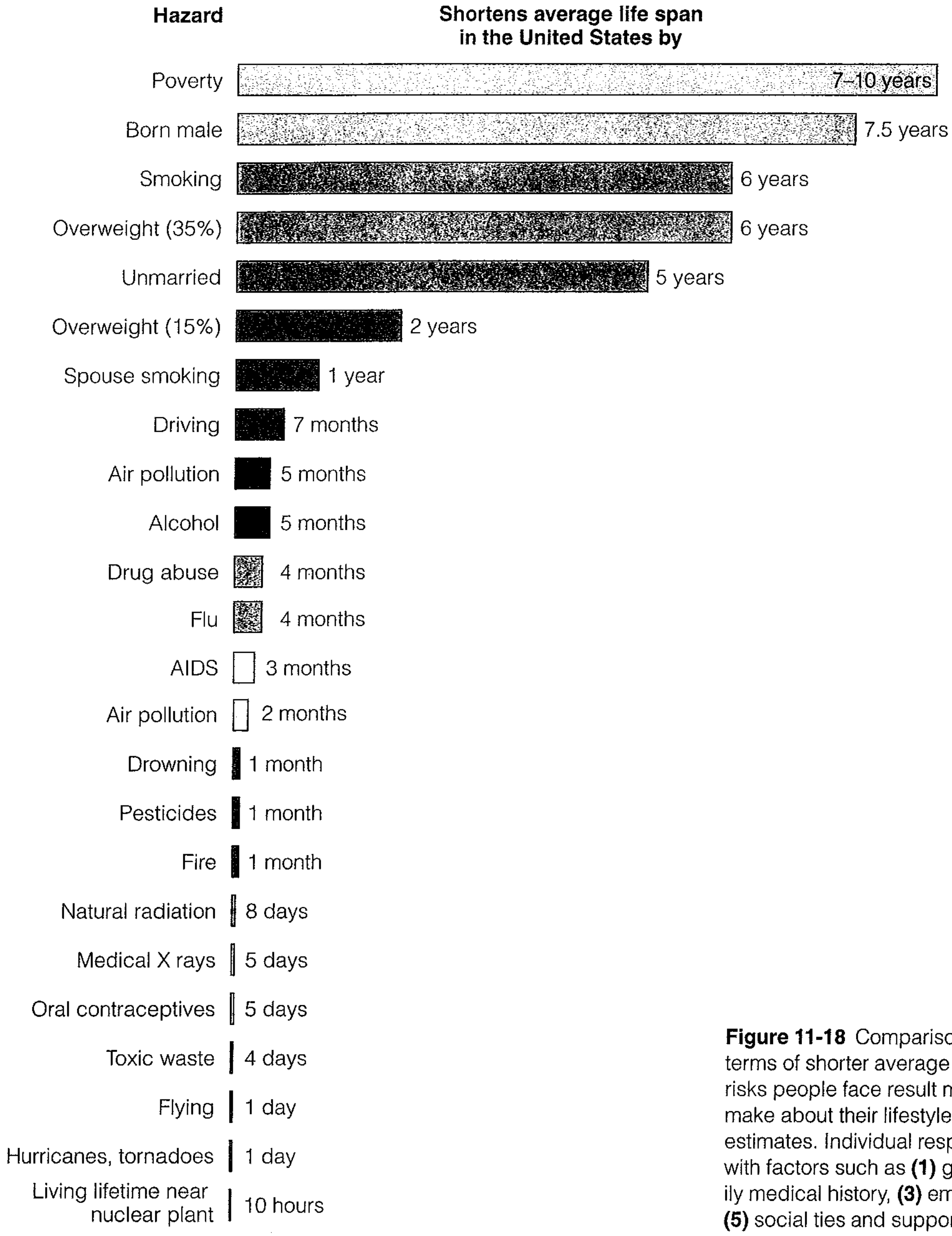


Figure 11-18 Comparison of risks people face, expressed in terms of shorter average life span. After poverty, the greatest risks people face result mostly from voluntary choices they make about their lifestyles. These are only generalized relative estimates. Individual response to some of these risks can vary with factors such as **(1)** genetic variation (Figure 11-3), **(2)** family medical history, **(3)** emotional makeup, **(4)** stress, and **(5)** social ties and support. (Data from Bernard L. Cohen)

systems can also contain human error or can be deliberately modified by computer viruses to malfunction.

What Are the Limitations of Risk Analysis? Here are some of the key questions involved in evaluating risk analysis:

- How reliable are risk assessment data and models?
- Who profits from allowing certain levels of harmful chemicals into the environment, and who suffers? Who decides this?
- Should estimates emphasize short-term risks, or should more weight be put on long-term risks? Who should make this decision?
- Should the primary goal of risk analysis be to **(1)** determine how much risk is acceptable (the current approach) or **(2)** figure out how to do the least damage (a prevention approach)?
- Who should do a particular risk analysis, and who should review the results? A government agency? Independent scientists? The public?

- Should cumulative effects of various risks be considered, or should risks be considered separately, as is usually done? Suppose a pesticide is found to have an annual risk of killing 1 person in 1 million from cancer, the current EPA limit. Cumulatively, however, effects from 40 such pesticides might kill 40, or 400, of every 1 million people. Is this acceptable, and to whom is it acceptable?
- How widespread is each risk?
- Should risk levels be higher for workers (as is almost always the case) than for the general public? What say should workers and their families have in this decision? For example, work-related illnesses and injuries kill about 80,000 workers each year in the United States—about twice the country's annual death toll from automobile accidents (Figure 11-1). The situation is much worse in developing countries, with more than 1 million work-related deaths occurring worldwide each year.
- How much risk is acceptable, and to whom is it acceptable? According to the National Academy of Sciences, exposure to toxic chemicals is responsible for 2–4% of the 521,000 cancer deaths in the United States; this amounts to 10,400–20,800 premature cancer deaths per year.

Proponents contend that risk analysis is a useful way to **(1)** organize and analyze available scientific information, **(2)** identify significant hazards, **(3)** focus on areas that need more research, **(4)** help regulators decide how money for reducing risks should be allocated, and **(5)** stimulate people to make more informed decisions about health and environmental goals and priorities.

However, critics point out that results of risk analysis are very uncertain. For example, a recent study documented the significant uncertainties involved in even simple risk analysis. Eleven European governments established 11 different teams of their best scientists and engineers (including those from private companies) to assess the hazards and risks from a small plant storing only one hazardous chemical (ammonia). The 11 teams, consisting of world-class experts analyzing this very simple system, disagreed with one another on fundamental points and varied in their assessments of the hazards by a factor of 25,000. Such inherent uncertainty explains why regulators setting human exposure levels for toxic substances usually divide the best results by 100 to 1,000 to provide the public with a margin of safety.

According to critics, the main decision-making tool we should rely on is not to find out how much risk is acceptable, which they contend is mostly a political decision. Instead, it should be to find out the least damaging reasonable alternatives by asking, "Which alternative will bring sufficient benefits and minimize damage to humans and to the earth?" To these critics, the emphasis should be on *alternative assessment,* not *risk assessment.*

How Should Risks Be Managed? *Risk management* includes the administrative, political, and economic actions taken to decide whether and how to reduce a particular societal risk to a certain level and at what cost.

Risk management involves answering the following questions:

- How reliable is the risk analysis for each risk?
- Which risks should be given the highest priority?
- How much risk is acceptable (Figure 11-16)?
- How much it will cost to reduce each risk to an acceptable level?
- How should limited funds be spent to provide the greatest benefit?
- How will the risk management plan be monitored, enforced, and communicated to the public?

Each step in this process involves making value judgments and weighing trade-offs to find some reasonable compromise among conflicting political, economic, health, and environmental interests.

How Well Do We Perceive Risks? How much risk is acceptable? Studies indicate that if the chance of death from a chemical or activity is less than 1 in 100,000, most people are not likely to be worried enough to change their ways.

However, most of us do poorly in assessing the relative risks from the hazards that surround us (Figures 11-15, 11-17, and 11-18). Also, many people deny or shrug off the high-risk chances of death (or injury) from voluntary activities they enjoy, such as **(1)** motorcycling (1 death in 50 participants), **(2)** smoking (1 in 300 participants by age 65 for a pack-a-day smoker), **(3)** hang gliding (1 in 1,250), and **(4)** driving (1 in 3,000 without a seatbelt and 1 in 6,000 with a seatbelt).

Yet some of these same people may be terrified about the possibility of dying from a **(1)** commercial airplane crash (1 in 1 million), **(2)** being killed by a handgun (1 in 2 million), **(3)** being struck by lightning (1 in 4 million), **(4)** a train crash (1 in 20 million), **(5)** snakebite (1 in 36 million), **(6)** shark attack (1 in 300 million), or **(7)** exposure to trichloroethylene (TCE) in drinking water at the trace levels allowed by the EPA (1 in 2 billion).

Being bombarded with news about people killed or harmed by various hazards distorts our sense of risk (Figures 11-17 and 11-18). However, *the most important good news each year is that about 99.1% of the people on the earth did not die.* Despite the greatly increased use of synthetic chemicals in food production and processing, the general health and average life expectancy of people in the United States (and most developed countries) have increased during the past 50 years.

Our perceptions of risk and our responses to perceived risks often have little to do with how risky the experts say something is (Figure 11-15). The public generally sees a technology or a product as being riskier than experts do when the following conditions exist:

- *It is new or complex rather than familiar.* Examples include genetic engineering and genetically modified food or nuclear power, as opposed to large dams or coal-fired power plants.
- *It is perceived as mostly involuntary.* Examples include nuclear power plants or food additives, as opposed to driving or smoking.
- *It is viewed as unnecessary rather than as beneficial or necessary.* Examples might include using chlorofluorocarbons (CFC) propellants in aerosol spray cans or using food additives that increase sales appeal, as opposed to cars or aspirin.
- *Its use involves a large, well-publicized death toll from a single catastrophic accident rather than the same or an even larger death toll spread out over a longer time.* Examples might 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 (Figure 11-17).
- *Its use involves unfair distribution of the risks.* 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 risk analysis. This decision is usually seen as politics, not science. Residents will not be satisfied by estimates that the lifetime risks of cancer death from the facility are not greater than, say, 1 in 100,000. Living near the facility means that they, not the vast majority of people living farther away, have a much higher risk of dying from cancer by having this risk involuntarily imposed on them.
- *The people affected are not involved in the decision-making process from start to finish.*
- *Its use does not involve a sincere search for and evaluation of alternatives.* People who believe their lives and the lives of their families are being threatened want to know **(1)** what the alternatives are and **(2)** which alternative causes the least harm to them and the earth.

Better education and communication about the nature of risks will help bring the public's perceptions of various risks closer to those of professional risk evaluators. However, such education will not eliminate the emotional, cultural, and ethical factors that decision makers must take into account in determining the acceptability of a particular risk and evaluating the possible alternatives.

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. Define the boldfaced terms in this chapter.

2. What voluntary human activity kills the largest number of people each year? List six ways to help reduce the harmful effects of smoking.

3. What are *risk* and *probability?* Distinguish between *risk assessment* and *risk management.*

4. List two **(a)** cultural hazards, **(b)** chemical hazards, **(c)** physical hazards, and **(d)** biological hazards.

5. What is *toxicity?* Distinguish between *dose* and *response* for a potentially harmful substance. List five factors that determine whether a chemical is harmful. Distinguish between *bioaccumulation* and *biomagnification.* List three mechanisms of the human body that can reduce the effects of most harmful chemicals.

6. What is a *poison?* What is an LD_{50}? List three methods used to determine toxicity, and list the limitations of each method. Describe how laboratory tests are used to determine toxicity. What is a *dose-response curve?* Distinguish between a *linear dose-response curve* and a *threshold dose-response curve.*

7. Distinguish between *toxic chemicals* and *hazardous chemicals.* Distinguish among *mutagens, teratogens,* and *carcinogens,* and give one example of each.

8. Distinguish among the *immune system, nervous system,* and *endocrine system,* and give an example of something that causes harm to each system. What are *hormone disrupters* and *hormone mimics?* List two examples of such chemicals.

9. About what percentage of the 75,000 chemicals in commercial use in the United States have been screened **(a)** to assess toxicity, **(b)** to determine whether they are carcinogens, teratogens, or mutagens, and **(c)** to determine whether they damage the nervous, endocrine, or immune systems?

10. List three reasons for the lack of information about the potentially harmful effects of most chemicals in commercial use. Distinguish between the regulation strategy and the pollution prevention strategy for protecting the public from potentially harmful chemicals. What is the *precautionary principle?* Why is it rarely used?

11. Distinguish between *nontransmissible* and *transmissible diseases,* and give two examples of each type. What are the seven deadliest infectious diseases in order of the number of deaths they cause each year?

12. How do infectious bacteria become resistant to antibiotics?

13. What is the best way to treat **(a)** a bacterial disease and **(b)** a viral disease? List two examples of each type of disease.

14. What causes tuberculosis, and how is it transmitted? About how many people died of TB during the past year? List five reasons for the increase in TB infections in recent years. How can the spread of this bacterial infectious disease be slowed?

15. Distinguish between *HIV* and *AIDS.* List four ways that HIV can be transmitted. About how many people in the world **(a)** are infected with HIV and **(b)** have died of AIDS? List ways to prevent the spread of this viral infectious disease.

16. List 11 factors that can affect the spread of infectious diseases.

17. What causes *malaria?* About how many people die from malaria each year? List seven ways to help prevent this protozoal infectious disease.

18. List 10 ways to prevent or reduce the incidence of infectious diseases throughout the world. List seven major ways to improve health care in developing countries.

19. What is *risk analysis?* What are its major limitations?

20. List five of the greatest risks people face in terms of **(a)** number of premature deaths per year and **(b)** reduced life span. List eight ways to reduce your risk of premature death and serious health problems. How can we estimate the risks from technological systems?

21. What is *risk management?* What six questions do risk managers try to answer? About what percentage of the people on the earth die each year? List seven reasons why people often perceive that certain risks are greater than experts say they are.

CRITICAL THINKING

1. Explain why you agree or disagree with the proposals made by health officials for reducing the death toll and other harmful effects of smoking listed on p. 228.

2. Do you think chemicals should be regulated based on their effects on the nervous, immune, and endocrine systems? Explain.

3. Should we have zero pollution levels for all hazardous chemicals? Explain.

4. Evaluate the following statements:

a. We should not get so worked up about exposure to toxic chemicals because almost any chemical can cause some harm at a large enough dosage.

b. We should not worry so much about exposure to toxic chemicals because through genetic adaptation we can develop immunity to such chemicals.

c. We should not worry so much about exposure to toxic chemicals because we can use genetic engineering to reduce or eliminate such problems.

5. Assume you are a government official responsible for regulating chemicals. What information would you require in order to make a decision about the safety of a particular chemical? What level of risk of exposure to the chemical would you consider acceptable for **(a)** society, **(b)** yourself, and **(c)** any child you might have?

6. Should pollution levels be set to protect the most sensitive people in a population (Figure 11-3, left) or the average person (Figure 11-3, middle)? Explain.

7. What are the five 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 five most important things you can do to reduce these risks. Which of these things do you actually plan to do?

8. How would you answer each of the questions raised about **(a)** risk analysis on pp. 248–249 and **(b)** risk assessment and risk management on p. 249? Explain each of your answers.

PROJECTS

1. Assume that members of your class (or small manageable groups in your class) have been appointed to a technology benefit–risk assessment board. As a group, decide why you would approve or disapprove of widespread use of each of the following: **(a)** drugs to retard aging, **(b)** electrical or chemical devices that would stimulate the brain to eliminate anxiety, fear, unhappiness, and aggression, and **(c)** genetic engineering to produce people with superior intelligence and strength.

2. Use the library or the Internet to find recent articles describing the rise of genetic resistance of disease-causing bacteria to commonly used antibiotics. Evaluate the evidence and claims in these articles.

3. Pick a specific viral disease and use the library or Internet to find out about **(a)** how it spreads, **(b)** its effects, **(c)** strategies for controlling its spread, and **(d)** possible treatments.

4. Use the library or the Internet to find bibliographic information about *Paracelsus* and *Joel Hirschorn*, whose quotes appear at the beginning and end of this chapter.

5. Make a concept map of this chapter's major ideas, using the section heads and subheads and the key terms (in boldface). Look on the website for this book for information about making concept maps.

INTERNET STUDY RESOURCES AND RESOURCES FOR FURTHER READING AND RESEARCH

The website for this book contains helpful study aids and many ideas for further reading and research. Log on to

www.info.brookscole.com/miller13

and click on the Chapter-by-Chapter area. Choose Chapter 11 and select a resource:

- Flash Cards allows you to test your mastery of the Terms and Concepts to Remember for this chapter.
- Tutorial Quizzes provides a multiple-choice practice quiz.
- Student Guide to InfoTrac will lead you to Critical Thinking Projects that use InfoTrac College Edition as a research tool.
- References lists the major books and articles consulted in writing this chapter.
- Hypercontents takes you to an extensive list of sites with news, research, and images related to individual sections of the chapter.

INFOTRAC COLLEGE EDITION

Improve your skills with InfoTrac College Edition, a searchable online database of articles from more than 700 periodicals. Log on to

http://www.infotrac-college.com

or access InfoTrac through the website for this book. Try to find the following articles:

1. Frank, C., A. D. Fix, C. A. Pena, and G. T. Strickland. 2002. Mapping Lyme disease incidence for diagnostic and preventive decisions, Maryland. *Emerging Infectious Diseases* 8: 427. *Keywords:* "lyme disease" and "mapping." GIS mapping technology was used to illustrate the distribution of Lyme disease in Maryland. This information could then be used by doctors and state health departments to assist in diagnosis and distribution of vaccine.

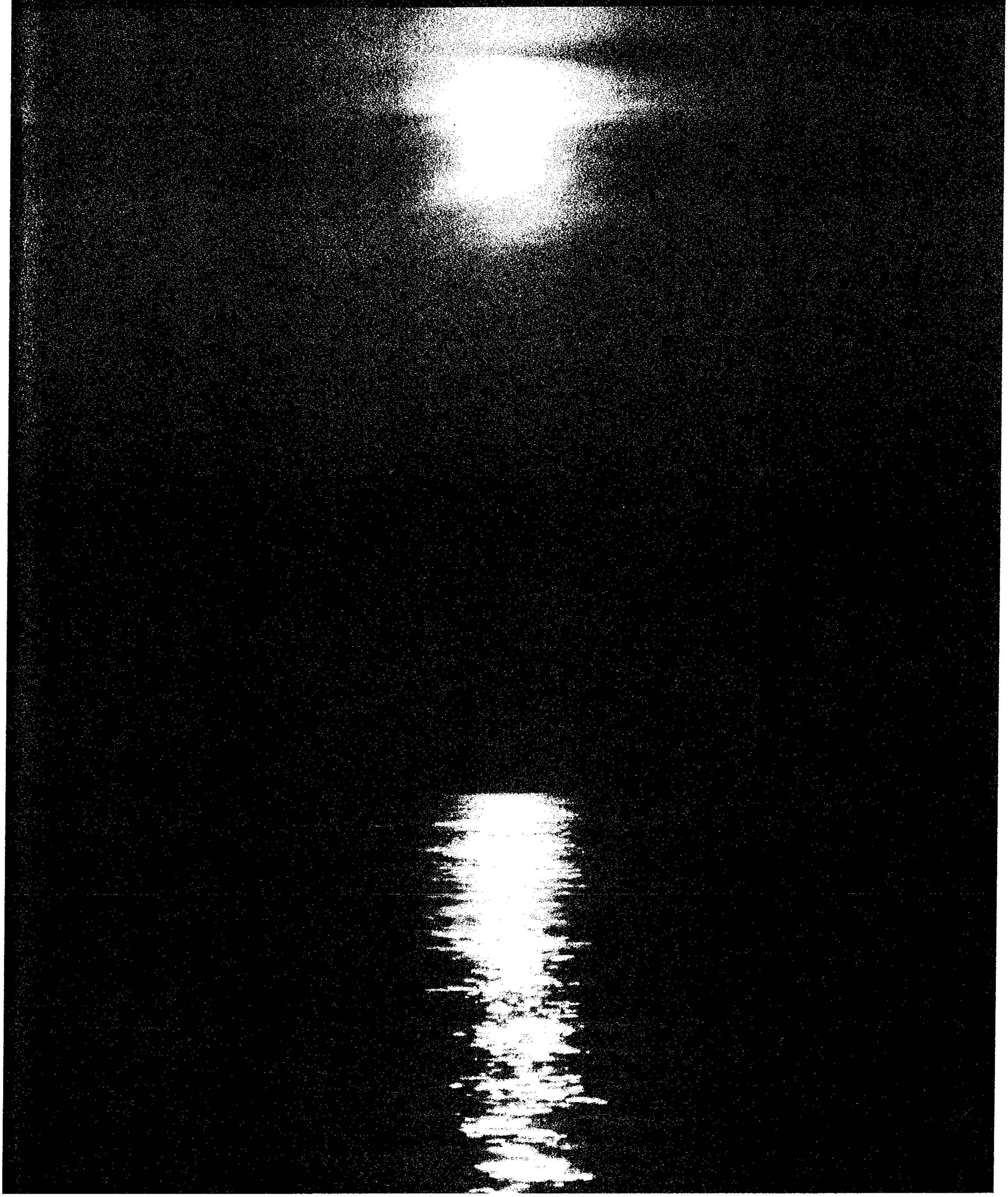
2. Thiele, L. P. 2000. Limiting risks: Environmental ethics as a policy primer. *Policy Studies Journal* 20: 540. *Keywords:* "risk" and "environmental ethics." This article explores the ethical aspects of evaluating involuntary human-caused environmental risks in a technologically driven society.

PART III

POPULATION, RESOURCES, AND SUSTAINABILITY

I recognize the right and duty of this generation to develop and use our natural resources, but I do not recognize the right to waste them, or to rob by wasteful use, the generations that come after us.

THEODORE ROOSEVELT, 1900



12 THE HUMAN POPULATION: GROWTH, DEMOGRAPHY, AND CARRYING CAPACITY

Slowing Population Growth in Thailand

Can a country sharply reduce its population growth in only 15 years? Thailand did.

In 1971, Thailand (Figure 12-7, p. 257) adopted a policy to reduce its population growth. When the program began, the country's population was growing at a rate of 3.2% per year, and the average Thai family had 6.4 children.

Fifteen years later in 1986, the country's population growth rate had been cut in half to 1.6%. By 2002, the rate had fallen to 0.8%, and the average number of children per family was 1.8. Thailand's population is projected to grow from 63 million in 2002 to 72 million by 2025.

Several reasons account for this impressive feat: **(1)** the creativity of the government-supported family planning program, **(2)** a high literacy rate among women (90%), **(3)** an increasing economic role for women and advances in women's rights, **(4)** better health care for mothers and children, **(5)** the openness of the Thai people to new ideas, **(6)** the willingness of the government to encourage and financially support family planning and to work with the private, nonprofit Population and Community Development Association (PCDA), and **(7)** support of family planning by the country's religious leaders (95% of Thais are Buddhist).

This transition was catalyzed by the charismatic leadership of Mechai Viravidaiya (Figure 12-1), a public relations genius and former government economist who launched the PCDA in 1974 to help make family planning a national goal. PCDA workers handed out condoms at festivals, movie theaters, and even traffic jams, and they developed ads and witty songs about contraceptive use. Between 1971 and 2002, the percentage of married women using modern birth control rose from 15% to 70%—higher than the 58% usage in developed countries and the 54% usage in developing countries.

Figure 12-1 Individuals Matter. *Mechai Viravidaiya*, a charismatic leader, played a major role in Thailand's successful efforts to reduce its population growth. In 1974, he established the private, nonprofit Population and Community Development Association (PCDA), to help implement family planning as a national goal.

Viravidaiya helped establish a German-financed revolving loan plan to enable people participating in family planning programs to install toilets and drinking water systems. Low-rate loans were offered to farmers practicing family planning. The government also offers loans to individuals from a fund that increases as their village's level of contraceptive use rises.

All is not completely rosy. Although Thailand has done well in slowing population growth and raising per capita income, it has been less successful in reducing pollution and improving public health. Its capital, Bangkok, remains one of the world's most polluted and congested cities. It is plagued with notoriously high levels of traffic congestion and air pollution (Figure 12-2). The typical motorist in Bangkok spends 44 days per year sitting in traffic, costing $2.3 billion in lost work time.

Figure 12-2 This policeman and schoolchildren in Bangkok, Thailand, are wearing masks to reduce their intake of air polluted mainly by automobiles. Bangkok is one of the world's most car-clogged cities, with car commutes averaging 3 hours per day. Roughly one of every nine of its residents has a respiratory ailment.

The problems to be faced are vast and complex, but come down to this: 6.2 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

This chapter addresses the following questions:

- How is population size affected by birth, death, fertility, and migration rates?
- How is population size affected by the percentage of males and females at each age level?
- How can population growth be slowed?
- What success have India and China had in slowing population growth?
- How can global population growth be reduced?

12-1 FACTORS AFFECTING HUMAN POPULATION SIZE

How Is Population Size Affected by Birth Rates and Death Rates? Populations grow or decline through the interplay of three factors: *births, deaths,* and *migration.* **Population change** is calculated 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 a year):

Population change = (Births + Immigration) − (Deaths + 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, demographers use **(1)** the **birth rate,** or **crude birth rate** (the number of live births per 1,000 people in a population in a given year) and **(2)** the **death rate,** or **crude death rate** (the number of deaths per 1,000 people in a population in a given year). Figure 12-3 shows the crude birth and death rates for various groupings of countries in 2002.

Birth rates and death rates are coming down worldwide, but death rates have fallen more sharply than birth rates. As a result, more births are occurring than deaths; every time your heart beats, 2.3 more babies are added to the world's population. At this rate, we share the earth and its resources with about

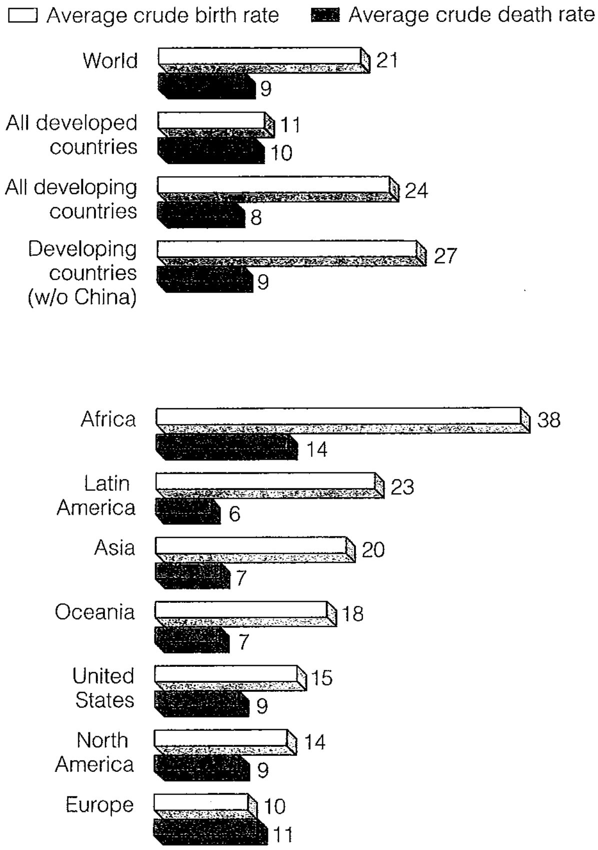


Figure 12-3 Average crude birth and death rates for various groupings of countries in 2002. (Data from Population Reference Bureau)

216,000 more people each day (95% of them in developing countries). This is equivalent to filling up a jumbo jet with 400 new passengers every 2.7 minutes around the clock.

The rate of the world's annual population change (excluding migration) usually is expressed as a percentage:

$$\text{Annual rate of natural population change (\%)} = \frac{\text{Birth rate} - \text{Death rate}}{1{,}000 \text{ persons}} \times 100 = \frac{\text{Birth rate} - \text{Death rate}}{10}$$

Exponential population growth has not disappeared but is occurring at a slower rate. The rate of the world's annual population growth (natural increase) dropped 42% between 1963 and 2002, from 2.2% to 1.28%. This is *good news,* but during the same period the population base rose by about 94%, from 3.2 billion to 6.2 billion. The *bad news* is that this drop in the rate of population increase is somewhat like learning that a truck heading straight at you has slowed from 100

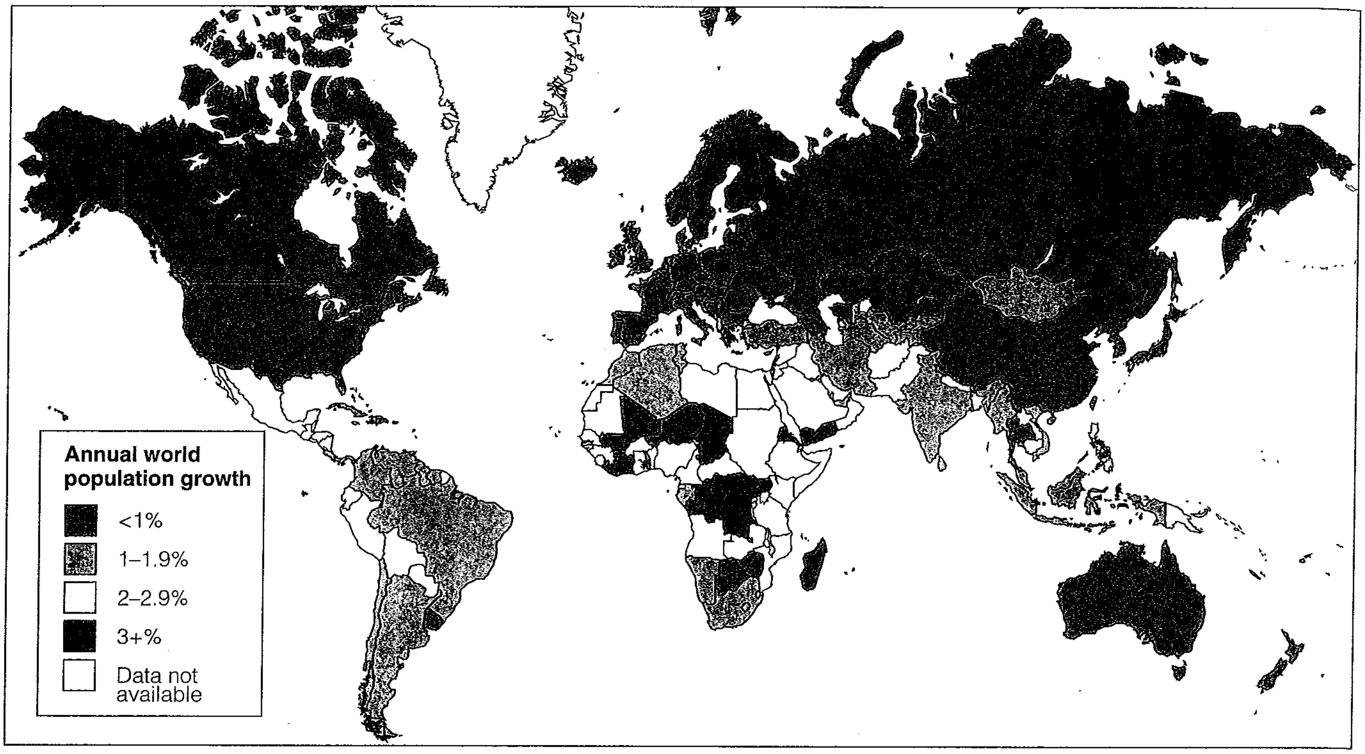


Figure 12-4 Average annual rate of population change (natural increase) in 2002. (Data from Population Reference Bureau)

kilometers per hour (kph) to 58 kph while its weight has almost doubled.

Figure 12-4 presents the annual rates of population change for major parts of the world in 2002. An exponential growth rate of 1.28% may seem small but it adds about 79 million people per year to the world's population. This is roughly equal to adding **(1)** another New York City every month, **(2)** a Germany every year, and **(3)** a United States every 3.6 years. Despite the drop in the rate of population growth, the larger base of population means that 79 million people were added in 2002, compared to 69 million in 1963, when the world's population growth rate reached its peak. Figure 12-5 shows **(1)** the average annual increase in the world's population and the increase in population size from 1950 to 2002 and **(2)** projected increases to 2050.

In numbers of people, China (with 1.28 billion in 2002, about one of every five people in the world) and India (with 1 billion) dwarf all other countries (Figures 12-6 and 12-7). Together they make up 37% of the

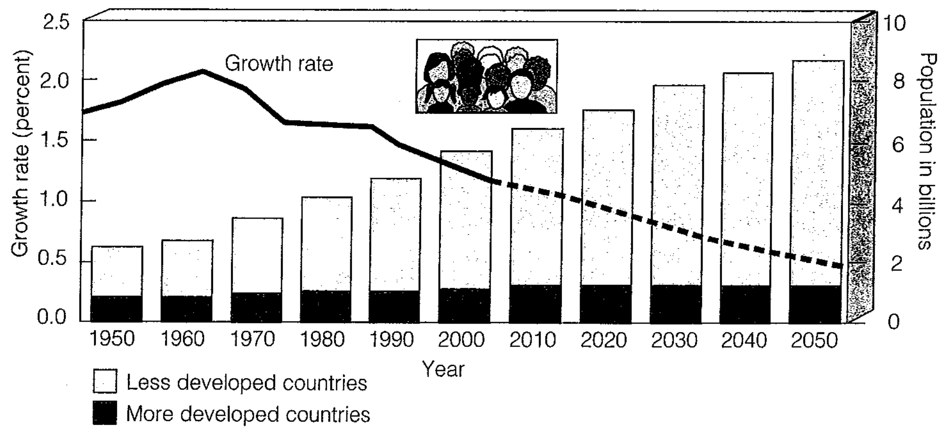


Figure 12-5 Average annual increase in the world's population, 1950–2002, and projected increase 2002–2050 (dotted line). (Data from United Nations)

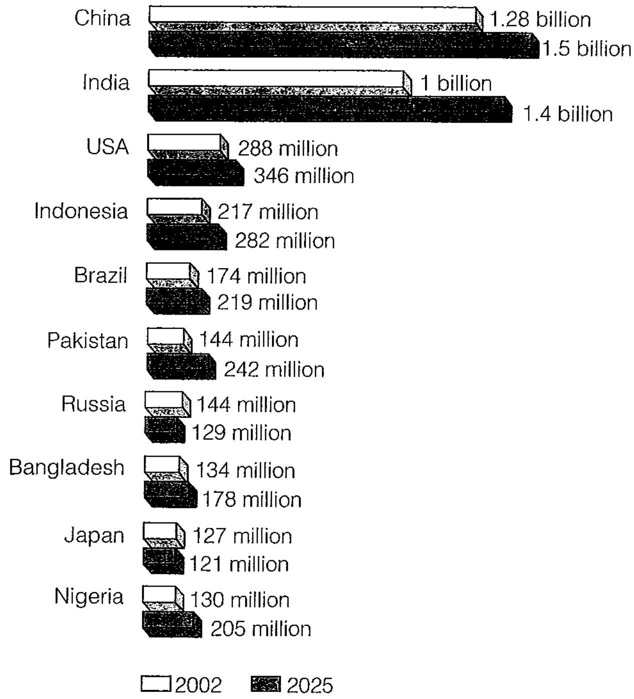
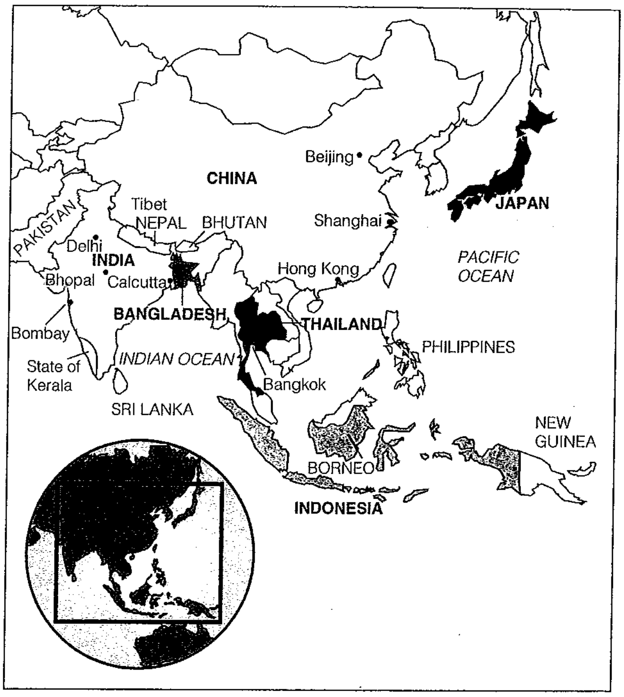


Figure 12-6 The world's 10 most populous countries in 2002, with projections of their population size in 2025. In 2002, more people lived in China than in all of Europe, Russia, North America, Japan, and Australia combined. (Data from World Bank and Population Reference Bureau)



.**Figure 12-7** Where are Japan, Thailand, Indonesia, India, China, and Bangladesh? Some of the countries highlighted here are discussed in other chapters.

world's population. The United States, with 288 million people in 2002, has the world's third largest population but only 4.6% of the world's people. Figure 12-8 gives projected population growth in various regions between 2002 and 2025.

How Have Global Fertility Rates Changed? Two types of fertility rates affect a country's population size and growth rate. The first type, **replacement-level fertility,** is the number of children a couple 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 female children die before reaching their reproductive years.

Does reaching replacement-level fertility mean an immediate halt in population growth? No, because so many future parents are alive. If each of today's couples had an average of 2.1 children and their children also had 2.1 children, the world's population would grow for 50 years or more (assuming death rates do not rise).

The second type of fertility rate is the **total fertility rate (TFR):** an estimate of the average number of children a woman will have during her childbearing years if between ages 15 and 49 she bears children at the same rate as women did this year. TFRs have dropped sharply since 1950 (Figure 12-9, p. 258). In 2002, the average global TFR was 2.8 children per woman. It was 1.6 in developed countries (down from 2.5 in 1950) and 3.1 in developing countries (down from 6.5 in 1950). This drop in the average number of

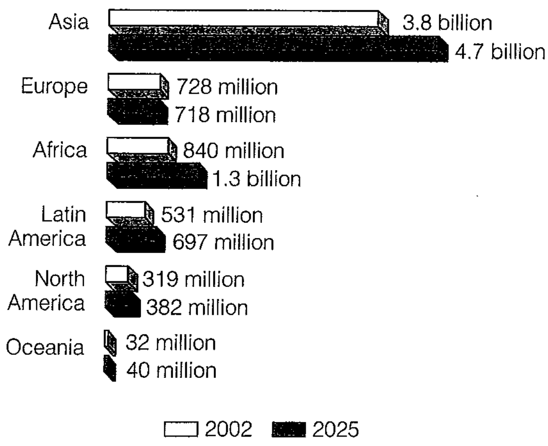


Figure 12-8 Population projections by region, 2002–2025. About 61% of the world's people live in Asia. (Data from United Nations and Population Reference Bureau)

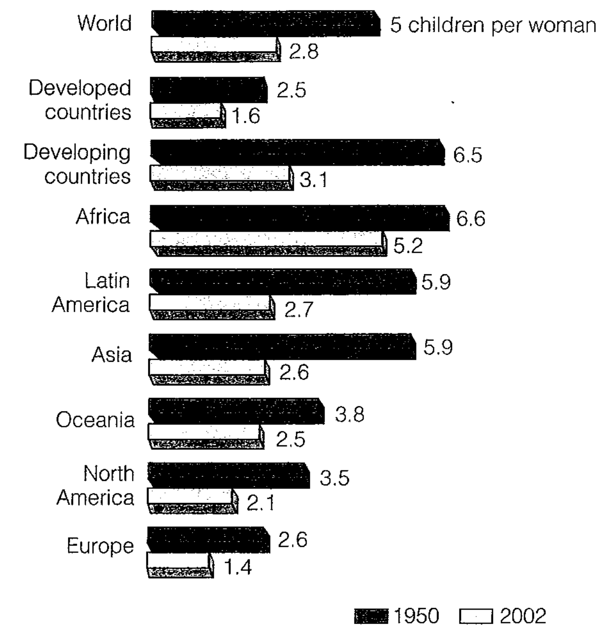


Figure 12-9 Decline in total fertility rates for various groupings of countries, 1950–2002. (Data from United Nations)

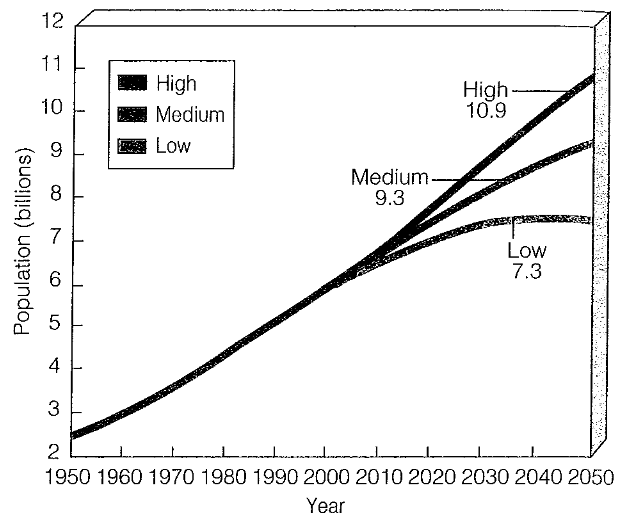


Figure 12-11 UN world population projection, assuming that by 2050 the world's total fertility rate is 2.6 (high), 2.1 (medium), or 1.7 (low) children per woman. (Data from United Nations, *World Population Prospects: The 2000 Revision*, 2001)

children born to women in developing countries is impressive, but this level of fertility is still far above the replacement level of 2.1 (Figure 12-10).

UN population projections to 2050 vary depending on the world's projected average TFR (Figure 12-11). More than 95% of this growth is projected to take place in developing countries (Figure 1-4, p. 6), where acute poverty (living on less than $1 per day) is a way of life for about 1.4 billion people. Between 2002 and 2050, using medium estimates, the population of developing countries is projected to increase from 5 billion to 8 billion. By 2050, the world's population is

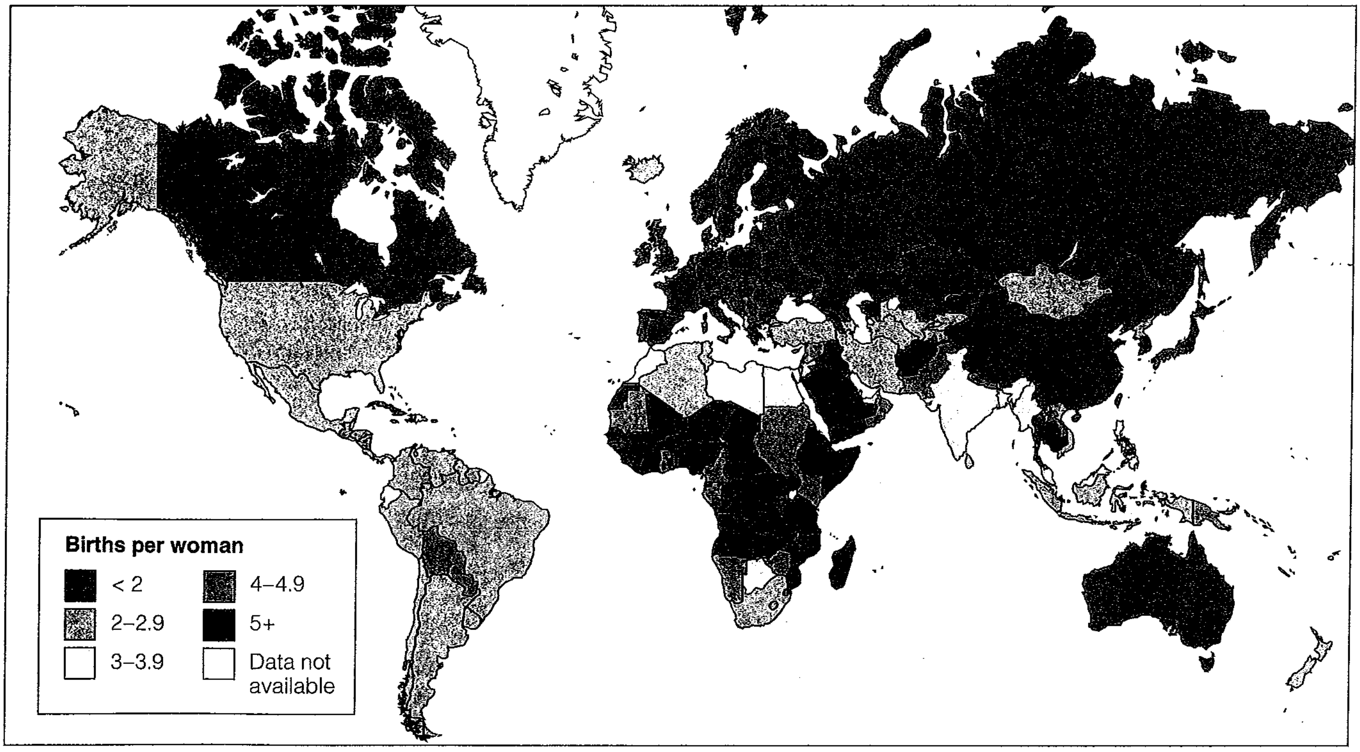


Figure 12-10 Total fertility rates in 2002. (Data from Population Reference Bureau)

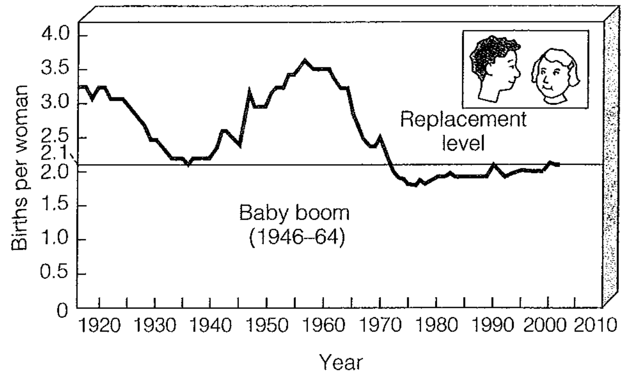


Figure 12-12 Total fertility rates for the United States between 1917 and 2002. (Data from Population Reference Bureau and U.S. Census Bureau)

projected to be 63% urban, more tropical, and considerably older than today.

Case Study: How Have Fertility Rates Changed in the United States? The population of the United States has grown from 76 million in 1900 to 288 million in 2002, even though the country's TFR has oscillated wildly (Figure 12-12). In 1957, the peak of the baby boom after World War II, the TFR reached 3.7 children per woman. Since then it has generally declined, remaining at or below replacement level since 1972.

The drop in the TFR has led to a decline in the rate of population growth in the United States. However, the country's population is still growing faster (1.2% a year, including immigration) than that of any other developed country and is not even close to leveling off. In 2002, this growth added about 2.9 million people: **(1)** 1.7 million more births than deaths (accounting for about 60% of the growth), **(2)** about 900,000 legal immigrants and refugees, and **(3)** an estimated 300,000 illegal immigrants.

Figure 12-13 shows U.S. birth rates between 1910 and 2002. Between 1910 and 1930, birth rates fell sharply as **(1)** the country underwent industrialization and urbanization, and **(2)** more women got an education and began working outside the home. This shift from high birth rates to low birth rates during industrialization is called a *demographic transition.*

Birth rates remained low in the 1930s because of the Great Depression and then began rising in the 1940s during World War II. A sharp rise in the birth rate occurred after World War II. This period of high birth rates between 1946 and 1964 is known as the *baby-boom period* (Figure 12-13), when 79 million people were added to the U.S. population. Between 1956 and 1972, birth rates began to decline as more women began working outside the home and the desired family size dropped from 4 to 2 (or no) children (Figure 12-13).

Between 1977 and 2000, a small *echo boom* in the number of births per year occurred as the large number of people born during the baby boom began having children. Birth rates are projected to rise again between 2002 and 2050. According to U.S. Bureau of Census medium projections, the U.S. population will increase from 288 million to 414 million between 2002 and 2050 and reach 571 million by 2100 (Figure 12-14, p. 260). Because of a high per capita rate of resource use, each addition to the U.S. population has an enormous environmental impact (Figure 1-8, p. 10).

Figure 12-15 (p. 260) lists basic demographic data for the United States and its two neighboring countries, Mexico and Canada.

What Factors Affect Birth Rates and Fertility Rates? Key factors affecting a country's average birth rate and TFR are the following:

- *Importance of children as a part of the labor force.* Rates tend to be higher in developing countries (especially in rural areas, where children begin working to help raise crops at an early age).

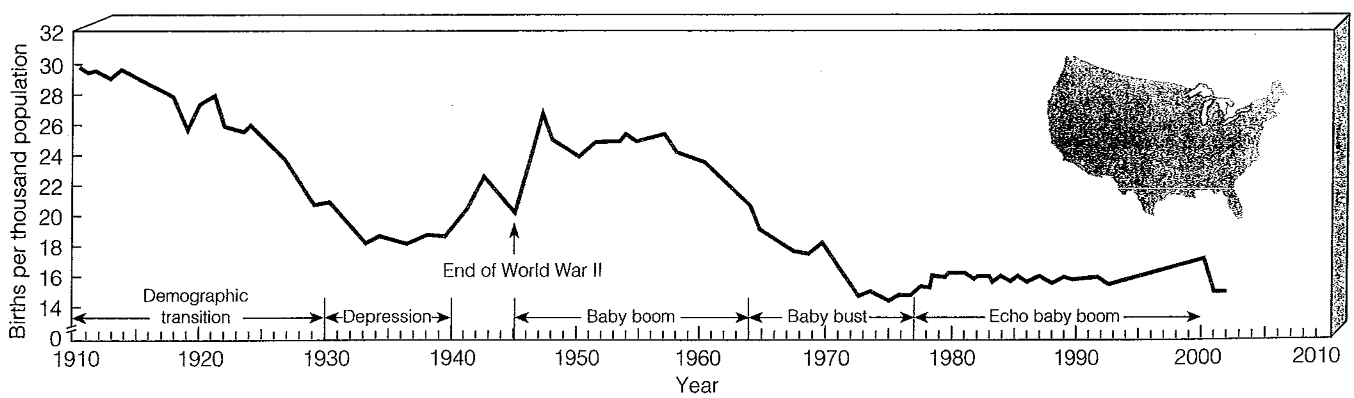


Figure 12-13 Birth rates in the United States, 1910–2002. (Data from U.S. Bureau of Census and U.S. Commerce Department)

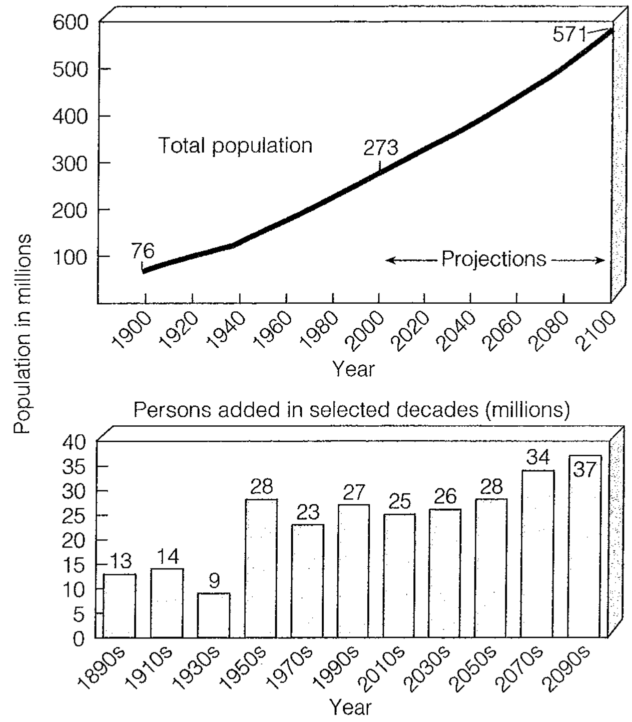


Figure 12-14 U.S. population growth, 1900–2000, and projections to 2100. (Data from U.S. Census Bureau)

- *Urbanization.* People living in urban areas **(1)** usually have better access to family planning services and **(2)** tend to have fewer children than those living in rural areas, where children are needed to perform essential tasks.
- *Cost of raising and educating children.* Rates tend to be lower in developed countries, where raising children is much more costly because children do not enter the labor force until their late teens or early 20s, or even later.
- *Educational and employment opportunities for women.* TFRs tend to be low when women have access to education and paid employment outside the home. In developing countries, women with no education generally have two more children than women with a secondary school education.
- *Infant mortality rate.* In areas with low infant mortality rates, people tend to have less children because fewer children die at an early age.
- *Average age at marriage* (or, more precisely, the average age at which women have their first child). Women normally have fewer children when their average age at marriage is 25 or older.

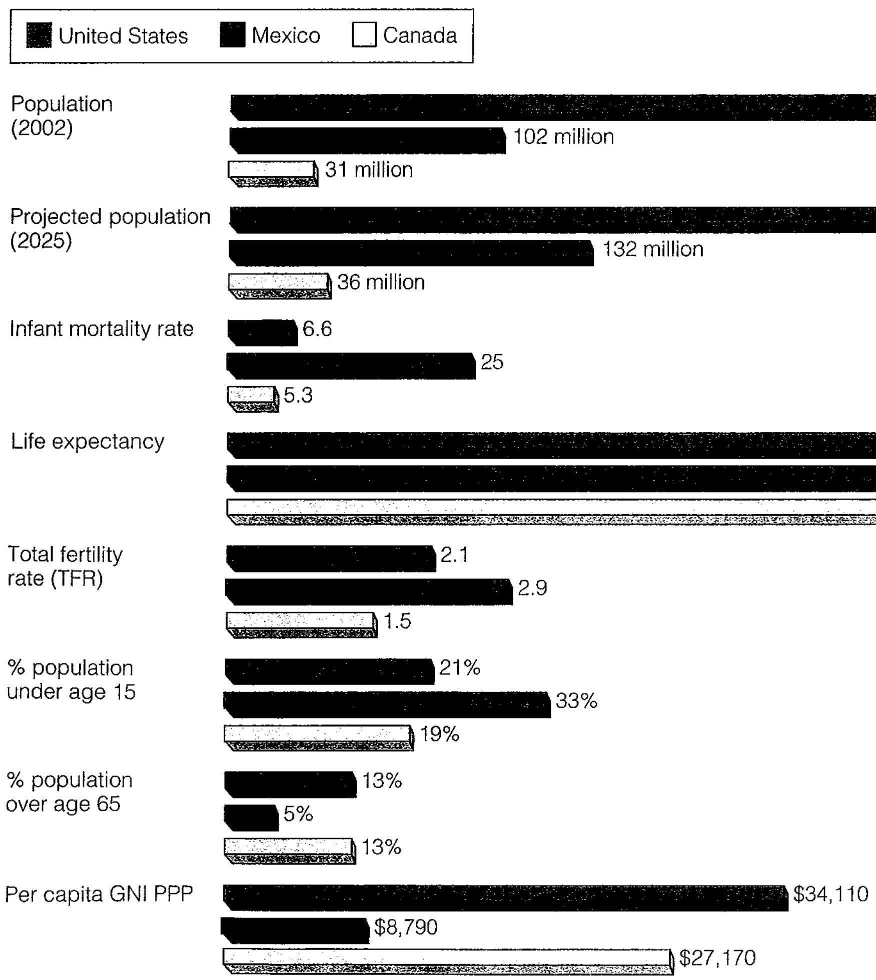


Figure 12-15 Comparison of basic demographic data for the United States (red), Mexico (blue), and Canada (yellow). (Data from U.S. Census Bureau and Population Reference Bureau)

- *Availability of private and public pension systems.* Pensions eliminate parents' need to have many children to help support them in old age.
- *Availability of legal abortions.* According to the United Nations and the World Bank, an estimated 26 million legal abortions and 20 million illegal (and often unsafe) abortions are performed worldwide each year among the roughly 190 million pregnancies per year.
- *Availability of reliable birth control methods* (Figure 12-16).
- *Religious beliefs, traditions, and cultural norms.* In some countries, these factors favor large families and strongly oppose abortion and some forms of birth control.

What Factors Affect Death Rates? The rapid growth of the world's population over the past 100 years is not 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 (Figure 12-17, p. 262).

More people started living longer (and fewer infants died) because of **(1)** increased food supplies and distribution, **(2)** better nutrition, **(3)** improvements in medical and public health technology (such as immunizations and antibiotics), **(4)** improved sanitation and personal hygiene, and **(5)** safer water supplies (which has curtailed the spread of many infectious diseases).

Two useful indicators of overall health of people in a country or region are **(1) life expectancy** (the average number of years a newborn infant can expect to live) and **(2)** the **infant mortality rate** (the number of babies out of every 1,000 born who die before their first birthday).

Some *good news* is that global life expectancy at birth **(1)** increased from 48 years to 67 years (76 years in developed countries and 65 years in developing countries) between 1955 and 2002 and **(2)** is projected to reach 73 by 2025. Between 1900 and 2002, life expectancy in the United States increased from 47 to 77 years and is projected to reach 81 years by 2025.

Some *bad news* is that in the world's 49 poorest countries, mainly in Africa, life expectancy is 55 years or less. In many African countries life expectancy is expected to fall further because of increased deaths from AIDS (Figure 11-10, p. 240).

Because it reflects the general level of nutrition and health care, infant mortality probably is the single most important measure of a society's quality of life. A high infant mortality rate usually indicates **(1)** insufficient food (undernutrition), **(2)** poor nutrition (malnutrition), and **(3)** a high incidence of infectious disease (usually from contaminated drinking water). Figure 12-18 (p. 262) shows the infant mortality rates in various parts of the world in 2002.

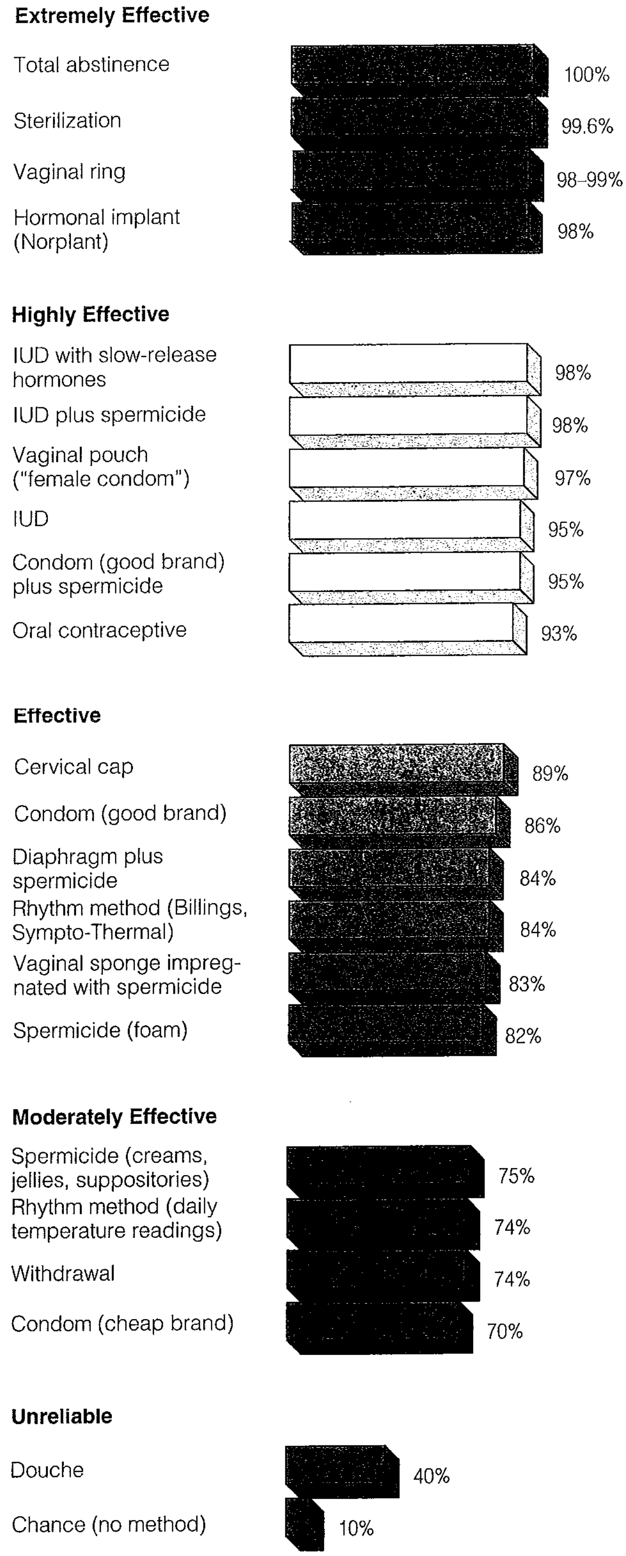
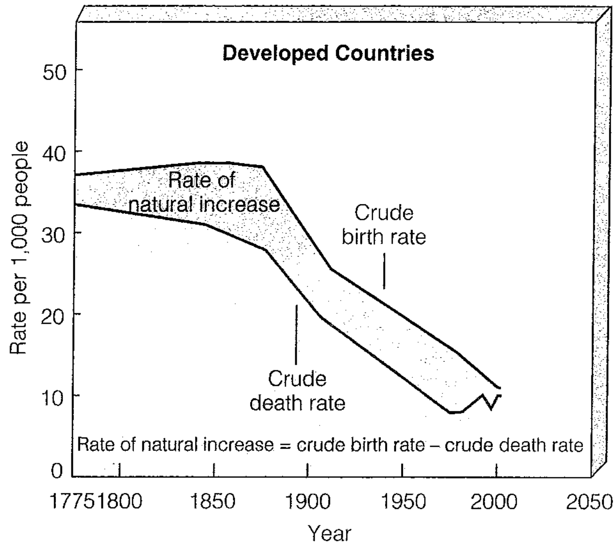


Figure 12-16 Typical effectiveness rates of birth control methods in the United States. Percentages are based on the number of undesired pregnancies per 100 couples using a specific method as their sole form of birth control for a year. For example, an effectiveness rating of 93% for oral contraceptives means that for every 100 women using the pill regularly for 1 year, 7 will get pregnant. Effectiveness rates tend to be lower in developing countries, primarily because of lack of education. (Data from Alan Guttmacher Institute)



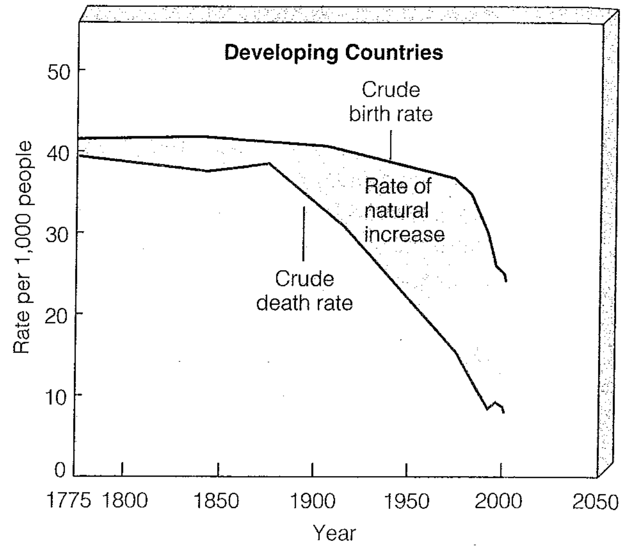


Figure 12-17 Changes in crude birth and death rates for developed and developing countries, 1775–2002. (Data from Population Reference Bureau and United Nations)

Between 1965 and 2002, the world's infant mortality rate dropped from 20 per 1,000 live births to 7 in developed countries and from 118 to 60 in developing countries. This is an impressive achievement, but it still means that at least 8 million infants (most in developing countries} die of preventable causes during their first year of life—an average of 22,000 mostly unnecessary infant deaths per day. This is equivalent to 55 jumbo jets, each loaded with 400 infants under age 1, crashing accidentally each day with no survivors.

Between 1900 and 2002, the U.S. infant mortality rate declined from 165 to 6.8. This sharp decline in

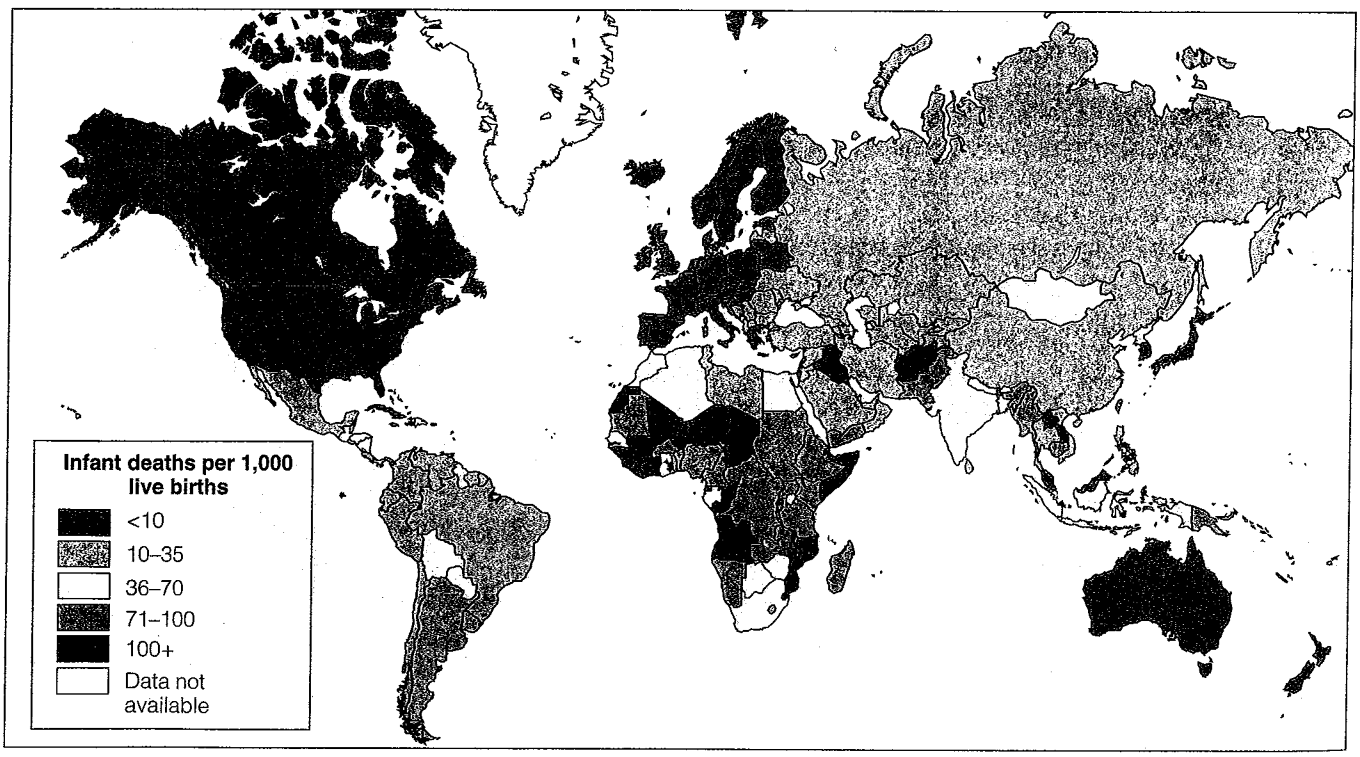


Figure 12-18 Infant mortality rates in 2002. (Data from Population Reference Bureau)

infant mortality rates was a major factor in the marked increase in U.S. average life expectancy during this period.

Despite this improvement, 37 countries had lower infant mortality rates than the United States in 2002. Three factors keeping the U.S. infant mortality rate higher than it could be are **(1)** inadequate health care (for poor women during pregnancy and for their babies after birth), **(2)** drug addiction among pregnant women, and **(3)** the high birth rate among teenagers.

Some *good news* is that the U.S. birth rate among girls ages 15–19 in 2002 was lower than at any time since 1940. Some *bad news* is that the United States has the highest teenage pregnancy rate of any industrialized country. Each year about 872,000 teenage girls become pregnant in the United States (78% of them unplanned) and about 253,000 of them have abortions. Babies born to teenagers are more likely to have low birth weights, the most important factor in infant deaths.

12-2 POPULATION AGE STRUCTURE

What Are Age Structure Diagrams? As mentioned earlier, even if the replacement-level fertility rate of 2.1 were magically achieved globally tomorrow, the world's population would keep growing for at least another 50 years. The reason for this is a population's **age structure:** the proportion of the population (or of each sex) at each age level.

Demographers typically 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: **(1)** *prereproductive* (ages 0–14), **(2)** *reproductive* (ages 15–44), and **(3)** *postreproductive* (ages 45 and up). Figure 12-19 presents generalized age structure diagrams for countries with rapid, slow, zero, and negative population growth rates.

How Does Age Structure Affect Population Growth? Any country with many people below age 15 (represented by a wide base in Figure 12-19, left) has a powerful built-in momentum to increase its population size unless death rates rise sharply. The number of births rises even if women have only one or two children because of the large number of girls who will soon be moving into their reproductive years.

In 2002, 30% of the people on the planet were under 15 years old. These 1.9 billion young people are poised to move into their prime reproductive years. In developing countries the number is even higher: 33%, compared with 18% in developed countries. This powerful force for continued population growth, mostly in developing countries, could be slowed by **(1)** an effective program to reduce birth rates or **(2)** a sharp rise in death rates. Suppose that somehow the world's average TFR fell immediately to the replacement level of 2.1 children. According to the UN Population Fund, even then more than 75% of the world's projected population growth (Figure 12-11) would still occur.

Figure 12-20 (p. 264) shows the age structure in developed and developing countries in 2002. We live in a *demographically divided world,* as shown by population data for the United States, Brazil, and Nigeria

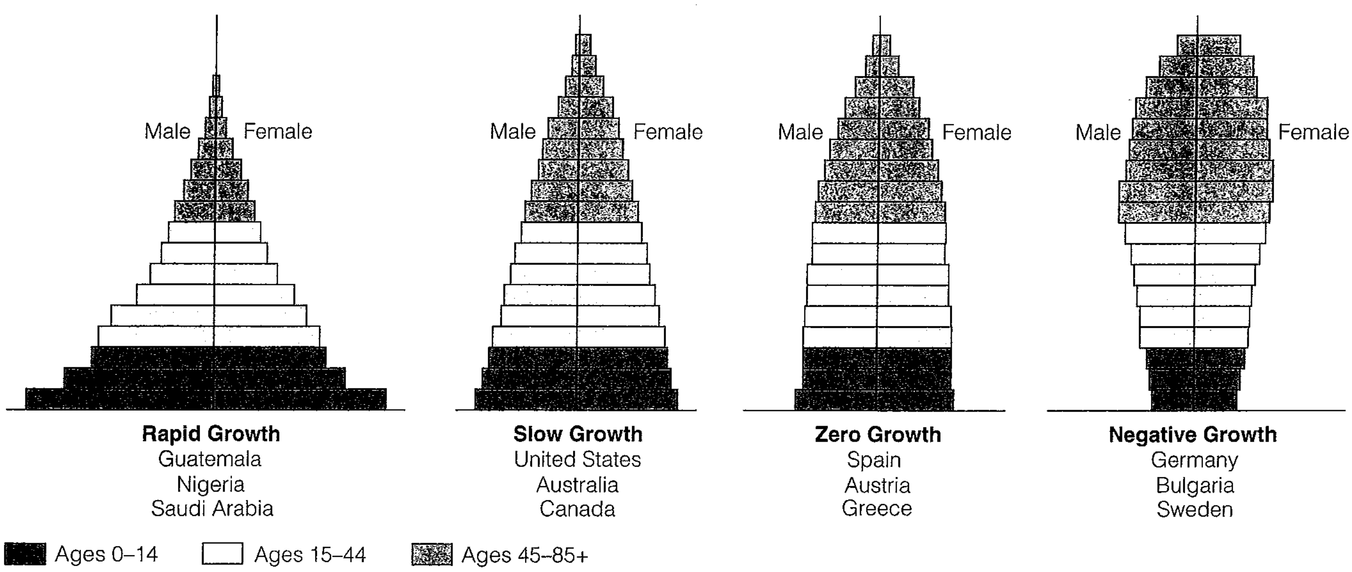


Figure 12-19 Generalized population age structure diagrams for countries with rapid (1.5–3%), slow (0.3–1.4%), zero (0–0.2%), and negative population growth rates. (Data from Population Reference Bureau)

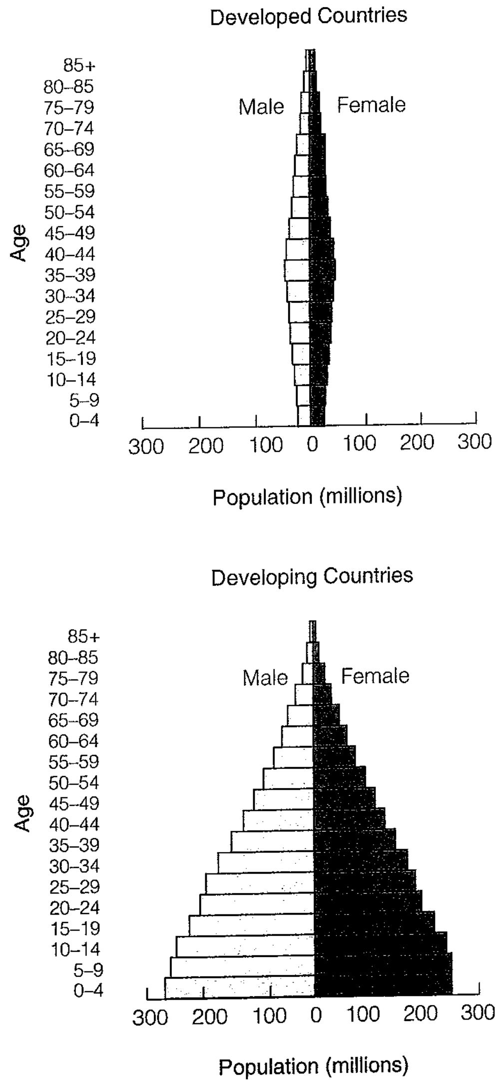


Figure 12-20 Population structure by age and sex in developing countries and developed countries, 2002. In 2002, **(1)** 1 billion young people were in their prime reproductive years of 15–24 and **(2)** 1.9 billion people were under age 15, moving into their reproductive years. (Data from United Nations Population Division and Population Reference Bureau)

(Figure 12-21). Population size has stabilized or is declining in Japan and most European countries. However, population size is projected to double or even triple before stabilizing for many developing countries with fairly large populations and large numbers of people under age 15. Examples of such countries are Nigeria, Ethiopia, Mexico, Brazil, Bangladesh, and Pakistan.

For example, 44% of Nigeria's population is under age 15 and its TFR is 5.8 children per woman. As a result, Nigeria's current population of about 130 million is projected to reach about 304 million by 2050. With 44% of its population under age 15 and a TFR of 5.2 children per woman, the population of the continent of Africa is projected to more than double from 840 million to 1.8 billion between 2002 and 2050.

How Can Age Structure Diagrams Be Used to Make Population and Economic Projections?

The 79-million-person increase that occurred in the U.S. population between 1946 and 1964, known as the *baby boom* (Figures 12-12 and 12-13), will continue to move up through the country's age structure as the members of this group grow older (Figure 12-22).

Baby boomers now make up nearly half of all adult Americans. As a result, they **(1)** dominate the population's demand for goods and services and **(2)** play an increasingly important role in deciding who gets elected and what laws are passed. Baby boomers who created the youth market in their teens and 20s are **(1)** now creating the 50-something market and **(2)** will soon move on to create a 60-something market.

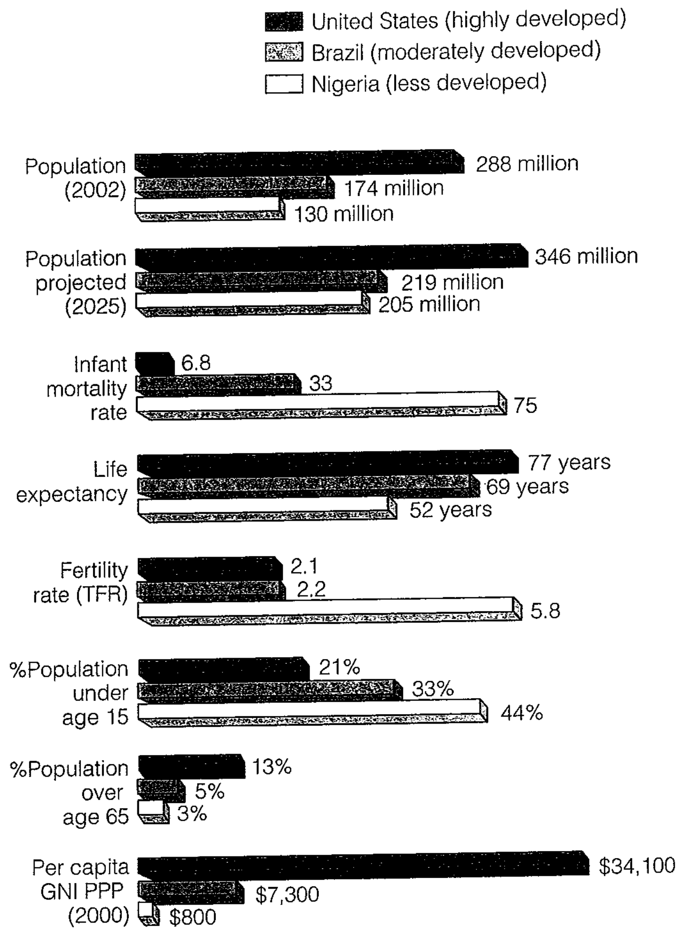


Figure 12-21 Comparison of key demographic indicators in **(1)** highly developed (United States), **(2)** moderately developed (Brazil), and **(3)** less developed (Nigeria) countries in 2002. (Data from Population Reference Bureau)

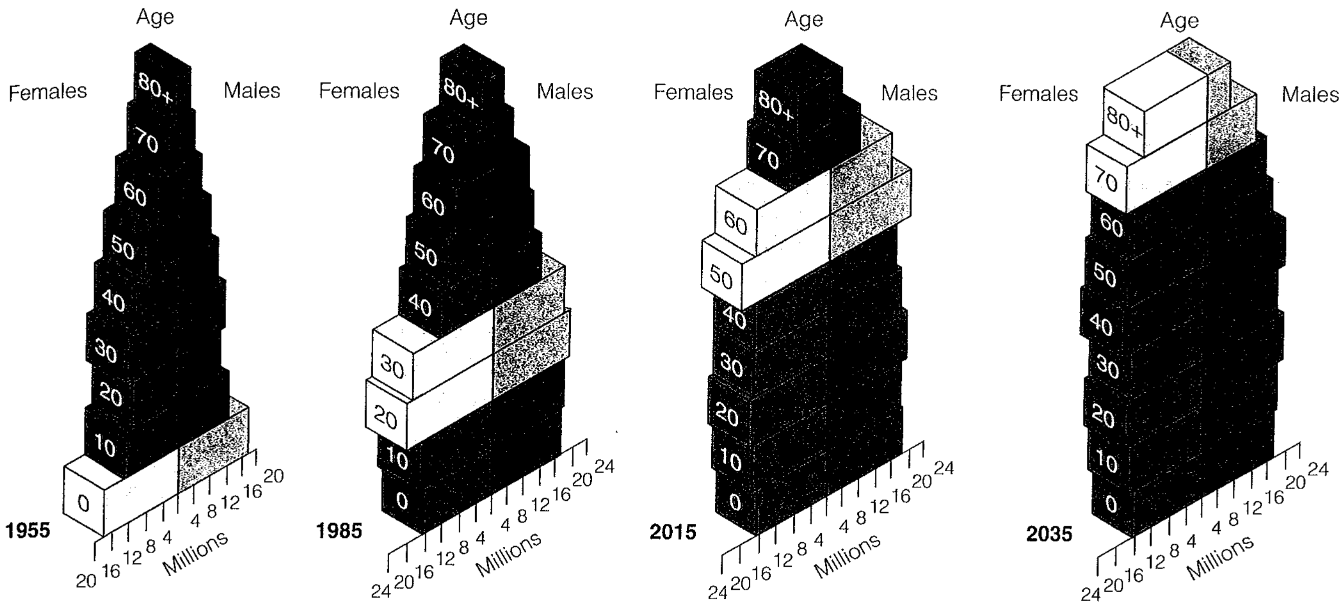


Figure 12-22 Tracking the baby-boom generation in the United States. (Data from Population Reference Bureau and U.S. Census Bureau)

Many Americans are unaware that Social Security taxes on workers in the current generation are used to pay off current beneficiaries. Thus, as the number of workers supporting each beneficiary declines (Figure 12-23), it will be necessary to **(1)** dramatically increase the Social Security taxes on workers, **(2)** decrease retirement benefits, **(3)** extend the official retirement age, or **(4)** make up the shortfall from other government funds (which could greatly increase income taxes).

Much of the economic burden of helping support a large number of retired baby boomers will fall on the *baby-bust generation* (also called *generation* X): the 44 million people born between 1965 and 1976 (when TFRs fell sharply and have remained below 2.1 since 1970; Figure 12-12). Retired baby boomers are likely to use their political clout to force the smaller number of people in the baby-bust generation to pay higher income, health-care, and Social Security taxes. This could cause resentment and conflicts between the two generations.

In some respects, the baby-bust generation should have an easier time than the baby-boom generation. Fewer people will be competing for educational opportunities, jobs, and services, and labor shortages may drive up their wages, at least for jobs requiring education or technical training beyond high school. But members of the baby-bust group may find it difficult to get job promotions as they reach middle age because members of the much larger baby-boom group will occupy most upper-level positions. Many baby boomers may delay retirement because of **(1)** improved health, **(2)** the need to accumulate adequate retirement funds, or **(3)** extension of the retirement age needed to begin collecting Social Security.

The baby-bust generation is being followed by the *echo-boom generation* (Figure 12-13) consisting of about 83 million people born from 1977 to 2000. This largest generation ever, also known as *generation Y* and the *millenials,* will soon have more economic power than their baby-boom parents.

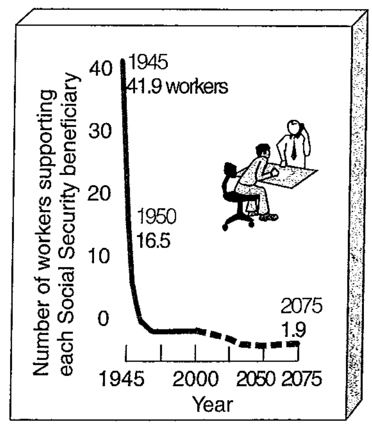


Figure 12-23 Number of workers supporting each beneficiary of the Social Security program in the United States, 1945–2075 (projected).

From these few projections, we can see that any booms or busts in the age structure of a population create social and economic changes that ripple through a society for decades.

What Are Some Effects of Population Decline from Reduced Fertility? The populations of most of the world's countries are projected to grow throughout most of the 21st century. By 2002, however, 38 countries (most of them in Europe) with about 815 million people had roughly stable populations (annual growth rates at or below 0.3%) or declining populations. In other words, about 13% of humanity in industrialized Europe plus Japan has achieved a stable population.

As the age structure of the world's population changes and the percentage of people age 60 or older increases (Figure 12-24), more and more countries will begin experiencing population declines. By 2020, an estimated 1 billion people will be age 60 or older. According to a 2001 UN study, by 2050 the populations of 39 countries (including Japan, Germany, Italy, Hungary, and Ukraine) are projected to be smaller than today.

If population decline is gradual, its harmful effects usually can be managed. However, rapid population decline, like rapid population growth, can lead to severe economic and social problems. A country undergoing rapid population decline **(1)** has a sharp rise in the proportion of older people, who consume a large share

Figure 12-24 *Global aging.* Projected percentage of world population **(1)** under age 15, **(2)** age 60 or over, and **(3)** age 80 or over, 1950–2150, assuming the medium fertility projection shown in Figure 12-11. Between 1998 and 2050 the number of people over age 80 is projected to increase from 66 million to 370 million. The cost of supporting a much larger elderly population will place enormous strains on the world's economy. (Data from the United Nations)

of medical care, Social Security, and other costly public services funded by working taxpayers, and **(2)** can face labor shortages unless it relies on greatly increased automation or immigration of foreign workers.

What Are Some Effects of Population Decline from a Rise in Death Rates? Demographers and health officials project that the current HIV/AIDS epidemic will claim more lives (mostly in Africa and eventually in India and China) in the early part of this century than World War II did near the middle of the last century.

The HIV/AIDS epidemic ravaging Africa (Figure 11-10, p. 240) kills over 6,000 people each day—equivalent to 15 jumbo jets, each containing 400 people, crashing accidentally each day with no survivors. This number of deaths is expected to double within the next decade.

Hunger and malnutrition kill mostly infants and children, but AIDS kills many young adults. This change in the young adult age structure of a country has a number of harmful effects. They include the following:

- A sharp drop in average life expectancy. In 16 African counties, where 10–36% of the adult population is infected with HIV, life expectancy could drop to 35–40 years.
- 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 greatly increases the dependency ratio—the number of productive adults available to support the young and elderly (Figure 12-23).
- A sharp rise in the number of orphans whose parents have died from AIDS. In Africa, the AIDS epidemic could easily result in 40 million orphans by 2010.
- A drop in food production because of a decline in the number of adults producing food.

Analysts call for the international community—especially developed countries—to develop a Marshall Plan (used to rebuild Europe after World War II) to help affected countries in Africa and elsewhere to

- Reduce the spread of HIV through a combination of improved education, health care, and family planning. Emphasis would be on delaying first sexual activity, using condoms, early detection of HIV infections, and reducing the number of sexual partners.
- Restore economic progress through **(1)** debt relief, **(2)** incentives to encourage investment, **(3)** financial assistance for education and health care, and **(4)** send-

ing in volunteer teachers and health-care and social workers to help compensate for the missing young adult generation.

12-3 SOLUTIONS: INFLUENCING POPULATION SIZE

How Is Population Size Affected by Migration? The population of an area is affected by movement of people into (immigration) and out of (emigration) that area. Most countries influence their rates of population growth to some extent by restricting immigration. Only a few countries—chiefly Canada, Australia, and the United States (Case Study, p. 268)—allow large annual increases in population from immigration.

International migration to developed countries absorbs only about 1% of the annual population growth in developing countries. Thus population change for most countries is determined mainly by the difference between their birth rates and death rates.

Migration within countries, especially from rural to urban areas, plays an important role in the population dynamics of cities, towns, and rural areas.

What Are the Pros and Cons of Reducing Births? The projected increase of the human population from 6.2 to 9.3 billion or more between 2002 and 2050 (Figure 12-11) raises an important question: *Can the world provide an adequate standard of living for 3.1 billion more people without causing widespread environmental damage?*

There is intense controversy over **(1)** this question, **(2)** whether the earth is already overpopulated, and **(3)** what measures, if any, should be taken to slow population growth. To some the planet is already overpopulated, but others disagree. Some analysts, mostly economists, argue that we should encourage population growth to help stimulate economic growth.

Others believe that asking how many people the world can support is the wrong question, equivalent to asking how many cigarettes one can smoke before getting lung cancer. Instead, they say, we should be asking what the *optimum sustainable population* of the earth might be, based on the planet's *cultural carrying capacity* (Guest Essay, p. 272).

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. No one knows what this optimum population might be. Some consider it a meaningless concept; some put it at 20 billion, others at 8 billion, and others as low as 2 billion.

Those who do not believe the earth is overpopulated point out that the average life span of the world's 6.2 billion people is longer today than at any time in the past. They say that **(1)** the world can support billions more people, and **(2)** people are the world's most valuable resource for solving the problems we face and stimulating economic growth by becoming consumers.

Some people view any form of population regulation as a violation of their religious beliefs, whereas others see it as an intrusion into their privacy and personal freedom. They believe all people should be free to have as many children as they want. Some developing countries and some members of minorities in developed countries regard population control as a form of genocide to keep their numbers and power from rising.

Proponents of slowing and eventually stopping population growth point out that we fail to provide the basic necessities for one out of six people on the earth today. If we cannot (or will not) do this now, they ask, how will we be able to do this for the projected 3.1 billion more people by 2050?

Proponents of slowing population growth contend that if we do not sharply lower birth rates, we are deciding by default to **(1)** raise death rates for humans (already occurring in parts of Africa) and **(2)** greatly increase environmental harm. In 1992, for example, the U.S. National Academy of Sciences and the Royal Society of London issued the following joint statement: "If current predictions of population growth and patterns of human activity on the planet remain unchanged, science and technology may not be able to prevent either irreversible degradation of the environment or continued poverty for much of the world."

Proponents of this view recognize that population growth is not the only cause of environmental and resource problems. However, they argue that adding several hundred million more people in developed countries and several billion more in developing countries can only intensify existing environmental and social problems.

These analysts believe people should have the freedom to produce as many children as they want. However, such freedom would apply only if it did not reduce the quality of other people's lives now and in the future, either by **(1)** impairing the earth's ability to sustain life or **(2)** causing social disruption. They point out that limiting the freedom of individuals to do anything they want to protect the freedom of other individuals is the basis of most laws in modern societies. What is your opinion on this issue?

How Can Economic Development Help Reduce Birth Rates? Demographers have examined the birth and death rates of western European countries that industrialized during the 19th century. From these data they developed a hypothesis of

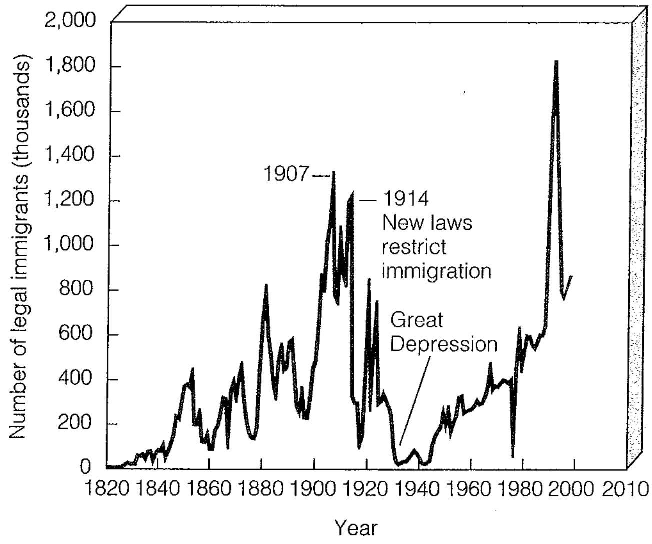
Immigration in the United States

CASE STUDY

Between 1820 and 2000, the United States admitted almost twice as many immigrants and refugees as all other countries combined. However, the number of legal immigrants has varied during different periods because of changes in immigration laws and rates of economic growth (see figure).

In 2000, the United States received about 850,000 legal immigrants and refugees and 300,000 illegal immigrants, together accounting for 40% of the country's population growth. The U.S. Census Bureau estimates that 8–11 million illegal immigrants currently live in the United States.

Currently, more than 75% of all legal immigrants live in six states: California, Florida, Illinois, New York, New Jersey, and Texas. If illegal immigrants are included, this figure rises to about 90%.



Legal immigration to the United States, 1820–2000. 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)

Immigrants place a tax burden on residents of such states. In California, for example, the average household pays an extra $1,200 in taxes per year because of immigrants. However, according to a 1997 study by the National Academy of Sciences, **(1)** the work and taxes paid by immigrants add $1–10 billion per year to the overall U.S. economy, largely because immigration holds down wages (and thus prices) for some jobs, and **(2)** during their lifetimes immigrants pay an average of $80,000 more per person in taxes than they cost in services.

Between 1820 and 1960, most legal immigrants to the United States came from Europe; since then, most have come from Latin America (53%) and Asia (30%). Between 2002 and 2050, the percentage of Latinos in the U.S. population is projected to double from 13% to 24%.

In 1995, the U.S. Commission on Immigration Reform recommended reducing the number of legal immigrants and refugees to about 700,000 per year for a transition period and then to 550,000 a year. Some demographers and environmentalists go further and call for **(1)** lowering the annual ceiling for legal immigrants and refugees into the United States to 300,000–450,000 or **(2)** limiting legal immigration to about 20% of annual population growth. They would accept immigrants only if they can support themselves, arguing that providing immigrants with public services turns the United States into a magnet for the world's poor.

Most of these analysts also support efforts to sharply reduce illegal immigration. However, some are concerned that a crackdown on illegal immigrants can also lead to discrimination against legal immigrants.

The public strongly supports reducing U.S. immigration levels. A 1998 *Wall Street Journal*/NBC News poll found that 72% of the people polled were against the country's high immigration rate. A 1993 Hispanic Research Group survey found 89% of Hispanic Americans supported an immediate moratorium on immigration.

Proponents argue that reducing immigration would allow the United States to stabilize its population sooner and help reduce the country's enormous environmental impact. Others oppose reducing current levels of legal immigration, arguing that **(1)** it would diminish the historical role of the United States as a place of opportunity for the world's poor and oppressed, **(2)** immigrants pay taxes and take many menial, low-paying jobs that other Americans shun, **(3)** few immigrants receive public assistance, **(4)** many immigrants open businesses and create jobs, and **(5)** according to the U.S. Census bureau, after 2020 higher immigration levels will be needed to supply enough workers as baby boomers retire.

Critical Thinking

Should the United States reduce its current level of legal immigration and crack down on illegal immigration? Explain.

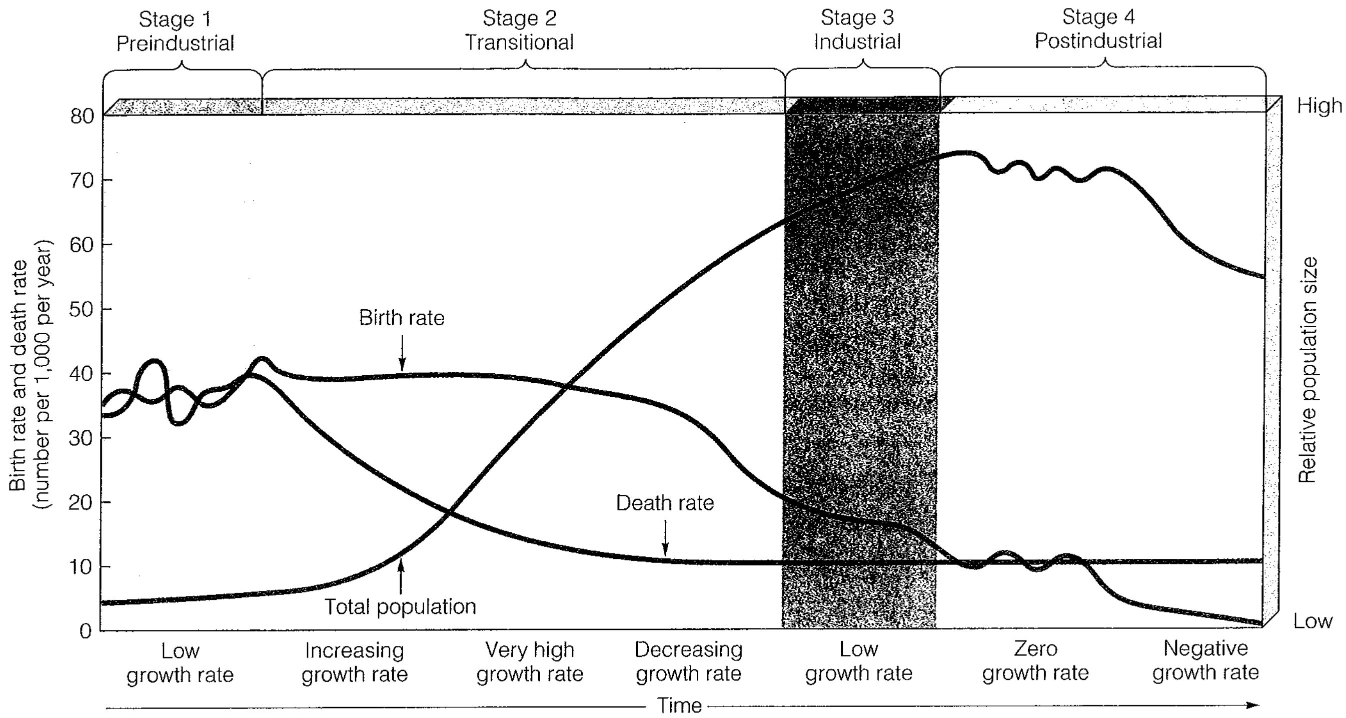


Figure 12-25 Generalized model of the demographic transition.

population change known as the **demographic transition:** as countries become industrialized, first their death rates and then their birth rates decline.

According to this hypothesis, the transition takes place in four stages (Figure 12-25):

- *Preindustrial stage,* when there is little population growth because harsh living conditions lead to both a high birth rate (to compensate for high infant mortality) and a high death rate.

- *Transitional stage,* when industrialization begins, food production rises, and health care improves. Death rates drop and birth rates remain high, so the population grows rapidly (typically 2.5–3% a year).

- *Industrial stage,* when the birth rate drops and eventually approaches the death rate as industrialization and modernization become widespread. Population growth continues, but at a slower and perhaps fluctuating rate, depending on economic conditions. Most developed countries are now in this third stage (Figure 12-25), and a few developing countries are entering this stage.

- *Postindustrial stage,* when the birth rate declines further, equaling the death rate and thus reaching zero population growth. Then the birth rate falls below the death rate and total population size decreases slowly. Thirty-eight countries (most of them in Europe) containing about 13% of the world's population have entered this stage.

In most developing countries today, death rates have fallen much more than birth rates (Figure 12-17). In other words, these developing countries are still in the transitional stage, halfway up the economic ladder, with high population growth rates. Some economists believe that developing countries will make the demographic transition over the next few decades without increased family planning efforts.

However, despite encouraging declines in fertility (Figure 12-9), some population analysts fear that the still-rapid population growth in many developing countries will outstrip economic growth and overwhelm local life-support systems. This could cause many of these countries to be caught in a *demographic trap* at stage 2, something that is currently happening 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 as their death rates rise.

Analysts also point out that some of the conditions that allowed developed countries to develop are not available to many of today's developing countries. Even with large and growing populations, many developing countries **(1)** do not have enough skilled workers to produce the high-tech products needed to compete in the global economy, **(2)** lack the capital and resources needed for rapid economic development, and **(3)** since 1980 have experienced a drop in economic assistance from developed countries and a rise in their debt to such countries. Indeed, since the mid-

1980s, developing countries have paid developed countries $40–50 billion a year (mostly in debt interest) more than they have received from these countries.

How Can Family Planning Help Reduce Birth and Abortion Rates and Save Lives? **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 **(1)** birth spacing, **(2)** birth control, and **(3)** health care for pregnant women and infants.

The advantages of family planning include the following:

- Helping increase the proportion of married women in developing countries who use modern forms of contraception from 10% of married women of reproductive age in the 1960s to 54% of these women in 2002 (41% if China is excluded) (Figure 12-26).
- Being responsible for at least 55% of the drop in TFRs in developing countries, from 6 in 1960 to 3.1 in 2002 (3.5 if China is excluded).
- Reducing the number of legal and illegal abortions per year.
- Decreasing the risk of death from pregnancy.

Despite such successes,

- According to John Bongaarts of the Population Council, 42% of all pregnancies in the developing countries are unplanned and 26% end with abortion.
- An estimated 250–350 million women in developing countries want to limit the number and determine the spacing of their children, but they lack access to services. According to the United Nations, extending family planning services to these women and to those who will soon be entering their reproductive years could prevent an estimated 5.8 million births a year and more than 5 million abortions a year.

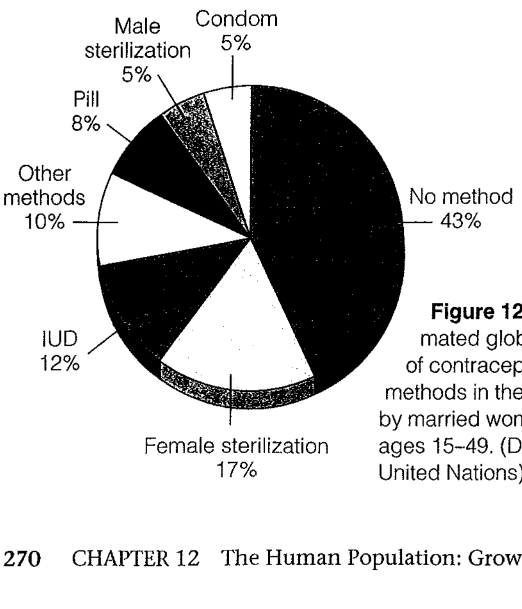


Figure 12-26 Estimated global use of contraceptive methods in the 1990s by married women, ages 15–49. (Data from United Nations)

Other analysts call for

- Expanding existing family planning programs to include teenagers and sexually active unmarried women, who often are excluded.
- Pro-choice and pro-life groups to join forces in greatly reducing unplanned births and abortions, especially among teenagers.
- Programs to educate men about the importance of having fewer children and taking more responsibility for raising them.
- Increased research on developing new, more effective, and more acceptable birth control methods for men.

According to the United Nations, family planning could be provided in developing countries to all couples who want it for about $17 billion a year, the equivalent of about 8 days worth of worldwide military expenditures. If developed countries provided one-third of this $17 billion, each person in the developed countries would spend only $4.80 a year to help reduce the world's population by about 3.1 billion people.

How Can Empowering Women Help Reduce Birth Rates? Studies show that women tend to have fewer and healthier children and live longer when they **(1)** have access to education and to paying jobs outside the home and **(2)** live in societies in which their rights are not suppressed.

Women, roughly half of the world's population, **(1)** do almost all of the world's domestic work and child care, **(2)** provide more health care with little or no pay than all the world's organized health services combined, and **(3)** do 60–80% of the work associated with growing food, gathering fuelwood, and hauling water in rural areas of Africa, Latin America, and Asia (Figure 12-27). As one Brazilian woman put it, "For poor women the only holiday is when you are asleep."

Women work two-thirds of all hours worked but **(1)** receive only 10% of the world's income and **(2)** own only 0.01% of the world's property. In most developing countries, women do not have the legal right to own land or to borrow money to increase agricultural productivity.

According to UNESCO, women also make up 70% of the world's poor and two-thirds of the more than 876 million adults who can neither read nor write. In developing countries, the adult literacy rate for men is almost twice as high as that for women.

Most analysts believe that women everywhere should have full legal rights and the opportunity to become educated and earn income outside the home. This would not only slow population growth but also promote human rights and freedom. However, empowering women by seeking gender equality will take some major social changes that will be difficult to achieve in male-dominated societies.

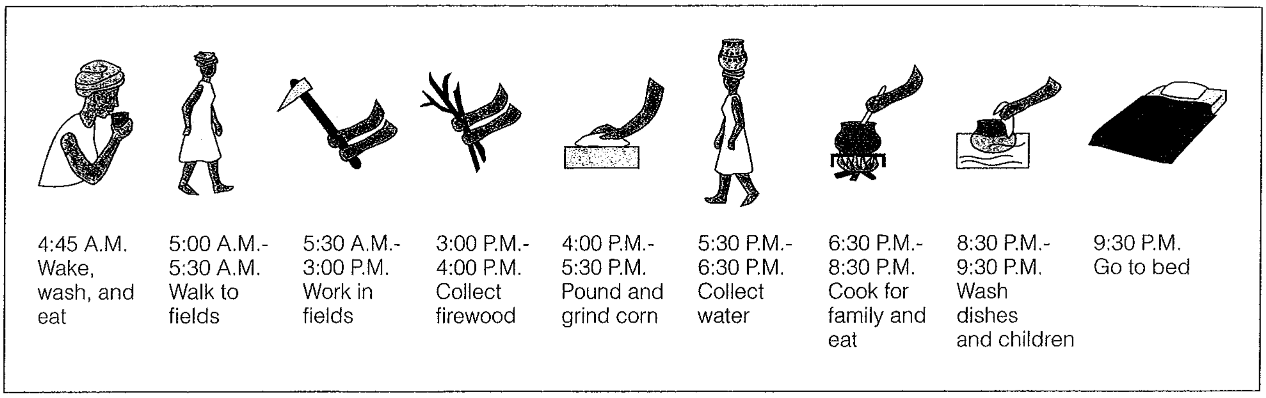


Figure 12-27 Typical workday for a woman in rural Africa. In addition to their domestic work, rural African women perform about 75% of all agricultural work. (Data from United Nations)

How Can Economic Rewards and Penalties Be Used to Help Reduce Birth Rates? Some population experts point out that most couples in developing countries want three or four children. This is well above the replacement-level fertility needed to bring about eventual population stabilization.

These analysts believe we must go beyond family planning and offer economic rewards and penalties to help slow population growth. About 20 countries offer small payments to people who agree to use contraceptives or to be sterilized. However, such payments are most likely to attract people who already have all the children they want.

Some countries, including China, penalize couples who have more than one or two children by **(1)** raising their taxes, **(2)** charging other fees, or **(3)** eliminating income tax deductions for a couple's third child (e.g., in Singapore, Hong Kong, and Ghana). Families who have more children than the prescribed limit may also lose health-care benefits, food allotments, and job options.

Economic rewards and penalties designed to lower birth rates work best if they **(1)** encourage (rather than coerce) people to have fewer children, **(2)** reinforce existing customs and trends toward smaller families, **(3)** do not penalize people who produced large families before the programs were established, and **(4)** increase a poor family's economic status. Once a country's population growth is out of control, it may be forced to use coercive methods to prevent mass starvation and hardship, as has been the case for China.

12-4 CASE STUDIES: SLOWING POPULATION GROWTH IN INDIA AND CHINA

What Success Has India Had in Controlling Its Population Growth? The world's first national family planning program began in India (Figure 12-7) in 1952, when its population was nearly 400 million. In 2002, after 50 years of population control efforts, India was the world's second most populous country, with a population of 1 billion.

In 1952, India added 5 million people to its population, and in 2002 it added 18 million. Figure 12-28 compares demographic data for India and China.

India faces the following already serious poverty, malnutrition, and environmental problems that could worsen as its population continues to grow rapidly:

- By global standards, India's people are poor, with an average per capita GNI PPP of about $2,340 a year; for 30% of the population it is less than $800 a year, or $2.19 a day.

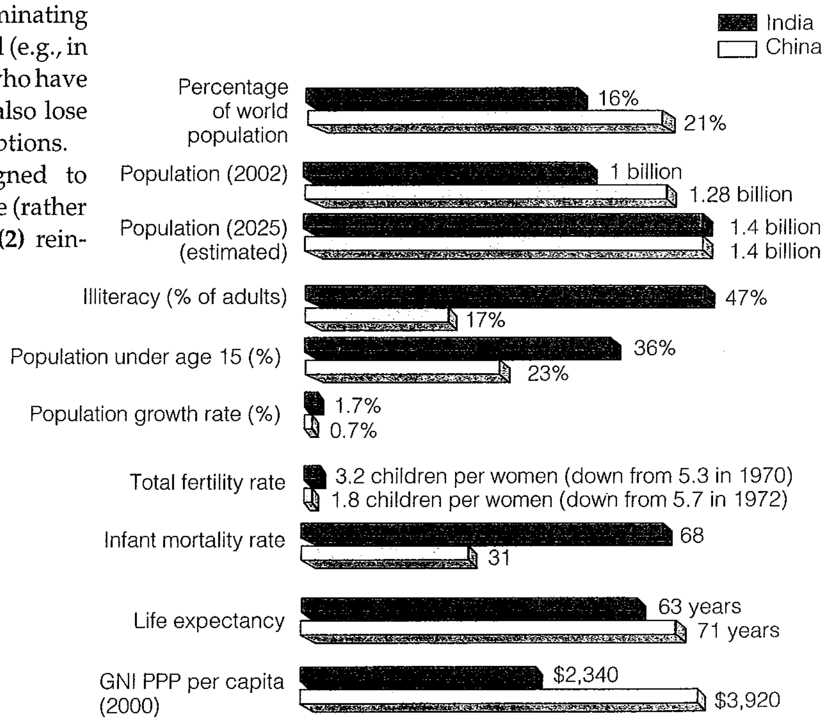


Figure 12-28 Comparison of basic demographic data for India (green) and China (yellow). (Data from United Nations and Population Reference Bureau).

Moral Implications of Cultural Carrying Capacity

GUEST ESSAY

Garrett Hardin

As a longtime professor of human ecology at the University of California at Santa Barbara, Garrett Hardin made important contributions in relating ethics to biology. He has raised hard ethical questions, sometimes taken unpopular stands, and forced people to think deeply about environmental problems and their possible solutions. He is best known for his 1968 essay "The Tragedy of the Commons," which has had a significant impact on the disciplines of economics and political science and on the management of potentially renewable resources. His 17 books include Filters Against Folly: How to Survive Despite Economists, Ecologists, and the Merely Eloquent, Living Within Limits, *and* The Ostrich Factor: Our Population Myopia *(see Further Readings for this chapter on the website for this book).*

For many years, Angel Island in San Francisco Bay was plagued with too many deer. A few animals transplanted there in the early 1900s lacked predators and rapidly increased to nearly 300 deer—far beyond the carrying capacity of the island. Scrawny, underfed animals tugged at the heartstrings of Californians, who carried extra food for them from the mainland to the island.

Such well-meaning charity worsened the plight of the deer. Excess animals trampled the soil, stripped the bark from small trees, and destroyed seedlings of all kinds. The net effect was to lower the island's carrying capacity, year by year, as the deer continued to multiply in a deteriorating habitat.

State game managers proposed that the excess deer be shot by skilled hunters. "How cruel!" some people protested. Then the managers proposed that coyotes be introduced onto the island. Though not big enough to kill adult deer, coyotes can kill fawns, thereby reducing the size of the herd. However, the Society for the Prevention of Cruelty to Animals was adamantly opposed to this proposal.

In the end, it was agreed that some deer would be transported to other areas suitable for deer. A total of 203 animals were caught and trucked many miles away. From the fate of a sample of animals fitted with radio collars, it was estimated that 85% of the transported deer died within a year (most of them within 2 months) from various causes: predation by coyotes, bobcats, and domestic dogs, shooting by poachers and legal hunters, and being run over by cars.

The net cost (in 1982 dollars) for relocating each animal surviving for a year was $2,876. The state refused to continue financing the program, and no volunteers stepped forward to pay future bills.

Angel Island is a microcosm of the planet as a whole. Organisms reproduce exponentially, but the environment does not increase at all. The moral is a simple ecological commandment: *Thou shalt not transgress the carrying capacity.*

Now let's examine the situation for humans. A competent physicist has placed global human carrying capacity at 50 billion, about eight times the current world population. Before you give in to the temptation to urge women to have more babies, consider what Robert Malthus said nearly 200 years ago: "There should be no more people in a country than could enjoy daily a glass of wine and piece of beef for dinner."

A diet of grain or bread and water is symbolic of minimum living standards; wine and beef are symbolic of higher living standards that make greater demands on the environment. When land that could produce plants for direct human consumption is used to grow grapes for wine or corn for cattle, more energy is expended to feed the human population. Because carrying capacity is defined as the *maximum* number of animals (humans) an area can support, using part of the area to support such cultural luxuries as wine and beef reduces the carrying capacity. This reduced capacity is called the *cultural carrying capacity,* and it is always smaller than simple carrying capacity.

Energy is the common coin of the realm for all competing demands on the environment. Energy saved by giving up a luxury can be used to produce more food staples and support more people. We could increase the simple carrying capacity of the earth by giving up any (or all) of the following "luxuries": street lighting, vacations, private cars, air conditioning, and artistic performances

- Nearly half of India'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 53% of its children suffer from malnutrition, mostly because of poverty.
- With 16% of the world's people, India has just 2.3% of the world's land resources and 2% of the world's forests.
- About half of India's cropland is degraded as a result of soil erosion, waterlogging, salinization, overgrazing, and deforestation.
- About 70% of India's water is seriously polluted, and sanitation services often are inadequate.

Without its long-standing family planning program, India's population and environmental problems would be growing even faster. Still, to its supporters the results of the program have been disappointing of all sorts. But what we consider luxuries depends on our values as individuals and societies, and values are largely matters of choice. At one extreme, we could maximize the number of human beings living at the lowest possible level of comfort. Or we could try to optimize the quality of life for a much smaller human population.

The carrying capacity of the earth is a scientific question. It may be possible to support 50 billion people at a bread-and-water level. Is that what we choose? The question, "What is the cultural carrying capacity?" requires that we debate questions of value, about which opinions differ.

An even greater difficulty must be faced. So far, we have been treating carrying capacity as a *global* issue, as if there were some global sovereignty capable of enforcing a solution on all people. But there is no global sovereignty ("one world"), nor is there any prospect of one in the foreseeable future. Thus, we must ask how some 200 nations are to coexist in a finite global environment if different sovereignties adopt different standards of living.

Consider a protected redwood forest that produces neither food for humans nor lumber for houses. Because people must travel many kilometers to visit it, the forest is a net loss in the national energy budget. However, for those fortunate enough to wander through the cathedral-like aisles beneath an evergreen vault, a redwood forest does something precious for the human spirit. But then intrudes an appeal from a distant land, where millions are starving because their population has overshot the carrying capacity; we are asked to save lives by sending food. As long as we have surpluses, we may safely indulge in the pleasures of philanthropy. But after we have run out of our surpluses, then what?

A spokesperson for the needy from that land makes a proposal: "If you would only cut down your redwood forests, you could use the lumber to build houses and then grow potatoes on the land, shipping the food to us. Since we are all passengers together on Spaceship Earth, are you not duty bound to do so? Which is more precious, trees or human beings?"

This last question may sound ethically compelling, but let's look at the consequences of assigning a preemptive and supreme value to human lives. At least 2 billion people in the world are poorer than the 34 million "legally poor" in America, and their numbers are increasing by about 1 million per year. Unless this increase is halted, sharing food and energy on the basis of need would require the sacrifice of one amenity after another in rich countries. The ultimate result of sharing would be complete poverty everywhere on the earth to maintain the earth's simple carrying capacity. Is that the best humanity can do?

To date, there has been overwhelmingly negative reaction to all proposals to make international philanthropy conditional on the cessation of population growth by overpopulated recipient nations. Foreign aid is governed by two apparently inflexible assumptions:

- The right to produce children is a universal, irrevocable right of every nation, no matter how hard it presses against the carrying capacity of its territory.
- When lives are in danger, the moral obligation of rich countries to save human lives is absolute and undeniable.

Considered separately, each of these two well-meaning doctrines might be defensible; taken together, they constitute a fatal recipe. If humanity gives maximum carrying capacity precedence over problems of cultural carrying capacity, the result will be universal poverty and environmental ruin.

Or do you see an escape from this harsh dilemma?

Critical Thinking

1. What population size would allow the world's people to have a good quality of life? What do you believe is the cultural carrying capacity of the United States? Should the United States have a national policy to establish this population size as soon as possible? Explain.

2. Do you support the two principles this essay lists as the basis of foreign aid to needy countries? If not, what changes would you make in the requirements for receiving such aid?

because of **(1)** poor planning, **(2)** bureaucratic inefficiency, **(3)** the low status of women (despite constitutional guarantees of equality), **(4)** extreme poverty, and **(5)** a lack of administrative and financial support.

Even though the government has provided information about the advantages of small families for years, Indian women still have an average of 3.2 children because most couples believe they need many children to do work and care for them in old age. Because of the strong cultural preference for male children, some couples keep having children until they produce one or more boys. These factors in part explain why even though 90% of Indian couples know of at least one modern birth control method, only 43% actually use one.

What Success Has China Had in Controlling Its Population Growth? Since 1970, China (Figure 12-7) has made impressive efforts to feed its people and bring its population growth under control.

Between 1972 and 2002, China cut its crude birth rate in half and cut its TFR from 5.7 to 1.8 children per woman (Figure 12-28).

To achieve its sharp drop in fertility, China has established the most extensive, intrusive, and strict population control program in the world. For example,

- Couples are strongly urged to postpone the age at which they marry and to have no more than one child.
- Married couples have ready access to free sterilization, contraceptives, and abortion. About 83% of married women in China use modern contraception.
- Married couples who pledge to have no more than one child receive **(1)** extra food, **(2)** larger pensions, **(3)** better housing, **(4)** free medical care, **(5)** salary bonuses, **(6)** free school tuition for their one child, and **(7)** preferential treatment in employment when their child enters the job market. Couples who break their pledge lose all the benefits.

Because of the success of its population control program, the United Nations projects that China's population will start declining in 2042. This has stirred some members of China's parliament to propose amending the country's one-child policy so that some urban couples can have a second child. The goal would be to provide more workers to help support China's aging population, which is expected to peak in 2040.

Government officials realized in the 1960s that the only alternative to strict population control was mass starvation. China is a dictatorship, and thus, unlike India, it has been able to impose a consistent population policy throughout its society.

China's large and still growing population has an enormous environmental impact that could reduce its ability to produce enough food and threaten the health of many of its people. China has 21% of the world's population but only 7% of its fresh water and cropland, 4% of its forests, and 2% of its oil. Soil erosion in China is serious and apparently getting worse.

In the 1970s, the Chinese government had a system of health clinics that provided moderate health care for its rural farm population. This system collapsed in the 1980s as China embraced capitalist reforms. According to government estimates, more than 800 million people—90% of rural Chinese—now have no health insurance or social safety net.

Most countries prefer to avoid the coercive elements of China's program. Perhaps the best lesson for other countries is to act to curb population growth before they must choose between mass starvation and coercive measures that severely restrict human freedom.

12-5 CUTTING GLOBAL POPULATION GROWTH

In 1994, the United Nations held its third once-in-a-decade 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 9.3 billion (Figure 12-11). The major goals of the resulting population plan, endorsed by 180 governments, are to do the following by 2015:

- Provide universal access to family planning services and reproductive health care
- Improve the health care of infants, children, and pregnant women (Solutions, p. 244)
- Encourage development and implementation of national population policies as part of social and economic development policies
- Bring about more equitable relationships between men and women, with emphasis on improving the status of women and expanding education and job opportunities for young women
- Increase access to education, especially for girls and women
- Increase the involvement of men in child-rearing responsibilities and family planning
- Take steps to eradicate poverty
- Reduce and eliminate unsustainable patterns of production and consumption

At the conference, developing countries agreed to cover two-thirds of the $17 billion annual cost, with developed countries paying the remainder. By 2002, developing countries had provided about 70% of their Cairo commitment, but developed countries had provided only about 40% of their commitment. Because of the funding shortfall, the United Nations estimated that by 2002 there were 122 million pregnancies and 41 million abortions that could have been prevented.

The *good news* is that the experience of Japan, Thailand (p. 255), South Korea, Taiwan, Iran, and China indicates that a country can achieve or come close to replacement-level fertility within 15–30 years. Such experience also suggests that the best way to slow population growth is a combination of **(1)** investing in family planning, **(2)** reducing poverty, and **(3)** elevating the status of women.

Our numbers expand but Earth's natural systems do not.
LESTER R. BROWN

REVIEW QUESTIONS

1. Define the boldfaced terms in this chapter.

2. How did Thailand reduce its birth rate?

3. How is population change calculated? What are the *crude birth rate* and the *crude death rate?* About how many people are added to the world's population each year and each day? How is the *annual rate of population change* calculated? What three countries have the world's largest populations?

4. Distinguish between *replacement-level fertility* and *total fertility rate.* Explain why replacement-level fertility is higher than 2. Explain why reaching replacement-level fertility does not mean an immediate halt in population growth.

5. How have fertility rates and birth rates changed in the United States since 1910? How rapidly is the U.S. population growing?

6. List 10 factors that affect birth rates and fertility rates.

7. List five reasons why the world's death rate has declined over the past 100 years.

8. Distinguish between *life expectancy* and *infant mortality rate.* Why is infant mortality the best measure of a society's quality of life? List three factors that keep the U.S. infant mortality higher than it could be.

9. What is the *age structure* of a population? Explain why the current age structure of the world's population means the world's population will keep growing for at least another 50 years even if the replacement-level rate of 2.1 is somehow reached globally tomorrow.

10. Draw the general shape of an age structure diagram for a country undergoing **(a)** rapid population growth, **(b)** slow population growth, **(c)** zero population growth, and **(d)** population decline.

11. What percentage of population is under age 15 in **(a)** the world, **(b)** developed countries, and **(c)** developing countries? Explain how age structure diagrams can be used to make population and economic projections.

12. What are the benefits and potentially harmful effects of rapid population decline?

13. List the major arguments for and against reducing birth rates globally.

14. Describe immigration in the United States in terms of numbers, and list the pros and cons of reducing immigration limits.

15. What is the *demographic transition,* and what are its four phases? What factors might keep many developing countries from making the demographic transition?

16. What is *family planning,* and what are the advantages of using this approach to reduce the birth rate?

17. Explain how empowering women can help reduce birth rates.

18. What economic rewards and penalties have some countries used to reduce birth rates? What four conditions increase the success of using such economic rewards and penalties?

19. Briefly describe and compare the success China and India have had in reducing their birth rates.

20. List the eight goals of the current UN plan to stabilize the world's population at 7.8 billion by 2050, instead of the projected 9.3 billion.

CRITICAL THINKING

1. Why is a drop in the birth rate not necessarily a reliable indicator of future population growth?

2. 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?

3. List what you consider to be a major local, national, or global environmental problem, and describe the role of population growth in this problem.

4. Suppose that all women in the world today began bearing children at replacement-level fertility rates of 2.1 children per woman. Explain why this would not immediately stop global population growth. About how long would it take for population growth to stabilize?

5. What do you believe is the world's **(a)** maximum human population and **(b)** optimum human population?

6. Do you believe the population of **(a)** your own country and **(b)** the area where you live is too high? Explain.

7. Evaluate the claims made by those opposing a reduction in births and those promoting a reduction in births, as discussed on p. 267. Which position do you support, and why?

8. Explain why you agree or disagree with each of the following proposals:

- **a.** The number of legal immigrants and refugees allowed into the United States each year should be reduced sharply.
- **b.** Illegal immigration into the United States should be decreased sharply. If you agree, how would you go about achieving this?
- **c.** Families in the United States should be given financial incentives to have more children to prevent eventual population decline.
- **d.** The United States should adopt an official policy to stabilize its population and reduce unnecessary resource waste and consumption as rapidly as possible.
- **e.** Everyone should have the right to have as many children as they want.

9. Some people have proposed that the earth could solve its population problem by shipping people off to space colonies, each containing about 10,000 people. Assuming we could build such large-scale, self-sustaining space stations, how many people would have to be shipped off each day to provide living spaces for the 79 million people being added to the earth's population each year? Current space shuttles can handle about 6 to 8 passengers. If this capacity could be increased to 100 passengers per shuttle, how many shuttles would have to be launched per day to offset the 79 million people being added each year? According to your calculations, determine whether this proposal is a logical solution to the earth's population problem.

10. Some people believe the most important goal is to sharply reduce the rate of population growth in developing countries, where 95% of the world's population growth is expected to take place. Some people in developing countries agree that population growth in these countries can cause local environmental problems. However, they contend that the most serious environmental problem the world faces is disruption of the global life-support system by high levels of resource consumption per person in developed countries, which use 80% of the world's resources. What is your view on this issue? Explain.

11. Some analysts contend that we have enough food and resources for everyone but these resources are not distributed equitably. To them, poverty, hunger, overpopulation, and environmental degradation are caused mainly by a lack of *social justice.* What is your view on this issue? Explain.

12. Suppose the cloning of human beings becomes possible without any serious health effects for cloned individuals. What effect might this have on the world's population size and growth rate? Explain.

13. Why has China been more successful than India in reducing its rate of population growth? Do you agree with China's current population control policies? Explain. What alternatives, if any, would you suggest?

14. Congratulations! You are in charge of the world. List the three most important features of your population policy.

PROJECTS

1. Survey members of your class to determine how many children they plan to have. Tally the results and compare them for men and women.

2. Assume your entire class (or manageable groups of your class) is charged with coming up with a plan for halving the world's population growth rate within the next 20 years. Develop a detailed plan that would achieve this goal, including any differences between policies in developing countries and developed countries. Justify each part of your plan. Predict what problems you might face in implementing the plan, and devise strategies for dealing with these problems.

3. Prepare an age structure diagram for your community. Use the diagram to project future population growth and economic and social problems.

4. Use the library or the Internet to find bibliographic information about *Theodore Roosevelt, Paul Hawken,* and *Lester R. Brown,* whose quotes appear at the beginning and end of this chapter.

5. Make a concept map of this chapter's major ideas, using the section heads and subheads and the key terms (in boldface). See material on the website for this book about how to prepare concept maps.

INTERNET STUDY RESOURCES AND RESOURCES FOR FURTHER READING AND RESEARCH

The website for this book contains helpful study aids and many ideas for further reading and research. Log on to

www.info.brookscole.com/miller13

and click on the Chapter-by-Chapter area. Choose Chapter 12 and select a resource:

- Flash Cards allows you to test your mastery of the Terms and Concepts to Remember for this chapter.
- Tutorial Quizzes provides a multiple-choice practice quiz.
- Student Guide to InfoTrac will lead you to Critical Thinking Projects that use InfoTrac College Edition as a research tool.
- References lists the major books and articles consulted in writing this chapter.
- Hypercontents takes you to an extensive list of sites with news, research, and images related to individual sections of the chapter.

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Improve your skills with InfoTrac College Edition, a searchable online database of articles from more than 700 periodicals. Log on to

http://www.infotrac-college.com

or access InfoTrac through the website for this book. Try to find the following articles:

1. Brown, R. W. 1999. When we hit the wall: The lesson is likely to be painful. *Free Inquiry* 19: 23. *Keywords:* "world population" and "exponential growth." This article discusses some of the social and ecological implications of the rapidly expanding human population, even though fertility rates are declining.

2. McMichael, A. J. 2002. Population, environment, disease, and survival: Past patterns, uncertain futures. *The Lancet* 359: 1145. *Keywords:* "human population" and "environment." Even though human populations are adversely affecting the environment, human life span continues to increase. This article looks at the relationship between human societies and their impacts on the environment and on individual survival.

13 FOOD RESOURCES

Perennial Crops on the Kansas Prairie

When you think about farms in Kansas, you probably picture seemingly endless fields of wheat or corn plowed up and planted each year. By 2040, the picture might change, thanks to pioneering research at the nonprofit Land Institute near Salina, Kansas (Figure 13-1).

The institute, headed by plant geneticist Wes Jackson, is experimenting with an ecological approach to agriculture on the midwestern prairie. This approach relies on planting a mixture of different crops in the same area, a technique called *polyculture.* The goal is to grow food crops by planting a mix of **(1)** perennial grasses (Figure 13-1, left), **(2)** legumes (a source of nitrogen fertilizer, Figure 13-1, right), **(3)** sunflowers, **(4)** grain crops, and **(5)** plants that provide natural insecticides in the same field.

The institute's goal is to raise food by mimicking many of the natural conditions of the prairie without losing fertile grassland soil (Figure 10-15, top right, p. 215). Institute researchers believe that *perennial polyculture* can be blended with *modern monoculture* to reduce its harmful environmental effects.

Because these plants are perennials, the soil does not have to be plowed up and prepared each year to replant them. This takes much less labor than conventional monoculture or diversified organic farms that grow annual crops. It also reduces **(1)** soil erosion because the unplowed soil is not exposed to wind and rain, **(2)** pollution caused by chemical fertilizers and pesticides, and **(3)** the need for irrigation because the deep roots of such perennials retain more water than annuals.

Thirty years of research by the institute have shown that various mixtures of perennials grown in parts of the midwestern prairie could be used as important sources of food. One such mix of perennial crops includes **(1)** *eastern gamma grass* (a warm season grass that is a relative of corn with three times as much protein as corn and twice as much as wheat; Figure 13-1, left), **(2)** *mammoth wildrye* (a cool season grass that is distantly related to rye, wheat, and barley), **(3)** *Illinois bundleflower* (a wild nitrogen-producing legume that can enrich the soil and whose seeds can serve as livestock feed; Figure 13-1, right), and **(4)** *Maximilian sunflower* (which produces seeds with as much protein as soybeans).

These discoveries may help us come closer to producing and distributing enough food to meet everyone's basic nutritional needs without degrading the soil, water, air, and biodiversity that support all food production.

Figure 13-1 The Land Institute in Salina, Kansas, is a farm, a prairie laboratory, and a school dedicated to changing the way we grow food. It advocates growing a diverse mixture (polyculture) of edible perennial plants to supplement traditional annual monoculture crops. Two of these perennial crops are **(1)** eastern gamma grass (above) and **(2)** the Illinois bundleflower (right).

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

This chapter addresses the following questions:

- How is the world's food produced?
- How are green revolution and traditional methods used to raise crops?
- How much has food production increased, how serious is malnutrition, and what are the environmental effects of producing food?
- How can we increase production of **(a)** crops, **(b)** meat, and **(c)** fish and shellfish?
- How do government policies affect food production?
- How can we design and shift to more sustainable agricultural systems?

13-1 HOW IS FOOD PRODUCED?

What Three Systems Provide Us with Food? Some Good and Bad News Historically, humans have depended on three systems for their food supply: **(1)** *croplands* (mostly for producing grains, which provide about 76% of the world's food), **(2)** *rangelands* (for producing meat mostly from grazing livestock, which supply about 17% of the world's food), and **(3)** *oceanic fisheries* (which supply about 7% of the world's food).

Some *good news* is that

- Since 1950 there has been a staggering increase in global food production from all three systems.
- This phenomenal growth in food productivity occurred because of technological advances such as **(1)** increased use of tractors and farm machinery and high-tech fishing boats and gear, **(2)** inorganic chemical fertilizers, **(3)** irrigation, **(4)** pesticides, **(5)** high-yield varieties of wheat, rice, and corn, **(6)** densely populated feedlots and enclosed pens for raising cattle, pigs, and chickens, and **(7)** aquaculture ponds and ocean cages for raising some types of fish and shellfish.

To feed the world's 9.3 billion people projected by 2050, we must **(1)** produce and equitably distribute more food than has been produced since agriculture began about 10,000 years ago and **(2)** do this in an environmentally sustainable manner. Some analysts believe we can continue expanding the use of industrialized agriculture to produce the necessary food.

Some *bad news* is that other analysts contend that **(1)** environmental degradation, **(2)** pollution, **(3)** lack of water for irrigation, **(4)** overgrazing by livestock, **(5)** overfishing, and **(6)** loss of vital ecological services (Figure 4-34, p. 92) may limit future food production as human activities continue to take over or degrade more of the planet's *net primary productivity* (Figure 4–26, p. 82), which supports all life. The rest of this chapter analyzes **(1)** the pros and cons of the world's crop, meat, and fish production systems and **(2)** how these systems can be made more sustainable.

What Plants and Animals Feed the World? Although the earth has perhaps 30,000 plant species with parts that people can eat, only 15 plant and 8 terrestrial animal species supply an estimated 90% of our global intake of calories. Just three grain crops—*wheat, rice,* and *corn*—provide more than half the calories people consume. These three grains, and most other food crops, are *annuals,* whose seeds must be replanted each year.

Two-thirds of the world's people survive primarily on traditional grains (mainly rice, wheat, and corn), mostly because they cannot afford meat. As incomes rise, people consume more grain, but indirectly in the form of meat (mostly beef, pork, and chicken), eggs, milk, cheese, and other products of grain-eating 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. But on a global scale fish and shellfish supply only **(1)** 7% of the world's food, **(2)** less than 6% of the protein in the human diet, and **(3)** 1% of the energy in the human diet.

What Are the Major Types of Food Production? All crop production involves replacing species-rich late successional communities such as mature grasslands (Figure 6-30, p. 131) and forests (Figure 6-38, p. 138) with an early successional community (Figure 8-15, p. 181) consisting of a single crop (*monoculture,* Figure 6-31, p. 132) or a mixture of crops (*polyculture*).

The two major types of agricultural systems are industrialized and traditional. **Industrialized agriculture,** or **high-input agriculture,** uses large amounts of fossil fuel energy, water, commercial fertilizers, and pesticides to produce huge quantities of single crops (monocultures) or livestock animals for sale. Practiced on about 25% of all cropland, mostly in developed countries (Figure 13-2), high-input industrialized agriculture has spread since the mid-1960s to some developing countries.

Plantation agriculture is a form of industrialized agriculture practiced primarily in tropical developing countries. It involves growing cash crops (such as bananas, coffee, soybeans, sugarcane, cocoa, and veg-

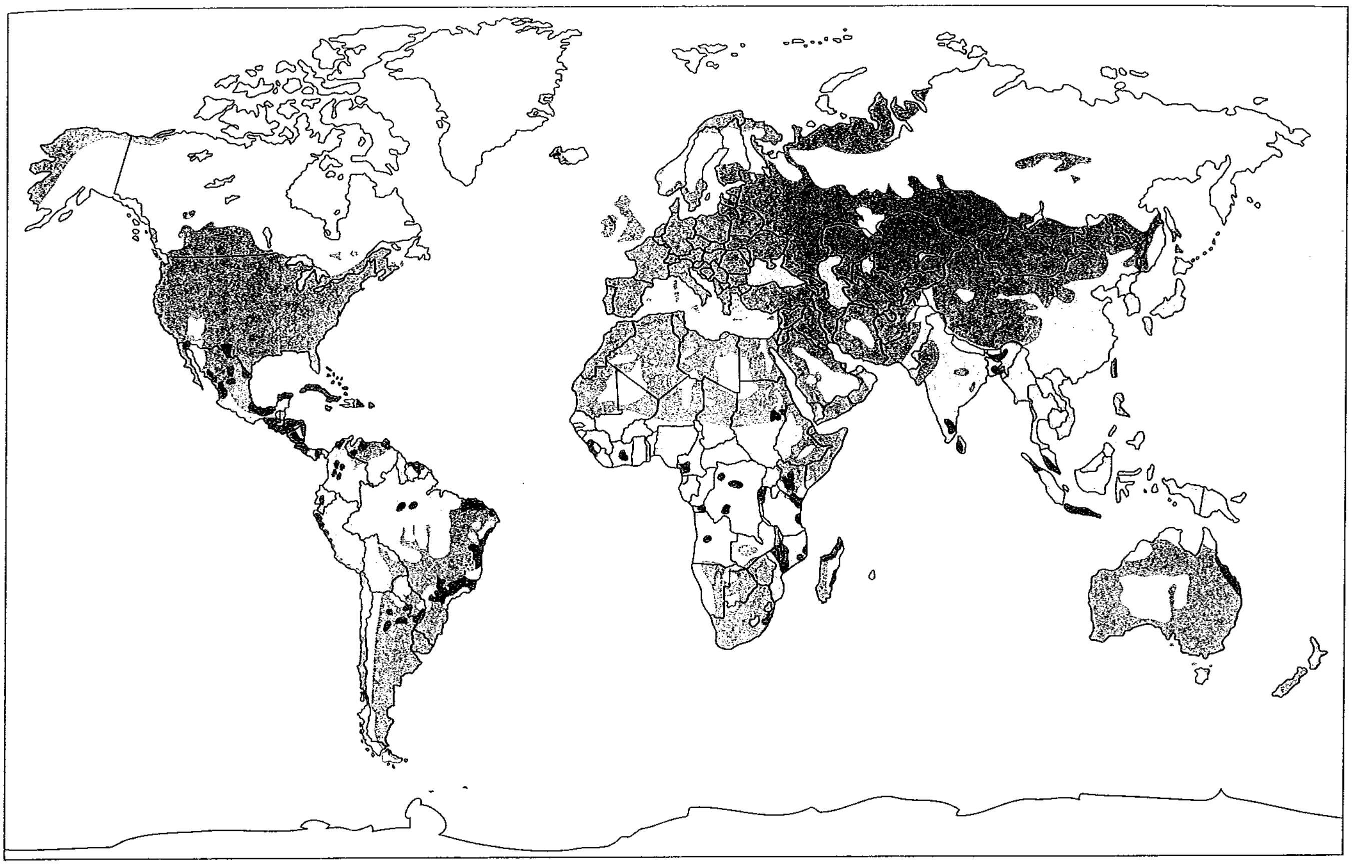


Figure 13-2 Locations of the world's principal types of food production. Excluding Antarctica and Greenland, agricultural systems cover almost one-third of the earth's land surface and account for an annual output of food worth about $1.3 trillion.

etables) on large monoculture plantations, mostly for sale in developed countries.

An increasing amount of livestock production in developed countries is industrialized. Large numbers of cattle are brought to densely populated feedlots, where they are fattened up for about 4 months before slaughter. Most pigs and chickens in developed countries spend their entire lives in densely populated pens and cages and are fed mostly grain grown on cropland.

Traditional agriculture consists of two main types, which together are practiced by about 2.7 billion people (44% of the world's people) in developing countries and provide about 20% of the world's food supply. **Traditional subsistence agriculture** typically uses mostly human labor and draft animals to produce only enough crops or livestock for a farm family's survival. Examples of this very low-input type of agriculture include numerous forms of shifting cultivation in tropical forests (Figure 2-2, p. 23) and nomadic livestock herding (Figure 13-2).

In **traditional intensive agriculture,** farmers increase their inputs of human and draft labor, fertilizer, and water to get a higher yield per area of cultivated land to produce enough food to feed their families and to sell for income. Figure 13-3 (p. 280) shows the relative inputs of land, human and animal labor, fossil fuel energy, and financial capital needed to produce one unit of food energy in various types of food production systems. In North America, only 2.4% of the labor force is engaged directly in food production, compared to 45–65% in developing countries. Figure 13-4 (p. 280) shows the estimated input of fossil fuel energy required to produce various foods.

Croplands, like natural ecosystems, provide ecological and economic services (Figure 13-5, p. 281). The food, fiber, and animal feed produced throughout the world is worth more than $1.3 trillion.

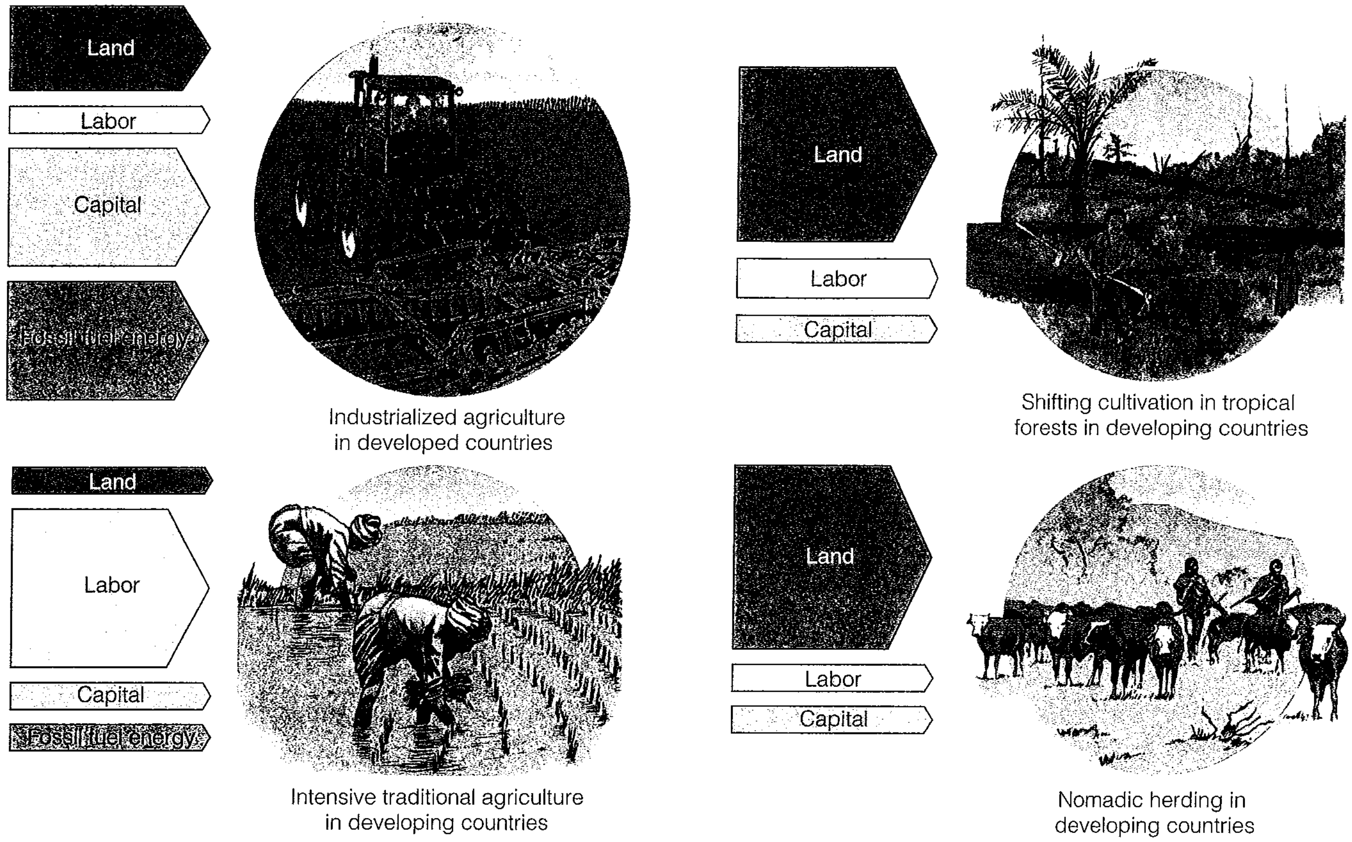


Figure 13-3 Relative inputs of land, labor, financial capital, and fossil fuel energy in four agricultural systems. An average of 60% of the people in developing countries are involved directly in producing food, compared with only 8% in developed countries (2% in the United States).

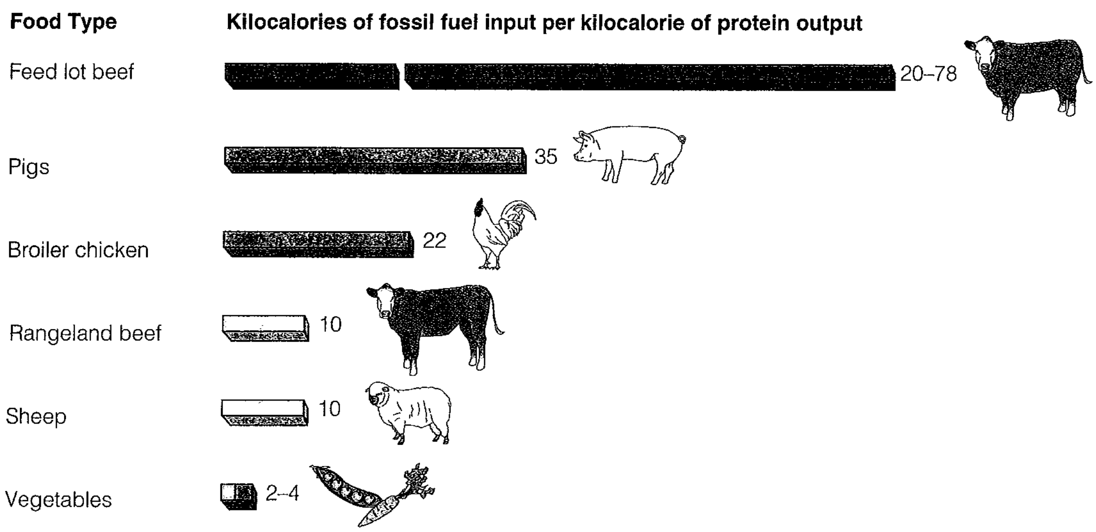


Figure 13-4 Estimated fossil fuel energy required for production of various foods. (Data from Malcolm Beveridge)

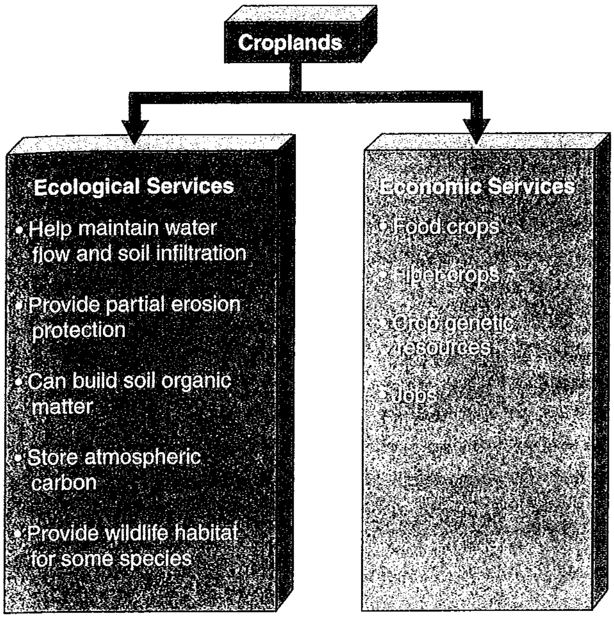


Figure 13-5 Ecological and economic services provided by croplands.

13-2 PRODUCING FOOD BY GREEN REVOLUTION AND TRADITIONAL TECHNIQUES

How Have Green Revolutions Increased Food Production? High-Input Monocultures in Action Farmers can produce more food by **(1)** farming more land or **(2)** getting higher yields per unit of area from existing cropland. Since 1950, most of the increase in global food production has come from increased yields per unit of area of cropland in a process called the **green revolution.**

This green revolution involves three steps:

- Developing and planting monocultures (Figure 6-31, p. 132) of selectively bred or genetically engineered high-yield varieties of key crops such as rice, wheat, and corn
- Producing high yields by using large inputs of fertilizer, pesticides, and water on crops
- Increasing 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* (Figure 13-6, p. 282).

A *second green revolution* has been taking place since 1967 (Figure 13-6, p. 282), by introducing fast-growing dwarf varieties of rice and wheat, specially bred for tropical and subtropical climates, into several developing countries. With enough fertile soil and fertilizer, water, and pesticides, yields of these new plants (Figure 13-7, p. 282) can be two to five times those of traditional wheat and rice varieties. The fast growth also allows farmers to grow two or even three crops a year (multiple cropping) on the same land. Producing more food on less land is also an important way to protect biodiversity by saving large areas of forests, grasslands, wetlands, and easily eroded mountain terrain from being used to grow food.

These yield increases depend not only on fertile soil and ample water but also on high inputs of fossil fuels to **(1)** run machinery, **(2)** produce and apply inorganic fertilizers and pesticides, and **(3)** pump water for irrigation. All told, high-input green revolution agriculture uses about 8% of the world's oil output.

Case Study: Food Production in the United States Since 1940, U.S. farmers have used green revolution techniques to more than double crop production without cultivating more land. This strategy has kept large areas of forests, grasslands, wetlands, and easily erodible land from being converted to farmland. Figure 13-8 (p. 283) shows the various uses of land in the United States.

Farming has become *agribusiness* as big companies and larger family-owned farms have taken control of almost three-fourths of U.S. food production. Only about 650,000 Americans (2% of the population) are full-time farmers. However, about 9% of the population is involved in the U.S. agricultural system, from growing and processing food to distributing it and selling it at the supermarket.

In terms of total annual sales, agriculture is bigger than the automotive, steel, and housing industries combined. It generates about 18% of the country's gross national product and 19% of all jobs in the private sector, employing more people than any other industry.

The U.S. agricultural system is highly productive. With only 0.3% of the world's farm labor force, U.S. farms produce about 17% of the world's grain (most consumed by U.S. livestock) and nearly half of the world's grain exports. U.S. residents spend an average of only 10–12% of their income on food (down from 21% in 1940), compared to 18% in Japan and 40–70% in most developing countries.

This industrialization of agriculture has been made possible by the availability of cheap energy, most of it from oil. Agriculture consumes about 17% of all commercial energy in the United States each year (Figure 13-9, p. 283). Most plant crops in the United States provide more food energy than the energy used to grow them. However, if we include livestock, the U.S. food production system uses about three units of fossil fuel energy to produce one unit of food energy.

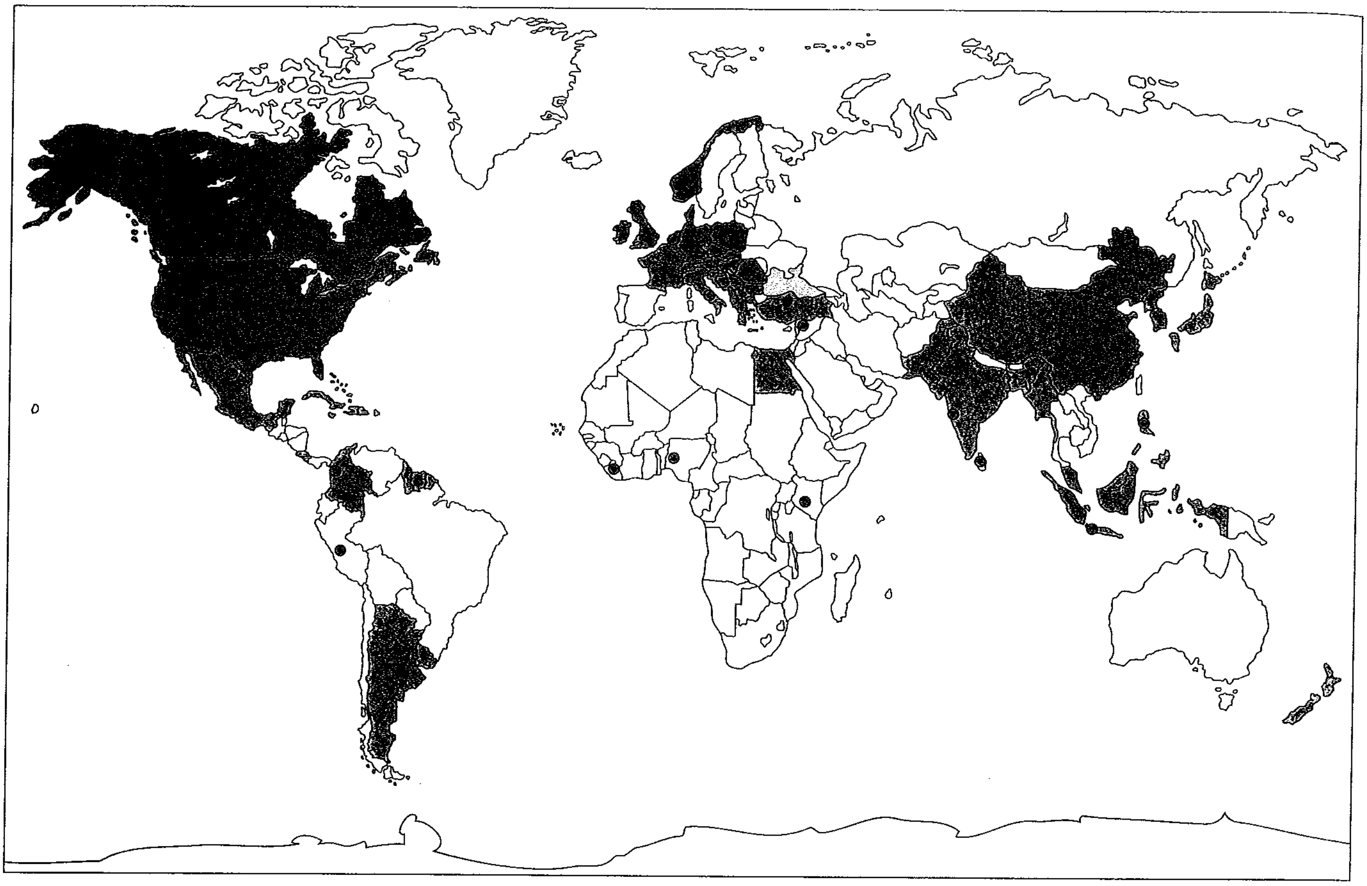


Figure 13-6 Countries whose crop yields per unit of land area increased during the two green revolutions. The first (blue) took place in developed countries between 1950 and 1970; the second (green) has occurred since 1967 in developing countries with enough rainfall or irrigation capacity. Several agricultural research centers and gene or seed banks (red dots) play a key role in developing high-yield crop varieties.

Figure 13-7 A high-yield, semidwarf variety of rice called IR-8 (left), a part of the second green revolution, was produced by crossbreeding two parent strains of rice: PETA from Indonesia (center) and DGWG from China (right). The shorter and stiffer stalks of the new variety allow the plants to support larger heads of grain without toppling over and increase the benefit of applying more fertilizer.

International Rice Research Institute, Manila

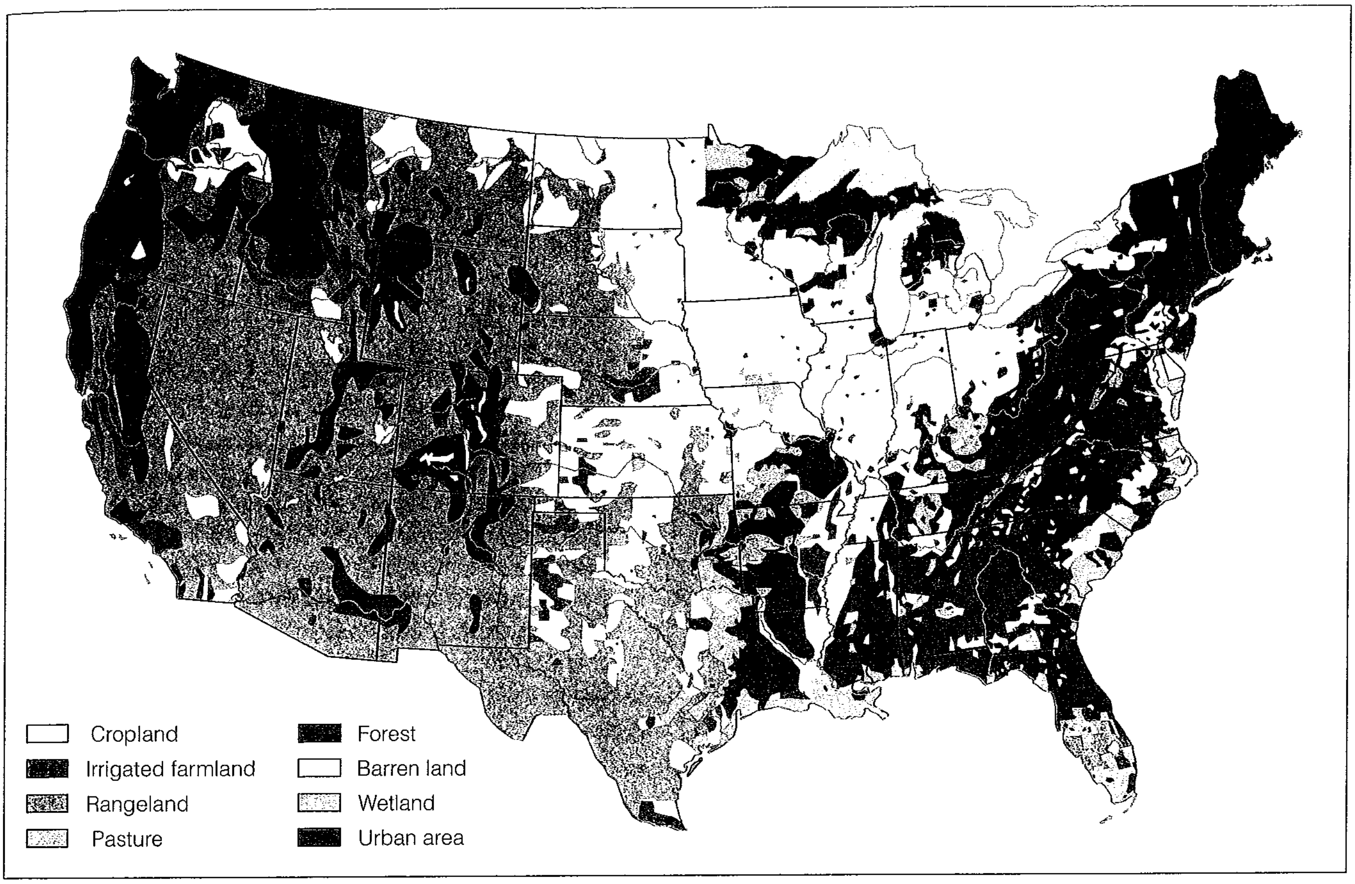


Figure 13-8 General uses of land in the United States. (Data from U.S. Geological Survey and U.S. Department of Agriculture)

Energy efficiency is much lower if we look at the whole U.S. food system. Considering 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.* By comparison, every unit of energy from human labor in traditional subsistence farming provides at least 1 unit of food energy and up to 10 units of food energy using traditional intensive farming.

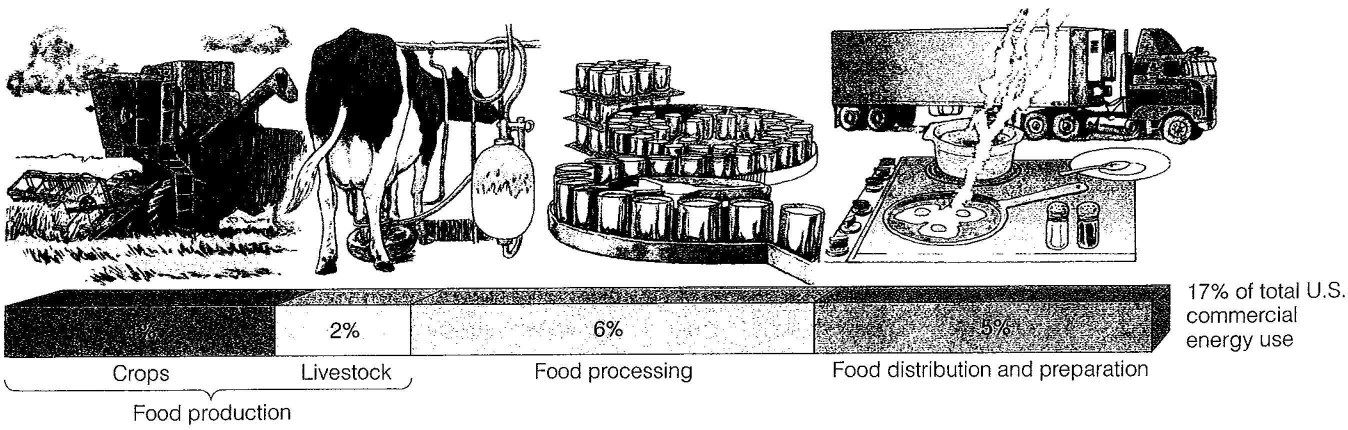


Figure 13-9 In the United States, industrialized agriculture uses about 17% of all commercial energy. On average, a piece of food eaten in the United States has traveled 2,100 kilometers (1,300 miles).

What Growing Techniques Are Used in Traditional Agriculture? Low-Input Agrodiversity in Action Traditional farmers in developing countries today grow about 20% of the world's food on about 75% of its cultivated land. Many traditional farmers simultaneously grow several crops on the same plot, a practice known as **interplanting.** Such crop diversity reduces the chance of losing most or all of the year's food supply to pests, bad weather, and other misfortunes.

Common interplanting strategies found throughout the world, mostly in developing countries, include the following:

- **Polyvarietal cultivation,** in which a plot is planted with several varieties of the same crop.
- **Intercropping,** in which two or more different crops are grown at the same time on a plot (for example, a carbohydrate-rich grain that uses soil nitrogen and a protein-rich legume that puts it back).
- **Agroforestry,** or **alley cropping,** in which crops and trees are planted together (Figure 10-26c, p. 224).
- **Polyculture,** a more complex form of intercropping in which many different plants maturing at various times are planted together. Advantages of this low-input approach include **(1)** less need for fertilizer and water because root systems at different depths in the soil capture nutrients and moisture efficiently, **(2)** protection from wind and water erosion because the soil is covered with crops year round, **(3)** little or no need for insecticides because multiple habitats are created for natural predators of crop-eating insects, **(4)** little or no need for herbicides because weeds have trouble competing with the multitude of crop plants, and **(5)** insurance against bad weather because of the diversity of crops raised. Wes Jackson is using this technique to grow perennial crops on prairie land in the United States (p. 277).

Recent ecological research on crop yields of 14 artificial ecosystems found that on average low-input polyculture (with four or five different crop species) produces higher yields per hectare of land than high-input monoculture. This finding has important implications for developing high-yield sustainable agriculture in developing countries by combining the techniques of traditional high-yield interplanting with increased inputs of organic fertilizer and irrigation. In 2001, 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.

Traditional farmers in arid and semiarid areas with low natural soil fertility have developed innovative methods to boost crop production. For example, in the African countries of Niger and Burkina Faso a farmer innovation called *tassas* has tripled yields on at least 100,000 hectares (250,000) acres of unproductive land. *Tassas* are small pits dug in the soil, filled with manure, and then planted with crops once they fill with infrequent rain.

13-3 FOOD PRODUCTION, NUTRITION, AND ENVIRONMENTAL EFFECTS

How Much Has Food Production Increased? Figure 13-10 illustrates the success of using high-input monoculture farming to produce food and ward off sharp rises in hunger, malnutrition, and food prices. Here is some *good news*:

- Between 1950 and 1990, world grain production almost tripled (Figure 13-10, left), and per capita grain production rose by about 36% (Figure 13-10, right).
- According to a 2001 World Bank study, the average inflation-adjusted price of all major types of food in 2000 was less than one-third of its price in 1957.

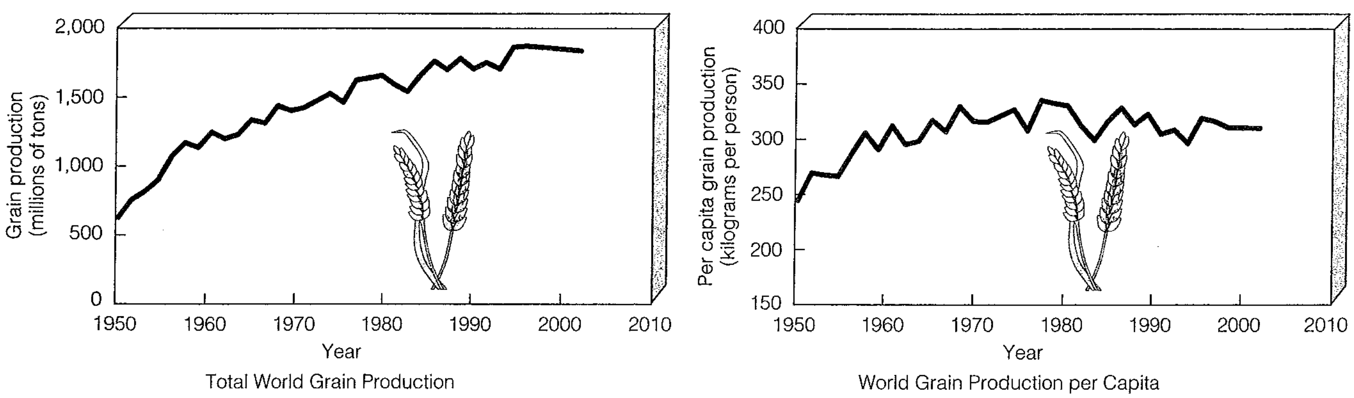


Figure 13-10 Total worldwide grain production of wheat, corn, and rice (left), and per capita grain production (right), 1950–2001. In order, the world's three largest grain-producing countries in 2001 were China, the United States, and India. (Data from U.S. Department of Agriculture, Worldwatch Institute, and UN Food and Agriculture Organization)

Despite these impressive achievements in food production, there is some *bad news:*

- Population growth is outstripping food production and distribution in areas that support about 2 billion people, especially in parts of **(1)** Africa with extreme poverty and very high population growth rates and **(2)** the former Soviet Union where economic growth, food production, and living standards have dropped sharply since 1990.
- Since 1985, global grain production has leveled off (Figure 13-10, left), and per capita grain production has declined (Figure 13-10, right).

There is controversy over why grain yields leveled off during the 1990s. According to some analysts, this occurred for economic and political reasons because **(1)** more efficient food production lowered the price that some farmers get for grain and reduced their incentive to grow more food and **(2)** grain yields per hectare dropped sharply in the former Soviet Union during the 1990s after its breakup.

Other analysts attribute much of this leveling off of grain production to environmental factors such as **(1)** limits on the amounts of water, fertilizer, and pesticides that green revolution crops can tolerate in some areas, and **(2)** loss of productivity from erosion and salinization of soil and lack of irrigation water in some areas, especially Africa.

What Is Undernutrition and Malnutrition? To maintain good health and resist disease, people need **(1)** fairly large amounts of *macronutrients* such as protein, carbohydrates, and fats, and **(2)** smaller amounts of *micronutrients* consisting of various 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 **undernutrition.** *Chronically undernourished* people consume between 100 and 400 fewer kilocalories per day than they need to maintain body weight and undertake light activity. Children in this category are likely to **(1)** suffer from mental retardation and stunted growth and **(2)** be much more susceptible to infectious diseases (such as measles and diarrhea).

People who are forced to live on a low-protein, high-carbohydrate diet consisting only of grains such as wheat, rice, or corn often suffer from **malnutrition:** deficiencies of protein and other key nutrients. Many of the world's desperately poor people, especially children, suffer from both undernutrition and malnutrition.

The two most common nutritional deficiency diseases are marasmus and kwashiorkor. *Marasmus* (from the Greek word *marasmos,* "to waste away") occurs when a diet is low in both calories and protein (see figure in Connections, p. 8). Most victims are either nursing infants of malnourished mothers or children who do not get enough food after being weaned from breast-feeding. If the child is treated in time with a balanced diet, most of these effects can be reversed.

Kwashiorkor (meaning "displaced child" in a West African dialect) is a severe protein deficiency occurring in infants and children ages 1–3, usually after the arrival of a new baby deprives them of breast milk. The displaced child's diet changes to grain or sweet potatoes, which provide enough calories but not enough protein. If it is caught soon enough, most of the harmful effects can be cured with a balanced diet. Otherwise, children who survive their first year or two suffer from stunted growth and mental retardation.

Chronically undernourished and malnourished people are disease prone and adults are too weak to work productively or think clearly. As a result, their children also tend to be underfed, malnourished, and susceptible to disease. If these children survive to adulthood, many are locked in a malnutrition and poverty cycle (Figure 13-11, p. 286) that can continue for generations.

How Serious Are Undernutrition and Malnutrition? Here is some *good news.* Despite population growth, according to the UN 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 2000, and is projected to continue rising through 2030 (Figure 13-12, p. 287).
- The estimated number of chronically undernourished or malnourished people fell from 918 million in 1970 to 826 million in 2000—792 million of them in developing countries (especially in Asia and Africa) and 34 million in developed countries.
- The estimated number of chronically undernourished or malnourished people in developing countries is projected to fall to 680 million by 2010 and 400 million by 2030.
- The percentage of the world's people suffering from chronic undernourishment or malnourishment fell **(1)** from 35% in 1970 to 17% in 2000, and **(2)** is projected to decline to 12% by 2010 and 6% by 2030.

However, according to the FAO, World Bank, and WHO some *bad news* is that

- About one of every six people in developing countries (including about one of every three children below age 5) is chronically undernourished or malnourished. This is an unacceptably high number in a world with the affluence and means to virtually eliminate poverty and hunger.
- The 1996 World Food Summit goal of cutting the number of undernourished and malnourished people

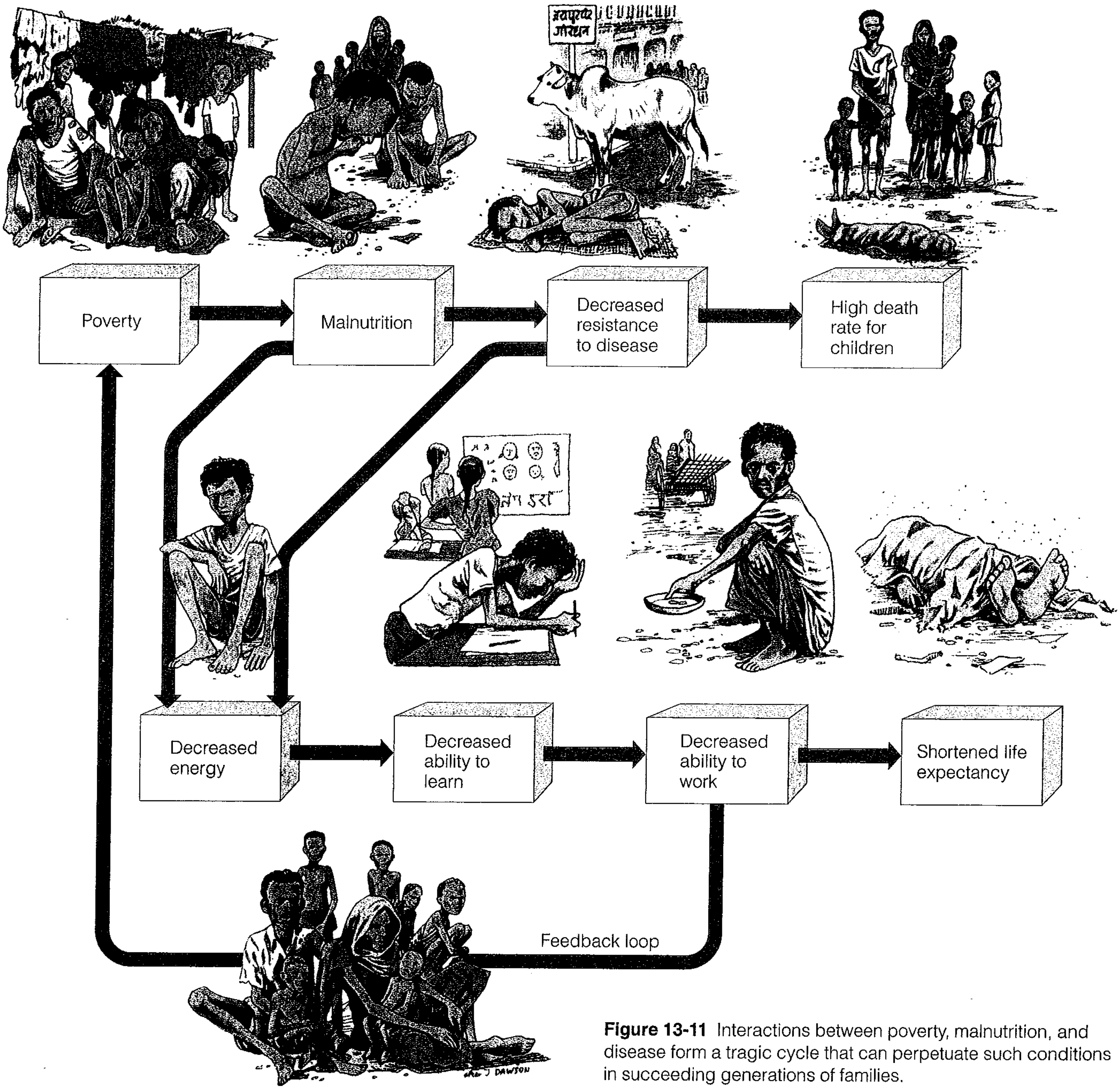


Figure 13-11 Interactions between poverty, malnutrition, and disease form a tragic cycle that can perpetuate such conditions in succeeding generations of families.

to 400 million by 2015 is not expected to be achieved before 2030—15 years late. According to the FAO, hungry people cannot wait another 15 years.

- Each year at least 10 million people, half of them children under age 5, die prematurely from **(1)** undernutrition, **(2)** malnutrition, **(3)** increased susceptibility to normally nonfatal infectious diseases such as measles and diarrhea because of their weakened condition from malnutrition, and **(4)** infectious diseases caused by drinking contaminated water.
- Disease and premature death from undernutrition and malnutrition is a "silent and invisible global emergency with a massive impact on children" that could be prevented (Solutions, p. 289).

How Serious Are Micronutrient Deficiencies? According to the WHO, about 2 billion people—about one out of three people—suffer from a deficiency of one or more vitamins and minerals. The most widespread micronutrient deficiencies in developing countries involve *vitamin A, iron,* and *iodine.*

The *bad news* that that 100–140 million children in developing countries are deficient in vitamin A. This puts them at risk for **(1)** blindness (about 500,000 cases per year) and **(2)** premature death because even mild vitamin A deficiency reduces children's resistance to infectious diseases such as diarrhea and measles.

Some *good news* is that Swiss scientists recently spliced genes into rice to make it rich in beta-carotene, the source of vitamin A. According to the

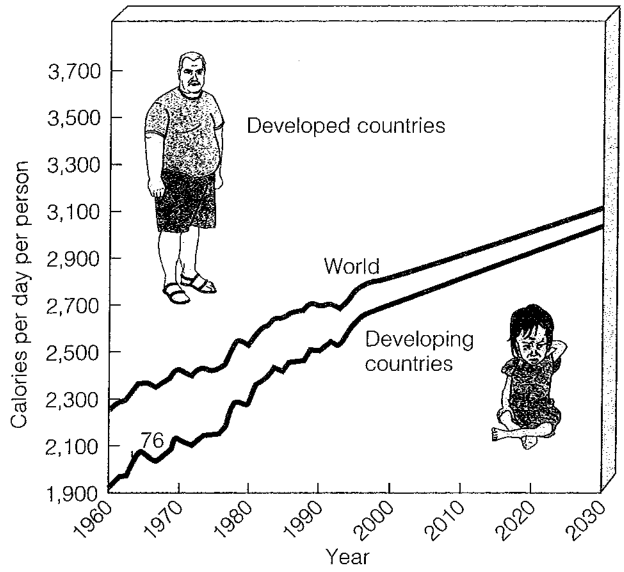


Figure 13-12 The average daily food intake in calories per person in the world, developing countries, and developed countries: 1961–2000 and projected increases to 2030. The average adult male needs about 2,500 calories per day for good health. (Data from UN Food and Agriculture Organization)

United Nations Children's Fund (UNICEF), improved vitamin A nutrition through use of this vitamin-fortified rice, called Golden Rice, could prevent 1–2 million premature deaths per year among children under age 5.

Some *bad news* is that **(1)** the average person would have to consume about 9 kilograms (20 pounds) of cooked rice per day to get the necessary amount of vitamin A, and **(2)** beta carotene can be converted to vitamin A only in the body of a well-nourished person.

Other nutritional deficiency diseases are caused by the lack of minerals. Too little *iron* (a component of hemoglobin that transports oxygen in the blood) causes anemia. Iron is found in whole grains, green leafy vegetables, and meat. Iron deficiency **(1)** causes fatigue, **(2)** makes infection more likely, **(3)** increases a woman's chances of dying in childbirth, **(4)** increases an infant's chances of dying of infection during its first year of life, and **(5)** cripples efforts to improve primary school education because developing brains need adequate iron to learn. According to a 1999 survey by the WHO, one of every three people, mostly women and children in tropical developing countries, suffers from iron deficiency.

Elemental *iodine,* found in seafood and crops grown in iodine-rich soils, is essential for the functioning of the thyroid gland, which produces a hormone that controls the body's rate of metabolism. Lack of iodine can cause **(1)** stunted growth, **(2)** mental retardation, and **(3)** goiter (an abnormal enlargement of the thyroid gland that can lead to deafness).

Some *good news* is that WHO and UNICEF programs to get countries to add iodine to salt slashed the percentage of the world's people with iodine deficiency from 29% to 12% between 1994 and 1999. Some *bad news* is that this still leaves at least 740 million people in developing countries—2.5 times the U. S. population—with too little iodine in their diet.

How Serious Is Overnutrition? About one out of seven adults in developed countries (one out of five in the United States) suffers from **overnutrition,** a condition in which food energy intake exceeds energy use and causes excess body fat (obesity). Too many calories (Figure 13-12, top curve), 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: **(1)** lower life expectancy, **(2)** greater susceptibility to disease and illness, and **(3)** lower productivity and life quality.

Overnutrition is the second leading cause of preventable deaths after smoking (p. 228), mostly from heart disease, cancer, stroke, and diabetes. An estimated 300,000 Americans die prematurely each year as a result of being overweight. This death toll is roughly equivalent to two fully loaded jumbo (400-passenger) jets crashing accidentally every day with no survivors.

A study of thousands of Chinese villagers indicates that the healthiest diet for humans is largely vegetarian, with only 10–15% of calories coming from fat. This is in contrast to the typical meat-based diet, in which 40% of the calories come from fat.

About 61% of the U.S. adult population is overweight and 27% is obese—the highest percentage of any developed country. The $36 billion Americans spend each year trying to lose weight is almost twice the $19 billion needed to eliminate undernutrition and malnutrition in the world.

Some nutrition analysts, including Yale University professor Kelly Brownwell, advocate discouraging consumption of unhealthful foods by

- Regulating advertising of junk foods.
- Taxing food based on its nutrient value per calorie. Sugary and fatty foods low in nutrients would be taxed the most, and fruits and vegetables would not be taxed.
- Using the resulting tax revenues to promote **(1)** healthful diets, **(2)** nutrition education, and **(3)** exercise programs in schools and communities.

Do We Produce Enough Food to Feed the World's People? The *good news* is that according to the FAO **(1)** we produce more than enough food to meet the basic nutritional needs of every person on the earth today and **(2)** there should be more food for more people in the future (Figure 13-12). If distributed equally, the grain currently produced worldwide is enough to give everyone a meatless subsistence diet.

The *bad news* for the one out of eight people not getting enough to eat is that food is not distributed equally among the world's people because of differences in **(1)** soil, **(2)** climate, **(3)** political and economic power, and **(4)** average per capita income throughout the world (Figure 1-3, p. 5).

Most agricultural experts agree that *the principal cause of hunger and malnutrition is and will continue to be poverty,* which prevents poor people from growing or buying enough food regardless of how much is available. For example, according to the United Nations, in the 1990s nearly 80% of all malnourished children lived in countries with food surpluses. Thus *poverty, not lack of food production, is the real food problem for about one out of eight people.*

What Are the Environmental Effects of Producing Food? Agriculture has significant harmful effects on air, soil, water, and biodiversity (Figure 13–13). Ecologist David Pimentel has estimated that the harmful environmental costs not included in

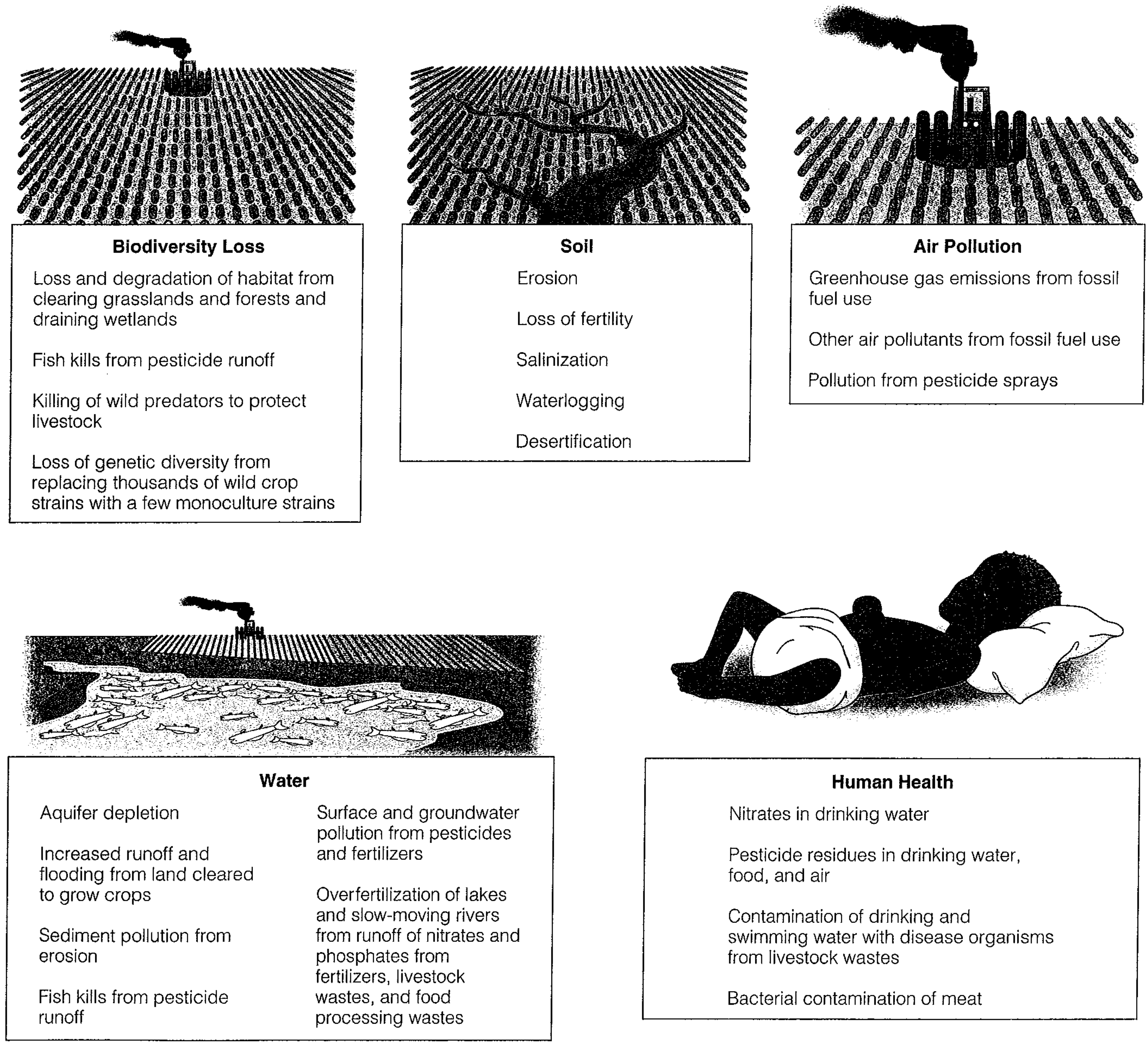


Figure 13-13 Major environmental effects of food production. According to UN studies, land degradation reduced cumulative food production worldwide by about 13% on cropland and 4% on pastureland between 1950 and 2000.

Saving Children

SOLUTIONS

According to the World Health Organization, 7 out of 10 of the deaths of children under age 5 in developing countries can be attributed to one or a combination of five main causes: malnutrition, pneumonia, diarrhea, measles, and malaria.

According to the United Nations Children's Fund (UNICEF), one-half to two-thirds of childhood deaths from nutrition-related causes could be prevented at an average annual cost of only $5–10 per child, or only 10–19¢ per week. This life-saving program would involve 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 people a vitamin A capsule twice a year at a cost of about 75¢ per person or fortifying common foods with vitamin A and other micronutrients at a cost of about 10¢ per person annually
- 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, and child care

Critical Thinking

How much money (if any) would you be willing to spend each year to help implement such a program for saving children? Why has insufficient money been allocated for such a program?

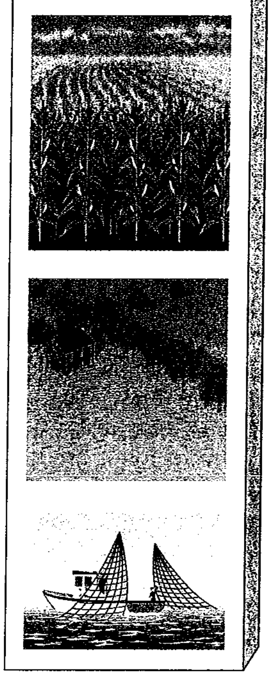
the prices of food in the United States are $150–200 billion per year.

According to Norman Myers (Guest Essay, p. 108), the future ability to produce more food will be limited by a combination of **(1)** soil erosion (Figure 10-19, p. 218), **(2)** desertification (Figure 10-20, p. 220), **(3)** salinization and waterlogging of irrigated lands (Figure 10-22, p. 221), **(4)** water deficits and droughts, **(5)** loss of wild species that provide the genetic resources for improved forms of foods, and **(6)** the effects of global warming (Figure 13-14).

According to a 2000 study by the UN-affiliated International Food Policy Research Institute, nearly 40% of the world's cropland is seriously degraded (including 75% in Central America, 20% in Africa, and 11% in Asia). Other studies indicate that 10–20% of the world's cropland suffers from degradation, with 7–14% seriously degraded (25% in developing countries). Such environmental factors may limit food production in India and China (Case Study, p. 293), the world's two most populous countries.

Advantages

- Increased crop yields in some areas
- Increased precipitation in some dry areas
- Longer growing seasons in currently cool areas
- Less precipitation in some areas with too much precipitation
- Increased yields of warm-water fish
- Expanded growing area



Disadvantages

- Lower crop yields in some areas
- Decreased precipitation is some areas
- Shorter growing seasons in some areas
- More unpredictable farming conditions
- Increased pest populations in warmer areas
- Loss of wetlands and fertile coastal land from rising sea levels
- Changes in distribution of fish supplies

Figure 13-14 Some affects of projected global warming on growing crops and catching fish.

13-4 INCREASING WORLD CROP PRODUCTION

How Can Crossbreeding Be Used to Develop Genetically Improved Crop Strains? For centuries, farmers and scientists have used traditional methods of *crossbreeding* through artificial selection to develop genetically improved varieties of crop strains and livestock (Spotlight, p. 100). For example, two crop plants such as a variety of a pear and of an apple can be crossbred with the goal of producing a pear with a more reddish color (Figure 13-15, p. 290). This is repeated for a number of generations until the desired trait in the pear predominates.

Agricultural experts expect most future increases in food yields per hectare on existing cropland to result from improved crossbred strains of plants and from expansion of green revolution technology to new parts of the world.

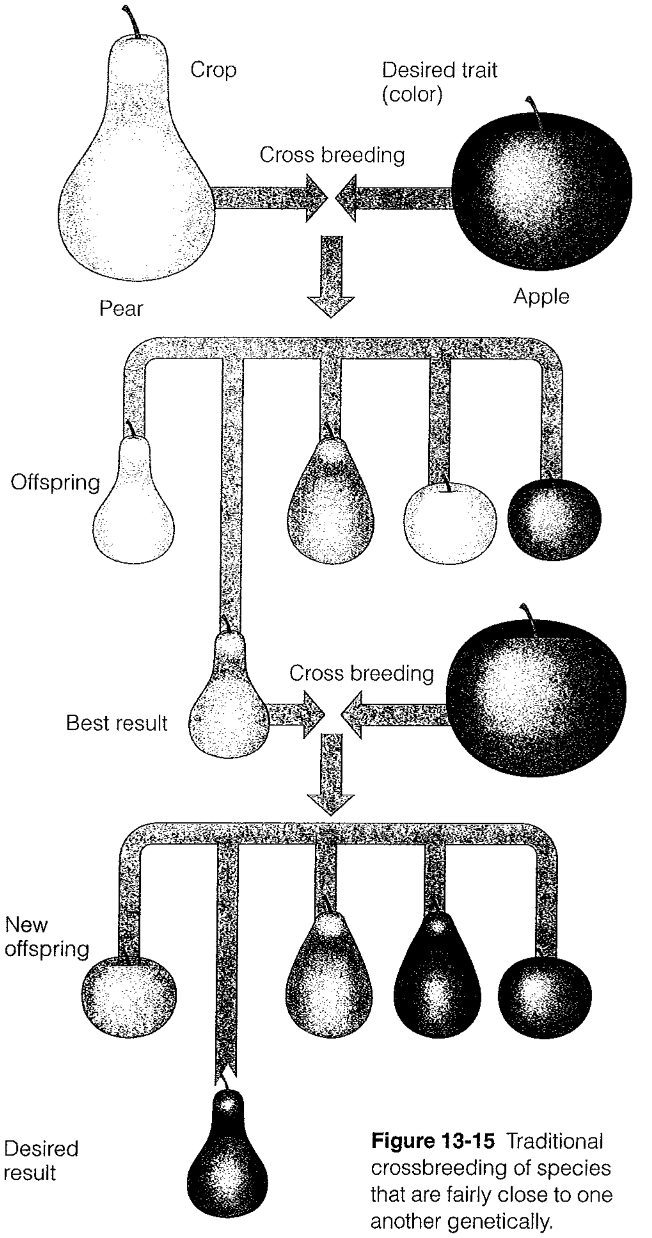


Figure 13-15 Traditional crossbreeding of species that are fairly close to one another genetically.

However, traditional crossbreeding **(1)** is a slow process, typically taking 15 years or more to produce a commercially valuable new variety, **(2)** can combine traits only from species that are close to one another genetically, and **(3)** provides varieties that are useful for only about 5–10 years before pests and diseases reduce their effectiveness.

Is Genetic Engineering the Answer? Scientists are working to create new green revolutions—actually *gene revolutions*—by using genetic engineering and other forms of biotechnology to develop new genetically improved strains of crops. **Genetic engineering,** or **gene splicing,** of food crops is the insertion of an alien gene into a commercially valuable plant (or animal) to give it new beneficial genetic traits. Such organisms are called **genetically modified organisms (GMOs).**

In comparison to traditional crossbreeding (Figure 13-15), gene splicing **(1)** takes about half as much time to develop a new crop or animal variety, **(2)** cuts costs, and **(3)** allows the insertion of genes from almost any other organism into crop or animal cells. Figure 13-16 outlines the steps involved in developing a genetically modified or transgenic plant.

Scientists are also using the following techniques:

- *Advanced tissue culture techniques* to produce only the desired parts of a plant such as its oils or fruits.
- *Transgenomics* in which an artificially created DNA sequence is introduced into a plant's DNA to stimulate a mutation that activates genes that provide the desired trait. If successful, **(1)** scientists will be able to speed up the rate of beneficial mutations that is a major driving force in biological evolution (p. 100), and **(2)** sidestep some of the current critics of biotechnology.

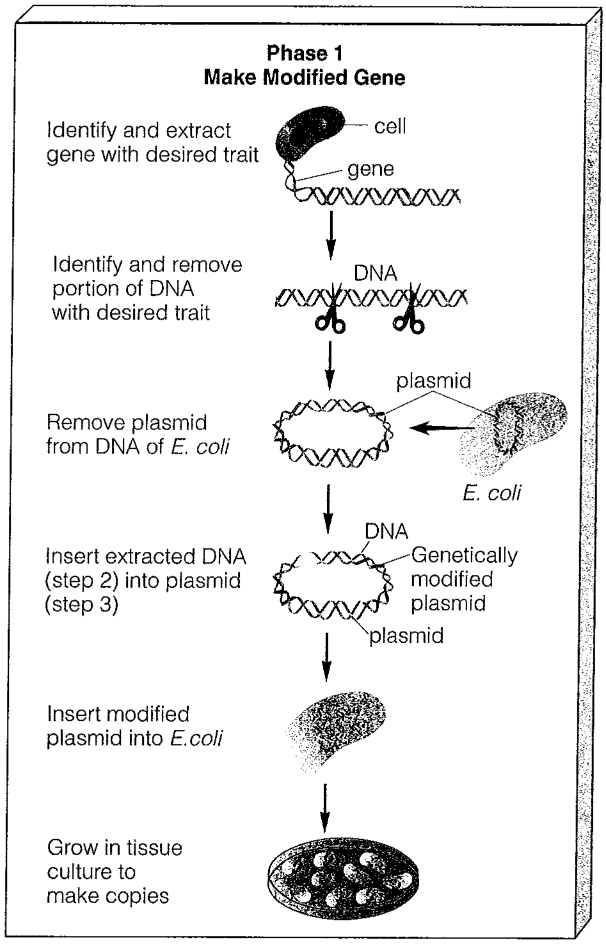
Ready or not, the world is entering the *age of genetic engineering.* Nearly two-thirds of the food products on U.S. supermarket shelves contain genetically engineered crops, and the proportion is increasing rapidly. The United States, Canada, and Argentina contain about 98% of the world's land currently planted with genetically engineered crops.

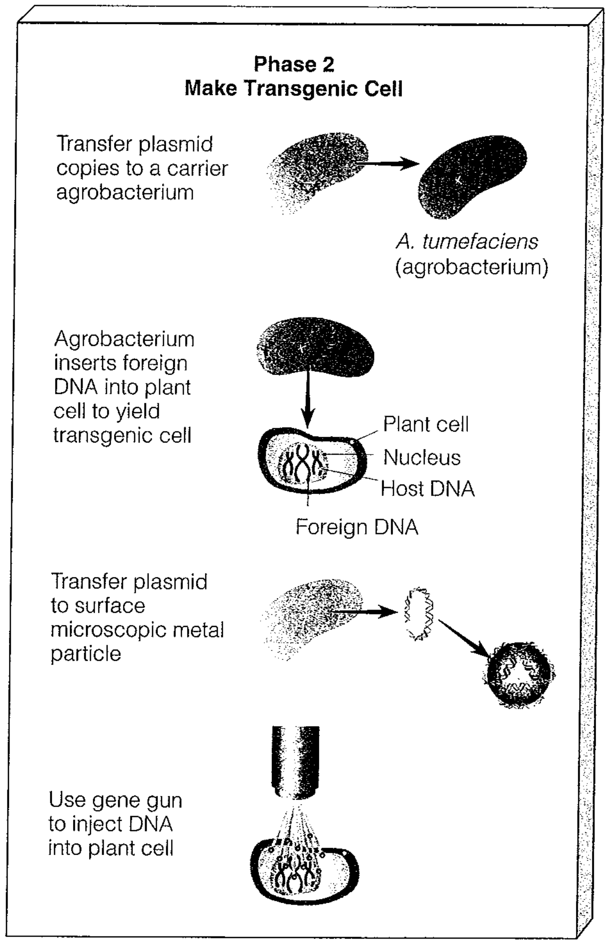
Controversy is growing over the use of *genetically modified food* (GMF). Such food is seen as a potentially sustainable way to solve world food problems by its producers and investors and called potentially dangerous "Frankenfood" by its critics. Figure 13-17 (p. 292) summarizes the pros and cons of this new technology.

Critics recognize the potential benefits of genetically modified crops but say **(1)** we know far too little about the potential harm from widespread use of such crops to human health and ecosystems, and **(2)** genetically modified organisms cannot be recalled if they cause harmful genetic and ecological effects. They call for **(1)** more controlled field experiments, **(2)** more research and long-term safety testing to better understand the risks, **(3)** stricter regulation of this technology, and **(4)** mandatory labeling of such foods to provide consumers with a choice (now required in Japan, Europe, South Korea, Canada, Australia, and New Zealand and favored by 81% of Americans polled in 1999). Industry representatives oppose this because **(1)** they claim the foods are not substantially different from conventional foods and **(2)** labeling such foods would hurt sales by arousing unwarranted suspicion.

According to a 2002 study by the U.S. National Academy of Sciences,

- There is no strong evidence suggesting that genetically engineered crops cause environmental harm.
- This lack of evidence does not necessarily mean that these crops do not cause environmental damage





because the United States does not have in place a system for systematic monitoring of agricultural and natural ecosystems.

There is also concern about the future use of genetic engineering to

- Use bioengineered pathogens to devastate a country's crops during warfare or as an act of terrorism. For example, the United States has developed a bioengineered pathogen to kill coca plants (used to produce cocaine) in Colombia in South America.
- Develop crop seed varieties that contain *terminator genes.* Such genes would prevent the seeds from a crop planted one year from reproducing in subsequent years unless the gene is unlocked by applying certain chemicals or antibiotics sold by the seed company. Thus terminator gene technology provides a seed company with control over any farmer who adopts it.

In 2001, member states of the FAO adopted an international treaty that affirms the right of farmers to **(1)** save, use, exchange, and sell farm-saved seed for 64 crops and **(2)** limits the genetic materials of plants biotechnology companies can patent in countries that ratify the treaty.

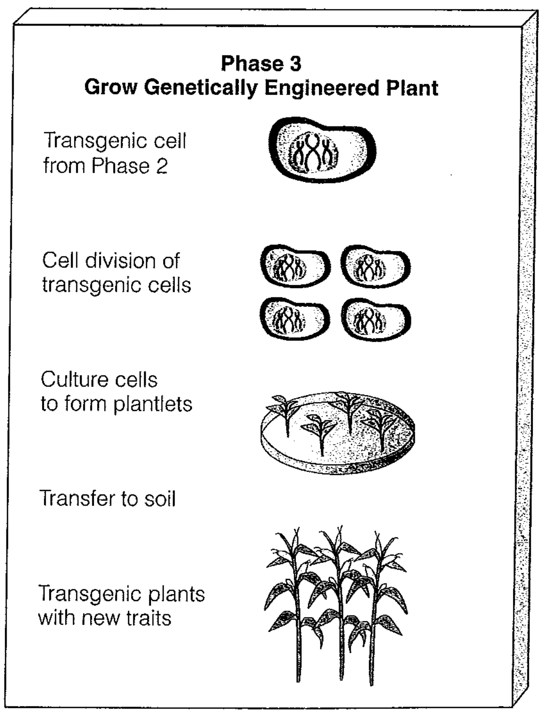


Figure 13-16 Steps in genetically modifying a plant.

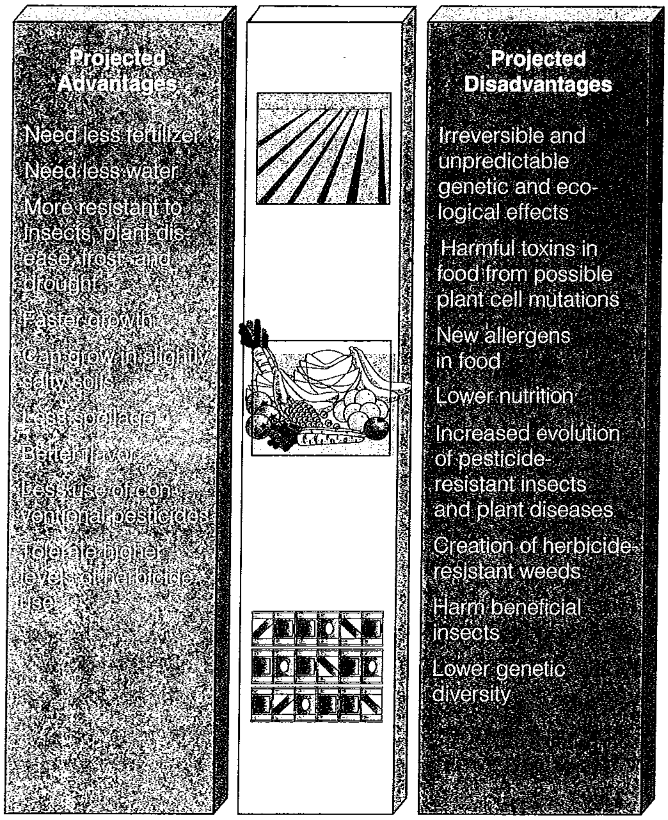


Figure 13-17 Projected advantages and disadvantages of genetically modified crops and foods.

Growing numbers of food manufacturers and retailers, first in Europe and now in the United States, have stopped selling GMFs. As a result, some major food biotech companies have made biotech crop operations a lower priority or are getting out of the business.

Can We Continue Expanding the Green Revolution? Many analysts believe it is possible to produce enough food to feed the 9.3 billion people projected by 2050 through **(1)** new advances in gene-splicing technology and **(2)** by spreading the use of new and existing high-yield green revolution techniques throughout most of the world.

Other analysts point to the following factors that have limited the success of the green and gene revolutions to date and may continue to do so:

- Without huge amounts of fertilizer and water, most green revolution crop varieties produce yields that are no higher (and are sometimes lower) than those from traditional strains; this is why the second green revolution has not spread to many arid and semiarid areas such as much of Africa and Australia (Figure 13-6).
- Green revolution and genetically engineered crop strains and their needed inputs of water, fertilizer, and pesticides cost too much for most subsistence farmers in developing countries.
- Continuing to increase fertilizer, water, and pesticide inputs eventually produces no additional increase in crop yields but we do not know when these biological and physiological limits on yields will be reached in various parts of the world.
- The *good news* is that grain yields per hectare are still increasing in many parts of the world. The *disturbing news* is that such yields are increasing at a much slower rate. For example, grain yields rose about 2.1% a year between 1950 and 1990 but dropped to 1.1% per year between 1990 and 2000.
- According to Indian economist Vandana Shiva, overall gains in crop yields from new green and gene revolution varieties may be much lower than claimed. The yields are based on comparisons between the output per hectare of old and new *monoculture* varieties rather than between the even higher yields per hectare for *polyculture* cropping systems and the new monoculture varieties that often replace them.
- Crop yields may start dropping for a number of environmental reasons: **(1)** the soil erodes, loses fertility, and becomes salty and waterlogged (Figure 10-22, p. 221), **(2)** underground and surface water supplies become depleted and polluted with pesticides and nitrates from fertilizers, and **(3)** populations of rapidly breeding pests develop genetic immunity to widely used pesticides. We do not know how close we are to such environmental limits in various parts of the world.
- Increased loss of biodiversity can limit the genetic raw material needed for future green and gene revolutions (Spotlight, p. 295).

Will People Try New Foods? Some analysts recommend greatly increased cultivation of less widely known plants to supplement or replace such staples as wheat, rice, and corn. One of many possibilities is the *winged bean,* a protein-rich legume now common only in New Guinea and Southeast Asia. This fast-growing plant produces so many different edible parts that it has been called a supermarket on a stalk. It also needs little fertilizer because of nitrogen-fixing nodules in its roots.

Insects—called *microlivestock*—are also important potential sources of protein, vitamins, and minerals in many parts of the world. There are about 1,500 edible insect species. Some are important food items in many parts of the world. Examples include **(1)** black ant larvae (served in tacos in Mexico), **(2)** giant waterbugs (crushed into vegetable dip in Thailand), **(3)** *Mopani,* or emperor moth caterpillars (eaten in South Africa), **(4)** cockroaches (eaten by Kalahari desert dwellers), **(5)** lightly toasted butterflies (a favorite food in Bali),

Can China's Population Be Fed?

CASE STUDY

Since 1970, China has made significant progress in feeding its people and slowing its rate of population growth (p. 273). Despite such efforts, China is projected to add about 275 million people between 2000 and 2030—about as many people as live in the United States today.

There is concern that crop yields may not be able to keep up with demand. A basic problem is that with 21% of the world's people, China has only **(1)** 7% of the world's cropland and fresh water, **(2)** 4% of its forests, and **(3)** 2% of its oil.

China depends on irrigated land to produce 70% of the grain for its population. According to projections by the Worldwatch Institute and the U.S. Central Intelligence Agency, China's grain production could fall by at least 20% between 1990 and 2030, mostly because of **(1)** water shortages, **(2)** degraded cropland, and **(3)** diversion of water from cropland to cities.

A growing amount of China's cropland is irrigated by withdrawing groundwater from aquifers faster than they are naturally recharged. An example is the heavily irrigated North China Plain, which produces over half of China's wheat and a third of its corn. According to a 2001 study by the Geological Environmental Monitoring Institute in Beijing, the water table under this plain is falling faster than thought.

As such groundwater deficits worsen, China's options are to **(1)** take land out of irrigation, **(2)** switch to less thirsty crops, **(3)** irrigate more efficiently, **(4)** divert water in rivers from the south to the north, and **(5)** import more grain.

As incomes in China have risen, so has meat consumption. The Chinese now equal Americans in consumption of pork and are now concentrating on increasing beef production.

Even if China's currently booming economy resulted in no increases in meat consumption, the 20% projected drop in grain production would mean that by 2030 China would need to import more than all of the world's current grain exports (roughly half from the United States).

However, if the increased demand for meat led to a rise in per capita grain consumption equal to the current level in Taiwan (one-half the current U.S. level), China would need to import more than the entire current grain output of the United States .

As pressures on grazing land increased, Japan began getting most of its animal protein from the ocean. If China—with 10 times more people—did this, its annual seafood consumption would be equal to the entire world fish catch.

The Worldwatch Institute and the U.S. Central Intelligence Agency warn that if either of these scenarios is correct, no country or combination of countries has the potential to supply even a small fraction of China's potential food supply deficit. This does not take into account the huge grain deficits that are projected in other parts of the world by 2030, especially in Africa and India.

However, other analysts disagree with this assessment. For example,

- According to a 1997 study by the International Food Policy Institute, China should be able to feed its population and begin exporting grain again by 2020 if the government invests in **(1)** expanding irrigation, **(2)** using more water-efficient forms of irrigation, and **(3)** increasing agricultural research.
- Recent satellite surveys show that China has about 40% more potential cropland than previously thought.
- The World Bank concluded in 1997 that China's domestic food production should keep up with its population growth for the next two or three decades without having to import large amounts of grain.

Critical Thinking

If the scenarios about China's future dependence on greatly increased food imports are accurate, how might this affect **(a)** world food prices and **(b)** your life? What actions, if any, do you suggest for dealing with this potential problem?

and **(6)** fried ants (sold on the streets of Bogota, Colombia). Most of these insects are 58–78% protein by weight—three to four times as protein rich as beef, fish, or eggs. Two problems are **(1)** getting farmers to take the financial risk of cultivating new types of food crops and **(2)** convincing consumers to try new foods.

Some plant scientists believe we should rely more on polycultures of perennial crops, which are better adapted to regional soil and climate conditions than most annual crops (p. 277). Using perennials would also **(1)** eliminate the need to till soil and replant seeds each year, **(2)** greatly reduce energy use, **(3)** save water, and **(4)** reduce soil erosion and water pollution from eroded sediment. However, large seed companies that make their money selling farmers seeds each year for annual crops generally oppose this idea.

Is Irrigating More Land the Answer? About 40% of the world's food production comes from the 18% of the world's cropland that is irrigated. Irrigated land produces about 70% of the grain harvest in China, 50% in India, and 15% in the United States.

Some *good news* is that between 1950 and 2002, the world's irrigated area tripled, with most of the growth occurring from 1950 to 1978. Some *bad news* is that since 1978, the amount of irrigated land per person has been falling and is projected to fall much more between 2000 and 2050 (Figure 13-18). Reasons for this downward trend include the following:

- World population has grown faster than irrigated agriculture since 1978.
- Water is being pumped more rapidly than it is replaced from aquifers in many of the world's food-growing areas.
- Irrigation water is used inefficiently.
- Crop productivity is decreased by soil salinization (Figure 10-23, p. 222) on irrigated cropland.
- Increasing urbanization puts city dwellers and farmers in competition for limited water supplies.
- Global warming may disrupt water supplies in some food-growing areas.
- The majority of the world's farmers do not have enough money to irrigate their crops. Thus rainfall is the source of water for 83% of the world's cropland.

Key methods for using water more sustainably in crop production are **(1)** increasing irrigation efficiency, **(2)** shifting to crops that need less water (for example, depending less on water-thirsty rice and sugarcane and more on wheat and sorghum), and **(3)** withdrawing water from aquifers no faster than they are replenished.

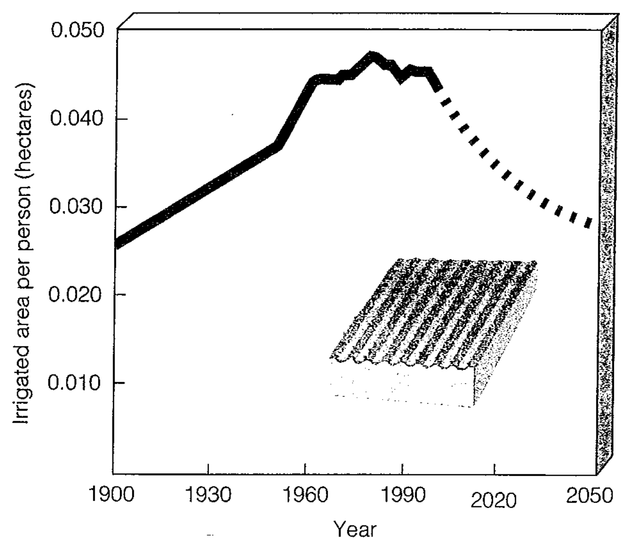


Figure 13-18 World irrigated area of cropland per person, 1900–2001, with projections to 2050. (Data from United Nations Food and Agriculture Organization, U.S. Census Bureau, and the Worldwatch Institute)

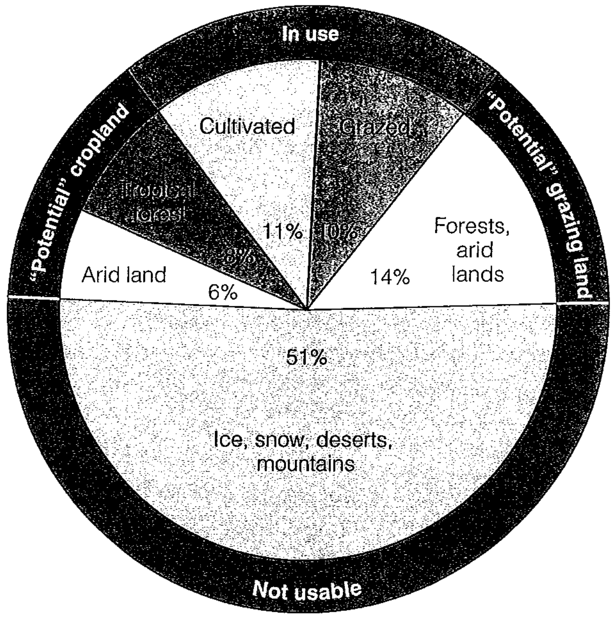


Figure 13-19 Classification of the earth's land. Theoretically, we could double the amount of cropland by clearing tropical forests and irrigating arid lands. However, converting these lands into cropland would **(1)** destroy valuable forest resources, **(2)** reduce the earth's biodiversity, **(3)** affect water quality and quantity, and **(4)** cause other serious environmental problems, usually without being cost effective.

Is Cultivating More Land the Answer?

Theoretically, the world's cropland could be more than doubled by clearing tropical forests and irrigating arid land (Figure 13-19). But much of this is *marginal land* with poor soil fertility, steep slopes, or both. Cultivation of such land is unlikely to be sustainable.

Most of the land cleared in tropical rain forests has nutrient-poor soils (Figure 10-15, lower left, p. 215) and cannot support crop growth for more than a couple of years. In addition, potential cropland in savanna and other semiarid land in Africa cannot be used for farming or livestock grazing. The reason is the presence of 22 species of the tsetse fly, which transmits a protozoan parasite that causes incurable sleeping sickness in humans and a fatal disease in livestock.

Some researchers hope to develop new methods of intensive cultivation in tropical areas. Other scientists argue that it makes more ecological and economic sense to combine ancient methods of shifting cultivation (Figure 2-2, p. 23) with various forms of polyculture.

Much of the world's potentially cultivable land lies in dry areas, especially in Australia and Africa. Large-scale irrigation in these areas would **(1)** require large, expensive dam projects with a mixture of beneficial and harmful impacts, **(2)** use large inputs of fossil fuel to pump water long distances, **(3)** deplete groundwater supplies by removing water faster than it is replenished, and **(4)** require expensive efforts to prevent erosion, groundwater contamination, salinization, and waterlogging, all of which reduce crop productivity.

Thus much of the world's new cropland that could be developed would be on land that is marginal for raising crops and requires expensive inputs of fertilizer, water, and energy. Furthermore, these potential increases in cropland would not offset the projected loss of almost one-third of today's cultivated cropland caused by erosion, overgrazing, waterlogging, salinization, and urbanization.

Such expansion in cropland would also reduce wildlife habitats and thus the world's biodiversity. According to the FAO, cultivating all potential cropland in developing countries would reduce forests, woodlands, and permanent pasture by 47%. Clearing these forests would also release a huge amount of carbon dioxide into the atmosphere and accelerate global warming, which is expected to cause shifts in the areas where crops could be grown.

Thus *many analysts believe that significant expansion of cropland is unlikely over the next few decades.* For example, the International Food Policy Institute and FAO estimate that 80% of projected increase in food production between 1993 and 2020 will come from increased yields per hectare and only 20% from expansion of cropland, If such assessments are correct, the world's grainland area per person, which dropped by half between 1950 and 1998 (because population growth grew seven times faster than expansion of grainland), is expected to decline further (Figure 13-20).

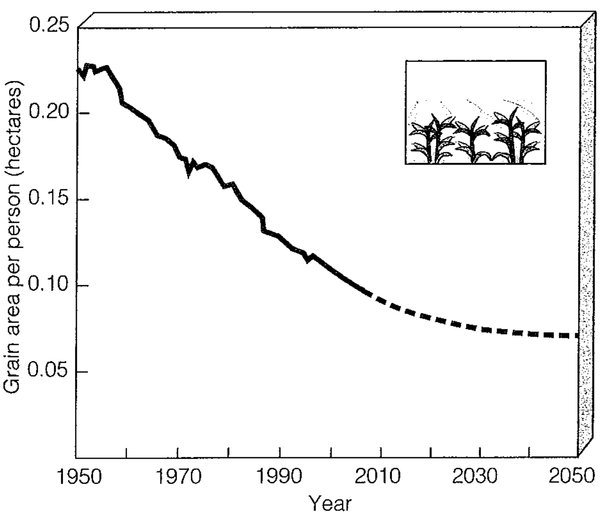


Figure 13-20 Average grain area per person worldwide, 1950–2001, with projections to 2030. (Data from U.S. Department of Agriculture and Worldwatch Institute)

SPOTLIGHT

Shrinking the World's Genetic Plant Library

The UN Food and Agriculture Organization estimates that by 2000, two-thirds of all seeds planted in developing countries were of uniform strains. Such genetic uniformity increases the vulnerability of food crops to pests, diseases, and harsh weather. Many biologists argue that this decreased variability, plus growing extinction rates of plant species, can limit the genetic raw material available to support future green and gene revolutions.

For example, in the mid-1970s, a valuable wild corn species, the only known perennial strain of corn, was barely saved from extinction. Crossbreeding this perennial strain with commercial varieties could reduce the need for yearly plowing and sowing, which would reduce soil erosion and save water and energy. Even more important, this wild corn **(1)** has a built-in genetic resistance to four of the eight major corn viruses and **(2)** grows better in cooler and damper habitats than established commercial strains. Overall, the economic benefits of cultivating this wild plant could total several billion dollars per year.

Wild varieties of the world's most important plants can be collected and stored in **(1)** gene or seed banks, **(2)** agricultural research centers, and **(3)** botanical gardens. However, space and money severely limit the number of species that can be preserved.

Other limitations include **(1)** inability to successfully store seeds of many plants (such as potatoes), **(2)** irreversible loss of stored seeds because of power failures, fires, or unintentional disposal, **(3)** death of stored seeds unless they are periodically planted (germinated) and then stored again, and **(4)** difficulty in reintroducing stored plants and seeds into changed habitats because they do not evolve during storage.

Because of these limitations, ecologists and plant 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.

Critical Thinking

What are the major advantages and disadvantages of relying on a shrinking number of crop varieties? Why do seed companies favor this approach?

To some analysts this drop in grainland area per person is not particularly harmful because it reduces the pressure on the earth's biodiversity by increasing yields per hectare. But environmentalists warn that this is true only if there is a decrease in the harmful environmental effects associated with modern industrialized agriculture (Figure 13-13).

Can We Grow More Food in Urban Areas? Food experts believe that people in urban areas could live more sustainably and save money by growing food in empty lots, on rooftops and balconies, and in their own backyards and by raising fish in tanks and sewage lagoons. Currently, about 800 million urban gardens provide about 15% of the world's food.

More food could be grown in urban areas. A study by the UN Center for Human Settlements estimated that up to 50% of the total area in many cities in developing countries is vacant public land that could be used to produce food.

13-5 PRODUCING MORE MEAT

What Are Rangeland and Pasture? About 40% of the earth's ice-free land is **rangeland** that is too dry, too steeply sloped, or too infertile to grow crops. This type of land supplies forage or vegetation for grazing (grass-eating) and browsing (shrub-eating) animals. About 3.3 billion cattle, sheep, and goats graze on about 42% of the world's rangeland (Figure 13-21). Much of the rest is too dry, cold, or remote from population centers to support large numbers of livestock. About 29% of the total U.S. land area is rangeland, most of it short-grass prairie in the arid and semiarid western half of the country (Figure 13-8). Livestock also graze in **pastures:** managed grasslands or enclosed meadows usually planted with domesticated grasses or other forage (Figure 13-8).

Livestock can be raised **(1)** on *open ranges* where rainfall is low but fairly regular and **(2)** by *nomadic herding* where rainfall is sparse and irregular and herders must move livestock to find ample grass and prevent overgrazing (Figure 13-21).

What Is the Ecology of Rangeland Plants? Most rangeland grasses have deep and complex root systems (Figure 10-15, top right, p. 215) that **(1)** help anchor the plants, **(2)** extract underground water so plants can withstand drought, and **(3)** store nutrients so plants can grow again after a drought or fire.

Blades of rangeland grass grow from the base, not the tip. Thus, as long as only its upper half—called its *metabolic reserve*—is eaten and its lower half remains, rangeland grass is a renewable resource that can be grazed again and again (Figure 13-22, top). The exposed metabolic reserve of a grass plant is where photosynthesis takes place to provide food for the deep

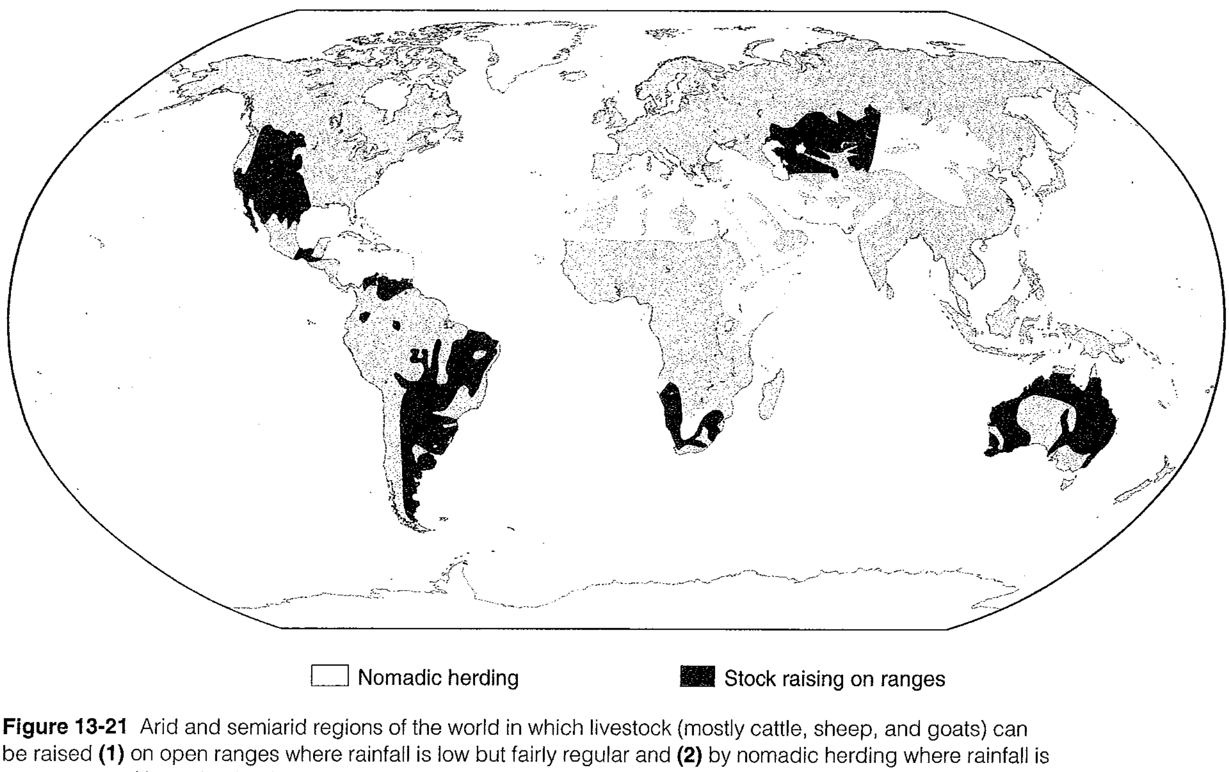


Figure 13-21 Arid and semiarid regions of the world in which livestock (mostly cattle, sheep, and goats) can be raised **(1)** on open ranges where rainfall is low but fairly regular and **(2)** by nomadic herding where rainfall is so sparse and irregular that livestock must be moved to find adequate grass.

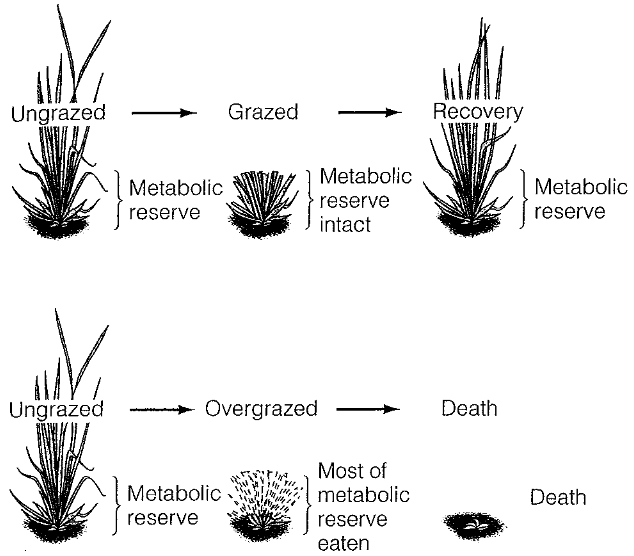


Figure 13-22 Rangeland grasses grow from the bottom up and are renewable as long as the bottom half of the plant (metabolic reserve), where photosynthesis takes place, is not eaten (top). If the metabolic reserve is eaten, the plant is weakened and can die (bottom). (From Chiras, *Environmental Science*, 5th ed., p. 208. Copyright © 1998 by Wadsworth)

roots of rangeland grasses. If all or most of the lower half (metabolic reserve) of the plant is eaten, the plant is weakened and can die (Figure 13-22, bottom).

Rangeland plants vary in their ability to recover from stresses such as fire, drought, and excessive grazing (Figure 13-23). When native plant species disappear from a rangeland, weedy invader plants move in and gradually decrease the nutritional value of the available forage (Figure 13-23, bottom).

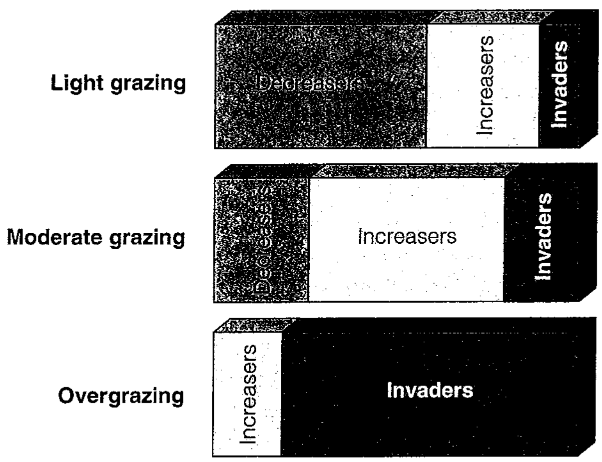


Figure 13-23 Effects of various degrees of grazing on the relative amounts of three major types of grassland plants: **(1)** *decreasers* that decline in abundance with moderate grazing, **(2)** *increasers* that increase with moderate to heavy grazing pressure, and **(3)** *invaders* that colonize an area because of overgrazing or other changes in rangeland conditions. (From Chiras, *Environmental Science*, 5th ed., p. 208. Copyright © 1998 by Wadsworth)

How Is Meat Produced, and What Are Its Environmental Consequences? Between 1950 and 2000, world meat production increased nearly fivefold, and per capita meat production more than doubled. Globally, animal products provide about 15% of the energy and 30% of the protein in the human diet. According to Worldwatch Institute estimates, the world's meat production is likely to more than double between 2000 and 2050 as affluence rises in middle-income developing countries and people begin consuming more meat.

About 80% of the world's cattle, sheep, and goats are raised on rangeland by open grazing or nomadic herding (Figure 13-21). These animals are **ruminants,** which have complex digestive systems that enable them to convert grass and other roughage into beef, mutton, and milk. These ruminants also supply us with leather and wool. Worldwide, about 180 million people try to make a living as *pastoralists* who tend cattle, sheep, and goats grazing on rangeland.

Some analysts expect most future increases in meat production to come from densely populated *feedlots,* where animals are fattened for slaughter by feeding on grain grown on cropland or meal produced from fish. Feedlots account for about 40% of the world's meat production and more than half of the world's poultry and pork. In the United States, most production of cattle, pigs, and poultry is concentrated in increasingly large, factorylike production facilities in only a few states (Figure 13-24, p. 298).

Most of the world's beef and mutton is still produced on rangeland, however. Even in the United States, which has most of the world's beef feedlots, a typical steer is fed in a feedlot only for a few months before being slaughtered.

This industrialized approach increases meat productivity. However, it also

- Concentrates pollution problems such as **(1)** foul odors, **(2)** water pollution when lagoons storing animal wastes collapse or are flooded, and **(3)** contamination of drinking water wells by nitrates from animal wastes.
- Increases pressure on the world's **(1)** grain supply because feedlot livestock consume grain produced on cropland instead of feeding on natural grasses and **(2)** fish supply because fish are diverted to feed livestock instead of being consumed directly by people.
- Requires increased inputs of fossil fuel (Figure 13-4).
- Increases the spread of infectious livestock diseases such as **(1)** *mad cow disease,* which since 1985 has infected cows in 12 European nations and killed more than 80 people in Great Britain and several people in France and Ireland, and **(2)** *highly infectious hoof-and-mouth disease,* which since 2000 has infected large numbers of cattle, pigs, and sheep in Europe and Brazil.

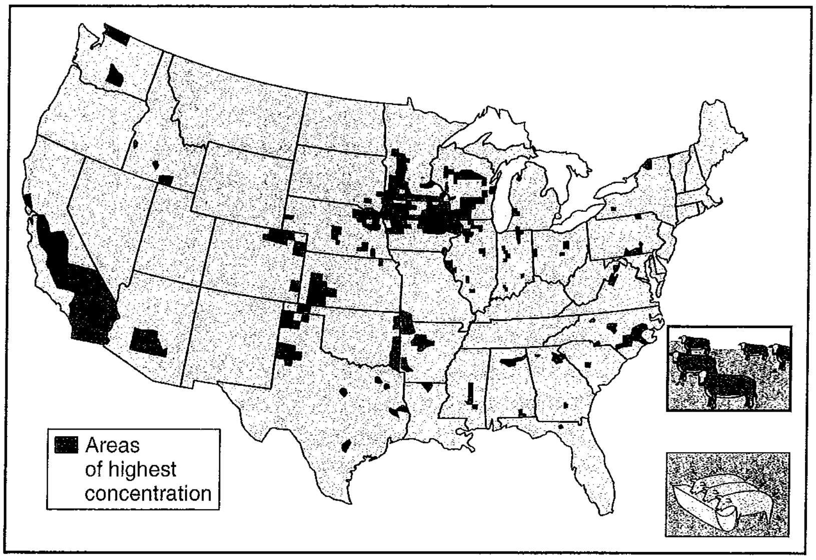


Figure 13-24 Large-scale, factorylike production of livestock—mostly cattle, pigs, and poultry—in the United States and the resulting pollution problems are concentrated mostly in a few states. (Data from the U.S. Department of Agriculture)

Livestock and fish vary widely in the efficiency with which they convert grain into animal protein (Figure 13-25). A more sustainable form of agriculture would involve shifting from less grain-efficient forms of animal protein, such as beef or pork, to more grain-efficient ones, such as poultry or farmed fish (Figure 13-25). Livestock production also has an enormous environmental impact (Connections, p. 299).

How Can We Raise Meat Production by Recycling Crop Residues? One way to increase yields of meat and milk without consuming more grain is to feed livestock ruminants crop residues such as wheat straw, rice straw, and corn stalks. Such roughage-based livestock feeding programs work only at the local level because roughage is too bulky and expensive to transport long distances.

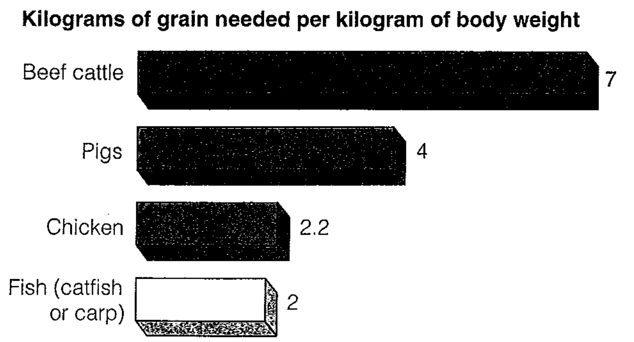


Figure 13-25 Efficiency of converting grain into animal protein. Data in kilograms of grain per kilogram of body weight added. (Data from U.S. Department of Agriculture)

This productive way to use crop residues is being employed in China and India to increase meat and milk productivity and reduce pressure on rangelands. However, some ecologists argue that it makes more sense to allow such residues to decompose naturally to increase soil fertility.

What Are the Effects of Overgrazing and Undergrazing? Overgrazing can also limit livestock production. **Overgrazing** occurs when too many animals graze for too long and exceed the carrying capacity of a grassland area. Excessive numbers of domestic livestock feeding for too long in a particular area causes most overgrazing.

Such overgrazing **(1)** lowers the net primary productivity of grassland vegetation (Figure 4-25, p. 81), **(2)** reduces grass cover and exposes the soil to erosion by water and wind (Figure 13-26), **(3)** compacts the soil (which diminishes its capacity to hold water), **(4)** enhances invasion of exposed land by woody shrubs such as mesquite and prickly pear cactus (Figure 13-23, bottom), and **(5)** is a major cause of desertification (Figure 10-20, p. 220).

Some grassland can suffer from **undergrazing,** where absence of grazing for long periods (at least 5 years) can reduce the net primary productivity of grassland vegetation and grass cover. Moderate grazing of such areas removes accumulation of standing dead material and stimulates new biomass production.

Undergrazing is more likely in *arid* areas (such as sub-Saharan Africa and parts of the Mediterranean area) with erratic rainfall and wide, largely unpredictable swings in plant productivity. These are mostly areas where livestock are raised by nomadic herding (Figure 13-21, yellow areas).

In recent years, nomadic herding has been reduced by **(1)** wars, **(2)** travel restrictions, **(3)** population growth, **(4)** increased crop growing and urbanization, and **(5)** the drilling of fairly inexpensive tubewells (narrow wells drilled into an aquifer to provide water for livestock). However, the resulting reduced movement of livestock can lead to loss of grass cover through overgrazing in areas around the wells and through undergrazing in other areas.

What Is the Condition of the World's Rangelands? *Range condition* usually is classified as **(1)** *excellent* (containing more than 75% of its potential forage production), **(2)** *good* (51–75%), **(3)** *fair* (26–50%),

Some Environmental Consequences of Meat Production

CONNECTIONS

The meat-based diet of affluent people in developed and developing countries has the following environmental effects:

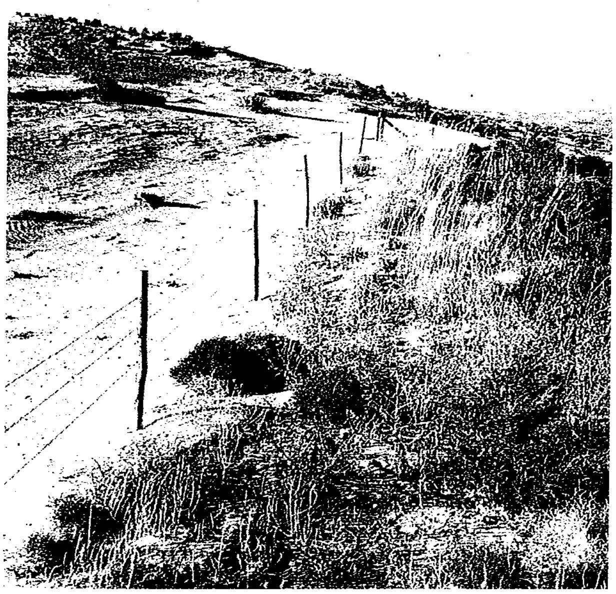
- More than half of the world's cropland (19% in the United States) is used to produce livestock feed grain (mostly field corn, sorghum, and soybeans).
- Livestock and fish raised for food consume about 36% of the world's grain. This includes 65% of grain production in the United States compared to 25% in China and 4% in India.
- Livestock use more than half the water withdrawn from rivers and aquifers each year, mostly to **(1)** irrigate crops fed to livestock and **(2)** wash away manure from crowded livestock pens and feedlots.
- Manure washing off the land or leaking from lagoons used to store animal wastes is a significant source of water pollution that kills fish by depleting dissolved oxygen.
- About 14% of U.S. topsoil loss is directly associated with livestock grazing.
- Overgrazing of sparse vegetation and trampling of the soil by too many livestock is the major cause of desertification in arid and semiarid areas (Figure 10-20, p. 220).
- Cattle belch out about 16% of the methane (a greenhouse gas that is about 25 times more potent than carbon dioxide) released into the atmosphere.
- Some of the nitrogen in commercial inorganic fertilizer used to grow livestock feed is converted to nitrous oxide, a greenhouse gas released from the soil into the atmosphere.
- More than one-third of all raw materials and fossil fuels consumed in the United States are used in animal production.
- Livestock in the United States produce at least 20 times more waste (manure) than is produced by the country's human population. Only about half of this nutrient-rich livestock waste is recycled into the soil.

Some environmentalists have called for reducing livestock production (especially cattle) to decrease its environmental effects and to feed more people. This would decrease the environmental impact of livestock production, but it would not free up much land or grain to feed more of the world's hungry people.

Cattle and sheep that graze on rangeland use a resource (grass) that humans cannot eat, and most of this land is not suitable for growing crops. Moreover, because of poverty, insufficient economic aid, and the nature of global economic and food distribution systems, very little if any additional grain grown on land used to raise livestock or livestock feed would reach the world's hungry people.

Critical Thinking

Would you be willing to eat less meat or not eat any meat? Explain.



USDA, Natural Resources Conservation Service

Figure 13-26 Rangeland: overgrazed (left) and lightly grazed (right).

or **(4)** *poor* (0–25%). Limited data from surveys in various countries indicate that overgrazing by livestock has caused as much as 20% of the world's rangeland to lose productivity, mostly by desertification (Figure 10-20, p. 220).

Most of the rangeland in the United States is in the West (Figures 13-8 and 13-21). About 60% is privately owned and the rest is public land managed by the Bureau of Land Management (BLM) and the U.S. Forest Service. Only about 2% of the 120 million cattle and 10% of the 20 million sheep raised in the United States graze on public rangelands.

According to a 2000 survey by the Bureau of Land Management, about 64% of the nonarctic U.S. public rangeland it managed was in unsatisfactory (fair or poor) condition, compared with 84% in 1936. This represents a great improvement, but there is still a long way to go. Conservation biologists and some range experts also point out that surveys of U.S. rangeland condition neglect the damage that livestock inflict on vital riparian zones (Spotlight, p. 300, and Figure 13-27, top, p. 300).

Endangered Riparian Zones

SPOTLIGHT

According to some wildlife and rangeland experts, estimates of rangeland condition do not take into account severe damage to heavily grazed thin strips of lush vegetation along streams called **riparian zones.** Because cattle need lots of water, they **(1)** congregate near riparian zones, **(2)** feed there, and **(3)** trample and overgraze riparian vegetation (Figure 13-27, top).

These ecologically important zones **(1)** help prevent floods, **(2)** help keep streams from drying out during droughts by storing and releasing water slowly from spring runoff and summer storms, and **(3)** provide habitats, food, water, and shade for wildlife in the arid and semiarid western lands.

Studies indicate that 65–75% of the wildlife in the western United States totally depends on riparian habitats. According to a 1999 study in the *Journal of Soil and Water Conservation,* livestock grazing has damaged approximately 80% of stream and riparian ecosystems in the United States.

Riparian areas can be restored by **(1)** using fencing to restrict access to degraded areas and **(2)** developing off-stream watering sites for livestock (Figure 13-27, bottom). Sometimes protected areas can recover in a few years.

Critical Thinking

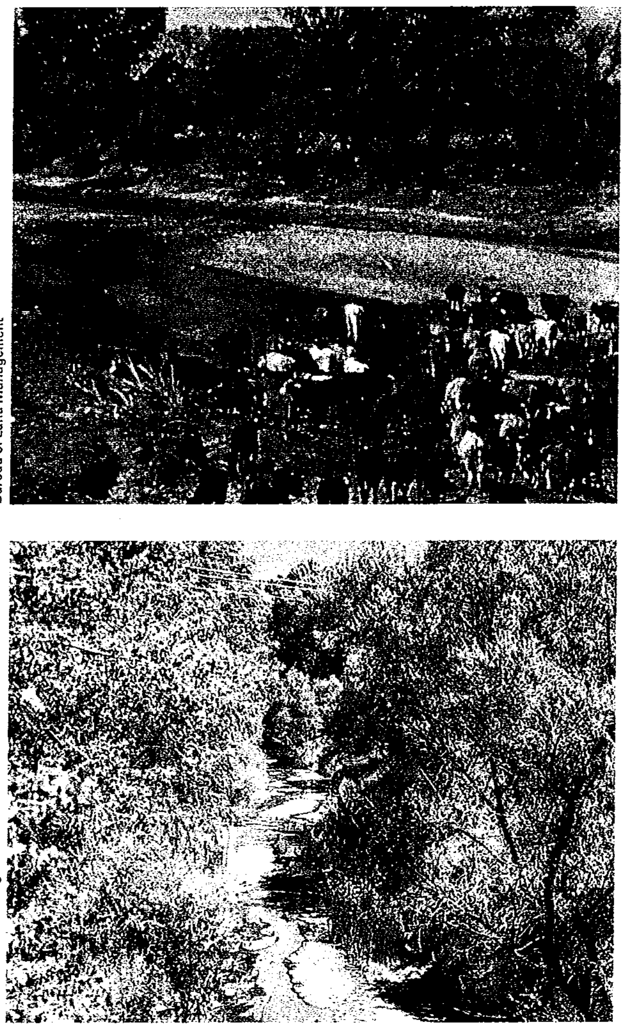
Do you believe that riparian zones on public rangelands in the United States should receive stronger protection? Explain. If so, how would you see that such protection is provided?

How Can Rangelands Be Managed Sustainably to Produce More Meat? The primary goal of sustainable rangeland management is to maximize livestock productivity without overgrazing or undergrazing rangeland vegetation. *Rangeland management* methods include **(1)** controlling the number, types, and distribution of livestock grazing on land, **(2)** deferred grazing, and **(3)** rangeland restoration and improvement.

The most widely used method for sustainable rangeland management is controlling 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. However, determining the carrying capacity of a range site is difficult and costly. In addition, carrying capacity varies with factors such as **(1)** climatic conditions (especially drought), **(2)** past grazing use, **(3)** soil type, **(4)** invasions by new species, **(5)** kinds of grazing animals, and **(6)** intensity of grazing.

Livestock tend to aggregate around natural water sources and stock ponds. As a result, areas around water sources tend to be overgrazed and other areas can be undergrazed. Managers can prevent this tendency and help promote more uniform use of rangeland by **(1)** fencing off damaged rangeland and riparian zones (Figure 13-27, bottom), **(2)** moving livestock from one grazing area to another, **(3)** providing supplemental feed at selected sites, and **(4)** situating water holes and tanks and salt blocks in strategic places.

One method used to help sustain rangeland grasses is *deferred grazing* (Figure 13-28). With this



Bureau of Land Management

Bureau of Land Management

Figure 13-27 Cattle on a riparian zone of a public rangeland along Arizona's San Pedro River (top) in the mid-1980s just before this section of waterway was protected by banning domestic livestock grazing for 15 years, eliminating sand and gravel operations and water pumping rights in nearby areas, and limiting access by off-highway vehicles. The bottom photo shows the recovery of this riparian area at the same time of year after 10 years of protection.

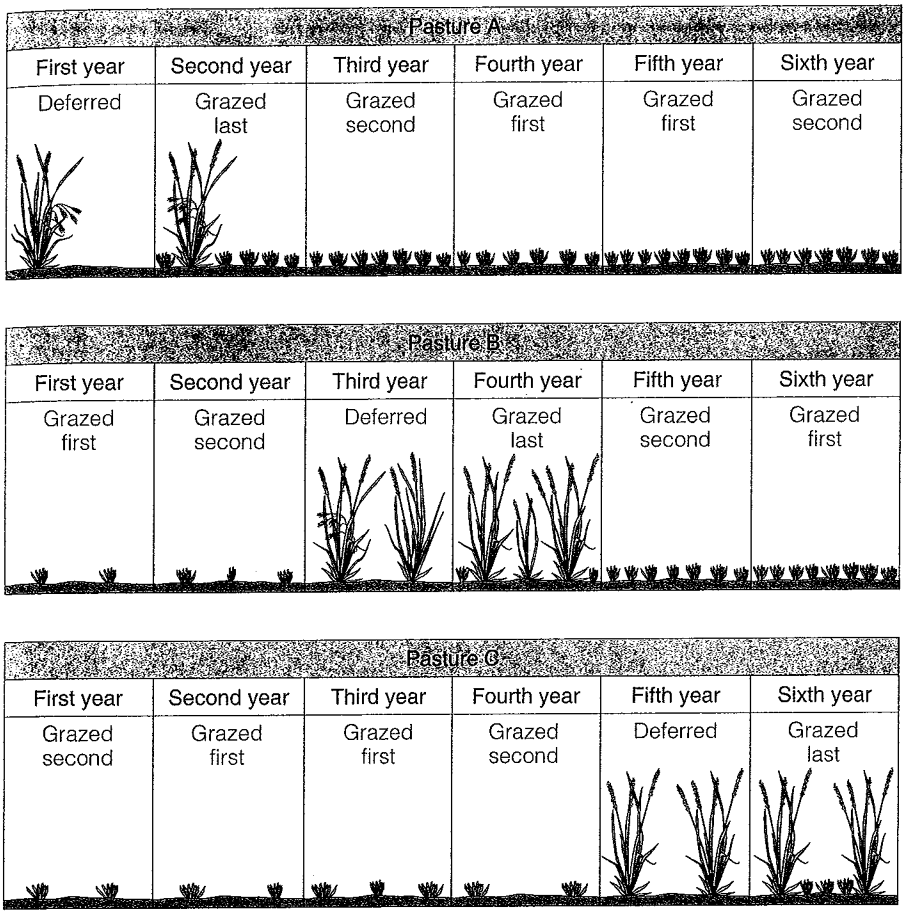


Figure 13-28 Deferred grazing plan in which during a 6-year rotation cycle each fenced-in field gets nearly a 2-year rest from grazing. (From Chiras, *Environmental Science*, 5th ed., p. 210. Copyright © 1998 by Wadsworth)

approach, livestock are rotated on a regular schedule from one fenced area to another so over a 6-year period each area is protected from grazing for 2 years to allow recovery. However, protecting areas too long (more than 5 years) can lead to undergrazing.

A more expensive and less widely used method of rangeland management involves suppressing the growth of unwanted plants (mostly invaders, Figure 13-23, bottom) by herbicide spraying, mechanical removal, or controlled burning. A cheaper way to discourage unwanted vegetation 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. Reseeding is an excellent way to restore severely degraded rangeland, but it is expensive.

13-6 CATCHING AND RAISING MORE FISH

How Are Fish and Shellfish Harvested? 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. Some commercially important marine species of fish and shellfish are shown in Figure 13-29 (p. 302).

The world's commercial fishing industry is dominated by industrial fishing fleets using **(1)** satellite positioning equipment, **(2)** sonar, **(3)** huge nets, **(4)** spotter planes, and **(5)** factory ships that can process and freeze their catches. About 55% of the annual commercial catch of fish and shellfish comes from the ocean using harvesting methods shown in Figure 13-30 (p. 303). They include using

- *Trawler fishing* to catch demersal (mostly bottom dwelling) fish and shellfish (especially shrimp) by dragging a funnel-shaped net held open at the neck along the ocean bottom (Figure 13-30). This scrapes up almost everything that lies on it and often destroys bottom habitats (Figure 7-18, right, p. 156). Newer trawling nets are large enough to swallow 12 jumbo jets in a single gulp, and even larger ones are on the way. The large mesh of the net allows most small fish to escape but can capture and kill other species such as seals and endangered and threatened sea turtles. Only the large fish are kept, with most of the fish and

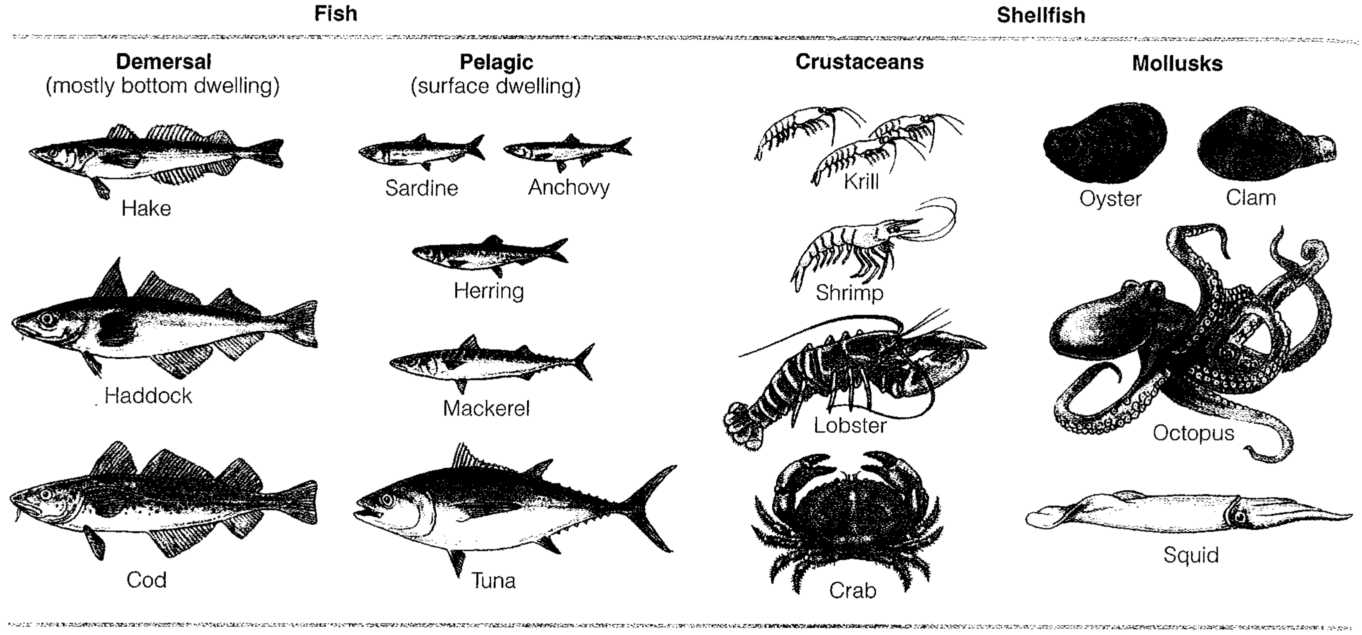


Figure 13-29 Some major types of commercially harvested marine fish and shellfish.

other aquatic species (called *bycatch*) thrown back into the ocean dead or dying. For commercially valuable shrimp, the bycatch can be up to eight times the weight of the shrimp that are kept.

- *Purse-seine fishing* (Figure 13-30) to catch pelagic (surface dwelling) species such as tuna, which feed in schools near the surface or in shallow areas. Once located, a tuna school is surrounded by a large purse-seine net, which is closed like a drawstring purse to trap the fish. Nets used to capture yellowfin tuna in the eastern tropical Pacific Ocean have killed large numbers of dolphins, which swim on the surface above schools of the tuna.
- *Longlining* in which fishing vessels put out lines up to 130 kilometers (80 miles) long, hung with thousands of baited hooks (Figure 13-30), to catch open-ocean fish species such as swordfish, tuna, and sharks (Case Study, p. 176). Longlines also hook pilot whales, dolphins, endangered sea turtles, and sea-feeding albatross.
- *Drift-net fishing* in which fish are caught by huge drifting nets (Figure 13-30). Nets can hang as much as 15 meters (50 feet) below the surface and be up to 55 kilometers (34 miles) long. This method can **(1)** lead to overfishing of the desired species and **(2)** trap and kill large quantities of unwanted fish and marine mammals (such as dolphins, porpoises, and seals), marine turtles, and seabirds. Since 1992, a UN ban on the use of drift nets longer than 2.5 kilometers (1.6 miles) in international waters has sharply reduced this harvesting technique. But **(1)** compliance is voluntary, **(2)** it is difficult to monitor fishing fleets over vast ocean areas, and **(3)** the decrease has led to increased use of longlines, which often have similar effects on marine wildlife.

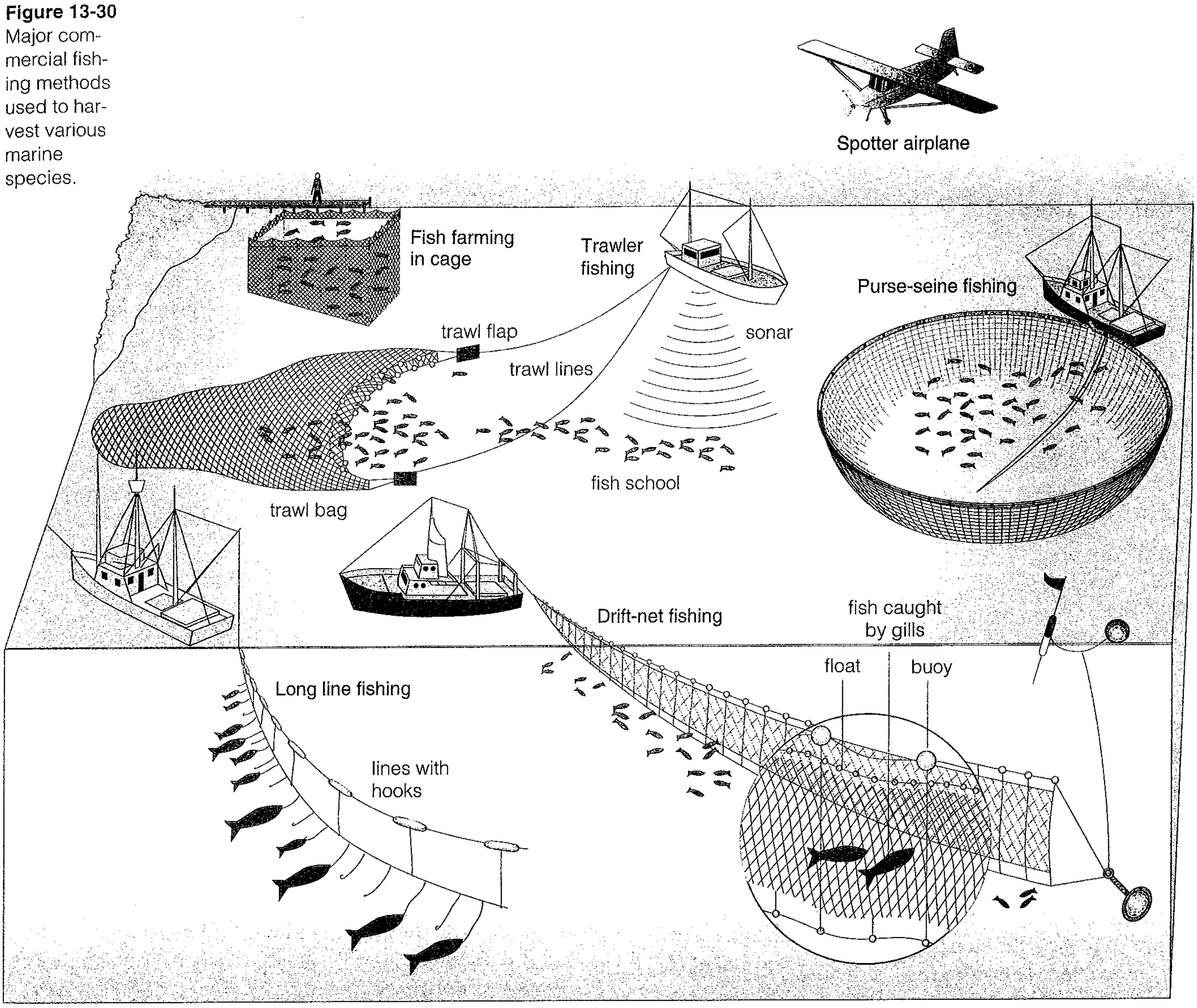
About 55% of the annual commercial catch of fish and shellfish comes from the ocean. About 99% of this catch is taken from plankton-rich coastal waters, but this vital coastal zone is being disrupted and polluted (p. 155).

The rest of the annual catch comes from using **(1)** aquaculture to raise marine and freshwater fish in ponds and underwater cages (33%) and **(2)** from inland freshwater fishing from lakes, rivers, reservoirs, and ponds (12%). About one-third of the world fish harvest (mostly small pellagic species such as anchovy, herring, and menhaden) is used as animal feed, fish meal, and oils. Figure 13-31 shows the estimated fossil fuel energy needed for harvesting or raising various species of oceanic fish or shellfish.

Can We Harvest More Fish and Shellfish? The *good news* is that between 1950 and 1982, **(1)** the annual commercial fish catch (marine plus freshwater harvest) increased almost fivefold (Figure 13-32, left, p. 304), and **(2)** the per capita seafood catch more than doubled (Figure 13-32, right).

The *bad news* is that **(1)** the commercial fish catch has increased little since 1982 (Figure 13-32, left), **(2)** the per capita commercial fish catch has been falling since 1982 (Figure 13-32, right) and may continue to decline because of overfishing, pollution, habitat loss,

Figure 13-30 Major commercial fishing methods used to harvest various marine species.



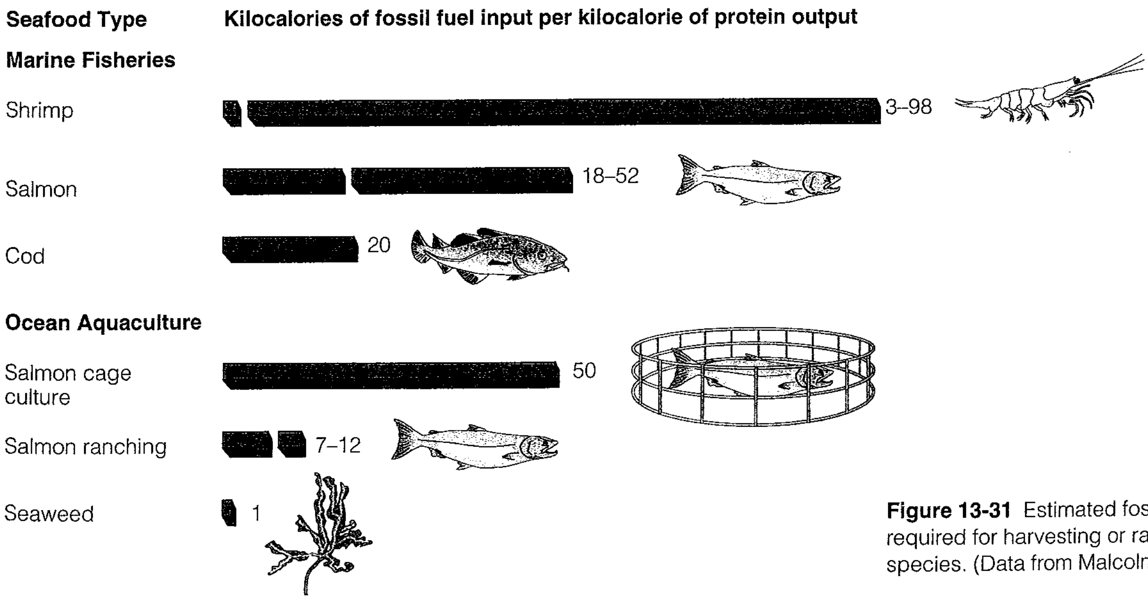


Figure 13-31 Estimated fossil fuel energy required for harvesting or raising various ocean species. (Data from Malcolm Beveridge)

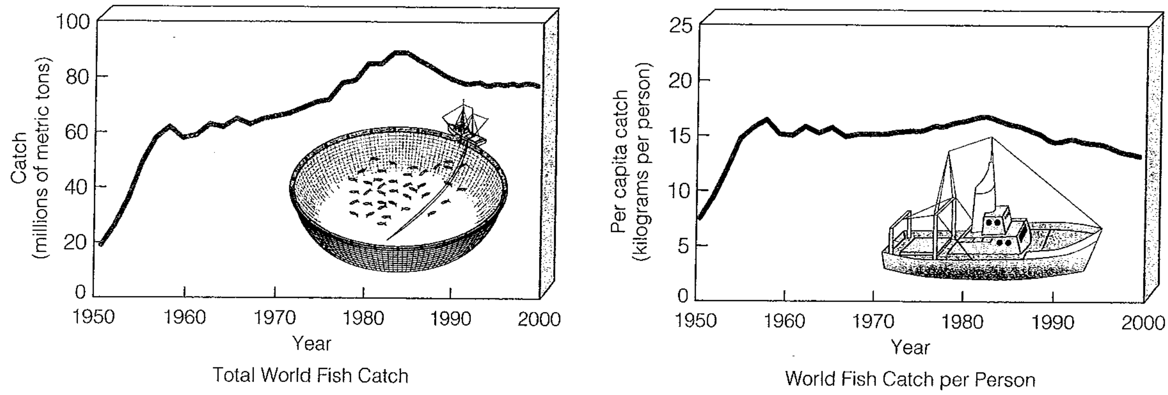


Figure 13-32 World fish catch (left) and world fish catch per person (right), 1950–2000. Worldwide per capita fish catch did not rise much between 1968 and 1989 and has dropped since then. The total catch and per capita catches since 1990 are probably about 10% lower than shown here because of the discovery in 2002 that since 1990 China had apparently been inflating its fish catches. (Data from UN Food and Agriculture Organization and Worldwatch Institute)

and population growth, and **(3)** the total catch and per capita catches are both estimated 10% lower than those shown in Figure 13-32 because in 2002 it was discovered that since 1990 China has apparently been inflating its fish catches.

Connections: How Are Overfishing and Habitat Degradation Affecting Fish Harvests? Fish are renewable resources as long as the annual harvest leaves enough breeding stock to renew the species for the next year. Ideally, an annual **sustainable yield**—the size of the annual catch that could be harvested indefinitely without a decline in the population of a species—should be established for each species to avoid depleting the stock.

However, determining sustainable yields is difficult because **(1)** it is hard to estimate mobile aquatic populations, and **(2)** sustainable yields shift from year to year because of changes in climate, pollution, and other factors. Furthermore, sustainably harvesting the entire annual surplus of one species may severely reduce the population of other species that rely on it for food.

Overfishing is the taking of so many fish that too little breeding stock is left to maintain numbers; that is, overfishing is a harvest of a species that exceeds its sustainable yield. Prolonged overfishing leads to **commercial extinction,** when the population of a species declines to the point at which it is no longer profitable to hunt for them. Fishing fleets then move to a new species or a new region, hoping the overfished species will recover eventually.

High levels of *bycatch* (the nontarget fish that are caught in nets and then thrown back into the sea) also deplete fisheries. Nearly one-fourth of the annual global fish catch is bycatch that depletes marine biodiversity and does not provide food for people.

According to a 2001 report by the UN Food and Agriculture Organization, about 75% of the world's 200 commercially valuable marine fish species are either overfished or fished to their estimated sustainable yield. The primary cause of this depletion of fish stocks is too many fishing boats pursuing too few fish—another example of the tragedy of the commons (Connections, p. 305). This decline in available fish in many areas helps explain why there are more than 100 disputes over rights to marine fisheries between countries.

The stocks of some marine fisheries have fallen dramatically.

- In 1992, the Newfoundland cod fishery collapsed and put some 40,000 Canadian fishers and fish processors out of work. Despite a ban on additional fishing, by 2002 the fishery had not recovered.
- In the Atlantic Ocean, the bluefin tuna has been heavily overfished primarily for use as sushi in Tokyo's restaurants. As a result, the stock of this fishery has dropped by 94%. Even if no more of these commercially valuable fish are caught, it will take decades for this long-lived species to recover.

According to the U.S. National Fish and Wildlife Foundation, 14 major commercial fish species in U.S. waters (accounting for one-fifth of the world's annual catch and half of all U.S. stocks) are so depleted that even if all fishing stopped immediately it would take up to 20 years for stocks to recover (Figure 13-33). A 2001 report by the U.S. Department of Commerce found that 107 out of 127 species taken in U.S. marine waters were in jeopardy of being overfished.

Degradation, destruction, and pollution of wetlands, estuaries, coral reefs, salt marshes, and mangroves also threaten populations of fish and shellfish. An estimated 80–90% of the global commercial marine

Commercial Fishing and the Tragedy of the Commons

CONNECTIONS

In the 1970s and 1980s, extensive investment in fishing fleets, aided by government and international development agency subsidies, helped boost the fish catch significantly (Figure 13-32, left). Since 1975, however, the size of the industrial fishing fleet has expanded twice as fast as the rise in catches.

Thus too many boats now fish for a declining number of fish. This leads to overfishing, an example of the tragedy of the commons (Connections, p. 11).

In a 1998 study, Daniel Pauly warned that the current harvesting of species at increasingly lower trophic levels in ocean food webs can lead to **(1)** decreased chances for recovery of species at the top of ocean food webs by reducing stocks of the smaller fish they feed on, **(2)** collapse of marine ecosystems, **(3)** a drop in aquatic biodiversity, and **(4)** a loss of high-quality protein for humans.

Because of overfishing and the overcapacity of the fishing fleet, it costs the global fishing industry about $125 billion a year to catch $70 billion worth of fish. Government subsidies such as fuel tax exemptions, price controls, low-interest loans, and grants for fishing gear make up most of the $55 billion annual deficit of the industry.

Critics contend that such subsidies promote overfishing. They argue that eliminating or significantly lowering these subsidies would reduce the size of the fishing fleet by encouraging free-market competition and would allow some of the economically and biologically depleted stocks to recover.

Eliminating these subsidies will cause a loss of jobs for some fishers and fish processors in coastal communities. However, to fishery biologists the alternative is worse. Continuing to subsidize excess fishing allows fishers to keep their jobs a little longer while making less and less money until the fishery collapses. Then all jobs are gone, and fishing communities suffer even more.

Critical Thinking

Do you believe government subsidies for the fishing industry should be eliminated or sharply reduced? Explain. How would you feel about eliminating such subsidies if your livelihood depended on fishing?

catch comes from coastal waters within 320 kilometers (200 miles) of the shoreline.

Projected global warming over the next 50–100 years is also a threat to the global fish catch. Warmer ocean water can degrade or **(1)** destroy highly productive coral reefs (p. 144) and **(2)** enhance the harmful effects of habitat degradation and pollution on fish populations. The thinning of the ozone layer in the lower stratosphere (Figure 4-8, p. 69) can also damage surface-dwelling marine species by leading to increased penetration of harmful UV radiation into ocean waters. Fish populations also are affected by shorter-term climatic changes such as El Niño–Southern Oscillations (ENSOs, Figure 6-14, p. 119).

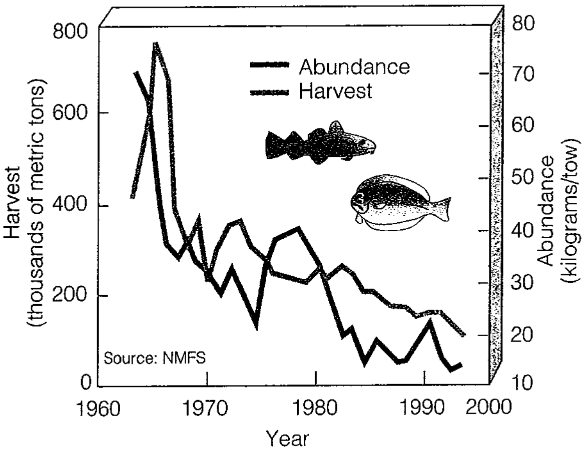


Figure 13-33 The harvest of groundfishes (yellowtail flounder, haddock, and cod) in the Georges Bank off the coast of New England in the North Atlantic, once one of the world's most productive fishing grounds, has declined sharply since 1965. Stocks dropped to such low levels that since December 1994 the National Marine Fisheries Services has banned fishing of these species in the Georges Bank. (Data from U.S. National Marine Fisheries Service)

Is Aquaculture the Answer? **Aquaculture,** in which fish and shellfish are raised for food, supplies about 33% of the world's commercial fish harvest, with production increasing fivefold between 1984 and 2001. China is the world leader in aquaculture (producing about 68% of the world's output), followed by India and Japan.

There are two basic types of aquaculture:

- **Fish farming,** which involves **(1)** cultivating fish in a controlled environment—often a coastal or inland pond, lake, reservoir, or rice paddy—and **(2)** harvesting them when they reach the desired size.
- **Fish ranching,** which involves **(1)** holding anadromous species such as salmon (that live part of their lives in fresh water and part in salt water) in captivity for the first few years of their lives (usually in fenced-in areas or floating cages in coastal lagoons and estuaries; Figure 13-30), **(2)** releasing them, and then **(3)** harvesting the adults when they return to spawn (Figure 13-34, p. 306).

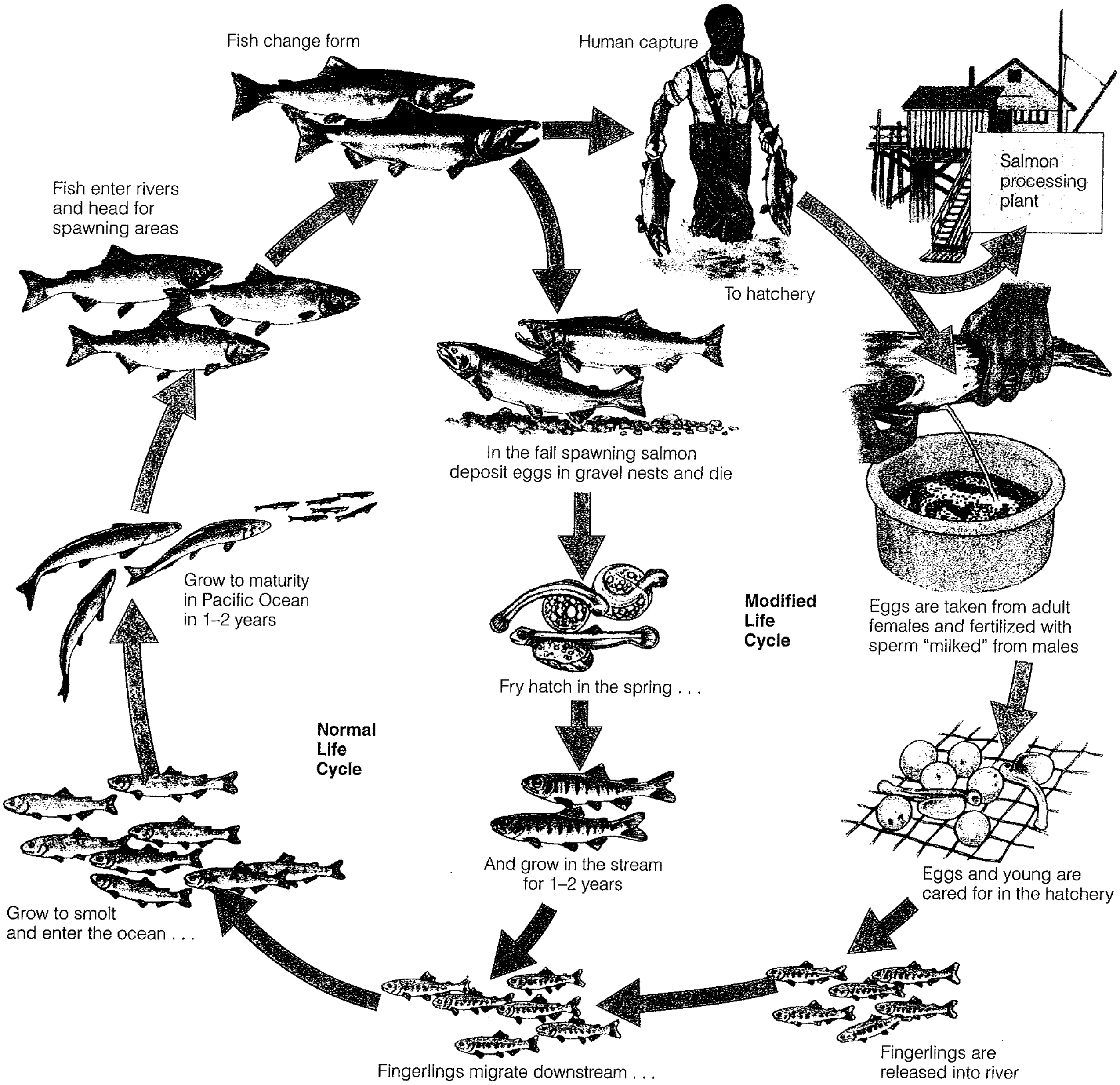


Figure 13-34 Normal life cycle of wild salmon (left) and human-modified life cycle of hatchery-raised salmon (right). Salmon spend part of their lives in fresh water and part in salt water.

Species cultivated in developing countries (mostly in inland aquaculture ponds and rice paddies) include carp (especially in China and India), catfish (in the United States), tilapia, milkfish, clams, and oysters. These species feed on phytoplankton and other aquatic plants and thus eat low on the food chain.

China has developed a fish polyculture in which four types of carp feed at different trophic levels in a food chain. They include **(1)** *silver carp* (a filter feeder eating phytoplankton), **(2)** *bighead carp* (a filter feeder eating zooplankton), **(3)** *grass carp* (feeding on aquatic vegetation), and **(4)** *common carp* (feeding on detritus that settles to the bottom). Fish polyculture is also widely used in India. Most aquaculture in China is integrated with agriculture. This allows farmers to use pig manure and other agricultural wastes to fertilize aquaculture ponds and thus promote the growth of phytoplankton to feed aquaculture species.

In developed countries and some rapidly developing countries in Asia, aquaculture is used mostly to stock lakes and streams with game fish or to raise expensive fish and shellfish such as oysters, catfish, crayfish, rainbow trout, shrimp, and salmon—mostly for export to Japan, Europe, and North America. Aquaculture now produces **(1)** 90% of all oysters, **(2)** 40% of all salmon (75% in the United States), **(3)** 50% of internationally traded shrimp and prawns, and **(4)** 65% of freshwater fish sold in the global marketplace.

Catfish are the leading aquacultural product in the United States. Most are produced in ponds in Mississippi, Louisiana, Arkansas, and Alabama.

Figure 13-35 lists the major advantages and disadvantages of aquaculture. Some analysts project that freshwater and saltwater aquaculture production could double during the next 10 years. Other analysts warn that the harmful environmental effects of aquaculture (Figure 13-35) could limit future production.

Aquaculture has been promoted as a way to boost the global seafood harvest while taking the pressure off the world's overharvested marine fisheries. But a 2000 study by Stanford University researcher Rosamond Taylor found that increased use of aquaculture has stressed marine fisheries by **(1)** raising the demand for some ocean fish such as anchovies that are ground into fish meal and fed to some aquaculture species and **(2)** creating vast amounts of animal waste that have fouled coastal areas, which are important sources of fish and shellfish.

Intensive farming of large carnivorous fish whose wild populations have been decimated by overfishing is replacing traditional aquaculture in which farmed fish eat plants and detritus. This increases overfishing of smaller marine species used to feed farmed carnivorous species. If kept up, this depleting the seas to feed aquaculture farms could cause the collapse of both marine fisheries and carnivorous aquaculture.

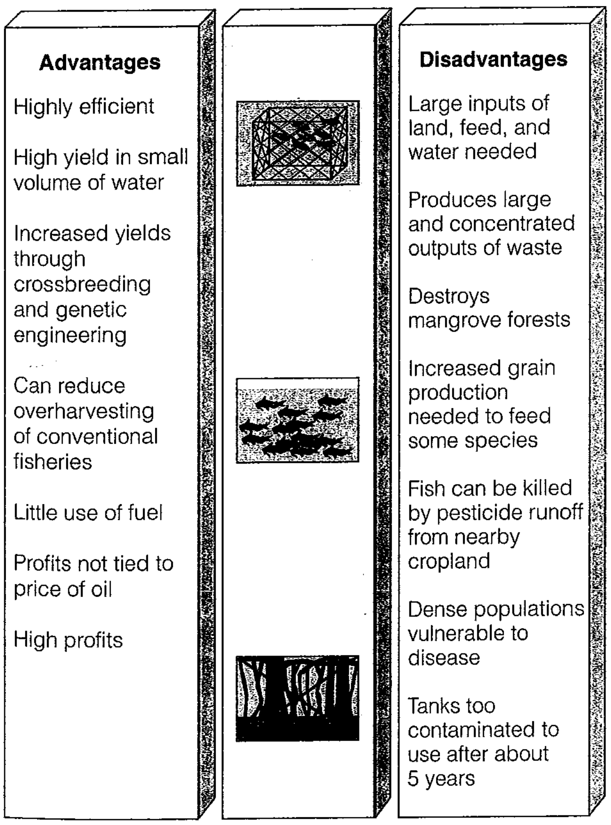


Figure 13-35 Advantages and disadvantages of aquaculture.

Aquaculture proponents point to new trends and research that may help decrease the harmful effects of aquaculture. They include the following:

- Abandonment of most attempts to raise shrimp and other species by clearing mangrove forests (Figure 7-2, p. 145, and 7-9, p. 149) and converting them to large aquaculture ponds.
- Relying more on smaller, more intensively managed aquaculture ponds. Recent research shows that warm water species can be intensively cultivated in small stirred ponds **(1)** in which bacteria are used to provide food for phytoplankton needed to feed the aquaculture species, and **(2)** the same water remains in the pond, which eliminates water pollution from dumping pond water on the land or into nearby aquatic systems.
- Increased use of intensive farming of some aquaculture species (such as salmon and cobia) in deeply submerged ocean cages that can be thought of as stationary fish schools. The cages **(1)** are located below wave action, **(2)** protect the species being raised from predators, **(3)** can be cleaned by species such as starfish, and **(4)** allow dispersion of the wastes produced by natural dilution in the surrounding ocean. Attached tubes can be used to feed the species as needed.

Even under the most optimistic projections, increasing both the wild catch and aquaculture will not increase world food supplies significantly. The reason is that currently fish and shellfish supply only about 1% of the energy and 6% of the protein in the human diet.

13-7 GOVERNMENT AGRICULTURAL POLICY

How Do Government Agricultural Policies Affect Food Production? Agriculture is a financially risky business. Whether farmers have a good year or a bad year depends on factors over which they have little control: weather, crop prices, crop pests and diseases, interest rates, and the global market. Because of the need for reliable food supplies despite fluctuations in these factors, most governments provide various forms of assistance to farmers and consumers.

Here are three approaches:

- *Keep food prices artificially low.* This makes consumers happy but means that farmers may not be able to make a living.
- *Give farmers subsidies to keep them in business and encourage them to increase food production.* Globally, government price supports and other subsidies for agriculture total more than $500 billion per year (including $100 billion per year in the United States).

If government subsidies are too generous and the weather is good, farmers 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. Moreover, the taxes paid by citizens in developed countries to provide agricultural subsidies can offset the lower food prices they enjoy.

- *Eliminate most or all price controls and subsidies and let farmers and fishers respond to market demand without government interference.* However, some analysts urge that any phaseout 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.

Many environmentalists believe that instead of eliminating all subsidies, we should use them to reward farmers and ranchers who **(1)** protect the soil, **(2)** conserve water, **(3)** reforest degraded land, **(4)** protect and restore wetlands, **(5)** conserve wildlife, and **(6)** practice more sustainable agriculture and fishing.

13-8 SOLUTIONS: SUSTAINABLE AGRICULTURE

What Is Sustainable Agriculture? As we have seen in this chapter, the two major ways to increase the world's food production are to increase crop yields per hectare or increase the amount of land used to grow crops.

The total area of cropland is unlikely to expand because of a lack of affordable and environmentally sustainable land, however. In addition, increasing the yields per area of existing cropland may be limited because of **(1)** a lack of water for irrigation (Figure 13-18), **(2)** reduced genetic diversity (Spotlight, p. 295), **(3)** a leveling off of yields per hectare as biological and physiological limits of crop productivity are reached, and **(4)** the environmental effects of food production, which degrade existing cropland (Figure 13-13).

If these projections are correct, the three main tools in trying to reduce hunger and malnutrition and the harmful environmental effects of agriculture will be **(1)** slowing population growth (Section 12-3, p. 267), **(2)** reducing poverty so that people can grow or buy enough food for their survival and good health, and **(3)** developing and phasing in systems of **sustainable agriculture** or **low-input agriculture** (also called **organic farming**) over the next three decades.

Gordon Conway, president of the Rockefeller Foundation, calls this a new *doubly green revolution* that will **(1)** increase crop yields in an environmentally sustainable manner and **(2)** benefit the poor more directly than the first two green revolutions.

Currently, organic farming is used on less than 1% of the world's cropland (0.2% in the United States) but on 6–10% of the cropland in many European countries. However, this type of farming is growing rapidly, and in 2000 it was a $25 billion global market.

Under U.S. Department of Agriculture regulations, foods labeled *organic* **(1)** must be produced without synthetic pesticides, fungicides, and herbicides, and **(2)** cannot include genetically engineered foods, be irradiated, or be grown on soil fertilized by sewage sludge. In addition to these restrictions, organic meat and dairy products must be **(1)** produced from 100% organically grown feed, **(2)** given access to outdoor range or pasture, and **(3)** produced without use of hormones and antibiotics.

Figure 13-36 lists the major components of more sustainable, low-input agriculture. Studies have shown that low-input organic farming **(1)** produces equivalent yields with lower carbon dioxide emissions, **(2)** uses about 50% less energy than conventional farming, **(3)** improves soil fertility, **(4)** provides more habitats for wild plant and animal species, and **(5)** generally is more profitable for the farmer than high-input farming.

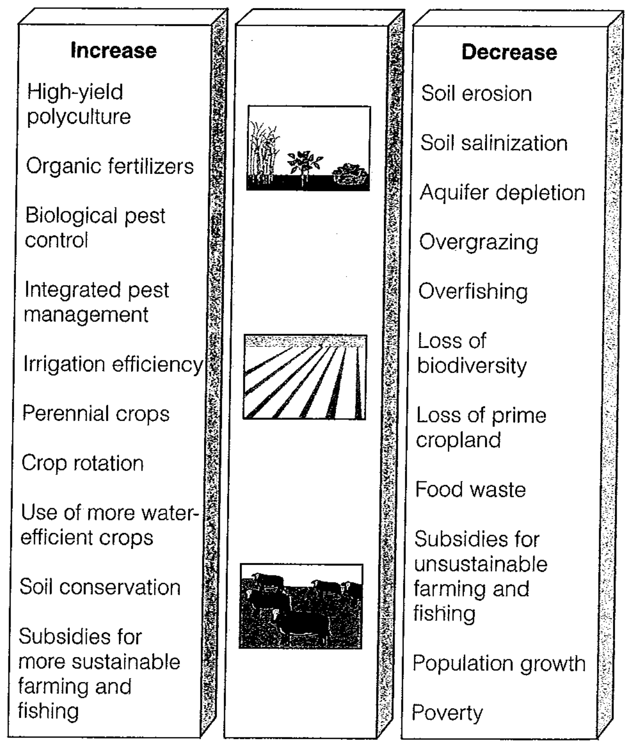


Figure 13-36 Components of more sustainable, low-throughput agriculture.

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 for growing crops.

Can We Make the Transition to More Sustainable Agriculture? A growing number agricultural analysts believe that over the next 30 years we must make a transition from unsustainable and environmentally harmful agriculture (Figure 13-13) to more sustainable forms of agriculture (Figure 13-36).

In developed countries, even a partial shift to more environmentally sustainable food production will not be easy. It will be opposed by **(1)** agribusiness, **(2)** successful farmers with large investments in unsustainable forms of industrialized agriculture, **(3)** specialized farmers unwilling to learn the more demanding art of farming sustainably, and **(4)** many consumers unwilling or unable to pay higher prices for food when more of agriculture's harmful environmental and health costs (Figure 13-13) are included in the market prices of food.

To help farmers make the transition to more sustainable agriculture, analysts call for

- Greatly increasing research on sustainable agriculture and improving human nutrition.
- Setting up demonstration projects throughout each country so farmers can see how sustainable agricultural systems work.
- Increasing agricultural aid to developing countries (which, when adjusted for inflation, declined by about 50% between 1982 and 1999), with emphasis on developing more sustainable, low-input agriculture.
- Establishing training programs in sustainable agriculture for farmers and government agricultural officials and encouraging the creation of college curricula in sustainable agriculture and human nutrition.

Sustainable agriculture involves applying the four principles of sustainability (Solutions, p. 201) to producing food. The goal is to feed the world's people while sustaining and restoring the earth's natural capital (Figure 4-34, p. 92). See the website material for this chapter for some actions you can take to help promote more sustainable agriculture.

The need to bring birth rates well below death rates, increase food production while protecting the environment, and distribute food to all who need it is the greatest challenge our species has ever faced.

PAUL AND ANNE EHRLICH

REVIEW QUESTIONS

1. Define the boldfaced terms in this chapter.
2. What are *perennial crops*? What advantages do they have over conventional annual crops?
3. What are the three main systems that supply our food? What three crops provide most of the world's food?
4. Distinguish among *industrialized agriculture, plantation agriculture, traditional subsistence agriculture,* and *traditional intensive agriculture.*
5. What is a *green revolution,* and what three steps does it involve? Distinguish between the first and second green revolutions.
6. Explain how producing more food on less land can help protect biodiversity.
7. Describe the nature and importance of the agricultural industry in the United States. How energy efficient is industrialized agriculture in the United States?
8. Distinguish among *interplanting, polyvarietal cultivation, intercropping, agroforestry,* and *polyculture.* What are the major advantages and disadvantages of polyculture?
9. List two pieces of *good* news about world food production since 1950. List two pieces of *bad* news about present and future food production.
10. Distinguish among *undernutrition, malnutrition,* and *overnutrition.* What are the two most common nutritional deficiency diseases, and how do they differ? What are the effects of deficiencies of **(a)** vitamin A, **(b)** iron, and **(c)** iodine?
11. About how many chronically malnourished people are there in the world? About how many people die each year from undernutrition, malnutrition, diseases worsened by malnutrition, and drinking contaminated water? List six major ways to reduce sickness and premature death of children from malnutrition. What is the primary cause of hunger in the world?
12. List the major harmful environmental effects of producing food.
13. What are China's major food problems? How could lower food production in China affect the rest of the world?
14. Describe how genetically improved crop strains are developed by **(a)** *crossbreeding* and **(b)** *genetic engineering.*
15. List the pros and cons of growing more food by **(a)** increasing crop yields through green revolutions, **(b)** genetically modifying crops and foods, **(c)** getting people to switch to new types of foods, **(d)** irrigating more cropland, **(e)** cultivating more land, and **(f)** growing more food in urban areas.
16. List seven factors that could limit greatly increased food production through green revolution and genetic engineering techniques. Why should we be concerned about loss of genetic diversity in agricultural crop strains?

17. What is *rangeland*? Explain how rangeland grass can be a renewable resource for livestock and wild herbivores. How is meat produced in developed and developing countries? What are the advantages and disadvantages of raising livestock in factorylike production facilities?

18. Distinguish between *overgrazing* and *undergrazing*. What are three major effects of overgrazing? Describe the general condition of rangelands throughout the world and in the United States. Describe three ways to manage rangelands more sustainably for meat production. What are *riparian areas,* and why are they important?

19. What are some of the harmful environmental effects of meat production?

20. What are *fisheries*? Distinguish among *trawling, purse-seine, longlining,* and *drift-net* methods for harvesting fish. Describe trends in the world's total fish catch and per capita fish catch since 1950, and explain why the per capita catch is expected to decline.

21. What is the *sustainable yield* of a fishery? Distinguish between *overfishing* and *commercial extinction* of a fish species. About what percentage of the world's fish stocks are in decline because of overfishing and pollution?

22. Distinguish between *fish farming* and *fish ranching*. What are the pros and cons of aquaculture?

23. List three policy types that governments use to affect food production. List the pros and cons of each approach.

24. What is *sustainable agriculture,* why is it important, and what are its major components?

CRITICAL THINKING

1. Summarize the major economic and ecological advantages and limitations of each of the following proposals for increasing world food supplies and reducing hunger over the next 30 years: **(a)** cultivating more land by clearing tropical forests and irrigating arid lands, **(b)** catching more fish in the open sea, **(c)** producing more fish and shellfish with aquaculture, and **(d)** increasing the yield per area of cropland.

2. Why should it matter to people in developed countries that many people in developing countries are malnourished and hungry? What are the three most important actions you believe should be taken to reduce hunger **(a)** in the country where you live and **(b)** in the world?

3. Some people argue that starving people could get enough food by eating nonconventional plants and insects; others point out that most starving people do not know what plants and insects are safe to eat and cannot take a chance on experimenting when even the slightest illness could kill them. If you had no money to grow or buy food, would you collect and eat protein-rich grasshoppers, moths, beetles, or other insects?

4. What could happen to energy-intensive agriculture in the United States and other industrialized countries if world oil prices rose sharply?

5. Some have suggested that some rangelands could be used to raise wild grazing animals for meat instead of conventional livestock. Others consider it unethical to raise and kill wild herbivores for food. What do you think? Explain.

6. Should **(a)** all price supports and other government subsidies paid to farmers be eliminated, and **(b)** governments phase in agricultural tax breaks and subsidies to encourage farmers to switch to more sustainable farming? Explain your answers. Try to consult one or more farmers in answering these questions.

7. What are the economic and ecological advantages and disadvantages of relying more on **(a)** a small number of genetic varieties of major crops and livestock, **(b)** genetically modified food, and **(c)** perennial food crops? Explain why you support or oppose each of these approaches.

8. 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?

9. How could knowledge about **(a)** secondary ecological succession (Figure 8-15, p. 181) and **(b)** the intermediate disturbance hypothesis (Figure 8-17, p. 184) be used to make agriculture more sustainable?

10. Congratulations! You are in charge of the world. List the three most important features of your agricultural policy.

PROJECTS

1. If possible, visit both a conventional industrialized farm and an organic or low-input farm. Compare **(a)** soil erosion and other forms of land degradation, **(b)** use and costs of energy, **(c)** use and costs of pesticides and inorganic fertilizer, **(d)** use and costs of natural pest control and organic fertilizer, **(e)** yields per hectare for the same crops, and **(f)** overall profit per hectare for the same crops.

2. Evaluate cattle grazing on private and public rangeland and pastures in your local area. Try to document any harmful environmental impacts. Have the economic benefits to the community outweighed any harmful environmental effects?

3. Gather information from your local planning office to determine how much cropland in your area has been lost to urbanization since 1980. What policies, if any, do your state and local community have for promoting cropland preservation?

4. Try to gather data evaluating the harmful environmental effects of nearby agriculture on your local community. What is being done to reduce these effects?

5. Use health and other local government records to estimate how many people in your community suffer from

undernutrition or malnutrition. Has this problem increased or decreased since 1980? What are the basic causes of this hunger problem, and what is being done to alleviate it? Share the results of your study with local officials, and present your own plan for improving efforts to reduce hunger in your community.

6. Use the library or the Internet to find out what controls now exist on genetically engineered organisms in the United States (or the country where you live) and how well such controls are enforced.

7. Make a survey in the nearest urban area to estimate what percentage of the food is grown by urban dwellers. Survey unused land and use it to estimate how much it could contribute to urban food production. Use these data to draw up a plan for increasing urban food production and present it to city officials.

8. Use the library or the Internet to find bibliographic information about *Aldo Leopold* and *Paul* and *Anne Ehrlich,* whose quotes appear at the beginning and end of this chapter.

9. Make a concept map of this chapter's major ideas, using the section heads and subheads and the key terms (in boldface type). Look on the website for this book for information about making concept maps.

INTERNET STUDY RESOURCES AND RESOURCES FOR FURTHER READING AND RESEARCH

The website for this book contains helpful study aids and many ideas for further reading and research. Log on to

www.info.brookscole.com/miller13

and click on the Chapter-by-Chapter area. Choose Chapter 13 and select a resource:

- Flash Cards allows you to test your mastery of the Terms and Concepts to Remember for this chapter.
- Tutorial Quizzes provides a multiple-choice practice quiz.
- Student Guide to InfoTrac will lead you to Critical Thinking Projects that use InfoTrac College Edition as a research tool.
- References lists the major books and articles consulted in writing this chapter.
- Hypercontents takes you to an extensive list of sites with news, research, and images related to individual sections of the chapter.

INFOTRAC COLLEGE EDITION

Improve your skills with InfoTrac College Edition, a searchable online database of articles from more than 700 periodicals. Log on to

http://www.infotrac-college.com

or access InfoTrac through the website for this book. Try to find the following articles:

1. Snell, M. B. 2001. Against the grain. *Sierra* 86: 30. *Keywords:* "transgenic crops" and "developing countries." Genetically engineered food crops may seem like a boon to the hungry populations in developing countries, but many of these countries are concerned about the overall environmental effects of these foods.

2. Finneran, K. 2001. What's food got to do with it? *Issues in Science and Technology* 17: 24. *Keyword:* "genetically modified food." This article looks at the debate over genetically modified foods, not so much from the standpoint of whether the technology is good or bad but from the point of view of human psychology.

14 WATER RESOURCES

Water and Grain Import Wars in the Middle East

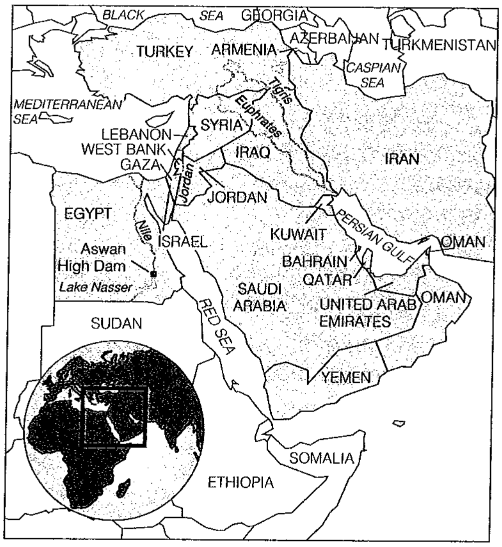


Figure 14-1 The Middle East, whose countries have some of the highest population growth rates in the world. Because of the dry climate, food production depends heavily on irrigation. Existing conflicts between countries in this region over access to water may soon overshadow both long-standing religious and ethnic clashes and attempts to take over valuable oil supplies.

Future wars between countries in the Middle East could be fought over water. Most water in this dry region comes from three shared river basins: the Nile, Jordan, and Tigris-Euphrates (Figure 14-1).

Ten countries share water from the Nile River basin (Figure 14-1), but three countries—Egypt, Sudan, and Ethiopia—use most of the water. Egypt, where it rarely rains, is mostly desert and would not exist without irrigation water from the Nile.

Because of water scarcity, Egypt already has to import 40% of its grain to feed its current population of 71 million. Yet by 2050, its population is expected to increase to 115 million, greatly increasing its demand for already scarce water.

Most of the precipitation that feeds 85% of the Nile's flow falls in Ethiopia. With a total fertility rate of 5.9 children, its population is projected to increase from 68 million in 2002 to 173 million by 2050, roughly tripling its water needs. To meet these needs and help lift its people out of poverty, Ethiopia plans to divert more water from the Nile.

Sudan also plans to divert more of the Nile's water to help feed its population, which is expected to increase from 33 million to 64 million between 2002 and 2050. This will at least double its water needs.

Such upstream diversions by Ethiopia and Sudan would reduce the amount of water available to water-short Egypt. Its options are to **(1)** go to war with Sudan and Ethiopia to obtain more water, **(2)** cut population growth, **(3)** improve irrigation efficiency, **(4)** spend $2 billion to build the world's longest concrete canal and pump water out of Lake Nasser (the reservoir created from the Nile by the Aswan High Dam) to create more irrigated farmland in the middle of the desert, **(5)** import more grain to reduce the need for irrigation water, **(6)** work out water-sharing agreements with other countries, or **(7)** suffer the harsh human and economic consequences of extreme 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 (Figure 14-1). The combined populations of these already water-short countries are projected to more than double from 33 million to 69 million between 2002 and 2050. Some *good news* is that in 1994, Israel and Jordan signed a peace treaty that addressed their disputes over water from the Jordan River basin.

Syria plans to build dams and withdraw more water from the Jordan River, decreasing the downstream water supply for Jordan and Israel. Israel warns that it will consider destroying the largest dam that Syria plans to build.

Turkey, located at the headwaters of the Tigris and Euphrates Rivers, controls how much water flows downstream to Syria and Iraq before emptying into the Persian Gulf (Figure 14-1). Turkey is building 24 dams along the upper Tigris and Euphrates Rivers to **(1)** generate huge quantities of electricity, **(2)** irrigate a large area of land, and **(3)** generate several million jobs for its 67 million people.

If completed, these dams will reduce the flow of water downstream to Syria and Iraq by up to 35% in normal years and much more in dry years. Syria also plans to build a large dam along the Euphrates River to divert water arriving from Turkey. This will leave little water for Iraq and could lead to war between Syria and Iraq.

Resolving these water distribution problems will require a combination of **(1)** regional cooperation in allocating water supplies, **(2)** slowed population growth, **(3)** improved efficiency in water use, **(4)** increased water prices to encourage water conservation and improve irrigation efficiency, and **(5)** increased grain imports to reduce water needs.

Instead of water military wars we could have grain-import economic wars. Water-short countries able to pay for imported grain instead of those that are the strongest militarily may win the competition for scarce water and food.

Thus the availability of water and food in water-short countries is connected to the interlocking problems of **(1)** *population growth and control* and *water conservation* to reduce water needs and **(2)** *environmentally sustainable economic growth* to provide enough money to reduce water needs through grain imports.

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

This chapter addresses the following questions:

- What are water's unique physical properties?
- How much fresh water is available to us, and how much of it are we using?
- What causes freshwater shortages, and what can be done about this problem?
- What are the pros and cons of using dams and reservoirs to supply more water?
- What are the pros and cons of transferring large amounts of water from one place to another?
- What are the pros and cons of withdrawing groundwater and converting salt water to fresh water?
- How can we waste less water?
- What are the causes of flooding, and what can be done to reduce the risk of flooding and flood damage?
- How can we use the earth's water more sustainably?

14-1 WATER'S IMPORTANCE AND UNIQUE PROPERTIES

Why Is Water So Important? We live on the water planet, with a precious film of water—most of it salt water—covering about 71% of the earth's surface (Figure 7-5, p. 147). All organisms are made up mostly of water; a tree is about 60% water by weight, and most animals are about 50–65% water.

Each of us needs only about a dozen cupfuls of water per day to survive, but huge amounts of water are needed to supply us with food, shelter, and our other needs and wants. Water also plays a key role in **(1)** sculpting the earth's surface, **(2)** moderating climate, and **(3)** diluting pollutants.

What Are Some Important Properties of Water? Water is a remarkable substance with a unique combination of properties:

- *There are strong forces of attraction (called hydrogen bonds,* Appendix 2, Figure 4) *between molecules of water.* These attractive forces are the major factor determining water's unique properties.
- *Water exists as a liquid over a wide temperature range because of the strong forces of attraction between water molecules.* Its high boiling point of 100°C (212°F) and low freezing point of 0°C (32°F) mean that water remains a liquid in most climates on the earth.
- *Liquid water changes temperature very slowly because it can store a large amount of heat without a large change in temperature.* This high heat capacity **(1)** helps protect living organisms from temperature fluctuations, **(2)** moderates the earth's climate, and **(3)** makes water an excellent coolant for car engines, power plants, and heat-producing industrial processes.
- *It takes a lot of heat to evaporate liquid water because of the strong forces of attraction between its molecules.* Water absorbs large amounts of heat as it changes into water vapor and releases this heat as the vapor condenses back to liquid water. This is a primary factor in distributing heat throughout the world (Figure 6-10, p. 117) and thus plays an important role in determining the climates of various areas. This property also makes water evaporation an effective cooling process, which is why you feel cooler when perspiration or bathwater evaporates from your skin.
- *Liquid water can dissolve a variety of compounds.* This enables it to **(1)** carry dissolved nutrients into the tissues of living organisms, **(2)** flush waste products out of those tissues, **(3)** serve as an all-purpose cleanser, and **(4)** help remove and dilute the water-soluble wastes of civilization. Water's superiority as a solvent also means that water-soluble wastes pollute it easily.
- *Water molecules can break down (ionize) into hydrogen ions (H^+) and hydroxide ions (OH^-), which help maintain a balance between acids and bases in cells, as measured by the pH of water solutions* (Figure 3-5, p. 49).
- *Water filters out wavelengths of ultraviolet radiation* (Figure 3-9, p. 52) *that would harm some aquatic organisms.*
- *The strong attractive forces between the molecules of liquid water cause its surface to contract (high surface tension) and to adhere to and coat a solid (high wetting ability).* These cohesive forces pull water molecules at the surface layer together so strongly that it can support small insects. The combination of high surface tension and wetting ability allow water to rise through a plant from the roots to the leaves (capillary action).
- *Unlike most liquids, water expands when it freezes.* This means that ice has a lower density (mass per unit of volume) than liquid water. Thus ice floats on water. Without this property, lakes and streams in cold climates would freeze solid and lose most of their current forms of aquatic life. Because water expands upon freezing, it can also **(1)** break pipes, **(2)** crack a car's engine block (which is why we use antifreeze), **(3)** break up streets, and **(4)** fracture rocks (thus forming soil).

Water is the lifeblood of the biosphere. It connects us to one another, to other forms of life, and to the entire planet. 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.

14-2 SUPPLY, RENEWAL, AND USE OF WATER RESOURCES

How Much Fresh Water Is Available? Only a tiny fraction of the planet's abundant water is available to us as fresh water (Figure 14-2). About 97.4 % by volume is found in the oceans and is too salty for drinking, irrigation, or industry (except as a coolant).

Most of the remaining 2.6% that is fresh water is **(1)** locked up in ice caps or glaciers or **(2)** in groundwater too deep or salty to be used (Figure 14-2).

Thus only about 0.014% of the earth's total volume of water is easily available to us as soil moisture, usable groundwater, water vapor, and lakes and streams (Figure 14-2). If the world's water supply were only 100 liters (26 gallons), our usable supply of fresh water would be only 0.014 liter (2.5 teaspoons).

Some *good news* is that the available fresh water amounts to a generous supply. Moreover, this water is continuously collected, purified, recycled, and distributed in the solar-powered *hydrologic cycle* (Figure 4-27, p. 83) as long as we do not **(1)** overload it with slowly degradable and nondegradable wastes or **(2)** withdraw it from underground supplies faster than it is replenished. The *bad news* is that in parts of the world we are doing both.

Differences in average annual precipitation divide the world's countries and people into water *haves* and *have-nots*. For example, Canada, with only 0.5% of the world's population, has 20% of the world's fresh water, whereas China, with 21% of the world's people, has only 7% of the supply.

As population, irrigation, and industrialization increase, water shortages in already water-short regions will intensify and heighten regional tensions between and within countries. Examples of such areas include **(1)** the Middle East, (p. 312), **(2)** sub-Saharan Africa, **(3)** South Asia, and **(4)** northern China. Global warming can **(1)** increase global rates of evaporation, **(2)** shift precipitation patterns, and **(3)** disrupt water supplies and thus food supplies. Some areas will get more precipitation and some less. Some river flows will change.

What Is Surface Water? Precipitation that does not infiltrate the ground or return to the atmosphere by evaporation (including transpiration) is called **surface runoff,** which flows into streams, lakes, wetlands, and reservoirs.

About two-thirds of the world's annual runoff is lost by seasonal floods and is not available for human use. The remaining one-third is **reliable runoff,** which generally we can count on as a stable source of water from year to year..

A **watershed,** also called a **drainage basin,** is a region from which water drains into a stream, lake, reservoir, wetland, or other body of water.

What Is Groundwater? Some precipitation infiltrates the ground and percolates downward through voids (pores, fractures, crevices, and other spaces) in soil and rock (Figure 14-3). The water in these voids is called **groundwater.**

Close to the surface, the voids have little moisture in them. However, below some depth, in the **zone of saturation,** the voids are completely filled with water.

The **water table** is located at the top of the zone of saturation. It falls in dry weather and rises in wet weather. An unsaturated zone, or **zone of aeration,** lies above the water table. In this zone, pores of rock and soil contain air and may be moist but not saturated with water.

Porous, water-saturated layers of sand, gravel, or bedrock through which groundwater flows are called **aquifers** (Figure 14-3). Aquifers are like large elongated sponges through which groundwater seeps. Any

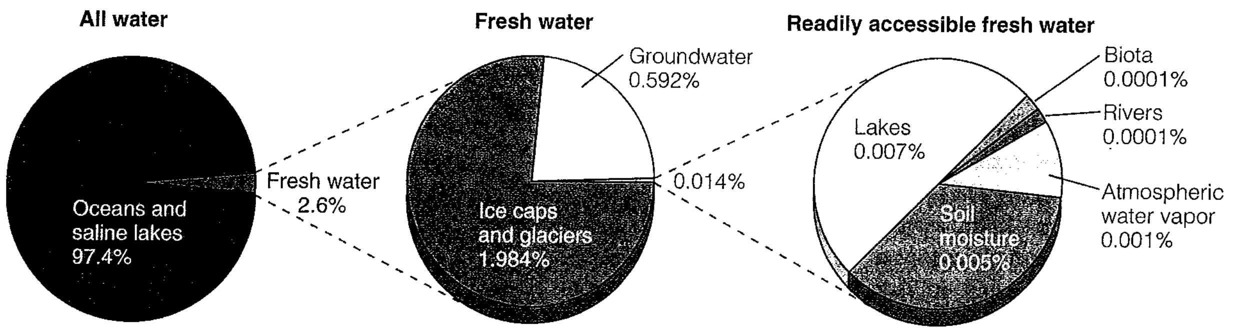


Figure 14-2 The planet's water budget. Only a tiny fraction by volume of the world's water supply is fresh water available for human use.

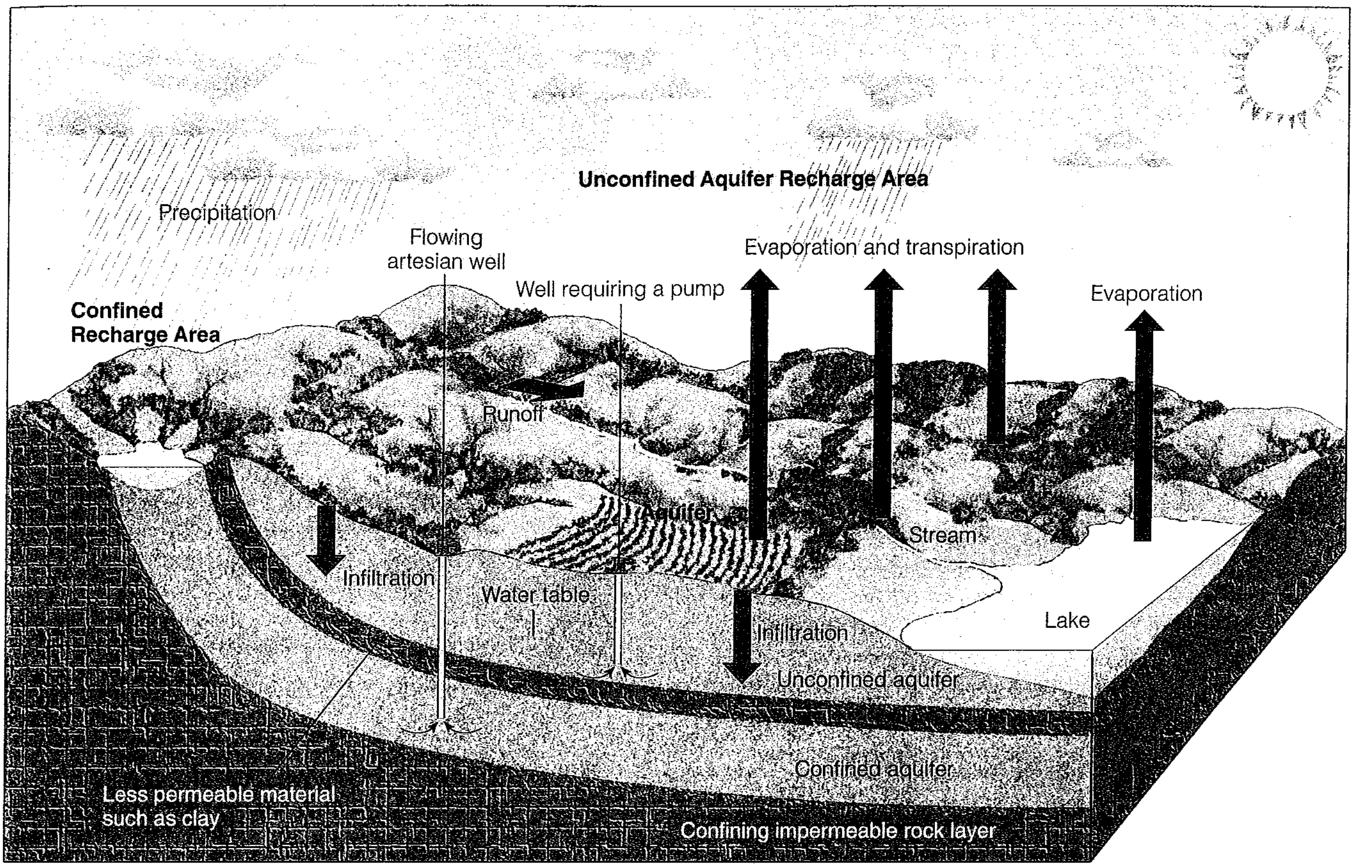


Figure 14-3 The groundwater system. An *unconfined aquifer* is an aquifer with a water table. A *confined aquifer* is bounded above and below by less permeable beds of rock. Groundwater in this type of aquifer is confined under pressure.

area of land through which water passes downward or laterally into an aquifer is called a **recharge area.**

Aquifers are replenished naturally by precipitation that percolates downward through soil and rock in what is called **natural recharge,** but some are recharged from the side by *lateral recharge.* Groundwater moves from the *recharge area* through an aquifer and out to a *discharge area* (well, spring, lake, geyser, stream, or ocean) as part of the hydrologic cycle (Figure 4-27, p. 83). Groundwater normally moves from **(1)** points of high elevation and pressure to **(2)** points of lower elevation and pressure. This movement is quite slow, typically only a meter or so (about 3 feet) per year and rarely more than 0.3 meter (1 foot) per day.

Some aquifers get very little (if any) recharge and on a human time scale are nonrenewable resources. They are often found fairly deep underground and were formed tens of thousands of years ago. Withdrawals from such aquifers amount to *water mining* that, if kept up, will deplete these ancient deposits of water.

How Much of the World's Reliable Water Supply Are We Withdrawing? Since 1900, global water withdrawal has increased about ninefold and per capita withdrawal has quadrupled, with irrigation accounting for the largest increase in water withdrawal (Figure 14-4, p. 316). As a result, humans now withdraw about 35% of the world's reliable runoff. At least another 20% of this runoff is left in streams to **(1)** transport goods by boats, **(2)** dilute pollution, and **(3)** sustain fisheries and wildlife.

Thus we directly or indirectly withdraw more than half of the world's reliable runoff. Because of increased population growth and economic development, global withdrawal rates of surface water are projected to **(1)** at least double in the next two decades and **(2)** exceed the reliable surface runoff in a growing number of areas.

Nature's water delivery does not match up with the distribution of much of the world's population. For example, Asia, with 61% of the world's people, has only 36% of the earth's reliable annual runoff. In contrast, South America, with 26% of the earth's reliable runoff, has only 6% of the world's people.

How Do We Use the World's Fresh Water? Uses of withdrawn water vary from one region to another and from one country to another (Figure 14-5).

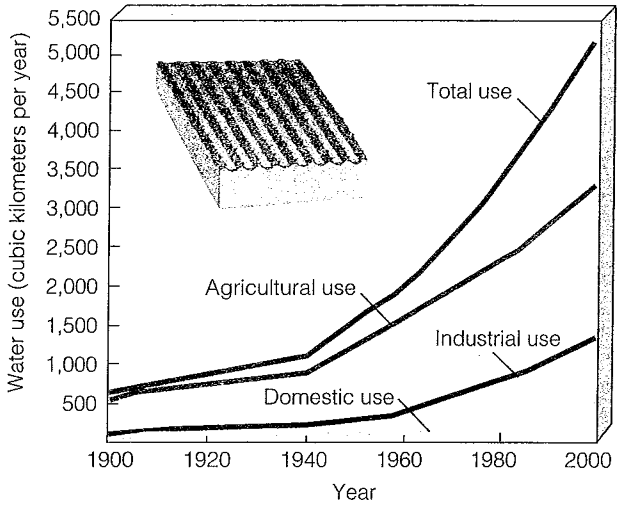


Figure 14-4 Global water withdrawal, 1900–2000. Between 2000 and 2050, the world's population is expected to increase by about 3.3 billion people and greatly increase the demand for water. (Data from World Commission on Water Use in the 21st Century)

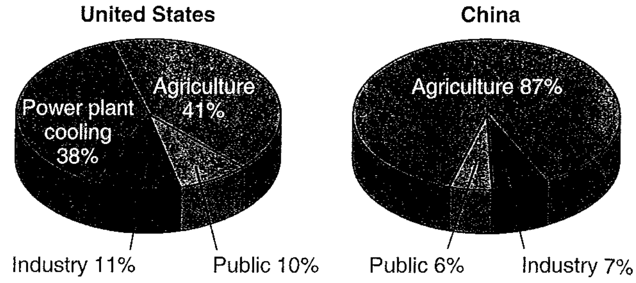


Figure 14-5 Use of water withdrawn in the United States and China. The United States has the world's highest per capita use of water, amounting to an average of 4,800 liters (1,280 gallons) per person per day in 1999. Between 1980 and 1999, total water use in the United States decreased by 10% despite a 17% increase in population, mostly because of more efficient irrigation. (Data from Worldwatch Institute and World Resources Institute)

Worldwide, about 70% of all water withdrawn each year from rivers, lakes, and aquifers is used to **(1)** irrigate 18% of the world's cropland and **(2)** produce about 40% of the world's food.

Industry uses about 20% of the water withdrawn each year, and cities and residences use the remaining 10%. Agriculture and manufacturing use large amounts of water (Figure 14-6).

Some of the water withdrawn from a source may be returned to that source for reuse. *Consumptive water use* occurs when water withdrawn becomes unavailable for reuse in the basin from which it was removed—mostly because of losses such as evaporation or contamination.

Case Study: Freshwater Resources in the United States The United States has plenty of fresh water. However, much of it is **(1)** in the wrong place at the wrong time or **(2)** contaminated by agricultural and industrial practices. The eastern states usually have ample precipitation, whereas many western states have too little (Figure 14-7, top).

In the East, the largest uses for water are for energy production, cooling, and manufacturing. The largest use by far in the West is for irrigation (which accounts for about 85% of all water use).

In many parts of the eastern United States, the most serious water problems are **(1)** flooding, **(2)** occasional urban shortages, and **(3)** pollution. For example, the 3 million residents of Long Island, New York, get most of their water from an increasingly contaminated aquifer.

The major water problem in the arid and semiarid areas of the western half of the country is a shortage of runoff, caused by **(1)** low precipitation (Figure 14-7, top), **(2)** high evaporation, and **(3)** recurring prolonged drought. Water tables in many areas are dropping rapidly as farmers and cities deplete aquifers faster than they are recharged.

In the United States, many major urban centers (especially those in the West and Midwest) are located in areas that do not have enough water (Figure 14-7, bottom). Water experts project that conflicts over

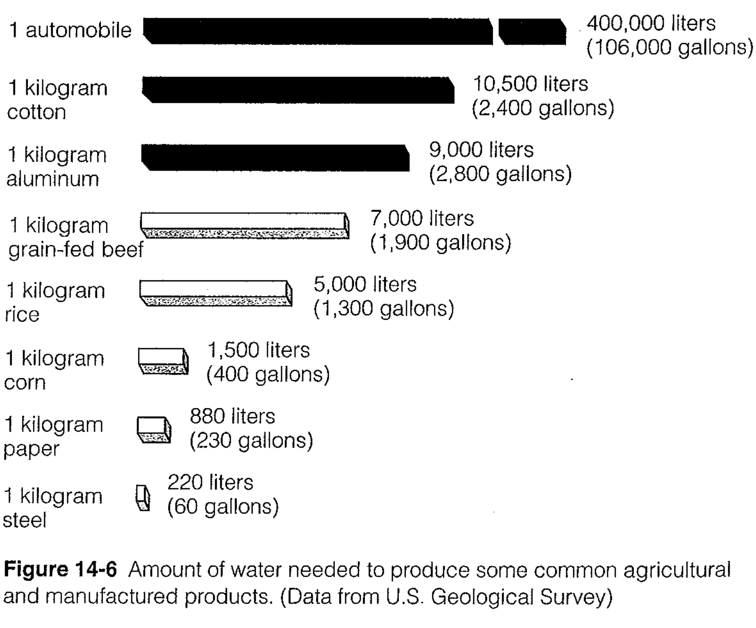


Figure 14-6 Amount of water needed to produce some common agricultural and manufactured products. (Data from U.S. Geological Survey)

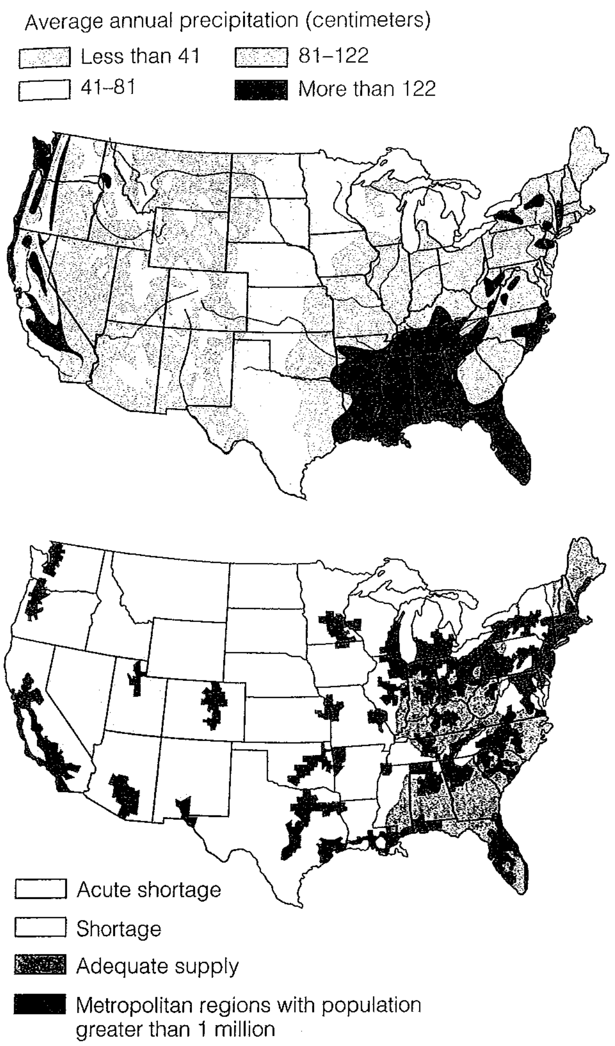


Figure 14-7 Average annual precipitation and major rivers (top) and water-deficit regions in the continental United States and their proximity to metropolitan areas having populations greater than 1 million (bottom). (Data from U.S. Water Resources Council and U.S. Geological Survey)

water supplies within and between states will intensify as more industries and people migrate west and compete with farmers for scarce water.

14-3 TOO LITTLE WATER

What Causes Freshwater Shortages? According to water expert Malin Falkenmark, the four causes of water scarcity are **(1)** a *dry climate* (Figure 6-7, p. 116), **(2)** *drought* (a period of 21 days or longer in which precipitation is at least 70% lower and evaporation is higher than normal), **(3)** *desiccation* (drying of the soil because of such activities as deforestation and overgrazing by livestock), and **(4)** *water stress* (low per capita availability of water caused by increasing numbers of people relying on limited runoff levels).

Figure 14-8 (p. 318) shows the degree of stress on the world's major river systems, based on comparing the amount of water available with the amount used by humans. A country is said to be:

- *Water stressed* when the volume of its reliable runoff per person drops to below about 1,700 cubic meters (60,000 cubic feet) per year.
- Suffering from *water scarcity* when yearly per capita water availability falls below 1,000 cubic meters (35,000 cubic feet)

According to the United Nations, currently about 500 million people live in countries that are water-scarce or water-stressed. By 2025, there may be 2.4–3.4 billion people in such countries. Income level and location determine how many of these people have access to a reliable and safe water supply.

Some areas have lots of water, but the largest rivers (which carry most of the runoff) are far from agricultural and population centers. For example, South America has the largest annual water runoff of any continent, but 60% of the runoff flows through the Amazon River in remote areas where few people live.

In some areas, overall precipitation may be plentiful but **(1)** most arrives during short periods or **(2)** cannot be collected and stored because of a lack of water storage capacity. For example, only a few hours of rain provide over half of India's rainfall during a four-month monsoon season.

Even when a plentiful supply of water exists, most of the 1.2 billion poor people living on less than $1 a day cannot afford a safe supply of drinking water and live in hydrological poverty. Most are cut off from municipal water supplies and **(1)** must collect water from unsafe sources or **(2)** buy water (often coming from polluted rivers) from private vendors at high prices. In developing countries, people not connected to municipal water supplies on average pay 12 times more per liter of water than people connected to such systems, and in some areas they pay up to 100 times as much.

Since the 1970s, water scarcity intensified by prolonged drought has killed more than 24,000 people per year and created millions of environmental refugees. In water-short rural areas in developing countries, many women (Figure 12-27, p. 271) and children must walk long distances each day, carrying heavy jars or cans, to get a meager and sometimes contaminated supply of water.

A number of analysts believe that *access to water resources, already a key foreign policy and environmental and economic security issue for water-short countries*

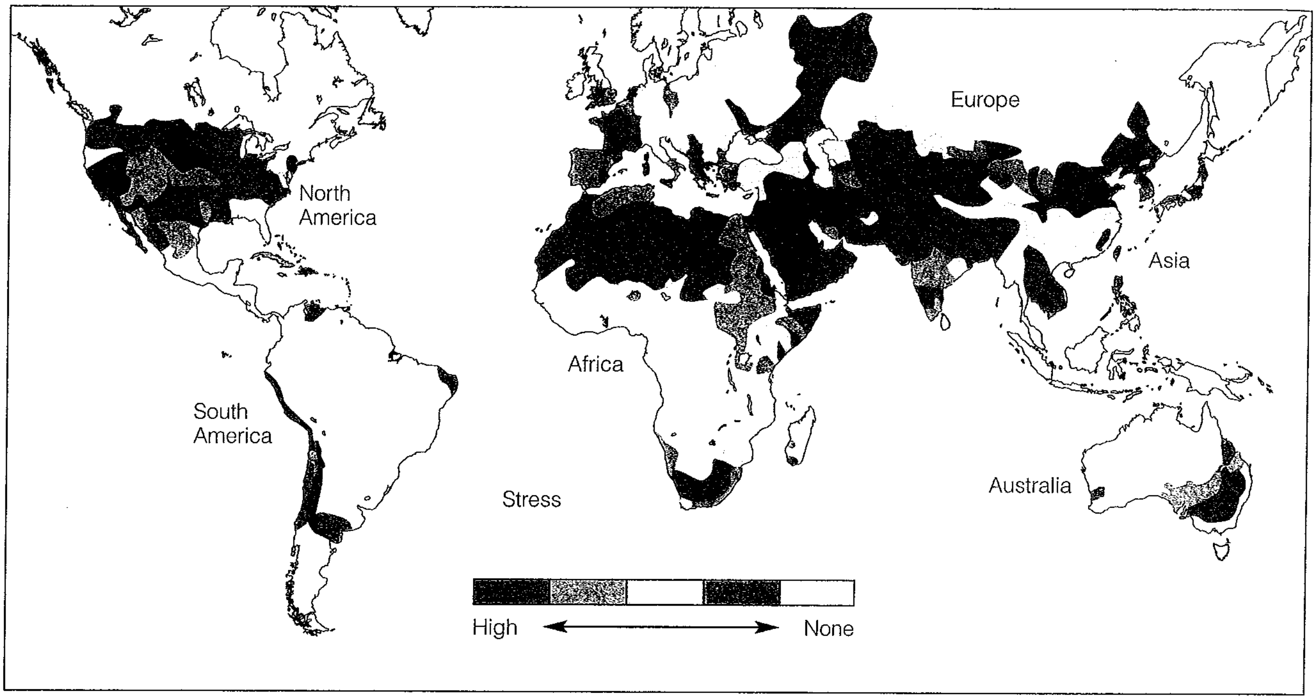


Figure 14-8 Stress on the world's major river basins, based on a comparison of the amount of water available with the amount used by humans. (Data from World Commission on Water Use in the 21st Century)

(p. 312), *will become even more important over the next 10–25 years.*

How Can We Increase Freshwater Supplies? Six ways to increase the supply of fresh water in a particular area are to **(1)** build dams and reservoirs to store runoff, **(2)** bring in surface water from another area, **(3)** withdraw groundwater, **(4)** convert salt water to fresh water (desalination), **(5)** waste less water, and **(6)** import food to reduce water use.

In *developed countries,* people tend to live where the climate is favorable and then bring in water from another watershed. For example, since 1900 the United States has spent at least $400 billion—mostly as government subsidies—in building dams, reservoirs, aqueducts, pipelines, and flood control levees to manage and supply farmers and cities with low-cost water and hydroelectric power.

In *developing countries,* most people (especially the rural poor) must settle where the water is and try to capture the precipitation they need. Millions of the more than 820 million undernourished people live in poor farm families in Asia and Africa, where long dry seasons make crop production difficult or impossible without irrigation. But conventional irrigation techniques are too expensive for many of these rural poor people. *Poverty is the principal cause of hunger, malnutrition, and lack of access to sufficient water, regardless of how much water is available.*

Thirty-six water-stressed countries in Asia, Africa, and the Middle East (Figure 14-8) account for 26% of global grain imports. As water stress increases in coming decades, such imports are likely to rise.

14-4 USING DAMS AND RESERVOIRS TO SUPPLY MORE WATER

What Are the Pros and Cons of Large Dams and Reservoirs? Large dams and reservoirs have benefits and drawbacks (Figure 14-9 and Case Study, p. 321). The main purpose is to capture and store runoff and release it as needed for **(1)** controlling floods, **(2)** producing hydroelectric power, and **(3)** supplying water for irrigation and for towns and cities. Reservoirs also provide recreational activities such as swimming, fishing, and boating.

Between 1950 and 2000, the number of large dams (more than 15 meters or 49 feet high) has increased nearly sevenfold, from about 5,700 to more than 45,000. In the United States, more than 70,000 dams are capable of capturing and storing half of the country's entire river flow.

As a result, many rivers resemble an elaborate plumbing system, with multiple dams used to control

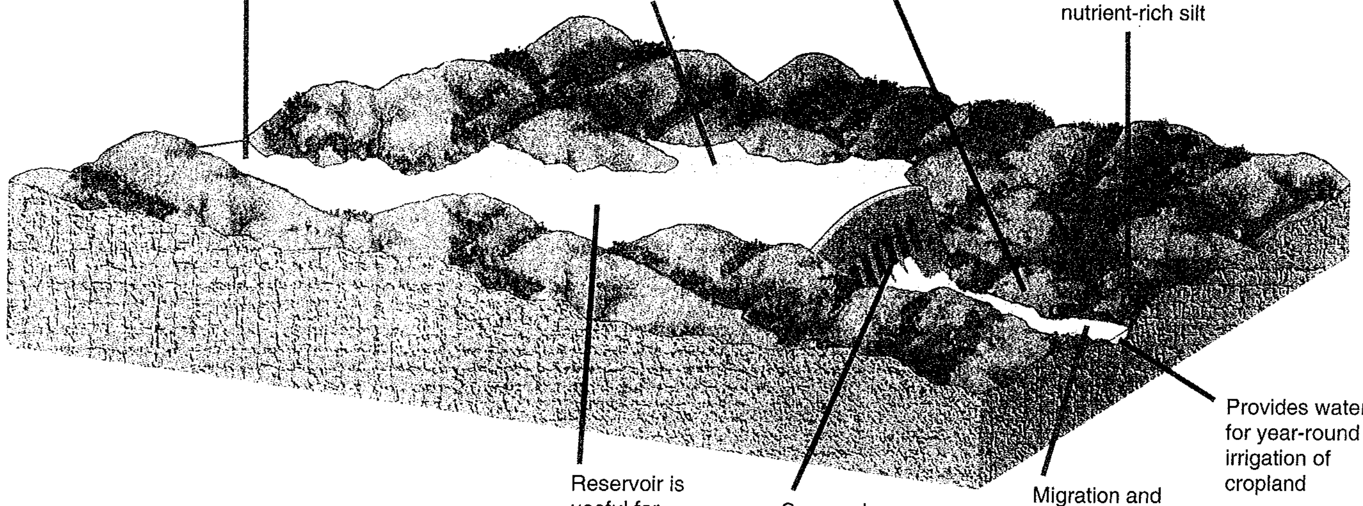


Figure 14-9 Main advantages (green) and disadvantages (orange) of large dams and reservoirs. The world's 45,000 large dams now impound about 14% of the world's runoff.

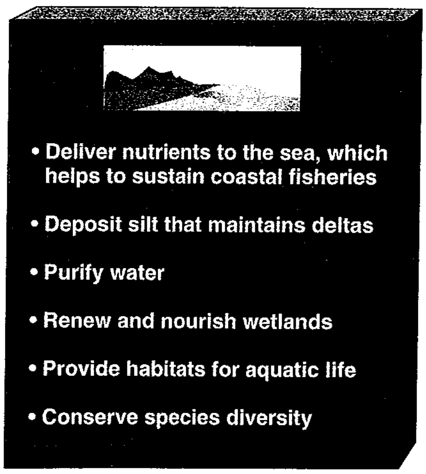
the timing and flow of water, like water from a faucet. This engineering approach to river management often impairs the important ecological services that rivers provide (Figure 14-10). For example, according to water-resource expert Peter H. Gleck, more than 24% of the world's freshwater fish species are threatened or endangered, primarily because dams and water withdrawals have destroyed the free-flowing river ecosystems (Figure 7-23, p. 160) where they once thrived.

Some *good news* is that these dams have increased the annual runoff available for human use by nearly one-third. Some *bad news* is that a series of dams on a river, especially in arid 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, half of the world's major rivers either **(1)** run dry part of the year and fail to reach the ocean or **(2)** have little water left in them when they get to the sea. Causes include a combination of **(1)** prolonged drought in some areas, **(2)** dams, and **(3)** increased diversion of water for irrigation and for cities.

Major rivers that run dry and do not reach the sea anymore during the dry season include the **(1)** Colorado in the southwestern United States (Figure 14-11, p. 320 and Case Study, p. 322), **(2)** Rio Grande along the border between Texas and Mexico, **(3)** Yellow in northern China, **(4)** Nile in the Middle East (Figure 14-1), **(5)** Ganges and Indus in South Asia, and **(6)** Amu Darya and Syr Darya in five counties that once were part of the Soviet Union.

A small number of countries have taken some steps to remove the old, dangerous, or environmentally harmful dams. In 1998 and 1999, for example, two dams in France's Loire River basin were demolished to help restore the region's fisheries. In 1999, a dam on Maine's Kennebac River was dismantled to open up a 29-kilometer(18-mile) stretch of the river for fish spawning. It is one of 500 dams that have been removed from U.S. rivers in the past few years.

Figure 14-10 Some 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. According to environmental economists, attaching even crudely estimated monetary values to these ecosystem services would help sustain them.



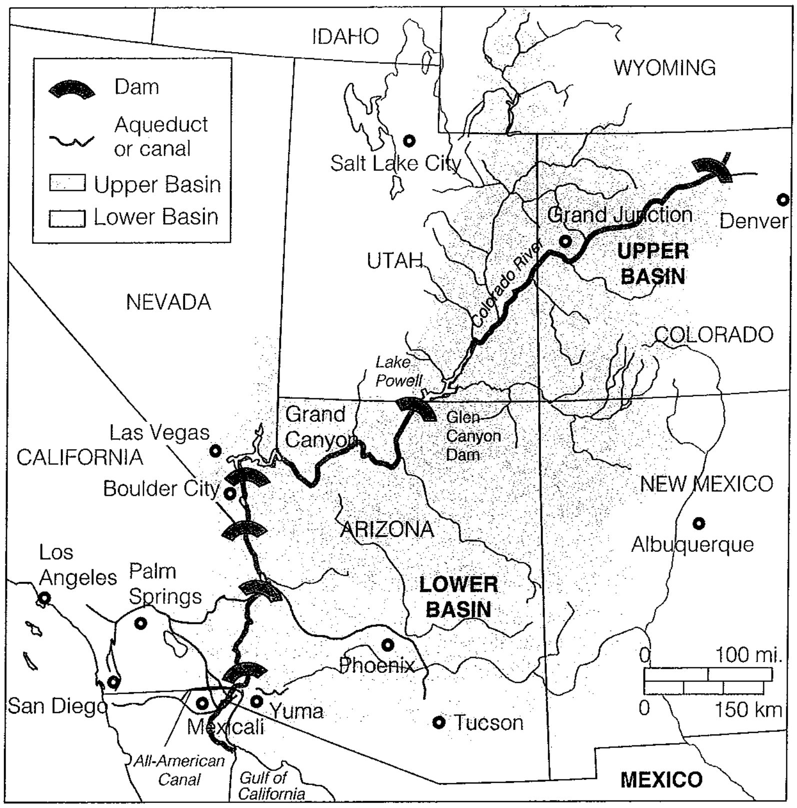


Figure 14-11 The *Colorado River basin.* The area drained by this basin is equal to more than one-twelfth of the land area of the lower 48 states.

Case Study: China's Three Gorges Dam When completed, China's Three Gorges project on the mountainous upper reaches of the Yangtze River (Figure 14-12) will be the world's largest hydroelectric dam and reservoir. This 2-kilometer-(1.2-mile-) long dam is supposed to be completed by 2009 at an estimated cost of $25–65 billion.

According to Chinese officials, this superdam, with the electric output of 20 large coal-burning or nuclear power plants, will

- Generate almost 10% of China's electricity for use by industries and about 150 million people.
- Help China reduce its dependence on coal, which causes severe air pollution and releases enormous amounts of the greenhouse gas carbon dioxide into the atmosphere.
- Hold back the Yangtze River's floodwaters, which have killed more than 500,000 people during the past 100 years including 4,000 people in 1998. According to Chinese officials, the 15 million people living in the Yangtze River Valley will benefit from such flood protection. This greatly exceeds the 1.9 million people who will be relocated from the area to be flooded to form a gigantic 600-kilometer-long (370-mile-long) reservoir behind the dam (Figure 14-12, right).
- Reduce flooding and silting of the river by eroded soil.

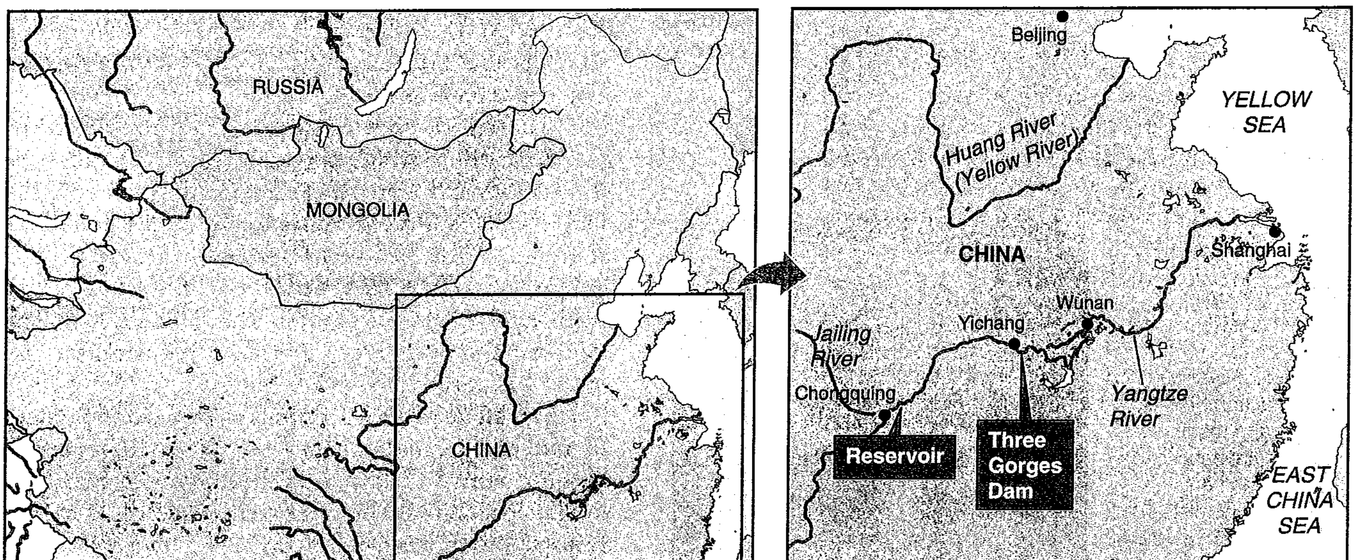


Figure 14-12 Site of the Three Gorges dam—the world's largest dam— on China's Yangtze River.

Egypt's Aswan High Dam: Blessing or Disaster?

CASE STUDY

The Aswan High Dam on the Nile River in Egypt and its Lake Nasser reservoir (Figure 14-1) were built in the 1960s and demonstrate the mix of advantages and disadvantages of such projects.

The project's major benefits include the following:

- Supplying about one-half of Egypt's electrical power and reducing electricity prices.
- Storing and releasing water for irrigation, which is used to grow all of Egypt's food. This saved Egypt's rice and cotton crops during severe droughts in the 1970s and 1980s and helped avert massive famines. To many Egyptians, this more than paid for the cost of the dam.
- Increasing food production by allowing year-round irrigation of land in the lower Nile basin. Since 1970, this has helped increase Egypt's agricultural income by about 200%.
- Improving navigation along the river.
- Providing flood control for the lower Nile basin.

However, the project has also produced the following harmful ecological and economic effects:

- Ending the yearly flooding that for thousands of years had fertilized the Nile's floodplain with silt, most of it washed down from the Ethiopian highlands. Now the river's silt accumulates behind the dam, filling Lake Nasser and eventually will make the dam useless.
- Necessitating the use of commercial fertilizer on cropland in the Nile Delta basin at an annual cost of more than $100 million to make up for plant nutrients once available at no cost. The country's new fertilizer plants use up much of the electrical power produced by the dam.
- Increasing salinization (Figure 10-22, p. 221) because there is no natural annual flooding to flush salts from the irrigated soil. This has offset about three-fourths of the gain in food production from new land irrigated by water from the reservoir.
- Eliminating 94% of Nile water that once reached the Mediterranean Sea each year and upsetting the ecology of waters near the mouth of the Nile.
- Eliminating the annual sediment discharge where the Nile reaches the sea. This has **(1)** caused the coastal delta to erode and advance inland and **(2)** reduced productivity on large areas of agricultural land.
- Eradicating most of Egypt's sardine, mackerel, shrimp, and lobster fishing industries because nutrient-rich silt no longer reaches the river's mouth. This has led to losses of **(1)** approximately 30,000 jobs, **(2)** millions of dollars annually, and **(3)** an important source of protein for Egyptians. However, a new fishing industry taking bass, catfish, and carp from Lake Nasser has offset some of these losses.
- Uprooting 125,000 people when land was flooded to create Lake Nasser and changing nomadic grazing patterns.

In 1997, the Egyptian government **(1)** opened a new canal to transfer Nile water under the Suez Canal to irrigate land in the Sinai desert and **(2)** began a 20-year project to divert Nile water upstream from Lake Nasser and transport it hundreds of kilometers to irrigate land in Egypt's southwestern desert. This will open up land for human settlement to relieve population pressures in the crowded Nile valley.

These plans are threatened because about 80% of the water flowing into Lake Nasser comes from Ethiopia (Figure 14-1), which plans to build dams for irrigation and hydropower projects. This may not leave enough water in the Nile to support Egypt's plans for increased irrigation and could increase tension between the two countries.

Some analysts believe the Aswan dam's benefits outweigh its economic and ecological costs. Other analysts consider it an economic and ecological disaster. Time will tell who is right.

Critical Thinking

1. Do you believe the benefits of the Aswan High Dam outweigh its drawbacks? Explain.

2. List two principles for designing and building large dams based on lessons from the Aswan High Dam.

Critics point to a number of drawbacks of the Yangtze dam and reservoir project:

- Forming the huge reservoir will **(1)** flood large areas of productive farmland and forests and **(2)** displace about 1.9 million people from their homes.
- The region's entire ecosystem will be radically changed.
- Water pollution will increase because of the river's reduced water flow.
- If the reservoir fills up with sediment and overflows (especially if the reservoir is kept filled at a high level, as planned, to provide maximum hydroelectric power), half a million people will be exposed to severe flooding.
- Annual deposits of nutrient-rich sediments below the dam will be reduced.
- The reduced downstream water flow will promote saltwater intrusion into drinking water supplies near the mouth of the river.

The Colorado River Basin

CASE STUDY

The Colorado River flows 2,300 kilometers (1,400 miles) from the mountains of central Colorado to the Mexican border and eventually to the Gulf of California (Figure 14-11, p. 320). During the past 50 years, this once free-flowing river has been tamed by a gigantic plumbing system consisting of **(1)** 14 major dams and reservoirs (Figure 14-11), **(2)** hundreds of smaller dams, and **(3)** a network of aqueducts and canals that supply water to farmers, ranchers, and cities.

Today, this domesticated river provides **(1)** electricity (from hydroelectric plants at major dams), **(2)** water for more than 25 million people in seven states, **(3)** water used to produce about 15% of the nation's produce and livestock, and **(4)** a multibillion-dollar recreation industry of whitewater rafting, boating, fishing, camping, and hiking enjoyed by more than 15 million people a year.

Take away this tamed river and **(1)** Las Vegas, Nevada, would be a mostly uninhabited desert area, **(2)** San Diego, California (which gets 70% of its water from the Colorado), could not support its present population, and **(3)** California's Imperial Valley (which grows a major portion of the nation's vegetables) would consist mostly of cactus and mesquite plants.

However, three major problems are associated with use of this river's water:

- The Colorado River basin includes some of the driest lands in the United States and Mexico (Figure 14-7).
- Legal pacts in 1922 and 1944 allocated more water to the states in the river's *upper basin* (Wyoming, Utah, Colorado, and New Mexico) and *lower basin* (Arizona, Nevada, and California; Figure 14-11) and to Mexico than now flows through the river, even in years without a drought.
- Because of so many withdrawals, the river rarely makes it to the Gulf of California. Instead, it fizzles into a trickle that disappears into the Mexican desert or (in drought years) the Arizona desert. This **(1)** threatens the survival of species that spawn in the river, **(2)** destroys estuaries that serve as breeding grounds for numerous aquatic species, and **(3)** increases saltwater contamination of aquifers near coasts.

Legal battles are increasing over how much of the river's limited water can be withdrawn and used by **(1)** cities, **(2)** farmers, **(3)** ranchers, and **(4)** Native Americans (who as senior owners of water rights dating back to the mid-1880s have the law on their side and have been winning legal battles to withdraw more water).

Environmentalists have initiated mostly unsuccessful attempts to keep more of the river wild by **(1)** not building so many large dams and **(2)** removing some of the existing dams to help protect the river's ecological services (Figure 14-10).

Traditionally, about 80% of the water withdrawn from the Colorado has been used to irrigate crops and raise cattle because ranchers and farmers (after Native Americans) got there first and established legal rights to use a certain amount of water each year. This large-scale use of water for agriculture was made possible because the government **(1)** paid for the dams and reservoirs and **(2)** under long-term contracts has supplied many of the farmers and ranchers with water at a very low price. This has led to inefficient use of irrigation water and growing crops such as rice, cotton, and alfalfa (for cattle feed) that need a lot of water.

Some cities (such as Tucson, Arizona, and Colorado Springs, Colorado) have been buying up the legal water rights of nearby farmers and ranchers. Others are paying farmers to install less wasteful irrigation systems (Figure 14-18, p. 330) so more water will be available to support urban areas. It is estimated that improving overall irrigation efficiency by about 10–15% would provide enough water to support projected urban growth in the areas served by the river to 2020.

These controversies illustrate the problems that governments and people in semiarid regions with shared river systems face as population and economic growth place increasing demands on limited supplies of surface water.

Critical Thinking

1. What are the pros and cons of reducing or eliminating government subsidies that provide U. S. farmers, ranchers, and cities with cheap water from the Colorado River?

2. If the legal system allowed it, put the following users in order of how much water you would allocate to them from the Colorado River: farmers, ranchers, cities, Native Americans, and Mexico. Explain your choices.

14-5 TRANSFERRING WATER FROM ONE PLACE TO ANOTHER

What Are the Pros and Cons of Large-Scale Water Transfers? Tunnels, aqueducts, and underground pipes can transfer stream runoff collected by dams and reservoirs from water-rich areas to water-poor areas. Although such transfers have benefits, they also create environmental problems (Case Study, p. 324). Indeed, most of the world's dam projects and large-scale water transfers illustrate the important ecological principle that *you cannot do just one thing.*

Figure 14-13 The California Water Project and the Central Arizona Project involve large-scale water transfers from one watershed to another. Arrows show the general direction of water flow.

One of the world's largest watershed transfer projects is the *California Water Project.* In California, the basic water problem is that 75% of the population lives south of Sacramento, but 75% of the state's rain occurs north of Sacramento.

The California Water Project uses a maze of giant dams, pumps, and aqueducts to transport water from water-rich northern California to heavily populated areas and to arid and semiarid agricultural regions, mostly in southern California (Figure 14-13).

For decades, northern and southern Californians have been feuding over how the state's water should be allocated under this project. Southern Californians say they need more water from the north to support Los Angeles, San Diego, and other growing urban areas and to grow more crops. Agriculture uses 74% of the water withdrawn in California, much of it for water-thirsty crops. For example, alfalfa, one of the most water-intensive crops, is grown in the southern California desert. It uses about one-fourth of California's irrigation water but makes up only 0.1% of the state's economy.

Opponents in the north say that sending more water south would **(1)** degrade the Sacramento River, **(2)** threaten fisheries, and **(3)** reduce the flushing action that helps clean San Francisco Bay of pollutants. They also argue that **(1)** much of the water sent south is wasted unnecessarily and **(2)** making irrigation just 10% more efficient would provide enough water for domestic and industrial uses in southern California. However, if water supplies in northern California and in the Colorado River basin (Figure 14-11) drop sharply because of global warming, the amount of water delivered by the huge distribution system will plummet.

Pumping out more groundwater is not the answer because groundwater is already being withdrawn faster than it is replenished throughout much of California. To most analysts, quicker and cheaper solutions are **(1)** improving irrigation efficiency and **(2)** allowing farmers to sell their legal rights to withdraw certain amounts of water from rivers.

Case Study: The James Bay Watershed Transfer Project Another major watershed transfer project is Canada's James Bay project. It is a $60-billion 50-year scheme to harness the wild rivers that flow into Quebec's James and Hudson Bays to produce electric power for Canadian and U.S. consumers (Figure 14-14).

If completed, this megaproject would **(1)** construct 600 dams and dikes that will reverse or alter the flow of 19 giant rivers covering a watershed three times the size of New York State, **(2)** flood an area of boreal forest and tundra equal in area to Washington State or Germany, and **(3)** displace thousands of indigenous Cree and Inuit, who for 5,000 years have lived off James Bay by subsistence hunting, fishing, and trapping.

After 20 years, the $16-billion phase I has been completed. The second and much larger phase was

Figure 14-14 If completed, the James Bay project in northern Quebec will alter or reverse the flow of 19 major rivers and flood an area the size of the state of Washington to produce hydropower for consumers in Quebec and the United States, especially in New York State. Phase I of this 50-year project is completed.

The Aral Sea Water Transfer Disaster

CASE STUDY

The shrinking of the Aral Sea (see figure) is a result of a large-scale water transfer project in an area of the former Soviet Union with the driest climate in central Asia. Since 1960, enormous amounts of irrigation water have been diverted from the inland Aral Sea and its two feeder rivers to create one of the world's largest irrigated areas. The irrigation canal, the world's longest, stretches over 1,300 kilometers (800 miles).

This water diversion project (coupled with droughts) and high evaporation rates in this hot, dry climate has caused a regional ecological, economic, and health disaster. Problems caused by this massive water-diversion project include:

- Tripling of the sea's salinity.
- Decreasing the sea's surface area by 54% (see figure) and its volume by 75%.
- Reducing the sea's two supply rivers to mere trickles.
- Converting about 36,000 square kilometers (14,000 square miles) of former lake bottom to a human-made desert covered with glistening white salt.
- Causing the presumed extinction of 20 of the area's 24 native fish species as the salt concentrations in the sea's water have increased. This has devastated the area's fishing industry, which once provided work for more than 60,000 people. Fishing villages and boats once on the sea's coastline now are in the middle of a salt desert and have been abandoned.
- Eliminating 85% of the area's wetlands, which along with increased pollution has greatly reduced waterfowl populations.
- Disappearance of roughly half the area's bird and mammal species.
- Causing one of the world's worst salinization problems. Winds pick up the salty dust that encrusts the lake's now-exposed bed and blow it onto fields as far as 300 kilometers (190 miles) away. As the salt spreads, it kills wildlife, crops, and other vegetation and pollutes water. Aral Sea dust settling on glaciers in the Himalayas is causing them to melt at a faster than normal rate.
- Increasing groundwater and surface water pollution. To raise yields, farmers have increased inputs of herbicides, insecticides, fertilizers, and irrigation water on some crops. Many of these chemicals have percolated downward and accumulated to dangerous levels in the groundwater, from which most of the region's drinking water comes. The lower river flows have also concentrated salts, pesticides, and other toxic chemicals, making surface water supplies hazardous to drink.
- Alteration of 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 **(1)** there is less rain, **(2)** summers are hotter and drier, **(3)** winters are colder, and **(4)** the growing season is shorter.
- Reduction of crop yields by 20–50% from a combination of climate change and severe salinization of almost a

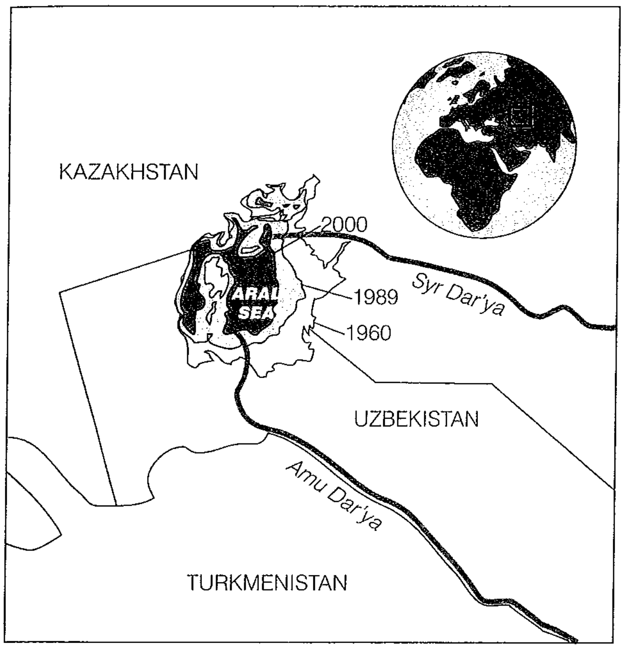
postponed indefinitely in 1994 because of **(1)** an excess of power generated, **(2)** opposition by the Cree (whose ancestral hunting grounds would have been flooded) and Canadian and U.S. environmentalists, and **(3)** New York State's cancellation of two contracts to buy electricity produced by phase II.

14-6 TAPPING GROUNDWATER, CONVERTING SALT WATER TO FRESH WATER, SEEDING CLOUDS, AND TOWING ICEBERGS

What Are the Advantages of Withdrawing Groundwater? Pumping groundwater from aquifers has several advantages over tapping more erratic flows from streams. Groundwater **(1)** can be removed as needed year round, **(2)** is not lost by evaporation, and **(3)** usually is less expensive to develop than surface water systems.

Aquifers provide drinking water for almost one-third of the world's people. In Asia alone, more than 1 billion people depend on groundwater for drinking. In the United States, water pumped from aquifers supplies about **(1)** 51% of the drinking water (96% in rural areas and 20% in urban areas) and **(2)** 43% of irrigation water.

What Are the Disadvantages of Withdrawing Groundwater? Withdrawing groundwater from aquifers faster than it is replenished can cause or intensify several problems: **(1)** *water table lowering* (Figure 14-15, p. 326), **(2)** *aquifer depletion* (Figure 14-16, top, p. 326), **(3)** *aquifer subsidence* (sinking of land when groundwater is withdrawn, Figure 14-16, bottom),



Once the world's fourth largest freshwater lake, the Aral Sea has been shrinking and getting saltier since 1960 because most of the water from the rivers that replenish it has been diverted to grow cotton and food crops. As the lake shrinks, it leaves behind a salty desert, economic ruin, increasing health problems, and severe ecological disruption.

third of the area's cropland. More water could be withdrawn to flush out and lessen the area's acute salt problem. But Russian scientists estimate that freeing up this much water would mean retiring about half of the area's irrigated cropland, an unthinkable solution considering the region's already dire economic conditions.

▪ Greatly increased health problems from a combination of toxic dust, salt, and contaminated water for a growing number of the 58 million people living in the Aral Sea's watershed. Such problems include abnormally high rates of **(1)** infant mortality, **(2)** tuberculosis, **(3)** anemia, **(4)** respiratory illness (one of the world's highest), **(5)** eye diseases (from salt dust), **(6)** throat cancer, **(7)** kidney and liver diseases (especially cancers), **(8)** arthritic diseases, **(9)** typhoid fever, and **(10)** hepatitis.

Can the Aral Sea be saved, and can the area's serious ecological and human health problems be reduced? Since 1999, the United Nations and the World Bank have spent about $600 million to **(1)** purify drinking water, **(2)** upgrade irrigation and drainage systems to improve irrigation efficiency, flush salts from croplands, and boost crop productivity, and **(3)** construct wetlands and artificial lakes to help restore aquatic vegetation, wildlife, and fisheries. However, this process will take decades and will not prevent the shrinkage of the Aral Sea into a few brine lakes.

Critical Thinking

What ecological and economic lessons can we learn from the Aral Sea tragedy?

(4) *intrusion of salt water into aquifers,* **(5)** *drawing of chemical contamination in groundwater toward wells,* and **(6)** *reduced stream flow* because of diminished flows of groundwater into streams. Also, industrial and agricultural activities, septic tanks, and other sources can contaminate groundwater.

According to Earth Policy Institute and the World Resources Institute, water tables are falling in many areas as the rate of water pumping exceeds the rate of recharge from precipitation. Such unsustainable *water mining* from overpumping aquifers produces about 8% of the world's current grain harvest. This is causing water tables to fall in

▪ The North China Plain, which produces more than half of China's wheat and a third of its corn. A 2001 survey found that the aquifer under North China's plain is falling faster than previously thought.

▪ Agricultural areas in **(1)** parts of the southern Great Plains of the United States, which are served by the gigantic but essentially nonrenewable Ogallala aquifer (Case Study, p. 327) and **(2)** in parts of the arid southwestern United States (Figure 14-7, top), especially California's Central Valley, which supplies about half the country's vegetables and fruits.

▪ Much of India, especially the Punjab. This jeopardizes as much as one-fourth of India's grain production.

▪ Parts of **(1)** Saudi Arabia, **(2)** northern Africa (especially Libya and Tunisia), **(3)** southern Europe, **(4)** the Middle East, and **(5)** Mexico, Thailand, and Pakistan.

According to water resource expert Sandra Postel, about 480 million of the world's 6.2 million people are being fed with grain produced with eventually unsustainable water mining from aquifers. This example of

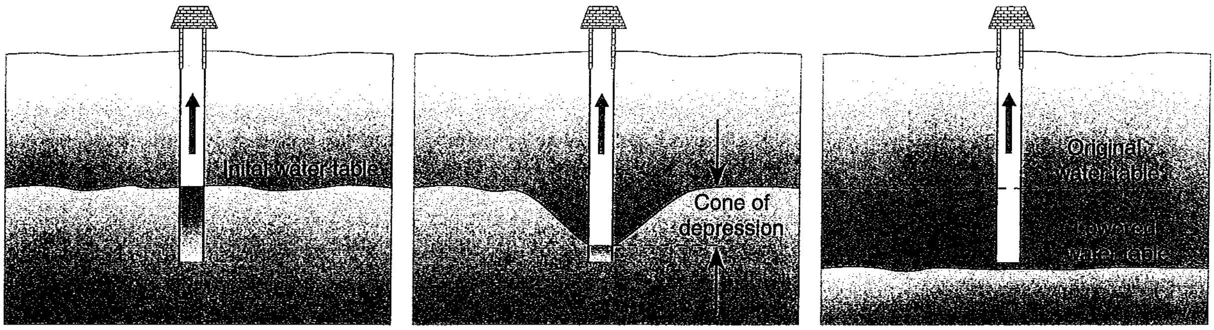


Figure 14-15 Lowering of the water table when a well is drilled into an aquifer (left). A cone of depression (middle) in the water table forms if groundwater is pumped to the surface faster than it can flow through the aquifer to the well. If this excessive water removal continues, the water table falls (right).

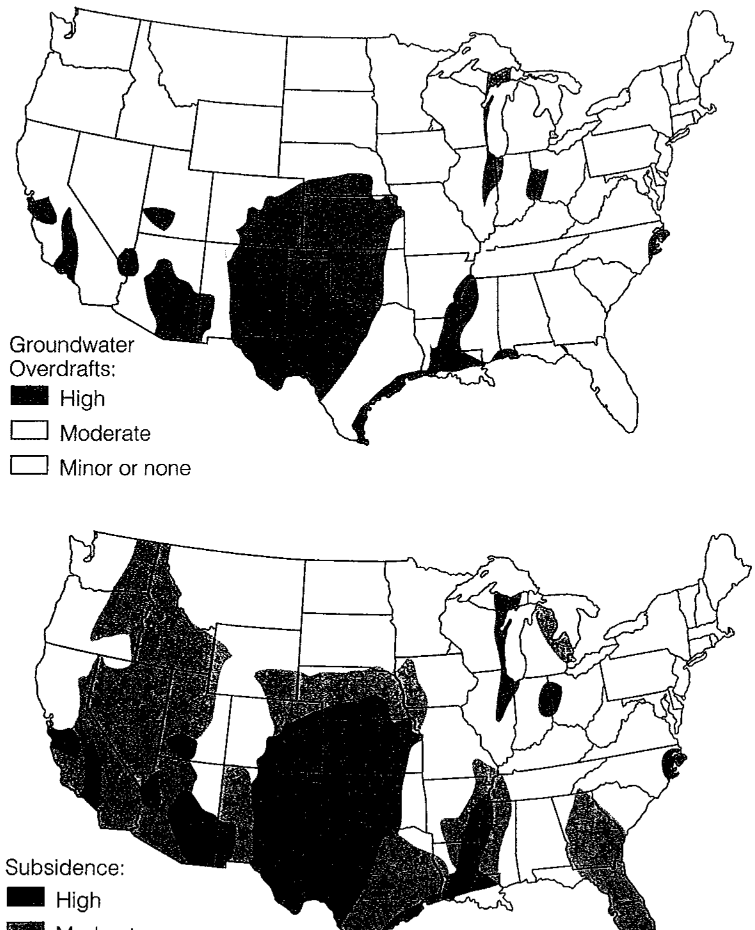


Figure 14-16 Areas of greatest aquifer depletion from groundwater overdraft (top) and ground subsidence (bottom) in the continental United States. Aquifer depletion is also high in Hawaii and Puerto Rico (not shown on map). (Data from U.S. Water Resources Council and U.S. Geological Survey)

the tragedy of the commons (Connections, p. 11) is expected to increase as irrigated areas are expanded to help feed the 3.1 billion more people projected to join the ranks of humanity between 2002 and 2050.

Overpumping is a new phenomenon that has largely occurred since 1950 because of the development of increasingly powerful electric and diesel pumps that can remove water from an aquifer faster than it is renewed by precipitation. With water worth up to 70 times more in industry and cities as in agriculture, farmers almost always lose in the competition for scarce water.

In addition to limiting future food production, overpumping aquifers is increasing the gap between the rich and poor in some areas. As water tables drop, farmers must **(1)** drill deeper wells, **(2)** buy larger pumps to bring the water to the surface, and **(3)** use more electricity to run the pumps. Poor farmers cannot afford to do this and end up losing their land and either working for richer farmers or hoping to survive by migrating to cities.

When fresh water from an aquifer near a coast is withdrawn faster than it is recharged, salt water intrudes into the aquifer (Figure 14-17, p. 328). Such intrusion can contaminate drinking water supplies of many towns and cities along coastal areas.

Ways to prevent or slow groundwater depletion include **(1)** controlling population growth, **(2)** not planting water-intensive crops such as cotton and sugarcane in dry areas, **(3)** shifting to crops that need less water in dry areas, **(4)** developing crop strains that need less water and are more resistant to heat stress, **(5)** wasting less irriga-

CASE STUDY

Mining Groundwater: The Shrinking Ogallala Aquifer

Large amounts of water have been pumped from the Ogallala, the world's largest known aquifer (see figure). This has helped transform vast areas of arid high plains prairie land into one of the largest and most productive agricultural regions in the United States.

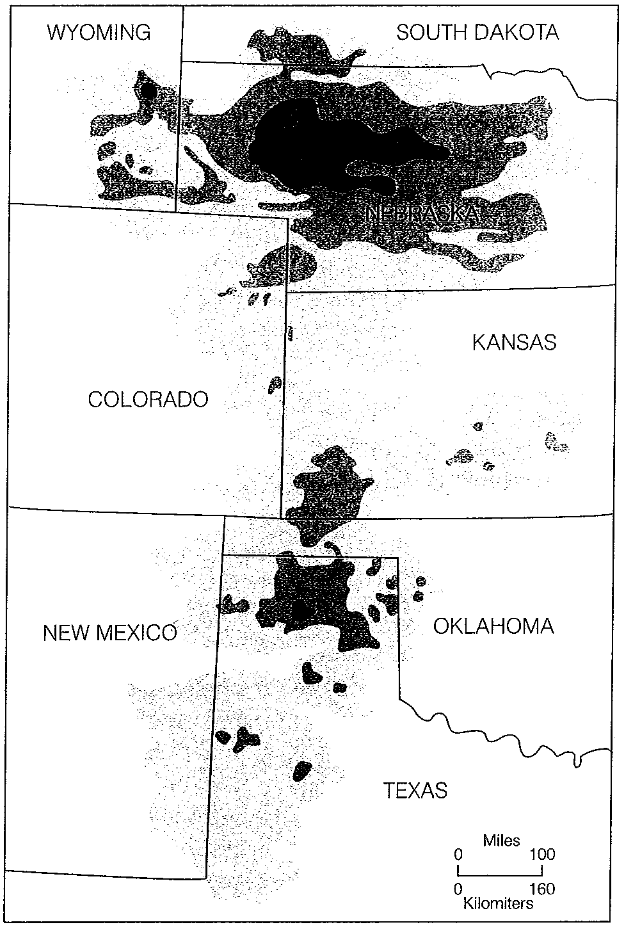
Mostly because of irrigated farming, this region produces 20% of U.S. agricultural output (including 40% of its feedlot beef), valued at $32 billion per year. This has brought prosperity to many farmers and merchants in this region. But the largely hidden environmental and economic cost has been increasing aquifer depletion in some areas.

Although this aquifer is gigantic, it is essentially nonrenewable (stored during the retreat of the last ice age about 15,000–30,000 years ago) with an extremely slow recharge rate. In some areas, water is being pumped out of the aquifer 8–10 times faster than the aquifer's natural recharge rate.

The northernmost states (Wyoming, North Dakota, South Dakota, and parts of Colorado) still have ample supplies. However, supplies in parts of the southern states, where the aquifer is thinner (see figure), are being depleted rapidly, with about two-thirds of the aquifer's depletion taking place in the Texas high plains.

Water experts project that at the current rate of withdrawal, one-fourth of the aquifer's original supply will be depleted by 2020 and much sooner in areas where it is shallow. It will take thousands of years to replenish the aquifer.

Government subsidies designed to increase crop production also increase depletion of the Ogallala by **(1)** encouraging farmers to grow water-thirsty cotton in the lower basin, **(2)** providing crop-disaster payments, and **(3)** providing tax breaks in the form of groundwater depletion allowances, with larger breaks for heavier groundwater use.



Saturated thickness of Ogallala Aquifer

- Less than 61 meters (200 ft.)
- 61–183 meters (200–600 ft.)
- More than 183 meters (600 ft.) (as much as 370 meters or 1,200 ft. in places)

The Ogallala is the world's largest known aquifer. If the water in this aquifer were above ground, it could cover all 50 states with 0.5 meter (1.5 feet) of water. Water withdrawn from this aquifer is used to grow crops, raise cattle, and provide cities and industries with water. As a result, this aquifer, which is renewed very slowly, is being depleted (especially at its thin southern end in parts of Texas, New Mexico, Oklahoma, and Kansas). (Data from U.S. Geological Survey)

Depletion of this essentially nonrenewable water resource can be delayed if farmers **(1)** use more efficient forms of irrigation (Figure 14-18, p. 330), **(2)** switch to crops that need less water, or **(3)** irrigate less land.

Cities using this groundwater can also implement policies and technologies to reduce their water use and waste. People enjoying the benefits of this aquifer can help by **(1)** installing water-saving toilets and showerheads and **(2)** converting their lawns to plants that can survive in an arid climate with little watering (Figure 14-21, p. 332).

Critical Thinking

1. What are the pros and cons of giving government subsidies to farmers and ranchers using water withdrawn from the Ogallala to grow crops and raise livestock that need large amounts of irrigation water? How do you benefit from such subsidies?

2. Should these government subsidies be reduced or eliminated and replaced with subsidies that encourage farmers to use more efficient forms of irrigation and switch to crops that need less water? Explain.

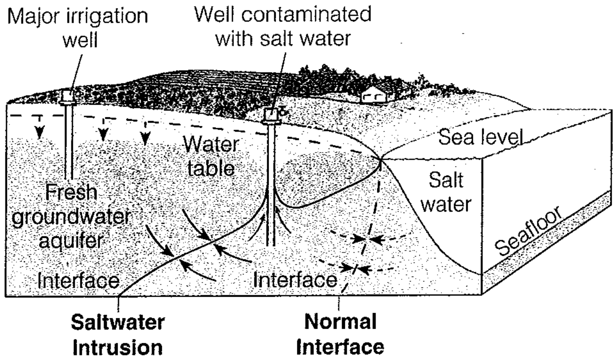


Figure 14-17 Saltwater intrusion along a coastal region. When the water table is lowered, the normal interface (dashed line) between fresh and saline groundwater moves inland (solid line), making groundwater drinking supplies unusable.

tion water, and **(6)** importing grain, with each imported metric ton of grain saving roughly 1,000 metric tons of water needed to produce the grain.

How Useful Is Desalination? Removing dissolved salts from ocean water or from brackish (slightly salty) groundwater, called **desalination,** is another way to increase supplies of fresh water. The two most widely used methods are:

- *Distillation,* which involves heating salt water until it evaporates (and leaves behind salts in solid form) and condenses as fresh water.

- *Reverse osmosis,* in which salt water is pumped at high pressure through a thin membrane whose pores allow water molecules, but not dissolved salts, to pass through. In effect, high pressure is used to push freshwater out of salt water.

About 13,300 desalination plants in 120 countries (especially in the arid, desert nations in the Middle East, North Africa, the Caribbean, and the Mediterranean) meet less than 0.2% of the world's water needs. Desalination would have to increase 25-fold just to supply 5% of current world water use.

This is unlikely because desalination has two major disadvantages:

- *It is expensive because it takes large amounts of energy.* Desalinating water costs 2–3 times as much as the conventional purification of fresh water.

- *It produces large quantities of wastewater (brine) containing high levels of salt and other minerals.* Dumping the concentrated brine into the ocean near the plants increases the local salt concentration and threatens food resources in estuary waters, and dumping it on land could contaminate groundwater and surface water.

Desalination can provide fresh water for coastal cities in arid countries (such as sparsely populated Saudi Arabia and Israel), where the cost of getting fresh water by any method is high. In the United States, desalination plants are used to meet some of the water needs along coastal areas of Florida, southern California, Virginia, North Carolina, and Texas.

Scientists are working to develop new membranes for reverse osmosis that can separate water from salt more efficiently and under less pressure. If successful, this strategy could help bring down the cost of using desalinization to produce drinking water. However, desalinated water probably will not be cheap enough to irrigate conventional crops or meet much of the world's demand for fresh water unless **(1)** affordable solar-powered distillation plants can be developed, and **(2)** someone can figure out what to do with the resulting mountains of salt.

Can Cloud Seeding and Towing Icebergs Improve Water Supplies? For decades, several countries, particularly the United States, have been experimenting with seeding clouds with tiny particles of chemicals (such as silver iodide). The particles form water condensation nuclei and thus produce more rain over dry regions and more snow over mountains.

However, cloud seeding **(1)** is not useful in very dry areas, where it is most needed, because rain clouds rarely are available there and **(2)** would introduce large amounts of the cloud-seeding chemicals into soil and water systems, possibly harming people, wildlife, and agricultural productivity.

Another obstacle to cloud seeding is legal disputes over the ownership of water in clouds. During the 1977 drought in the western United States, the attorney general of Idaho accused officials in neighboring Washington of "cloud rustling" and threatened to file suit in federal court.

Some have proposed towing huge icebergs to arid coastal areas (such as Saudi Arabia and southern California) and then pumping the fresh water from the melting bergs ashore. But the technology for doing this is not available and the costs may be too high, especially for water-short developing countries.

14-7 USING WATER MORE EFFICIENTLY

What Are the Benefits of Reducing Water Waste? 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.* The United States, the world's largest user of water, does slightly better but still loses about 50% of

Water Rights in the United States

SPOTLIGHT

Laws regulating access to and use of surface water differ in the eastern and western parts of the United States. In most of the East, water use is based on the *doctrine of riparian rights.*

Basically, this system of water law gives anyone whose land adjoins a flowing stream the right to use water from the stream as long as some is left for downstream landowners. However, as population and water-intensive land uses grow, there is often too little water to meet the needs of all the people along a stream.

In the arid and semiarid West, the riparian system does not work because large amounts of water are needed in areas far from major surface water sources. In most of this region, the *principle of prior appropriation* regulates water use.

In this first-come, first-served approach, the first user of water from a stream establishes a legal right for continued use of the amount originally withdrawn. If a shortage occurs, later users are cut off in order until enough water is available to satisfy the demands of the earlier users. Some states have a combination of riparian and prior appropriation water rights.

Most groundwater use in the United States is based on *common law,* which holds that subsurface water belongs to whoever owns the land above such water. This allows landowners to withdraw as much groundwater as they want. Because the largest users have little incentive to conserve, this can deplete the aquifer for everyone and create a tragedy of the commons (Connections, p. 11).

A system of legally protected water rights allows individuals owning rights to **(1)** sell, trade, or lease them to make money, **(2)** ease water shortages, or **(3)** protect the ecosystem services of rivers (Figure 14-10). For example, some water-short cities in the western United States are paying nearby farmers to install more efficient irrigation methods in exchange for the water the farmers save.

Private organizations and government agencies are also buying up water rights and using them to help restore aquatic environments by returning the water to rivers and wetlands. However, water markets must be regulated to avoid excessive water prices (especially for the poor) and inequalities in water distribution.

Critical Thinking

What are the advantages and disadvantages of **(a)** the principles of riparian rights and prior appropriation for access to surface water and **(b)** the common law approach to groundwater use in the United States? If you disagree with these approaches, how would you divide up water rights?

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.

Accomplishing this will require greatly increased use of water-saving technologies and practices. It will **(1)** decrease the burden on wastewater plants, **(2)** reduce the need for expensive dams and water transfer projects that destroy wildlife habitats and displace people, **(3)** slow depletion of groundwater aquifers, and **(4)** save energy and money.

Why Do We Waste So Much Water? According to water resource experts, there are three major causes of water waste. One is *water subsidy policies.* Governments and international lending agencies often provide subsidies for development of water supply projects such as dams and large-scale water transfer schemes. This creates artificially low water prices that help water users but discourage improvements in water efficiency. Similar subsidies for improving water efficiency are rare. 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."

Government-subsidized irrigation water in the western United States costs U.S. taxpayers an estimated $2–2.5 billion per year. However, farmers, industries, and others benefiting from government water subsidies argue that they **(1)** promote settlement and agricultural production in arid and semiarid areas, **(2)** stimulate local economies, and **(3)** help lower prices of food, manufactured goods, and electricity for consumers.

Water prices may rise as water supplies are being rapidly privatized worldwide. Transnational corporations are buying large supplies of water in dozens of water-short countries for resale at huge profit. Two byproducts of this lucrative business are **(1)** decreased ability of poor farmers and city dwellers to buy enough water to meet their needs and **(2)** political control by such large corporations over any country that imports privately owned water from outside its borders.

A second cause of water waste is *water laws* that determine the legal rights of water users in countries such as the United States (Spotlight, above).

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Solutions: How Can We Waste Less Water in Irrigation? About 57% of the irrigation water applied throughout the world does not reach the targeted crops. Most irrigation systems distribute water from a groundwater well or a surface water source and allow it to flow by gravity through unlined ditches in crop fields so the water can be absorbed by crops (Figure 14-18, left). This *flood irrigation* method **(1)** delivers far more water than needed for crop growth and **(2)** typically allows only 60% of the water to reach crops because of evaporation, seepage, and runoff.

Some *good news* is that more efficient and environmentally sound irrigation technologies exist that could reduce water demands and waste on farms by up to 50%. Here are some examples:

- *Center-pivot low-pressure sprinklers* (Figure 14-18, right), which typically allow 80% of the water input to reach crops and reduce water use over conventional gravity flow systems by 20–25%.
- *Low-energy precision application (LEPA) sprinklers.* This form of center-pivot irrigation allows 90–95% of the water input to reach crops by spraying it closer to the ground and in larger droplets than the center-pivot low-pressure system. LEPA sprinklers use 20–30% less energy than low-pressure sprinklers and typically use 37% less water than conventional gravity flow systems.
- *Using surge or time-controlled valves on conventional gravity flow irrigation systems* (Figure 14-18, left). These valves send water down irrigation ditches in pulses instead of in a continuous stream, which can raise irrigation efficiency to 80% and reduce water use by 25%.
- *Using soil moisture detectors to water crops only when they need it.* For example, some farmers in Texas bury a $1 cube of gypsum, the size of a lump of sugar, at the root zone of crops. Wires embedded in the gypsum are run back to a small portable meter that indicates soil moisture. Farmers using this technique can use 33–66% less irrigation water.
- *Drip irrigation systems* (Figure 14-18, center, and Solutions, p. 333)

Other ways to reduce water waste in irrigating crops are listed in Figure 14-19. Since 1950, water-short Israel has used many of these techniques to slash irrigation water waste by about 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 **(1)** gradually removed most government water subsidies to raise the price of irrigation water to one of the highest in the world, **(2)** imports most of its water-intensive wheat and meat, and **(3)** concentrates on growing fruits, vegetables, and flowers that need less

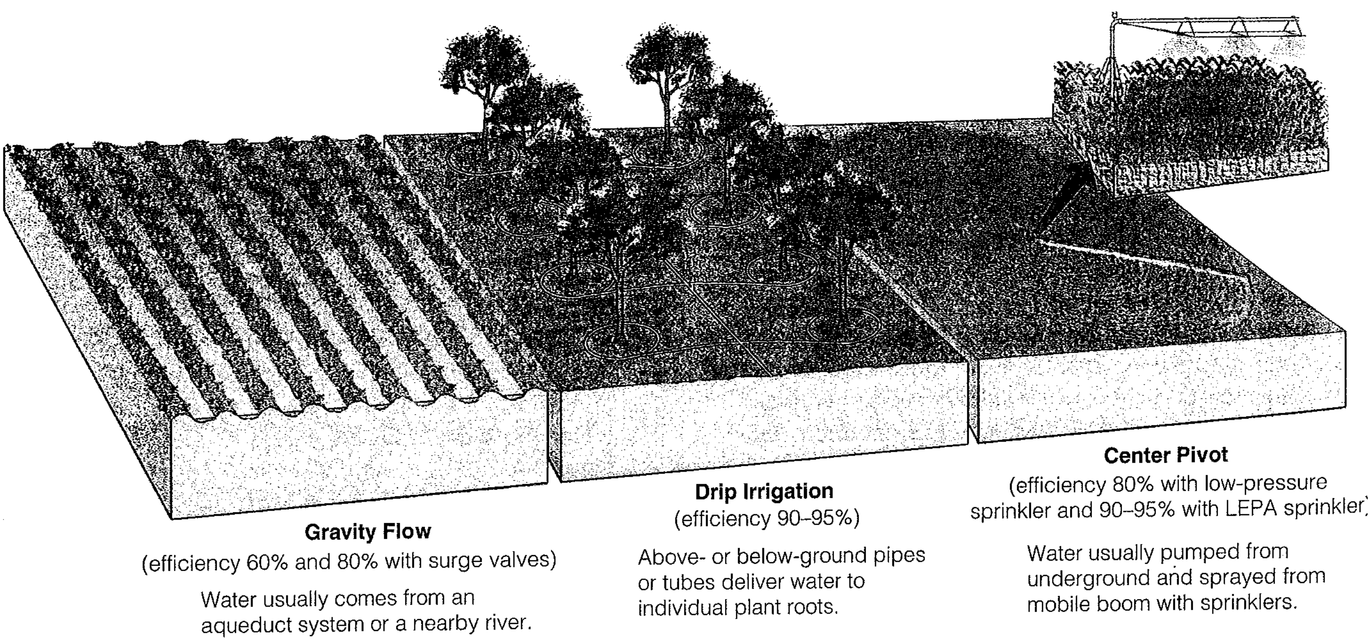

Figure 14-18 Major irrigation systems. Because of high initial costs, center-pivot irrigation and drip irrigation are used on only about 1% of the world's irrigated cropland each. However, this may change because of the development of new low-cost drip irrigation systems (Solutions, p. 333).

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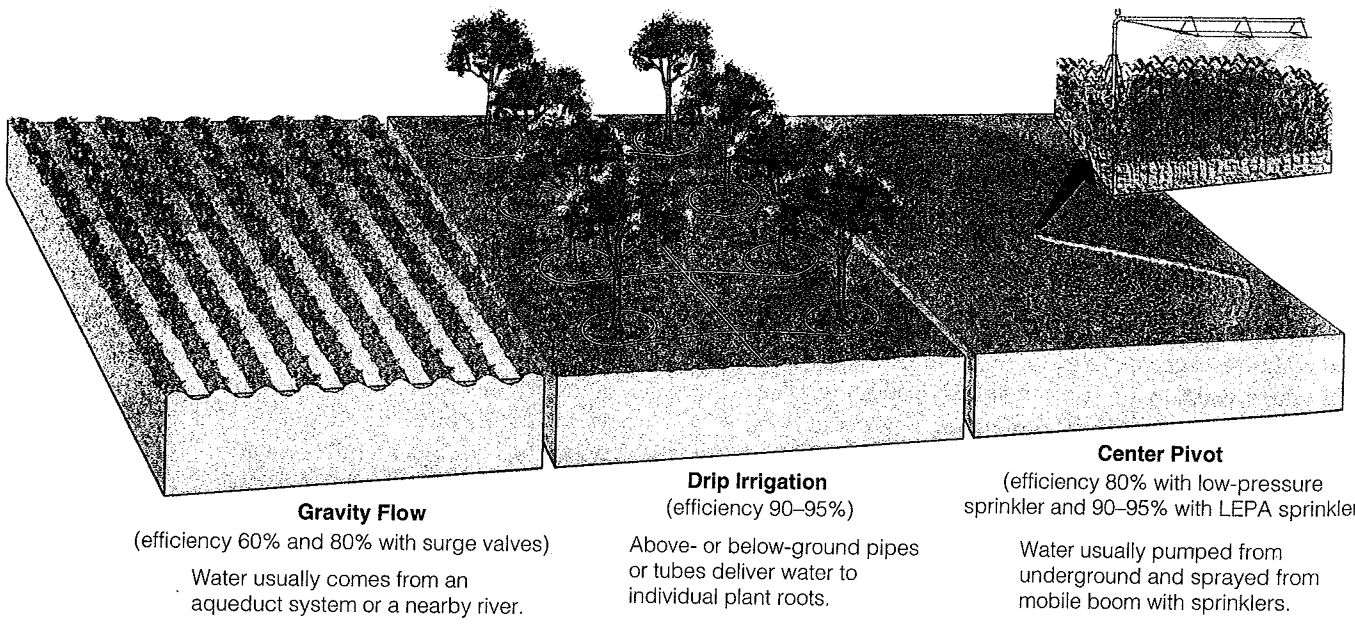


Figure 14-18 Major irrigation systems. Because of high initial costs, center-pivot irrigation and drip irrigation are used on only about 1% of the world's irrigated cropland each. However, this may change because of the development of new low-cost drip irrigation systems (Solutions, p. 333).

- Lining canals bringing water to irrigation ditches
- Leveling fields with lasers
- Irrigating at night to reduce evaporation
- Using soil and satellite sensors and computer systems to monitor soil moisture and add water only when necessary
- Polyculture
- Organic farming
- Growing water efficient crops using drought-resistant and salt-tolerant crop varieties
- Irrigating with treated urban waste water
- Importing water intensive crops and meat

Figure 14-19 Methods for reducing water waste in irrigation.

water. In 2001, China announced a policy to raise water prices gradually over a 5-year period to cut down water waste and help prevent a looming water shortage crisis.

Some *bad news* is that more efficient sprinklers are used on only 10% and drip irrigation on just over 1% of the world's irrigated cropfields. This could change with **(1)** development of cheaper sprinkler and drip irrigation technologies (Solutions, p. 333) and **(2)** increased government subsidies for farmers using more efficient irrigation methods.

Many of the world's poor farmers cannot afford to use most of the modern technological methods for increasing irrigation and irrigation efficiency. These farmers increase irrigation by using small-scale and low-cost traditional technologies such as **(1)** pedal-powered treadle pumps to move water through irrigation ditches (widely used in Bangladesh), **(2)** animal-powered irrigation pumps, **(3)** buckets with holes for drip irrigation, **(4)** small dams, ponds, and tanks to collect rainwater for irrigation, **(5)** terracing (Figure 10-26a, p. 224) to reduce water loss on crops grown on steep terrain, and **(6)** cultivating seasonally waterlogged wetlands, delta lands, and valley bottoms.

Paul Polak, a pioneer in low-cost irrigation technologies and president of International Development Enterprises, believes that a realistic goal for the next 15 years is to reduce hunger and poverty for 150 million of the world's poorest rural people by spreading the use of these and other low-cost irrigation techniques for small farms.

Solutions: How Can We Waste Less Water in Industry, Homes, and Businesses? Figure 14-20 lists ways to use water more efficiently in industries, homes, and businesses. Many homeowners and businesses in water-short areas are replacing green lawns in arid and semiarid regions with vegetation adapted to a dry climate (Figure 14-21, p. 332). This form of landscaping, called *xeriscaping* (pronounced "ZER-i-scaping"), reduces water use by 30–85% and sharply reduces inputs of labor, fertilizer, and fuel and the production of polluted runoff, air pollution, and yard wastes.

In Boulder, Colorado, introducing water meters reduced water use by more than one-third. 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. Many apartment dwellers have little incentive to conserve water because their water use is included in their rent.

Because of laws requiring water conservation, the desert city of Tucson, Arizona, consumes half as much water per person as Las Vegas, a desert city with even less rainfall and less emphasis on water conservation (Spotlight, p. 334).

About 50–75% of the water from bathtubs, showers, bathroom sinks, and clothes washers in a typical house could be stored and reused as *gray water* for irrigating lawns and nonedible plants. In the United States, California has become the first state to legalize reuse of gray water to irrigate landscapes. About 65% of the wastewater in Israel is reused in this way. See the website for this chapter for ways you can reduce your personal water use and waste.

- Redesign manufacturing processes
- Landscape yards with plants that require little water
- Use drip irrigation
- Fix water leaks
- Use water meters and charge for all municipal water use
- Raise water prices
- 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 14-20 Methods of reducing water waste in industries, homes, and businesses.

Figure 14-21 *Xeriscaping.* This technique can reduce water use by as much as 85% by landscaping with rocks and plants that need little water and are adapted to the growing conditions in arid and semiarid areas. The term Xeriscape® was first used 1978 in Denver, Colorado, and means "water conservation through creative landscaping."

14-8 TOO MUCH WATER

What Are the Causes and Effects of Flooding? Heavy rain or rapid melting of snow is the major cause of natural flooding by streams. This causes water in a stream to overflow its normal channel and flood the adjacent area, called a **floodplain** (Figure 14-22). Floodplains, which include highly productive wetlands (Figure 7-25, p. 162), provide important ecological and economic services by helping to **(1)** provide natural flood and erosion control, **(2)** maintain high water quality, and **(3)** recharge groundwater.

People have settled on floodplains since the beginnings of agriculture. They have many advantages, including **(1)** fertile soil, **(2)** ample water for irrigation, **(3)** flat land suitable for crops, buildings, highways, and railroads, and **(4)** availability of nearby rivers for transportation and recreation. In the United States, 10 million households and businesses with property valued at $1 trillion are located in flood-prone areas.

Floods are a natural phenomenon and have several benefits. They **(1)** provide the world's most productive farmland because they are regularly covered with nutrient-rich silt left after floodwaters recede, **(2)** recharge groundwater, and **(3)** refill wetlands.

Floods, like droughts, usually are considered natural disasters, but since the 1960s human activities have contributed to the sharp rise in flood deaths and damages. Three ways humans increase the severity of flood damage are by **(1)** removing water-absorbing vegetation, especially on hillsides (Figure 14-23), **(2)** draining wetlands that absorb floodwaters and reduce the severity of flooding, and **(3)** living on floodplains (Connections, p. 335). Urbanization also increases flooding by replacing water-absorbing vegetation, soil, and wetlands with highways, parking lots, and buildings that cannot absorb rainwater.

In developed countries, people deliberately settle on floodplains and then expect dams, levees, and other devices to protect them from floodwaters. However,

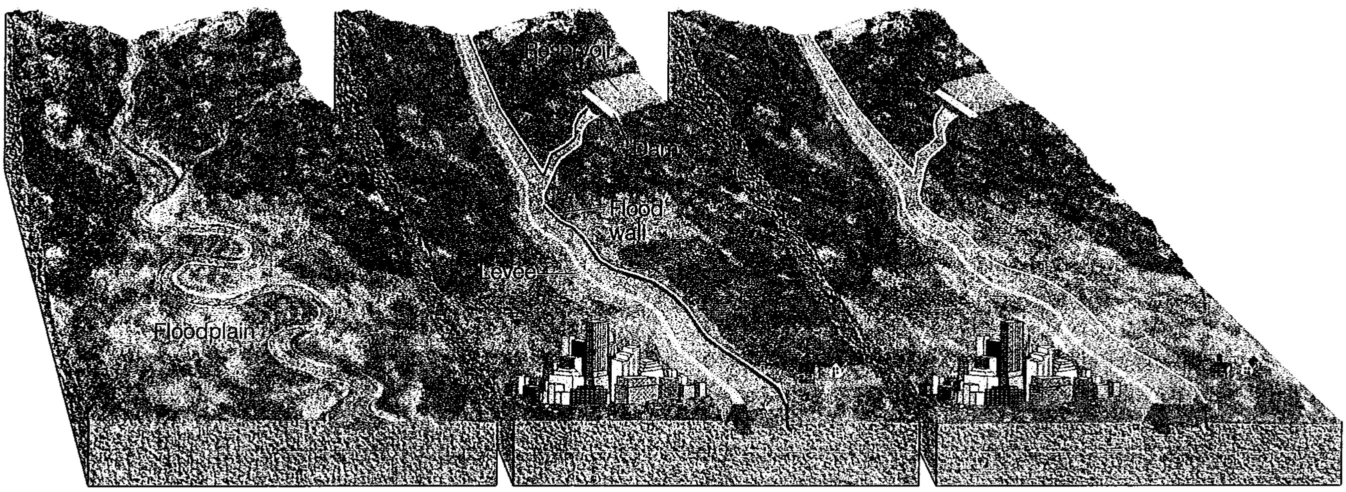
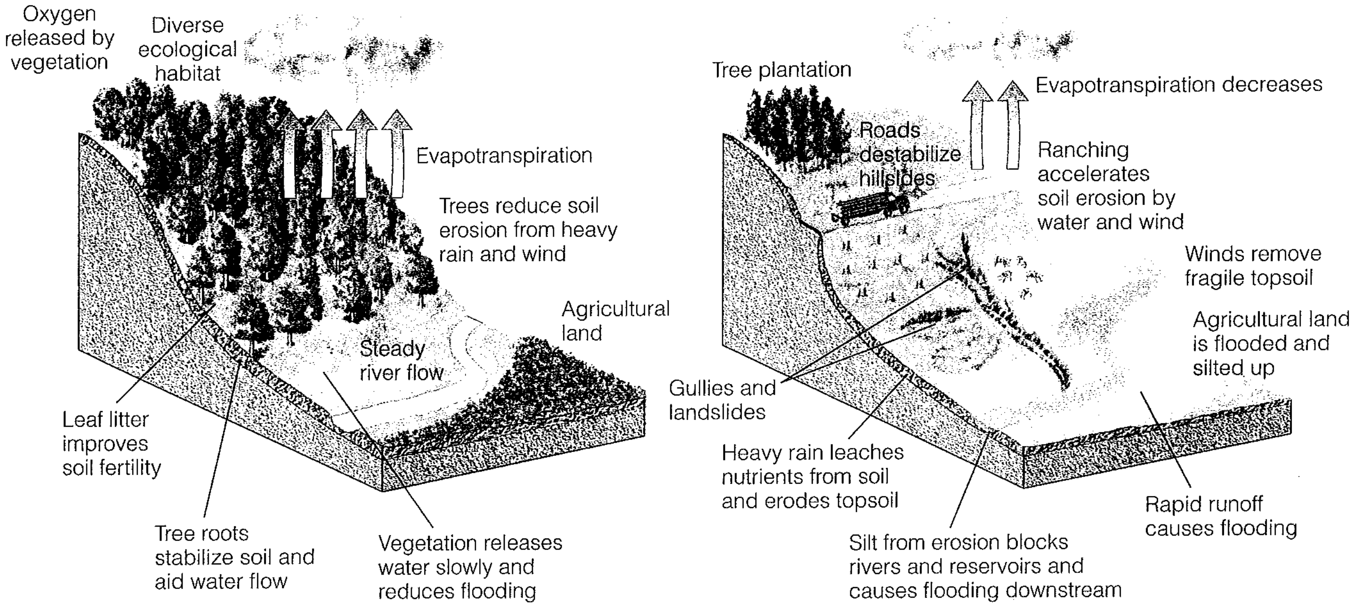


Figure 14-22 Land in a natural floodplain (left) often is flooded after prolonged rains. When the floodwaters recede, deposits of silt are left behind, creating a nutrient-rich soil. To reduce the threat of flooding (and thus allow people to live in floodplains), rivers have been **(1)** dammed to create reservoirs that store and release water as needed, **(2)** narrowed and straightened (channelization), and **(3)** equipped with protective levees and walls (middle). These alterations can give a false sense of security to floodplain dwellers living in high-risk areas. In the long run, such measures can greatly increase flood damage because they can be overwhelmed by prolonged rains (right), as happened along the Mississippi River in the midwestern United States during the summer of 1993.



Forested Hillside **After Deforestation**

Figure 14-23 A hillside before and after deforestation. Once a hillside has been deforested for timber and fuelwood, livestock grazing, or unsustainable farming, water from precipitation **(1)** rushes down the denuded slopes, **(2)** erodes precious topsoil, and **(3)** floods downstream areas. A 3,000-year-old Chinese proverb says, "To protect your rivers, protect your mountains."

The Promise of Drip Irrigation

SOLUTIONS

The development of inexpensive, weather-resistant, and flexible plastic tubing after World War II paved the way for a new form of micro-irrigation called *drip irrigation* (Figure 14-18, middle, p. 330). It consists of a network of perforated plastic tubing, installed at or below the ground surface. The small holes or emitters in the tubing deliver drops of water at a slow and steady rate close to plant roots.

This technique, developed in Israel in the 1960s and now used by half of the country's farmers, has a number of advantages, including the following:

- *Adaptability.* The tubing system can easily be fitted to match the patterns of crops in a field and left in place or moved to different locations.
- *Efficiency,* with 90–95% of the water input reaching crops.
- *Lower operating costs* because 37–70% less energy is needed to pump this water at low pressure, and less labor is needed to move sprinkler systems.
- *Ability to apply fertilizer solutions in precise amounts,* which reduces **(1)** fertilizer use and waste, **(2)** salinization, and **(3)** water pollution from fertilizer runoff.
- *An increase in crop yields of 20–90% by getting more crop growth per drop of water.*
- *Healthier plants and higher yields* because plants are neither underwatered nor overwatered.

Despite these advantages, drip irrigation is used on less than 1% of the world's irrigated area. The capital cost of conventional drip irrigation systems is too high for most poor farmers and for use on low-value row crops. However, drip irrigation is economically feasible for high-profit fruit, vegetable, and orchard crops and for home gardens.

Some *good news* is that the capital cost of a new drip irrigation system is one-tenth as much per hectare as conventional drip systems. Another innovation is DRiWATER®, called "drip irrigation in a box." It consists of 1-liter (1.1-quart) packages of gel-encased water that is released slowly into the soil after being buried near plant roots. It wastes almost no water and lasts about 3 months. Egypt is using it to help grow 17 million trees in a desert community.

These and other low-cost drip irrigation systems could bring about a revolution in more sustainable irrigated agriculture that would **(1)** increase food yields, **(2)** reduce water use and waste, and **(3)** lessen some of the environmental problems associated with agriculture (Figure 13-13, p. 288).

Critical Thinking

Should governments provide subsidies to farmers who use drip irrigation based on how much water they save? Explain.

when heavier-than-normal rains occur, these devices do not work. In many developing countries, the poor have little choice but to try to survive in flood-prone areas (Connections, p. 335). Between 1985 and 2001, floods prematurely killed about 300,000 people, 96% of them in developing countries.

Solutions: How Can We Reduce Flood Risks? Ways humans can reduce the risk from flooding include

- *Straightening and deepening streams* (channelization, Figure 14-22, middle). Channelization can reduce upstream flooding, but the increased flow of water can also **(1)** increase upstream bank erosion and downstream flooding and sediment deposition and **(2)** reduce habitats for aquatic wildlife by removing bank vegetation and increasing stream velocity.
- *Building levees* (Figure 14-22, middle). Levees contain and speed up stream flow but **(1)** increase the water's capacity for doing damage downstream and **(2)** do not protect against unusually high and powerful floodwaters, as occurred in 1993 when two-thirds of the levees built along the Mississippi River were damaged or destroyed.
- *Building dams.* A flood control dam built across a stream can reduce flooding by storing water in a reservoir and releasing it gradually. Dams have a number of advantages and disadvantages (Figure 14-9).
- *Restoring wetlands* to take advantage of the natural flood control provided by floodplains.
- *Identifying and managing flood-prone areas* (Figure 14-24). Such actions include **(1)** prohibiting certain

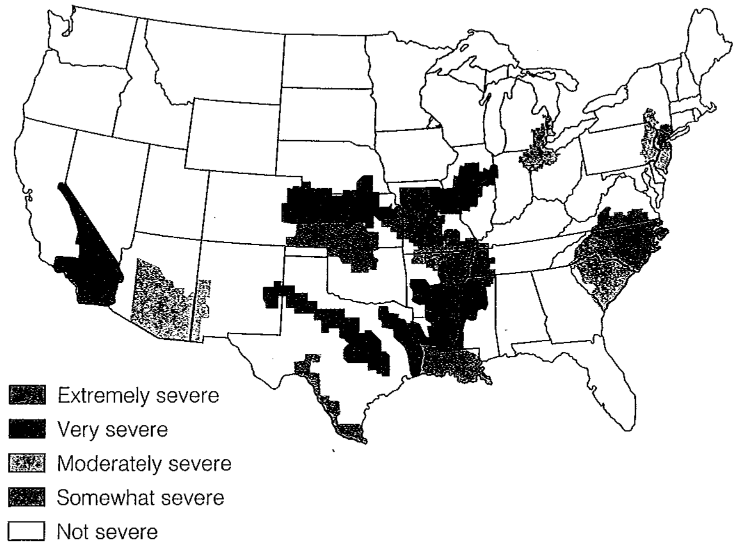


Figure 14-24 Generalized map of *flood-prone areas* in the United States. State boundaries are shown in black. More detailed state and local maps are used to show the likelihood and severity of floods within these general areas. Flood frequency data and maps of flood-prone areas do not tell us when floods will occur, but they give a general idea of how often and where floods might occur, based on an area's history. (Data from U.S. Geological Survey)

SPOTLIGHT

Running Short of Water in Las Vegas, Nevada

Las Vegas, Nevada, located in the Mojave Desert, is an artificial aquatic wonderland of large trees, green lawns and golf courses, waterfalls, and swimming pools. The city is also one of the fastest growing cities in the United States, with its population more than doubling from 550,000 in 1985 to 1.4 million in 2001. It is estimated that the city uses more water per person than any other city in the world.

Tucson, Arizona, in the Sonora Desert, gets only 30 centimeters (12 inches) of rainfall a year, and Las Vegas averages only 10 centimeters (4 inches). Tucson, now a model of water conservation, began a strict water conservation program in 1976, including raising water rates 500% for some residents.

In contrast, Las Vegas only recently started to encourage water conservation by **(1)** raising water rates sharply (but they are still less than half those in Tucson) and **(2)** encouraging replacement of lawns with rocks and native plants that survive on little water (Figure 14-21, p. 332).

Water experts project that even if these recent water conservation efforts are successful, Las Vegas should begin running short of water by 2007.

Critical Thinking

1. If you were an elected official in charge of Las Vegas, what three actions would you take to improve water conservation? What might be the political implications of instituting such a program?

2. If water shortages by 2007 limit the growth of the population of Las Vegas, would you consider this outcome good or bad? Explain.

Living Dangerously on Floodplains in Bangladesh

CONNECTIONS

Bangladesh (Figure 12-7, p. 257) is one of the world's **(1)** most densely populated countries, with 134 million people packed into an area roughly the size of Wisconsin, and **(2)** poorest countries, with an average per capita GNI PPP of about $1,590, or $4.36 per day.

The people of Bangladesh depend on moderate annual flooding during the summer monsoon season. They need these seasonal floodwaters to grow rice and help maintain soil fertility in the delta basin by receiving an annual deposit of eroded Himalayan soil.

However, excessive flooding can be disastrous. In the past, great floods occurred every 50 years or so, but since the 1970s they have come about every 4 years.

Bangladesh's increased flood problems begin in the Himalayan watershed. A combination of rapid population growth, deforestation, overgrazing, and unsustainable farming on steep, easily erodible mountain slopes has greatly diminished the soil's ability to absorb water. Instead of being absorbed and released slowly, water from the monsoon rains runs off the denuded Himalayan foothills, carrying vital topsoil with it (Figure 14-23, p. 333).

This runoff, combined with heavier-than-normal monsoon rains, has increased the severity of flooding along Himalayan rivers and downstream in Bangladesh. For example, a disastrous flood in 1998 **(1)** covered two-thirds of Bangladesh's land area for 9 months, **(2)** leveled 2 million homes, **(3)** drowned at least 2,000 people, **(4)** left 30 million people homeless, **(5)** destroyed more than one-fourth of the country's crops, which caused thousands of people to die of starvation, and **(6)** caused at least $3.4 billion in damages.

Living on Bangladesh's coastal floodplain also carries dangers from storm surges and cyclones. Since 1961, 17 devastating cyclones have slammed into Bangladesh. In 1970, as many as 1 million people drowned in one storm, and another surge killed an estimated 139,000 people in 1991.

In their struggle to survive, the poor in Bangladesh have cleared many of the country's coastal mangrove forests (Figures 7-2, p. 145, and 7-9, p. 149) for fuelwood, farming, and aquaculture ponds for raising shrimp. This has led to more severe flooding because these coastal wetlands shelter Bangladesh's low-lying coastal areas from storm surges and cyclones. 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.

Critical Thinking

1. Bangladesh's population is growing rapidly and expected to increase from 134 million to 178 million between 2002 and 2025. How could slowing its rate of population growth help reduce poverty and the harmful impacts of excessive flooding?

2. How could reforestation in the upstream countries of Bhutan, China, India, and Nepal reduce flooding in those countries and in Bangladesh?

types of buildings or activities in high-risk flood zones, **(2)** elevating or otherwise floodproofing buildings that are allowed on legally defined floodplains, and **(3)** constructing a floodway that allows floodwater to flow through the community with minimal damage. This *prevention*, or *precautionary*, approach to reducing flood damage is based on thousands of years of experience that can be summed up in one idea: *Sooner or later the river (or the ocean) always wins.*

14-9 SOLUTIONS: ACHIEVING A MORE SUSTAINABLE WATER FUTURE

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 14-25 (p. 336) lists ways to implement this principle.

The challenge in developing such a *blue revolution* is to implement a mix of strategies built around **(1)** irrigating crops more efficiently, **(2)** using water-saving technologies in industries and homes, and **(3)** improving and integrating management of water basins and groundwater supplies.

Accomplishing such a revolution in water use and management will be difficult and controversial. However, water experts contend that not developing such strategies will eventually lead to **(1)** economic and health problems, **(2)** increased environmental degradation and loss of biodiversity, **(3)** heightened tensions and perhaps armed conflicts or economic competition over water supplies and food imports (p. 312), and **(4)** larger numbers of environmental refugees from water-scarce areas.

It is not until the well runs dry that we know the worth of water.

BENJAMIN FRANKLIN

Figure 14-25 Methods for achieving more sustainable use of the earth's water resources.

REVIEW QUESTIONS

1. Define the boldfaced terms in this chapter.

2. Explain why there is a danger of water wars or economic competition between countries for food imports in the Middle East.

3. List nine unique properties of water and explain the importance of each property.

4. What percentage of the earth's total volume of water is available for use by us? How might global warming alter the hydrologic cycle?

5. Distinguish among *surface runoff, reliable runoff, watershed, groundwater, zone of saturation, water table, aquifer, recharge area,* and *natural recharge.* Explain how the water in some aquifers can be depleted.

6. Since 1900, how much has the total use and per capita use of water by humans increased? About what percentage of the world's reliable surface runoff is used by humanity?

7. About what percentage of the water we withdraw each year is used for **(a)** irrigation, **(b)** industry, and **(c)** residences and cities?

8. What are the major water uses and problems of **(a)** the eastern United States and **(b)** the western United States?

9. List four causes of water scarcity. What is *water stress?* How can growth in the number of water-stressed countries affect **(a)** global grain exports and prices, **(b)** hunger and malnutrition in developing countries, **(c)** the number of environmental refugees, and **(d)** the daily workload of many poor women and children?

10. List six ways to increase the supply of fresh water in a particular area.

11. List six ecological services that rivers provide.

12. List the major pros and cons of building large dams and reservoirs to supply fresh water. List the pros and cons of **(a)** Egypt's Aswan High Dam project, **(b)** building numerous dams along the Colorado River basin, and **(c)** China's Three Gorges dam project.

13. List the major pros and cons of supplying water by transferring it from one watershed to another. List the pros and cons of **(a)** the California Water Project, **(b)** the James Bay project in Canada, and **(c)** the Aral Sea water transfer project in central Asia.

14. List the pros and cons of supplying more water by withdrawing groundwater. Explain why excessive groundwater withdrawal can be viewed as an example of the tragedy of the commons and how it can increase the gap between the world's rich and poor. Summarize the problems of withdrawing groundwater from the Ogallala Aquifer in the United States. List five ways to prevent or slow groundwater depletion.

15. List the pros and cons of increasing supplies of fresh water by **(a)** desalination of salt water, **(b)** cloud seeding, and **(c)** towing icebergs to water-short areas.

16. What percentage of the water used by people throughout the world is wasted? List four benefits of conserving water. List three major causes of water waste.

17. Define and give the pros and cons of **(a)** the *doctrine of riparian rights,* **(b)** the *principle of prior appropriation* used to govern legal rights to surface water, and **(c)** the *common law* approach used to govern legal rights to groundwater in the United States. How can such rights promote **(a)** water waste and **(b)** water conservation?

18. List ways to reduce water waste in **(a)** irrigation and **(b)** industry, homes, and businesses. List six advantages of *drip irrigation,* and explain how it could help bring about a revolution in improving water efficiency.

19. What is a *floodplain?* What three major ecological and economic services does it provide? List four reasons why so many people live on floodplains. List the major benefits and disadvantages of floods. List three ways in which humans increase the damages from floods. Describe the nature and causes of the flooding problems in Bangladesh.

20. List the pros and cons of trying to reduce flood risks by **(a)** stream channelization, **(b)** building levees, **(c)** building dams, and **(d)** managing floodplains.

21. List 11 ways to use the world's water more sustainably and 4 disadvantages of not implementing such strategies.

CRITICAL THINKING

1. What would happen to your body if suddenly your water molecules no longer formed hydrogen bonds with one another (Appendix 2, Figure 4)?

2. How do human activities increase the harmful effects of prolonged drought? How can we reduce these effects?

3. Explain how dams and reservoirs can cause more flood damage than they prevent. Should all proposed large dam and reservoir projects be scrapped? Explain.

4. Do you believe the projected benefits of China's Three Gorges dam and reservoir project on the Yangtze River will outweigh its potential drawbacks? Explain. What are the alternatives?

5. What role does population growth play in water supply problems?

6. Explain why you are for or against **(a)** gradually phasing out government subsidies of irrigation projects in the western United States (or in the country where you live) to raise the price of water and promote using water more efficiently and **(b)** providing government subsidies to farmers for improving irrigation efficiency.

7. Should the prices of water for all uses be raised sharply to include more of its environmental costs and to encourage water conservation? Explain. What harmful and beneficial effects might this have on **(a)** business and jobs, **(b)** your lifestyle and the lifestyles of any children or grandchildren you might have, **(c)** the poor, and **(d)** the environment?

8. Should we use up slowly renewable underground water supplies such as the Ogallala aquifer (Case Study, p. 327) or save them for future generations? Explain.

9. Calculate how many liters and gallons of water are wasted in 1 month by a toilet that leaks 2 drops of water per second (1 liter of water equals about 3,500 drops and 1 liter equals 0.265 gallon).

10. List five major ways to conserve water for personal use (see website material for this chapter). Which, if any, of these practices do you now use or intend to use?

11. How do human activities contribute to flooding and flood damage? How can these effects be reduced?

12. Congratulations! You are in charge of managing the world's water resources. What are the three most important things you would do?

PROJECTS

1. In your community,
   a. What are the major sources of the water supply?
   b. How is water use divided among agricultural, industrial, power plant cooling, and public uses?
   c. Who are the biggest consumers of water?
   d. What has happened to water prices (adjusted for inflation) during the past 20 years? Are they too low to encourage water conservation and reuse?
   e. What water supply problems are projected?
   f. How is water being wasted?

2. Use the library or the Internet to discover **(a)** which industries in the country where you live use the most water and **(b)** which industries have done the most to improve water-use efficiency in the last 20 years.

3. Develop a water conservation plan for your school and submit it to school officials.

4. Consult with local officials to identify any floodplain areas in your community. Develop a map showing these areas and the types of activities (such as housing, manufacturing, roads, and recreational use) found on these lands.

5. Use the library or the Internet to find bibliographic information about *John Todd* and *Benjamin Franklin*, whose quotes appear at the beginning and end of this chapter.

6. Make a concept map of this chapter's major ideas, using the section heads and subheads and the key terms (in boldface type). See material on the website for this book about how to prepare concept maps.

INTERNET STUDY RESOURCES AND RESOURCES FOR FURTHER READING AND RESEARCH

The website for this book contains helpful study aids and many ideas for further reading and research. Log on to

www.info.brookscole.com/miller13

and click on the Chapter-by-Chapter area. Choose Chapter 14 and select a resource:

- Flash Cards allows you to test your mastery of the Terms and Concepts to Remember for this chapter.
- Tutorial Quizzes provides a multiple-choice practice quiz.
- Student Guide to InfoTrac will lead you to Critical Thinking Projects that use InfoTrac College Edition as a research tool.
- References lists the major books and articles consulted in writing this chapter.
- Hypercontents takes you to an extensive list of sites with news, research, and images related to individual sections of the chapter.

INFOTRAC COLLEGE EDITION

Improve your skills with InfoTrac College Edition, a searchable online database of articles from more than 700 periodicals. Log on to

http://www.infotrac-college.com

or access InfoTrac through the website for this book. Try to find the following articles:

1. University of California at Irvine. 2002. Satellite data on underground aquifer levels can be vital to water resource management, UC Irvine hydrologist finds; Use of NASA technology seen as breakthrough to understanding water availability, movement. *Ascribe Higher Education News Service* (June 10). *Keywords:* "satellite," "aquifer," and "levels." A new satellite now allows hydrologists to asses more accurately the condition of the world's aquifers. This has important implications for water management.

2. Postel, S. 1999. When the world's wells run dry. *World Watch* 12: 30. Keywords: "aquifer" and "depletion." This article represents a good summary of groundwater-use issues, including sustainability, conservation, and government policy.

15 GEOLOGIC RESOURCES: NONRENEWABLE MINERAL AND ENERGY RESOURCES

Bitter Lessons from Chernobyl

Chernobyl is a chilling word recognized around the globe as the site of a major nuclear disaster (Figure 15-1). 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 the reactor building and flung radioactive debris and dust high into the atmosphere. A huge radioactive cloud spread over much of Belarus, Russia, Ukraine, and other parts of Europe and eventually encircled the planet.

According to various UN studies, here are some consequences of this disaster, caused by poor reactor design and human error:

- By the year 2000, an estimated 8,000 people had died prematurely from radiation-related diseases because of the accident. The Ukrainian Health Ministry says that 125,000 people have died and 3.5 million people have become ill because of the accident.
- Almost 400,000 people had to leave their homes. Most were not evacuated until at least 10 days after the accident.
- Some 160,000 square kilometers (62,000 square miles)—about the size of the state of Florida—of the former Soviet Union remains highly contaminated with radioactivity.
- Despite the danger, between 100,000 and 200,000 people either illegally remained or have returned to live inside this highly radioactive zone.
- More than half a million people were exposed to dangerous levels of radioactivity. About 2,000 people have been diagnosed with thyroid cancer and 8,000–10,000 additional thyroid cancer cases are expected between 2000 and 2010.
- The total cost of the accident will reach at least $358 billion, many times more than the value of all the nuclear electricity ever generated in the former Soviet Union.

The environmental refugees evacuated from the Chernobyl region had to leave their possessions behind and say good-bye to **(1)** lush green wheat fields and blossoming apple trees, **(2)** land their families had farmed for generations, **(3)** cows and goats that would be shot because the grass they ate was radioactive, and **(4)** their radioactivity-poisoned cats and dogs. They will not be able to return without exposing themselves to potentially harmful doses of ionizing radiation. In 2002—16 years after the accident—the Chernobyl power plant remains one of the most dangerous places on the earth.

Chernobyl taught us that *a major nuclear accident anywhere is a nuclear accident everywhere.*

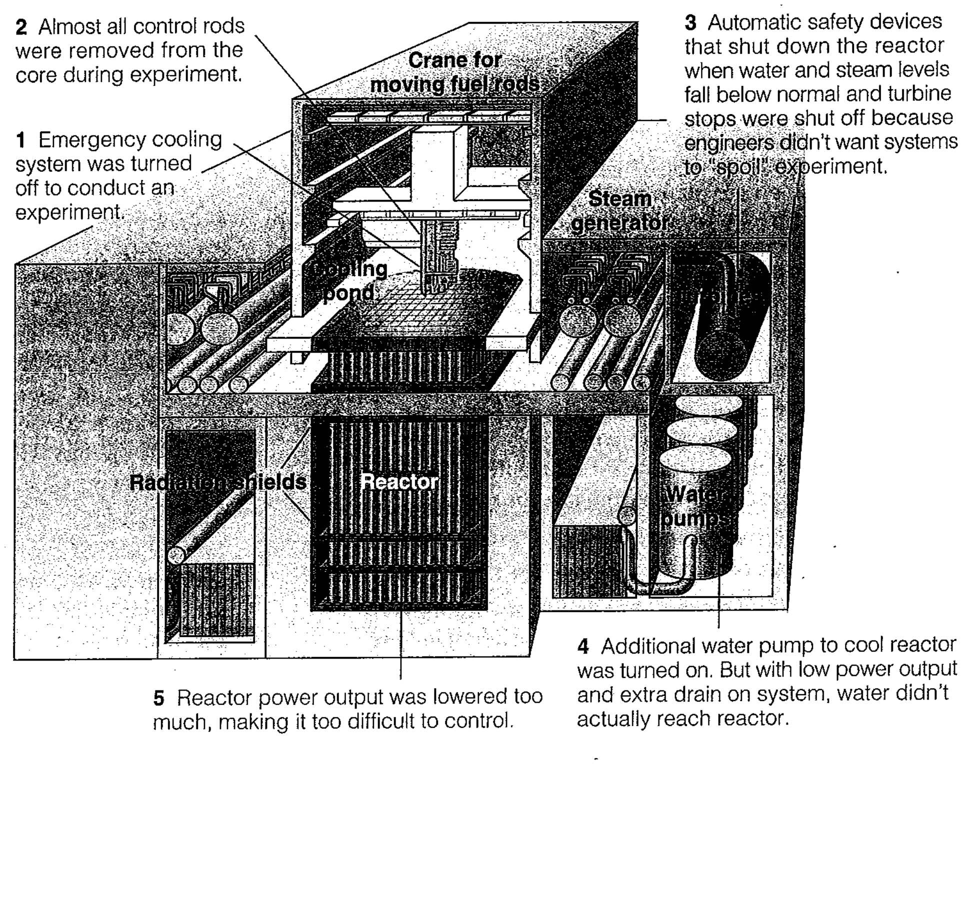


Figure 15-1 Major events leading to the Chernobyl nuclear power plant accident on April 26, 1986, in the former Soviet Union. The accident happened because **(1)** engineers turned off most of the reactor's automatic safety and warning systems (to keep them from interfering with an unauthorized safety experiment), **(2)** the safety design of the reactor was inadequate (there was no secondary containment shell, as in Western-style reactors), and **(3)** a design flaw led to unstable operation at low power. After the reactor exploded, crews exposed themselves to lethal levels of radiation to put out fires and encase the shattered reactor in a hastily constructed concrete tomb. This 19-story concrete tomb is sagging and full of holes that allow water to seep in and radioactive dust to drift out. Building a new tomb for the reactor will cost at least $1.5 billion—money the Ukrainian government does not have.

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

This chapter addresses the following questions:

- What are nonrenewable mineral resources, and how are they formed?
- How do we find and extract nonrenewable mineral and energy resources from the earth's crust?
- What are the environmental effects of extracting and using mineral resources?
- How fast are nonfuel mineral supplies being used up?
- How can we increase supplies of key nonfuel minerals?
- How should we evaluate energy alternatives?
- What are the advantages and disadvantages of oil?
- What are the advantages and disadvantages of natural gas?
- What are the advantages and disadvantages of coal?
- What are the advantages and disadvantages of conventional nuclear fission, breeder nuclear fission, and nuclear fusion?

15-1 NATURE AND FORMATION OF MINERAL RESOURCES

What Are Mineral Resources? 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. Over millions to billions of years, the earth's internal and external geologic processes (Section 10-2, p. 205, and Figure 10-8, p. 210) have produced numerous nonfuel mineral resources and fossil fuel energy resources. Because they take so long to produce, they are classified as *nonrenewable resources.*

We know how to find and extract more than 100 nonrenewable minerals from the earth's crust. They include **(1)** *metallic mineral resources* (iron, copper, aluminum), **(2)** *nonmetallic mineral resources* (salt, clay, sand, phosphates, and soil), and **(3)** *energy resources* (coal, oil, natural gas, and uranium).

Ore is rock containing enough of one or more metallic minerals to be mined profitably. We convert about 40 metals extracted from ores into many everyday items that we either **(1)** use and discard (Figure 3-20, p. 60) or **(2)** learn to reuse, recycle, or use less wastefully (Figure 3-21, p. 61).

The U.S. Geological Survey (USGS) divides nonrenewable mineral resources into several categories (Figure 15-2):

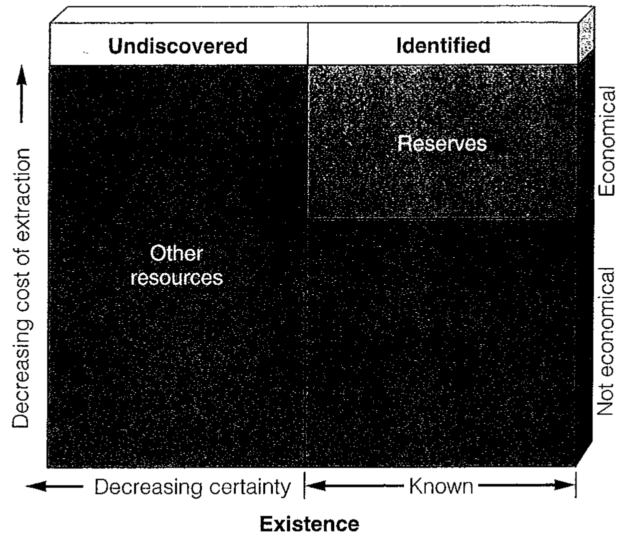


Figure 15-2 General classification of mineral resources. (The area shown for each class does not represent its relative abundance.) In theory, all mineral resources classified as *other resources* could become reserves because of rising mineral prices or improved mineral location and extraction technology. In practice, geologists expect only a fraction of other resources to become reserves.

- **Identified resources**: deposits of a nonrenewable mineral resource **(1)** with a *known* location, quantity, and quality, or **(2)** whose existence is based on direct geological evidence and measurements.
- **Undiscovered resources**: potential supplies of a nonrenewable mineral resource assumed to exist on the basis of geologic knowledge and theory but with unknown specific locations, quality, and amounts.
- **Reserves**: identified resources from which a usable nonrenewable mineral can be extracted profitably at current prices.
- **Other resources**: identified and undiscovered resources not classified as reserves.

Most published estimates of the supply of a given nonrenewable resource refer to *reserves*. Reserves can increase when **(1)** new deposits are found or **(2)** price increases or improved mining technology make it profitable to extract deposits that previously were too expensive to extract. Theoretically, all of the *other resources* could eventually be converted to reserves, but this is highly unlikely.

How Do Ores Form from Magma? Ores form as a result of several internal and external geologic processes. Plate tectonics (Figure 10-4, p. 206, and Figure 10-5b, p. 207) **(1)** shapes the earth's crust as the earth's plates collide, retreat, and slide across one another at the boundaries between them (Figure 10-6, p. 208) and **(2)** determines where the earth's richest mineral deposits form.

One way this happens is when movement of the earth's plates allows *magma* (molten rock) to flow up into the earth's crust at divergent and convergent plate boundaries (Figure 10-6, p. 208). As this magma cools, it crystallizes into various layers of mineral-containing igneous rocks.

The most common way ore deposits form is through *hydrothermal processes*. When two tectonic plates retreat from one another, gaps created in the earth's crust fill with upwelling magma and seawater. The seawater seeping into these cracks becomes superheated and dissolves metals from rock or magma. As these metal-bearing solutions cool, their dissolved minerals cool and form *hydrothermal ore deposits*.

Hydrothermal ore deposits also occur when upwelling magma solidifies into chimney-shaped *black smokers* (Figure 15-3) in volcanically active regions of the ocean floor near spreading oceanic centers (Figure 10-4, p. 206). These smokers are miniature volcanoes that shoot out jets of hot, black, mineral-rich water through vents in solidified magma on the seafloor. As the hot water comes into contact with cold seawater, black particles of various metal sulfides precipitate out and accumulate as chimneylike structures near the hot water vents (Figure 15-3). These ore deposits are especially rich in copper, lead, zinc, silver, gold, and other minerals.

Because they are so rich in nutrients (especially sulfur), these hydrothermal deposits on the dark ocean floor support colonies of bacteria that **(1)** produce food through *chemosynthesis* and **(2)** support a variety of animals such as red tube worms, clams, crustaceans, and other forms of marine life (Figure 15-3).

Another potential source of metals from the ocean floor is *manganese nodules* that cover about 25–50% of the Pacific Ocean floor. These cherry- to potato-sized rocks contain **(1)** 30–40% manganese by weight and **(2)** small amounts of other important metals such as iron, copper, and nickel. Geologists believe these modules crystallized from hot solutions arising from volcanic activity at midoceanic ridges, perhaps by black smokers.

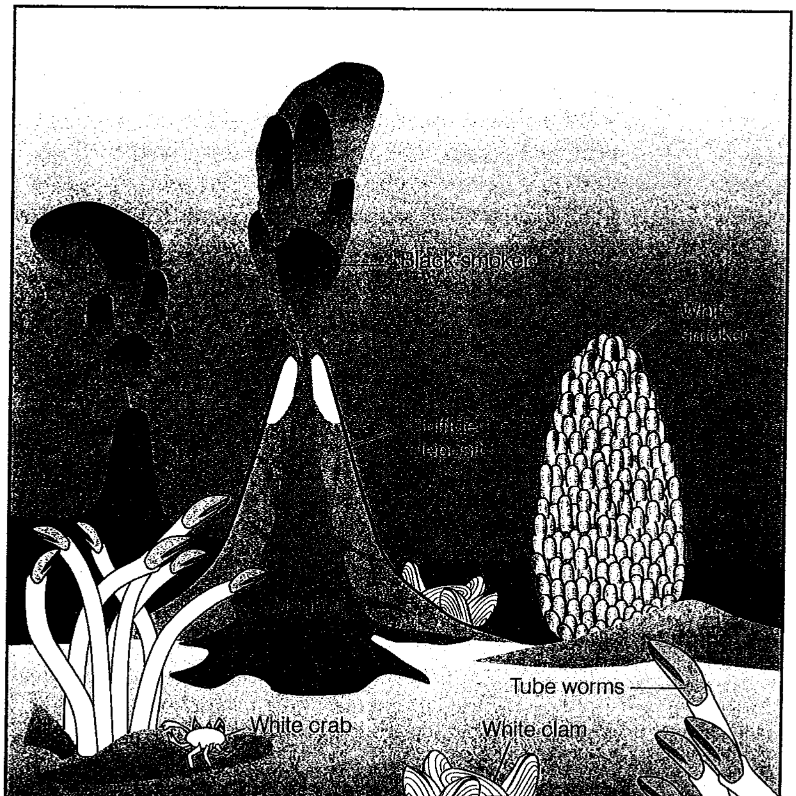


Figure 15-3 Hydrothermal ore deposits form when mineral-rich, superheated water shoots out of vents in solidified magma on the ocean floor. After mixing with cold seawater, black particles of metal ore precipitate out and build up as chimneylike ore deposits around the vents. A variety of organisms, supported by bacteria producing food by chemosynthesis, exist in the dark ocean around the black smokers.

How Do Ores and Other Minerals Form from Sedimentary and Weathering Processes? As sediments settle they can form ore deposits by *sedimentary sorting* and *precipitation*. For example, many streams carry a mixture of silt, sand, gravel, and occasional small grains of gold. When the stream current slows down, these minerals settle out on the basis of their density. Because gold is denser than any other mineral, it falls to the bottom of a stream first in this *sedimentary sorting* process. Over time, fairly rich deposits of settled gold particles, called *placer deposits*, concentrate near bedrock or coarse gravel in streams. Miners use pans or sieves to scoop up such streambed material and sort out the gold particles.

In deserts, groundwater flows can form lakes with no outlets to the sea. Some of the mineral-containing groundwater flowing into these lakes (or into enclosed seas) evaporates. This causes the concentrations of the dissolved salts to increase to the point where they precipitate to form *evaporite mineral deposits*. Important minerals formed this way include table salt, borax, and sodium carbonate.

Ore deposits can also form because of the *weathering* of rock by water. Torrents of water dissolve and remove most soluble metal ions from rock and soil near the earth's surface. This weathering process leaves ions of insoluble compounds in the soil to form *residual deposits* of metal ores such as iron and aluminum (bauxite ore).

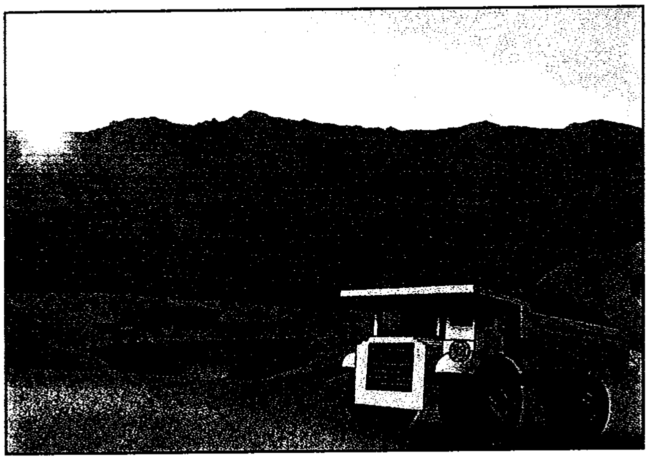
15-2 FINDING AND REMOVING NONRENEWABLE MINERAL RESOURCES

How Are Buried Mineral Deposits Found? Mining companies use several methods to find promising mineral deposits. They include

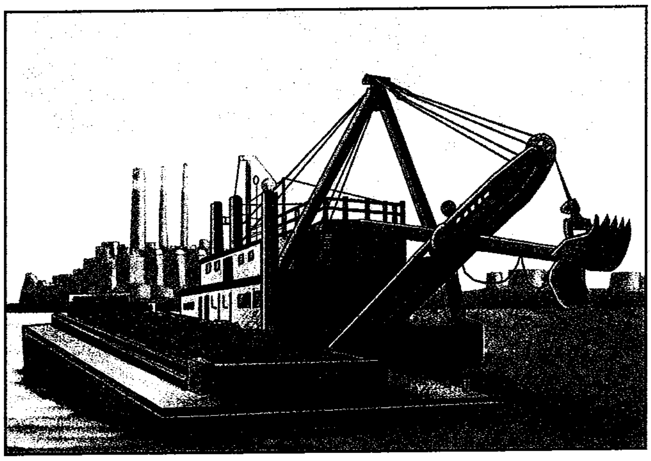
- Using aerial photos and satellite images to reveal protruding rock formations (outcrops) associated with certain minerals.
- Using planes equipped with **(1)** *radiation-measuring equipment* to detect deposits of radioactive metals such as uranium and **(2)** a *magnetometer* to measure changes in the earth's magnetic field caused by magnetic minerals such as iron ore.
- Using a *gravimeter* to measure differences in gravity because the density of an ore deposit usually differs from that of the surrounding rock.
- Drilling a deep well and extracting core samples.
- Putting sensors in existing wells to detect electrical resistance or radioactivity to pinpoint the location of oil and natural gas.
- Making *seismic surveys* on land and at sea by **(1)** detonating explosive charges and **(2)** analyzing the resulting shock waves to get information about the makeup of buried rock layers.
- Performing *chemical analysis* of water and plants to detect deposits of underground minerals that **(1)** have leached into nearby bodies of water or **(2)** have been absorbed by plant tissues.

After suitable mineral deposits are located, several different types of mining techniques are used to remove the deposits, depending on their location and type. Shallow deposits are removed by **surface mining** (Figure 15-4), and deep deposits are removed by **subsurface mining** (Figure 15-5, p. 342).

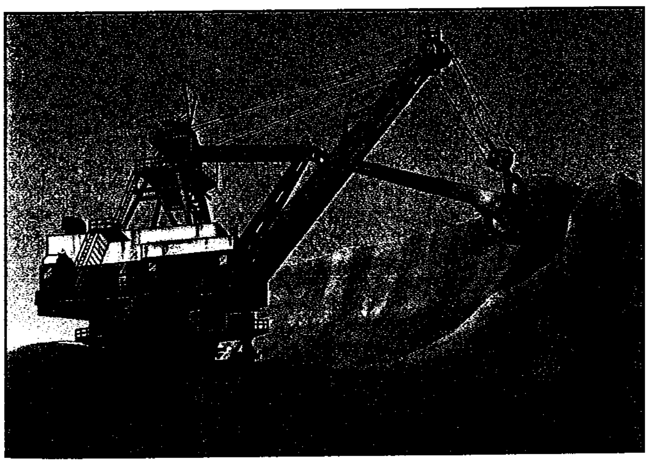
In surface mining, mechanized equipment strips away the **overburden** of soil and rock and usually



(a) Open Pit Mine



(b) Dredging

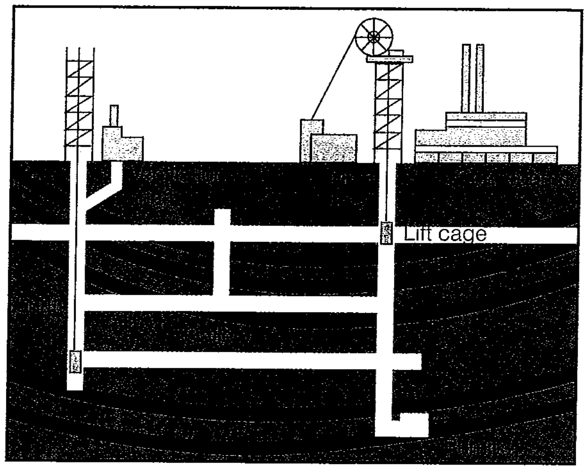


(c) Area Strip Mining

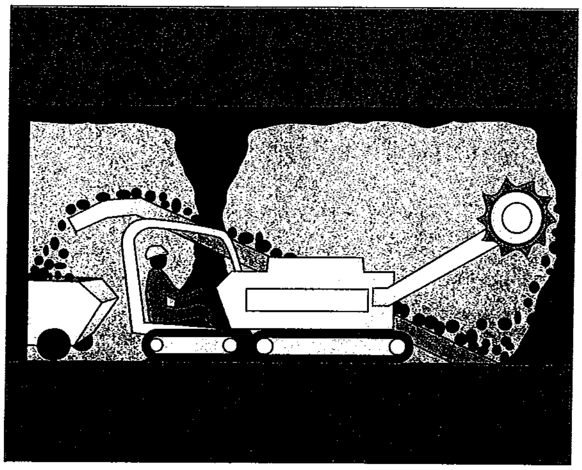
(d) Contour Strip Mining

Figure 15-4 Major mining methods used to extract surface deposits of solid mineral and energy resources.

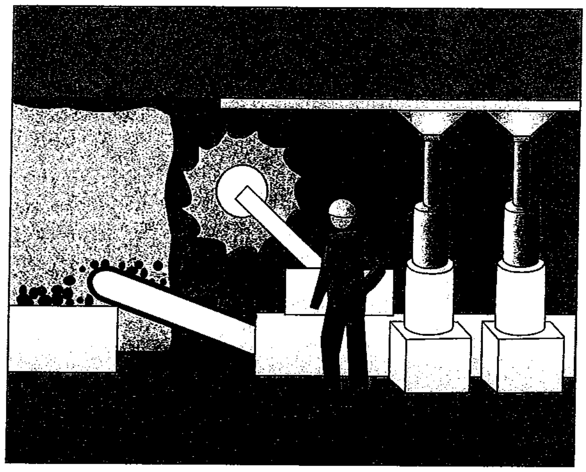
Figure 15-5 Major mining methods used to extract underground deposits of solid mineral and energy resources (primarily coal); **(a)** mine shafts and tunnels are dug and blasted out; **(b)** in *room-and-pillar* mining, machinery is used to gouge out coal and load it onto a shuttle car in one operation, and pillars of coal are left to support the mine roof; and **(c)** in *longwall coal mining*, movable steel props support the roof and cutting machines shear off the coal onto a conveyor belt. As the mining proceeds, roof supports are moved forward and the roof behind is allowed to fall (often causing the land above to sink or subside).



(a) Underground Coal Mine



(b) Room-and-Pillar



(c) Longwall Mining of Coal

discards it as waste material called **spoils.** In the United States, surface mining extracts about **(1)** 90% of the nonfuel mineral and rock resources and **(2)** 60% of the coal by weight.

The type of surface mining used depends on the resource being sought and on local topography. Methods include the following:

- **Open-pit mining** (Figure 15-4a), in which machines dig holes and remove ores (such as iron and copper) sand, gravel, and stone (such as limestone and marble).
- **Dredging** (Figure 15-4b), in which chain buckets and draglines scrape up underwater mineral deposits.
- **Area strip mining** (Figure 15-4c), used where the terrain is fairly flat. An earthmover strips away the overburden, and a power shovel digs a cut to remove the mineral deposit. After the mineral is removed, the trench is filled with overburden and a new cut is made parallel to the previous one. The process is repeated over the entire site. If the land is not restored, area strip mining leaves a wavy series of highly erodible hills of rubble called *spoil banks.*
- **Contour strip mining** (Figure 15-4d), 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, 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.*
- **Mountaintop removal.** This method uses explosives, massive shovels, and even larger machinery called draglines to remove the top of a mountain and expose seams of coal underneath. This form of surface mining—increasingly used in West Virginia—causes considerable environmental damage. In 2002, the Bush administration changed a government rule to allow rock and dirt from mountaintop strip mining of coal to be dumped into the streams and valleys below.

Although surface-mined land can be restored (except in arid and semiarid areas), it is expensive and not done in many countries. In the United States, the *Surface Mining Control and Reclamation Act of 1977*

- Requires mining companies to restore most surface-mined land so it can be used for the same purpose as it was before it was mined.
- Levied a tax on mining companies to restore land that was disturbed by surface mining before the law was passed.

Subsurface mining (Figure 15-5) is used to remove coal and various metal ores that are too deep to be extracted by surface mining. Miners **(1)** dig a deep vertical shaft, **(2)** blast subsurface tunnels and chambers to get to the deposit, and **(3)** use machinery to remove the ore or coal and transport it to the surface.

Subsurface mining **(1)** disturbs less than one-tenth as much land as surface mining and **(2)** usually produces less waste material. But it leaves much of the resource in the ground and is more dangerous and expensive than surface mining. Hazards include **(1)** collapse of roofs and walls of underground mines, **(2)** explosions of dust and natural gas, and **(3)** lung diseases caused by prolonged inhalation of mining dust.

15-3 ENVIRONMENTAL EFFECTS OF EXTRACTING, PROCESSING, AND USING MINERAL RESOURCES

What Are the Environmental Impacts of Using Mineral Resources? The mining, processing, and use of mineral resources takes enormous amounts of energy and often causes land disturbance, soil erosion, and air and water pollution (Figure 15-6).

Mining can affect the environment in the following ways:

- Scarring and disruption of the land surface (Figures 15-4 and 15-7, p. 344). The Department of the Interior estimates that about 500,000 mines dot the U.S. landscape, mostly in the West. Cleanup costs are estimated in the tens of billions of dollars.
- Collapse or subsidence of land above underground mines, which can cause **(1)** houses to tilt, **(2)** sewer lines to crack, **(3)** gas mains to break, and **(4)** groundwater systems to be disrupted.
- Wind- or water-caused erosion of toxin-laced mining wastes. The EPA estimates that mining has polluted 40% of Western watersheds.
- Acid mine drainage, when rainwater seeping through a mine or mine wastes **(1)** carries sulfuric acid

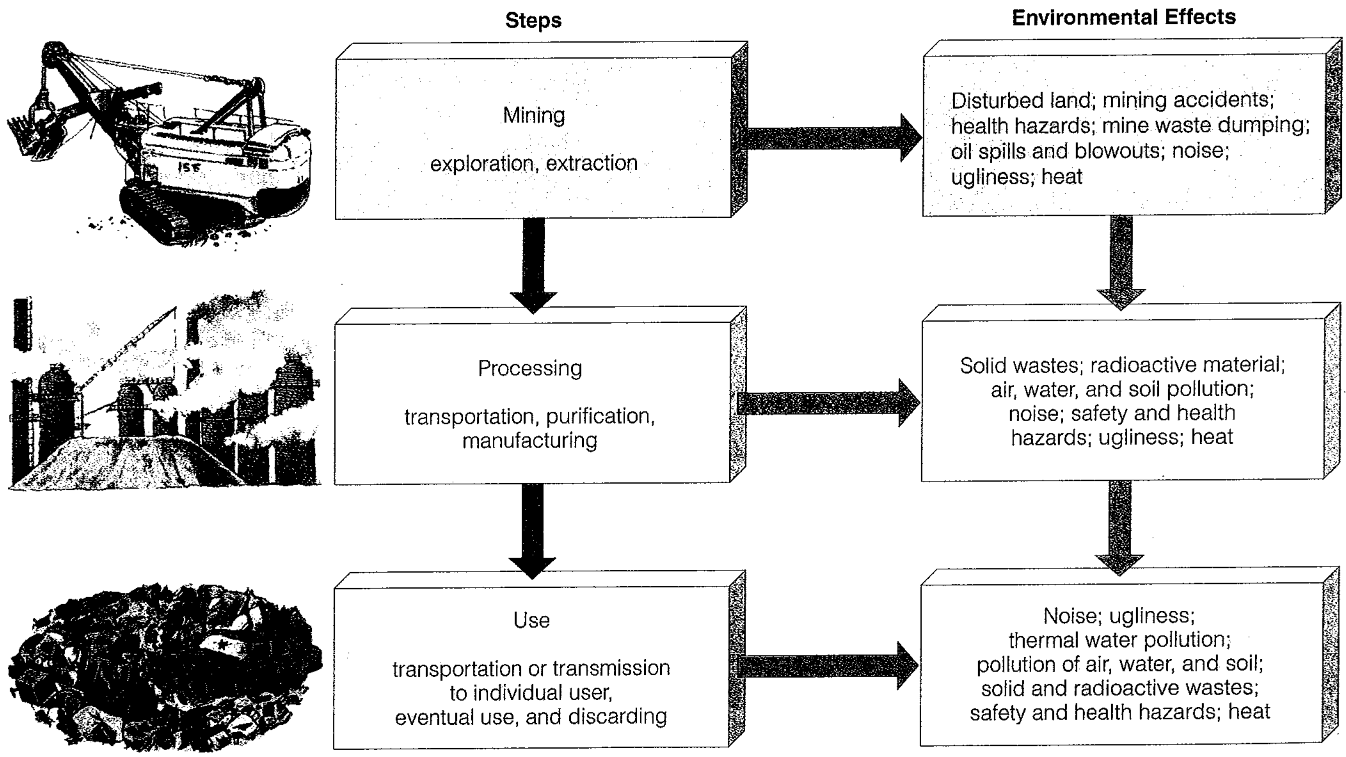


Figure 15-6 Some harmful environmental effects of extracting, processing, and using nonrenewable mineral and energy resources. The energy used to carry out each step causes additional pollution and environmental degradation.

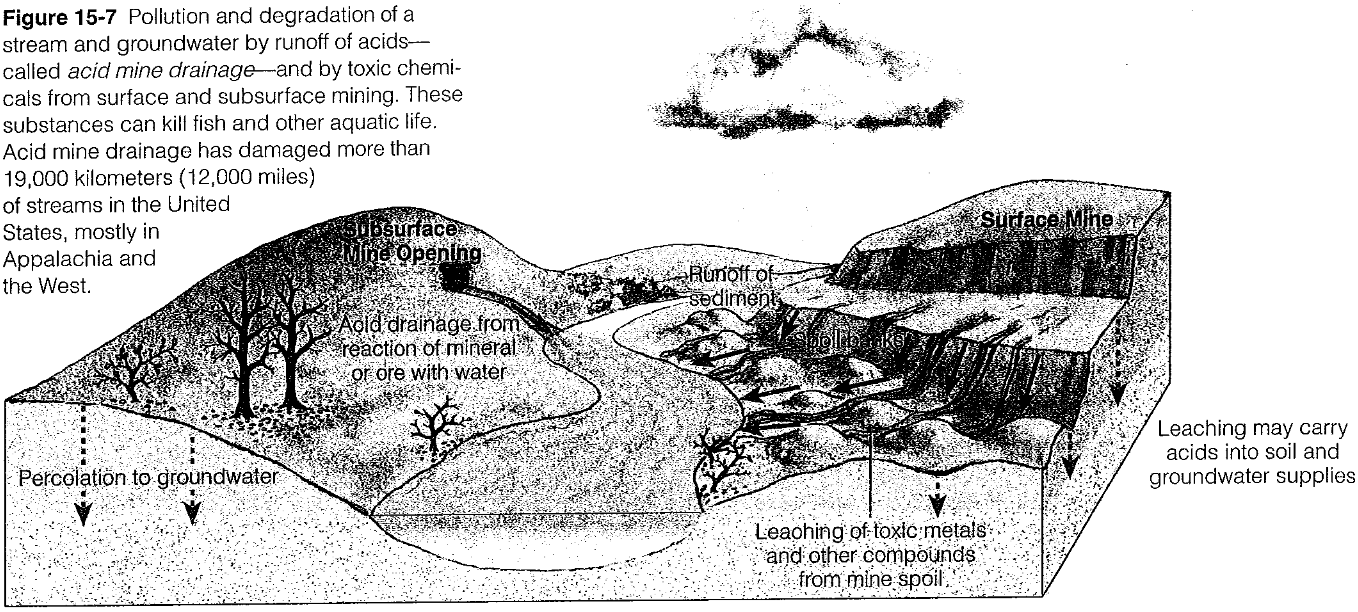


Figure 15-7 Pollution and degradation of a stream and groundwater by runoff of acids—called *acid mine drainage*—and by toxic chemicals from surface and subsurface mining. These substances can kill fish and other aquatic life. Acid mine drainage has damaged more than 19,000 kilometers (12,000 miles) of streams in the United States, mostly in Appalachia and the West.

(H_2SO_4, produced when aerobic bacteria act on iron sulfide minerals in spoils) to nearby streams and groundwater (Figure 15-7), **(2)** contaminates water supplies, and **(3)** destroys aquatic life.

- Emission of 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).

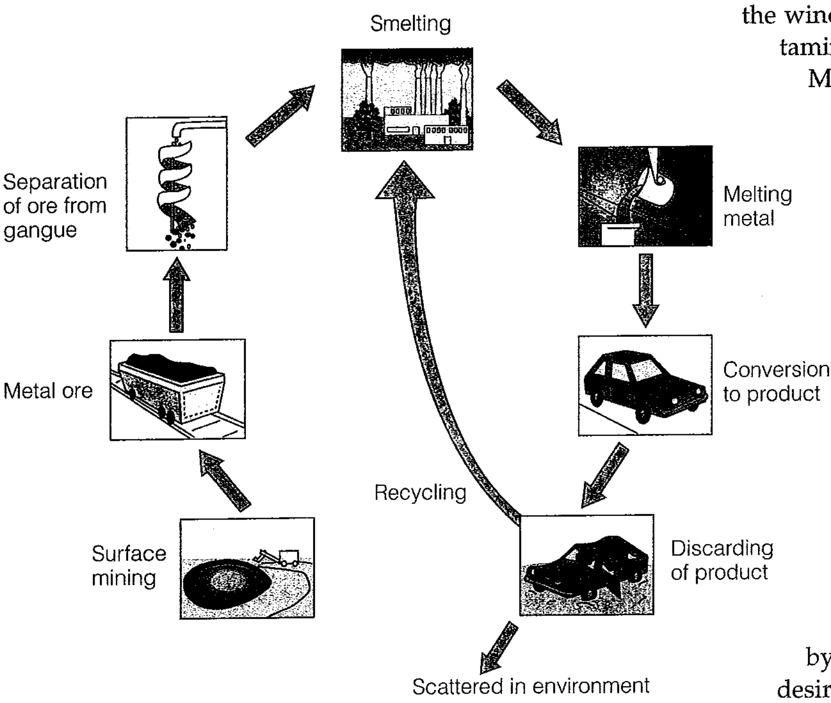


Figure 15-8 Typical *life cycle of a metal resource.* Each step in this process uses energy and produces some pollution and waste heat.

- Exposure of wildlife to toxic mining wastes stored in holding ponds and leakage of toxic wastes from such ponds.

Figure 15-8 shows the typical life cycle of a metal resource. Ore extracted from the earth's crust typically has two components: **(1)** the *ore mineral* containing the desired metal and **(2)** waste material called *gangue.* 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.

Most ores consist of one or more compounds of the desired metal. After gangue has been removed, **smelting** is used to separate the metal from the other elements in the ore mineral. Without effective pollution control equipment, smelters emit enormous quantities of air pollutants, which damage vegetation and soils in the surrounding area.

Smelters also cause water pollution and produce liquid and solid hazardous wastes that must be disposed of safely. Some companies are using improved technology to **(1)** reduce pollution from smelting, **(2)** lower production costs, **(3)** save costly cleanup bills, and **(4)** decrease liability for damages.

Once the pure metal has been produced by smelting, it is usually melted and converted to desired products, which are then used and discarded or recycled (Figure 15-8). Removing and processing ores to produce metals uses enormous amounts of energy, which pollutes the air and water and adds

Some Environmental Effects of Gold Mining

CASE STUDY

Gold miners typically remove ore equal to the weight of 50 automobiles to extract an amount of gold that would fit inside your clenched fist. Most newlyweds would be surprised to know that about 5.5 metric tons (6 tons) of mining waste was created to make their two gold wedding rings.

The solid waste remaining after gold is extracted from its ore is left piled near the mine sites and can pollute the air, surface water (Figures 15-6 and 15-7), and groundwater. In South Africa, each metric ton of gold that is mined kills an average of 1 worker and seriously injures 11 others.

In Australia and North America, a mining technology called *cyanide heap leaching* is cheap enough to allow mining companies to level entire mountains containing very low-grade gold ore. To extract the gold, miners spray a cyanide solution (which reacts with gold) onto huge open-air piles of crushed ore. They then **(1)** collect the solution in leach beds and overflow ponds, **(2)** recirculate it a number of times, and **(3)** extract gold from it.

A problem is that cyanide is extremely toxic to birds and mammals drawn to cyanide solution collection ponds as a source of water. Cyanide leach pads and collection ponds can also leak or overflow, posing threats to underground drinking water supplies and wildlife (especially fish) in lakes and streams.

Special liners beneath the ore heaps and in the collection ponds can prevent leaks, but some have failed. According to the EPA, all such liners will leak eventually.

On January 30, 2000, snow and heavy rains washed out an earthen dam containing an aboveground cyanide leach pond at an Australian-operated gold mine in Romania. The dam's collapse released large amounts of water laced with cyanide and toxic metals into the Tisza and Danube Rivers flowing through parts of Romania, Hungary, and Yugoslavia.

Several hundred thousand people living along these rivers were told not to fish or to drink or extract water from affected rivers or from wells along the rivers. Food industries and paper mills were shut down. Thousands of fish and other forms of aquatic life were killed. The accident and another one that occurred in January 2001 could have been prevented if the mine had installed a stronger containment dam and a backup collection pond to prevent leakage into nearby surface water.

Some gold mining companies take care to avoid environmental damage, but other companies do not. A glaring example is the Summitville gold mine site in the San Juan Mountains of southern Colorado. A Canadian company used the 1872 mining law (Pro/Con, p. 347) to buy the land from the federal government for only $7,000, spent $1 million developing the site, and then removed more than $130 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.

The company then 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 on the country's list of highly toxic (Superfund) sites, with the EPA spending $40,000 a day to contain the site's toxic wastes. Ultimately, the EPA expects to spend about $232 million on the cleanup.

Since 1980, millions of miners have streamed into tropical forests and other areas in search of gold. These small-scale miners use destructive mining techniques such as **(1)** digging large pits by hand, **(2)** river dredging, and **(3)** hydraulic mining (a technique, outlawed in the United States, in which water jets wash entire hillsides into sluice boxes).

Highly toxic mercury usually is used to extract the gold from the other materials. In the process, much of the mercury ends up contaminating water supplies and fish consumed by people. Just one teaspoon of mercury in a 1-hectare (2.5-acre) lake can make its fish unfit for human consumption.

Critical Thinking

What regulations, if any, would you impose on gold mining operations?

greenhouse gases to the atmosphere. For example, the U.S. steel industry uses as much electricity each year as the country's 90 million homes.

Are There Environmental Limits to Resource Extraction and Use? Some environmentalists and resource experts believe the greatest danger from the world's continually increasing consumption of nonrenewable mineral resources is not exhaustion of their supplies but the environmental damage caused by their extraction, processing, and conversion to products (Figure 15-6).

The mineral industry accounts for 5–10% of world energy use. This makes it a major contributor to air and water pollution and to emissions of greenhouse gases such as carbon dioxide (CO_2). The environmental impacts from mining an ore are affected by its percentage of metal content, or *grade* (Case Study, above).

Usually more accessible and higher-grade ores are exploited first. As they are depleted, it takes more money, energy, water, and other materials to exploit lower-grade ores. This in turn increases land disruption, mining waste, and pollution.

Currently, most of the harmful environmental costs of mining and processing minerals are not included in the prices for processed metals and consumer products produced from such minerals. This gives mining companies and manufacturers little incentive to reduce resource waste and pollution because they can pass many of the harmful environmental costs of their production on to society and future generations.

15-4 SUPPLIES OF MINERAL RESOURCES

Will There Be Enough Mineral Resources? The future supply of nonrenewable minerals depends on two factors: **(1)** the actual or potential supply and **(2)** the rate at which that supply is used. We never completely run out of any mineral. However, a mineral becomes *economically depleted* when it costs more to find, extract, transport, and process the remaining deposit than it is worth. At that point, there are five choices: **(1)** recycle or reuse existing supplies, **(2)** waste less, **(3)** use less, **(4)** find a substitute, or **(5)** do without.

Depletion time is the time it takes to use up a certain proportion (usually 80%) of the reserves of a mineral at a given rate of use (Figure 1-7, p. 10). When experts disagree about depletion times, they are often using different assumptions about supply and rate of use (Figure 15-9).

A traditional measure of the projected availability of nonrenewable resources is the **reserve-to-production ratio:** the number of years that proven reserves of a particular nonrenewable mineral will last at current annual production rates. Reserve estimates are continually changing because **(1)** new deposits often are discovered, and **(2)** new mining and processing can allow some of the minerals classified as other resources (Figure 15-2) to be converted to reserves. Under these circumstances, the reserve-to-production ratio is the best available projection of the current estimated supply and its estimated depletion time.

The shortest depletion time assumes no recycling or reuse and no increase in reserves (curve A, Figure 15-9). 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 15-9). 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 15-9). Finding a substitute for a resource leads to a new set of depletion curves for the new resource.

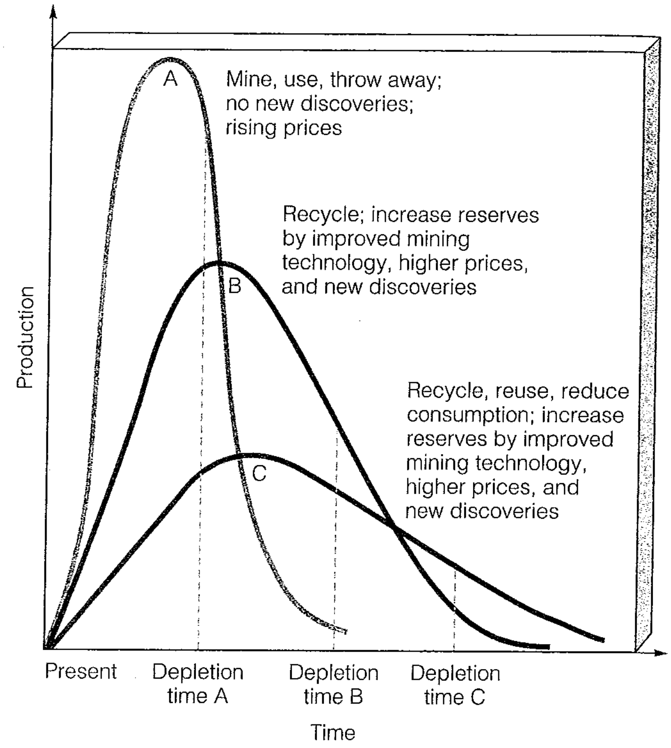


Figure 15-9 *Depletion curves* for a nonrenewable resource (such as aluminum or copper) using three sets of assumptions. Dashed vertical lines represent times when 80% depletion occurs.

How Does Economics Affect Mineral Resource Supplies? Geologic processes determine the quantity and location of a mineral resource in the earth's crust, but economics determines what part of the known supply is extracted and used.

According to standard economic theory, in a competitive free market a plentiful mineral resource is cheap when its supply exceeds demand. However, when a resource becomes scarce its price rises. This can **(1)** encourage exploration for new deposits, **(2)** stimulate development of better mining technology, **(3)** make it profitable to mine lower-grade ores, **(4)** encourage a search for substitutes, and **(5)** promote conservation.

However, according to some economists, this theory may no longer apply to most developed countries. One reason is that industry and government in such countries control the supply, demand, and prices of minerals to such an extent that a truly competitive free market does not exist.

Most mineral prices are 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 **(1)** get depletion allowances amounting to 5–22% of their gross income (depending on the mineral) and **(2)** can reduce the taxes they pay by deducting much of their costs for finding and developing mineral deposits. In addition, hardrock mining

Controversy over the General Mining Law of 1872

PRO/CON

Some people have gotten rich by using the little known General Mining Law of 1872. This law was designed to **(1)** encourage mineral exploration and mining of gold, silver, copper, zinc, nickel, uranium, and other *hardrock minerals* on U.S. public lands and **(2)** help develop the then sparsely populated West.

Under this 1872 law, a person or corporation can assume legal ownership of parcels of land on essentially all U.S. public land except parks and wilderness areas by *patenting* it. This involves **(1)** declaring the belief that the land contains valuable hardrock minerals, **(2)** spending $500 to improve the land for mineral development, **(3)** filing a claim, **(4)** paying an annual fee of $100 for each 8 hectares (20 acres) to maintain the claim whether or not a mine is in operation, and, if desired, **(5)** paying the federal government $6–12 per hectare ($2.50–5.00 an acre) for the land. Once purchased, the land can be used, leased, or sold for essentially any purpose.

So far, public lands containing an estimated $240–385 billion (adjusted for inflation) of publicly owned mineral resources have been transferred to private interests at 1872 prices. Domestic and foreign mining companies operating under this law remove mineral resources worth at least $2–3 billion per year on once-public land they bought at very low prices.

In addition, the Congressional Budget Office estimates that mining companies remove hardrock minerals worth at least $650 million per year from public land that has not been transferred to private ownership.

Hardrock mining companies also pay no royalties on the minerals they extract from such lands. In contrast, **(1)** oil and natural gas companies pay a gross royalty of 12.5% and **(2)** coal companies a gross royalty of 8–12.5% on the wholesale price of the resources they remove from public lands. Congress has also given hardrock mining companies tax breaks worth an estimated $823 million between 2002 and 2012.

No provision in the 1872 law requires mining companies to pay for environmental cleanup of any damage they cause to these lands and nearby water resources. Cleanup costs for land and streams damaged by 557,000 abandoned hardrock mines (Case Study, p. 345) and open pits (mostly in the West) will cost U.S. taxpayers an estimated $33–72 billion.

Mining companies defend the 1872 law. They point out that

- They must invest large sums of money (often $100 million or more) to locate and develop an ore site before they make any profits from mining hardrock minerals.
- Their mining operations **(1)** provide high-paying jobs to miners, **(2)** supply vital resources for industry, **(3)** stimulate the national and local economies, **(4)** reduce trade deficits, and **(5)** save American consumers money on products produced from such minerals.
- Paying royalties on their profits and requiring them to pay cleanup costs would force them to move their mining operations to other countries.

For decades, environmentalists have been trying, without success, to have this law revised to protect taxpayers and the environment by

- Permanently banning the patenting (sale) of public lands but allowing 20-year leases of designated public land for hardrock mining.
- Requiring mining companies to pay a *gross* royalty of 8–12% on the wholesale value of all minerals removed from public land—similar to what oil, natural gas, and coal companies pay. Hardrock mining companies want to **(1)** continue paying no royalties or **(2)** if the law is changed pay no more than a 5% *net* royalty based on gross sales minus production costs—a system that would yield a much lower return on sales of these minerals owned jointly by all taxpayers.
- Making mining companies legally and financially responsible for environmental cleanup and restoration of each site or charging them an additional mining fee to help pay for cleanup costs. Currently, mining companies are required to post bonds to cover 100% of the estimated cleanup costs in case they go bankrupt.

Canada, Australia, South Africa, and other countries that are major extractors of hardrock minerals have laws with such requirements.

Critical Thinking

Do you support or oppose the three major changes that environmentalists believe should be made in the U.S. General Mining Law of 1872? Explain.

companies operating in the United States can buy public land at 1872 prices and pay no royalties to the government on the minerals they extract (Pro/Con, above).

Between 1982 and 2001, U.S. mining companies received more than $6 billion in government subsidies. Critics argue that taxing rather than subsidizing the extraction of nonfuel mineral resources would **(1)** provide governments with revenue, **(2)** create incentives for more efficient resource use, **(3)** promote waste reduction and pollution prevention, and **(4)** encourage recycling and reuse.

Mining company representatives say they need subsidies and low taxes to **(1)** keep the prices of minerals low for consumers and **(2)** encourage them not to move their mining operations to other countries without such taxes and less stringent mining regulations.

Two other economic problems hinder the development of new supplies of mineral resources:

- Mineral scarcity does not raise the market price of products very much because the cost of mineral resources is only a small part of the final cost of goods.
- Exploring for new mineral resources takes a lot of increasingly scarce investment capital and is a risky financial venture. 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.

Should More Mining Be Allowed on Public Lands in the United States? About one-third of the land in the United States is public land owned jointly by all U.S. citizens. This land, consisting of national forests, parks, resource lands, and wilderness, is managed by various government agencies under laws passed by Congress. About 72% of this public land is in Alaska, and 22% is in western states (where 60% of all land is public land).

For decades, resource developers, environmentalists, and conservationists have argued over how this land should be used. Mineral resource extractors of mineral resources complain that three-fourths of the country's vast public lands, with many areas containing rich deposits of mineral resources, are off limits to mining.

In recent decades, they have stepped up efforts to have Congress **(1)** open up most of these lands to mineral development, **(2)** sell off mineral-rich public lands to private interests, or **(3)** turn their management over to state and local governments that usually can be more readily influenced by mining and development interests. In 2002, the Bush administration proposed using a mix of these three approaches for management of mineral and timber resources on U.S. public lands.

Conservation biologists and environmentalists strongly oppose such efforts. They argue that this would increase environmental degradation and decrease biodiversity.

Can We Get Enough Minerals by Mining Lower-Grade Ores? 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 **(1)** new earth-moving equipment, **(2)** improved techniques for removing impurities from ores, and **(3)** other technological advances in mineral extraction and processing.

In 1900, for instance, the average copper ore mined in the United States was about 5% copper by weight. Today it is 0.5%, and copper costs less (adjusted for inflation). New methods of mineral extraction may allow even lower-grade ores of some metals to be used (Solutions, p. 349).

However, the mining of lower-grade ores can be limited by **(1)** increased cost of mining and processing larger volumes of ore, **(2)** availability of fresh water needed to mine and process some minerals (especially in arid and semiarid areas), and **(3)** the environmental impact of the increased land disruption, waste material, and pollution produced during mining and processing (Figure 15-6).

Can We Get Enough Minerals by Mining the Oceans? Ocean mineral resources are found in **(1)** seawater, **(2)** sediments and deposits on the shallow continental shelf (Figure 7-7, p. 148), **(3)** hydrothermal ore deposits (Figure 15-3), and **(4)** manganese-rich nodules on the deep-ocean floor.

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. Only magnesium, bromine, and sodium chloride are abundant enough to be extracted profitably at current prices with existing technology.

Deposits of minerals (mostly sediments) along the continental shelf and near shorelines are significant sources of sand, gravel, phosphates, sulfur, tin, copper, iron, tungsten, silver, titanium, platinum, and diamonds.

Rich deposits of gold, silver, zinc, and copper are found as sulfide deposits in the deep-ocean floor and around black smokers (Figure 15-3). Currently, it is too expensive to extract these minerals even though some of these deposits contain large concentrations of important metals.

Manganese-rich nodules found on the deep-ocean floor at various sites may be a future source of manganese and other key metals. They might be **(1)** sucked up from the ocean floor by giant vacuum pipes or **(2)** scooped up by buckets on a continuous cable operated by a mining ship.

So far these nodules and resource-rich mineral beds in international waters have not been developed because of high costs and squabbles over who owns these common-property resources and how any profits from extracting them should be distributed among the world's nations. Some of these issues may be resolved by the international Law of the Sea Treaty.

Some environmentalists believe seabed mining probably would cause less environmental harm than mining on land. But they are concerned that removing seabed mineral deposits and dumping back unwanted material will **(1)** stir up ocean sediments, **(2)** destroy seafloor organisms, and **(3)** have potentially harmful effects on poorly understood ocean food webs and marine biodiversity.

Mining with Microbes

SOLUTIONS

One way to improve mining technology is to use microorganisms for in-place (*in situ*, pronounced "in-SY-too") mining. This biological approach to mining would (1) remove desired metals from ores while leaving the surrounding environment undisturbed, (2) reduce air pollution associated with the smelting of metal ores, and (3) reduce water pollution associated with using hazardous chemicals such as cyanides and mercury to extract gold (Case Study, p. 345).

Once a commercially viable ore deposit has been identified, wells are drilled into it and the ore is fractured. Then the ore is inoculated with natural or genetically engineered bacteria to extract the desired metal. Next the well is flooded with water, which is pumped to the surface, where the desired metal is removed. Then the water is recycled.

This technique permits economical extraction from low-grade ores, which are increasingly being used as high-grade ores are depleted. Since 1958, the copper industry has been using natural strains of the bacterium *Thiobacillus ferroxidans* to remove copper from low-grade copper ore. Currently, more than 30% of all copper produced worldwide, worth more than $1 billion a year, comes from such *biomining*. If naturally occurring bacteria cannot be found to extract a particular metal, genetic engineering techniques could be used to produce such bacteria.

However, 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 ore (such as gold and copper) for which conventional techniques are too expensive.

Critical Thinking

1. If you had a large sum of money to invest, would you invest it in the microbiological mining of aluminum ore? Explain.

2. Are the ecological and human health risks from using genetically engineered organisms to mine metals likely to be higher or lower than those of genetically engineered organisms in food (Figure 13-16, p. 291, and Figure 13-17, p. 292)? Explain.

Can We Find Substitutes for Scarce Nonrenewable Mineral Resources? The Materials Revolution Some analysts believe that even if supplies of key minerals become very expensive or scarce, human ingenuity will find substitutes. They point to the current *materials revolution* in which silicon and new materials, particularly ceramics and plastics, are being developed and used as replacements for metals.

Ceramics have many advantages over conventional metals. They are harder, stronger, lighter, and longer lasting than many metals, and they withstand intense heat and do not corrode. Within a few decades we may have high-temperature ceramic superconductors in which electricity flows without resistance. Such a development may lead to faster computers, more efficient power transmission, and affordable electromagnets for propelling high-speed magnetic levitation trains.

Plastics also have advantages over many metals. High-strength plastics and composite materials strengthened by lightweight carbon and glass fibers are likely to transform the automobile and aerospace industries. They (1) cost less to produce than metals because they take less energy, (2) do not need painting, and (3) can be molded into any shape. New plastics and gels also are being developed to provide superinsulation without taking up much space. One new plastic can withstand extremely high temperatures and is not even affected by exposure to the most intense laser beams.

Substitutes undoubtedly can be found for many scarce mineral resources. But finding substitutes for some key materials may be difficult or impossible. Examples are (1) helium, (2) phosphorus for phosphate fertilizers, (3) manganese for making steel, and (4) copper for wiring motors and generators.

In addition, some substitutes are inferior to the minerals they replace. For example, aluminum could replace copper in electrical wiring. But producing aluminum takes much more energy than producing copper and aluminum wiring is a greater fire hazard than copper wiring.

15-5 EVALUATING ENERGY RESOURCES

What Types of Energy Do We Use? *Some 99% of the energy used to heat the earth and all of our buildings comes directly from the sun* (see photo on p. 253). Without this direct input of essentially inexhaustible solar energy, the earth's average temperature would be −240°C (−400°F), and life as we know it would not exist.

This incoming solar energy is based on the nuclear fusion of hydrogen atoms that make up the sun's mass

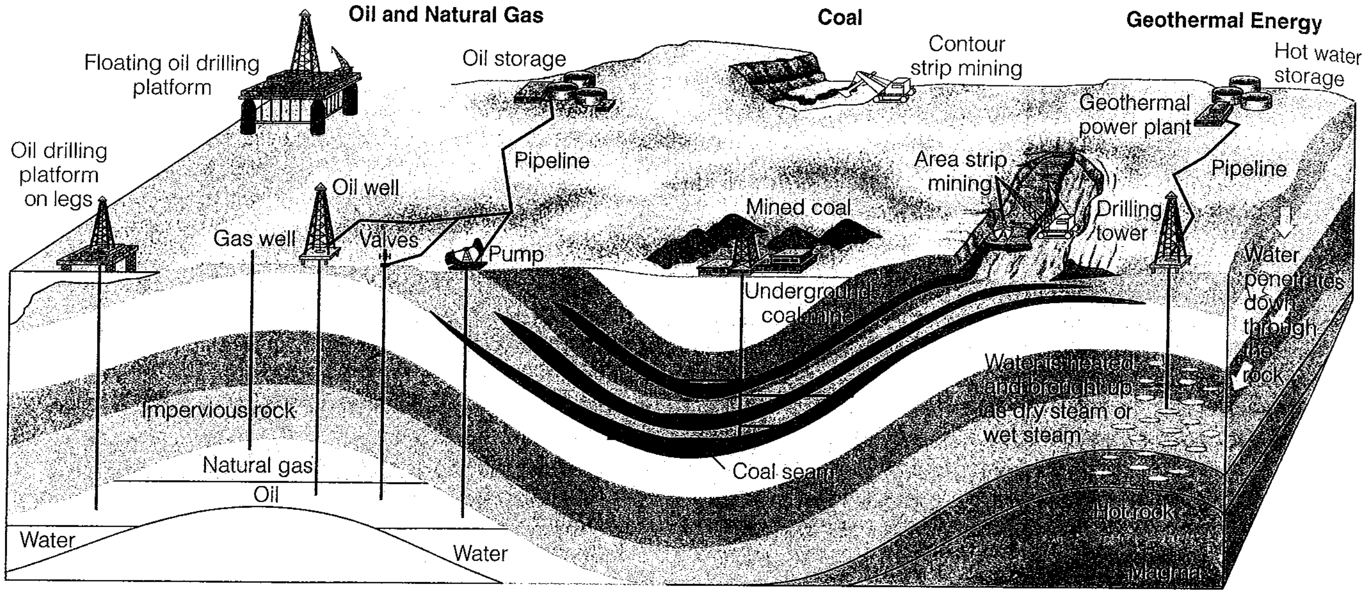


Figure 15-10 Important *nonrenewable energy resources* that can be removed from the earth's crust are coal, oil, natural gas, and some forms of geothermal energy. Nonrenewable uranium ore is also extracted from the earth's crust and then processed to increase its concentration of uranium-235, which can be used as a fuel in nuclear reactors to produce electricity.

(Figure 3-18, p. 58). Thus *life on earth is made possible by a gigantic nuclear fusion reactor safely located about 150 million kilometers (93 million miles) away.*

This direct input of solar energy also produces several other *indirect forms of renewable solar energy:* **(1)** wind, **(2)** falling and flowing water (hydropower), and **(3)** biomass (solar energy converted to chemical energy stored in chemical bonds of organic compounds in trees and other plants).

Commercial energy sold in the marketplace makes up the remaining 1% of the energy we use to supplement the earth's direct input of solar energy. Most commercial energy comes from extracting and burning *nonrenewable mineral resources* obtained from the earth's crust, primarily carbon-containing fossil fuels (oil, natural gas, and coal; Figure 15-10).

What Types of Energy Does the World Depend On, and How Might This Change? Over the past 60,000 years, major cultural changes (Section 2-1, p. 22) and technological advances have greatly increased energy use per person (Figure 15-11). As a result of such advances, about 82% of the commercial energy consumed in the world comes from *nonrenewable* energy resources (76% from fossil fuels and 6% from nuclear power; Figure 15-12, left).

Figure 15-13 shows the world's increase in consumption of oil, coal, and natural gas between 1950 and 2000, and Figure 15-14 (p. 352) shows past and projected future trends in the use of nuclear power to produce electricity.

Here are some important trends in the use of fossil fuels, nuclear power, and biomass (mostly from wood):

- Between 1996 and 2000, global use of *coal* declined by 7% (Figure 15-13) and in the long run is expected to continue to decline because it is the world's most polluting and climate-disrupting fossil fuel. China, the world's second largest user of coal, after the United

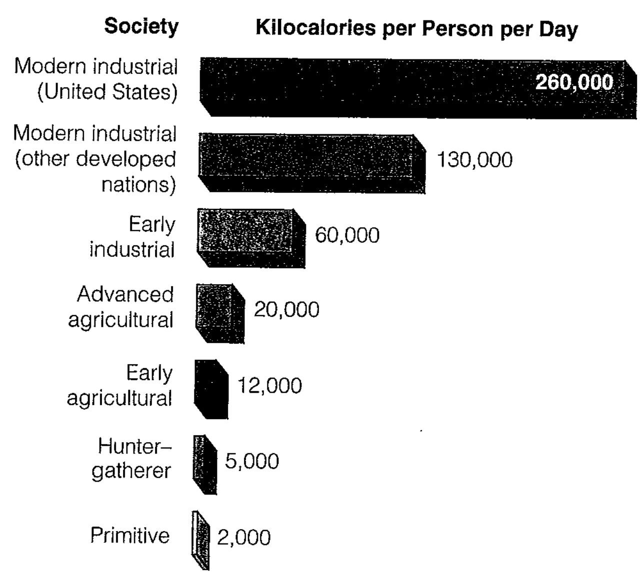


Figure 15-11 Average direct and indirect daily energy use per person at various stages of human cultural development. A typical citizen in a modern industrial society uses 65–130 times as much energy per day as a hunter–gatherer.

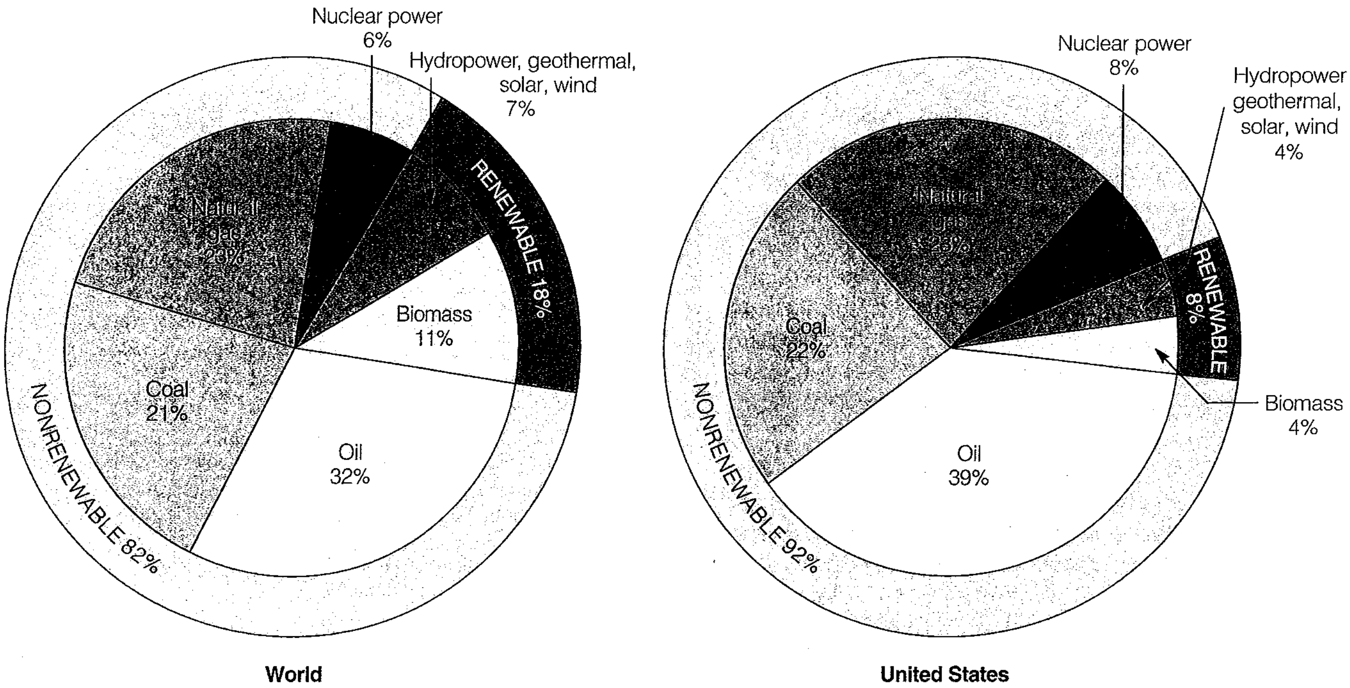


Figure 15-12 Commercial energy use by source for the world (left) and the United States (right) in 2000. Commercial energy amounts to only 1% of the energy used in the world; the other 99% is direct solar energy received from the sun and is not sold in the marketplace. (Data from U.S. Department of Energy, British Petroleum, and Worldwatch Institute)

States, reduced its coal use by an estimated 14% between 1996 and 2000.

- Use of *oil* continues to climb by about 1% a year (Figure 15-13), primarily because of its **(1)** abundance, **(2)** low price (bolstered by huge government subsidies and failure to include its environmental costs in its market price), and **(3)** ease of use as a motor vehicle fuel. Global oil production is expected to peak between 2010 and 2030 and then begin declining.
- Natural gas use is increasing by about 2% per year. Since 1999, it has produced more of the world's energy than coal (Figure 15-13) mostly because of ample supplies and because it is the cleanest and least climate disrupting of the three major fossil fuels.

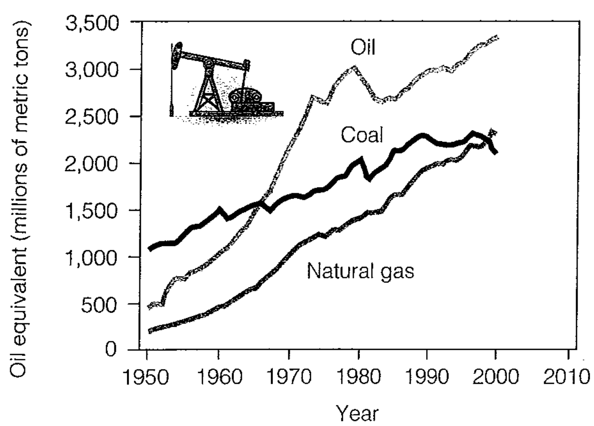


Figure 15-13 Global consumption of fossil fuels—oil, coal, and natural gas—1950–2000. (Data from Worldwatch Institute)

- Global production of electricity by nuclear power plants has leveled off since 1989 (Figure 15-14). Without greatly increased government subsidies, it is projected to decline as aging reactors wear out and are retired.
- In developing countries, the main source of energy for heating and cooking for roughly half the world's population is renewable energy from *biomass* (mostly fuelwood and charcoal made from fuelwood)—as long as wood supplies are not harvested faster than they are replenished. Some *bad news* is many of the world's people in developing countries **(1)** face a fuelwood shortage that is expected to get worse because of unsustainable harvesting, **(2)** die prematurely from breathing particles emitted by burning wood indoors in open fires and poorly designed primitive stoves, and **(3)** cannot afford to use fossil fuels.

What Types of Energy Does the United States Depend On, and How Might That Change? The United States is the world's largest energy user. With only 4.6% of the population, it uses 24% of the world's commercial energy. This is more energy than the combined total used by the next four largest energy-consuming countries—China, Russia, Japan,

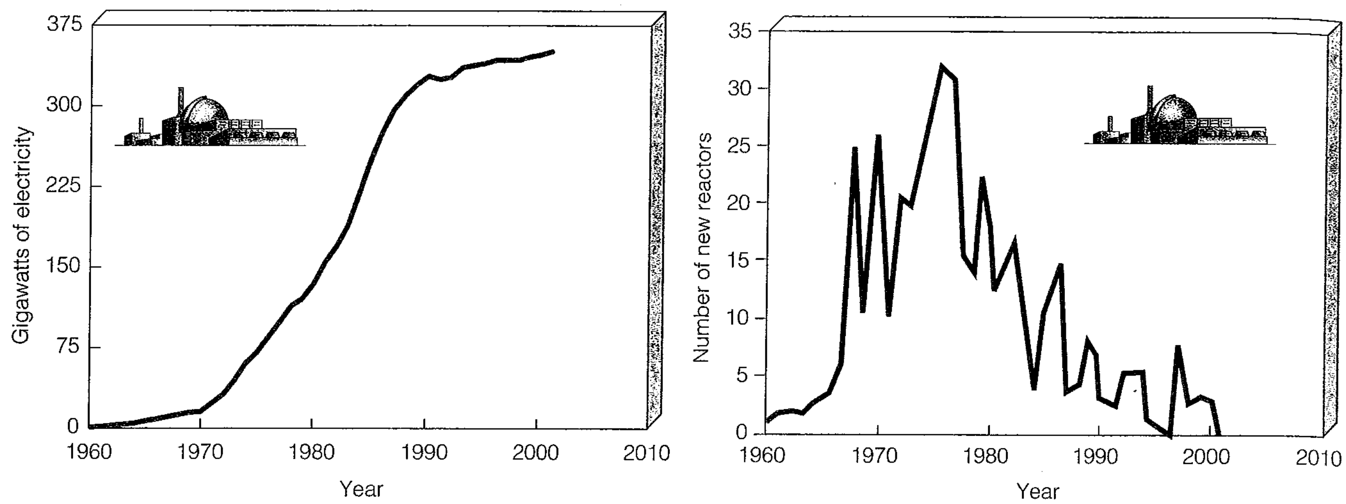


Figure 15-14 Global nuclear power generating capacity peaked in the 1990s and is projected to decline because of the **(1)** sharp decline in construction of new nuclear reactors since 1975 (right), **(2)** retirement of many of the world's existing reactors as they wear out or cost too much to run, **(3)** lower projected electricity demand because of energy savings from increased energy efficiency, and **(4)** increased availability of safer, easier, quicker to install, and less costly ways to produce electricity from alternatives such as turbines burning natural gas, wind power, and solar cells (as prices continue to fall). (Data from U.S. Department of Energy and the Worldwatch Institute)

and Germany. In contrast, India, with 16% of the world's people, uses about 3% of the world's commercial energy.

About 92% of the commercial energy used in the United States comes from *nonrenewable* energy resources (84% from fossil fuels and 8% from nuclear power; Figure 15-12, right). Energy use per person in the United States and Canada is **(1)** about twice as high as in Japan, Germany, France, and the United Kingdom and **(2)** at least 100 times as high as that in China and India. According to Maurice Strong, secretary-general of the 1992 United Nations (UN) Earth Summit, "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."

Figure 15-15 shows energy consumption by fuel in the United States from 1970 to 2000, with projections to 2020. Note that the main projected trends between 2000 and 2020 are increased use of oil and natural gas and a leveling off of coal use.

An important environmental, economic, and political issue is what energy resources the United States might be using by 2050 and 2100. Figure 15-16 shows shifts in use of various sources of energy in the United States since 1800 and one scenario showing projected changes to a solar-hydrogen energy age by 2100.

Current global and U.S. dependence on nonrenewable fossil fuels (Figures 15-12 and 15-13) is the primary cause of **(1)** air and water pollution, **(2)** land disruption, and **(3)** greenhouse gas emissions. According to many energy experts, the need to use cleaner and less climate-disrupting forms of energy—not the depletion of fossil fuels—is the driving force behind the projected global transition to a solar-hydrogen energy age in the United States and other parts of the world before the end of this century (Figure 15-16).

Whether this shift occurs depends primarily on a combination of technological developments and what energy resources the U.S. government decides to **(1)** *promote* by use of subsidies and tax breaks and **(2)** *dampen* by reducing subsidies and tax breaks and taxing energy use for fuels that cause environmental harm or produce CO_2. This is primarily a political decision made by elected officials with pressure from officials of energy companies and citizens.

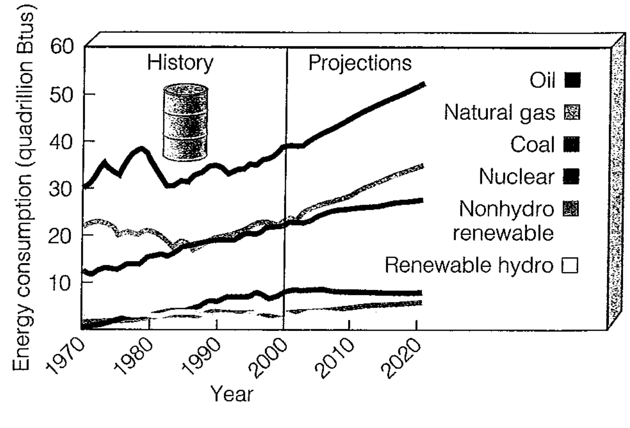


Figure 15-15 Energy consumption by fuel in the United States, 1970–2000, with projections to 2020. (Data from U.S. Department of Energy, *Annual Energy Review, 2002*)

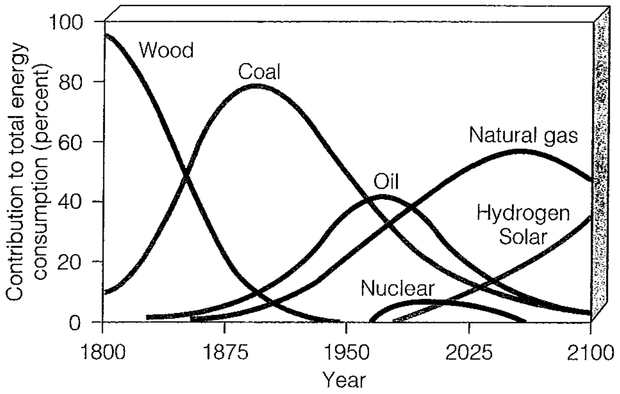


Figure 15-16 Shifts in the use of commercial energy resources in the United States since 1800, with projected changes to 2100. Shifts from wood to coal and then from coal to oil and natural gas have each taken about 50 years. The projected shift to 2100 is only one of many possible scenarios depending on a variety of assumptions. (Data from U.S. Department of Energy)

How Can We Decide Which Energy Resources to Use? There is intense scientific, economic, and political controversy over which energy resources we should rely on now and in the future. As you will learn in this chapter and the one that follows, each energy resource has advantages and disadvantages that must be carefully evaluated.

Energy policies need to be developed with the future in mind because experience shows that it usually takes at least 50 years and huge investments to phase in new energy alternatives to the point where they provide 10–20% of total energy use. Making projections such as those in Figure 15-16 involves answering the following questions for *each* energy alternative:

- How much of the energy source will be available in the **(1)** near future (the next 15–25 years) and **(2)** long term (the next 25–50 years)?
- What is this source's net energy yield?
- How much will it cost to develop, phase in, and use this energy resource?
- What government research and development subsidies and tax breaks will be provided for each energy resource to spur or hinder its development?
- How will dependence on each energy resource affect national and global economic and military security?
- How vulnerable is each source of energy to terrorism?
- How will extracting, transporting, and using the energy resource affect the environment, human health, and the earth's climate? Should these harmful costs be included in the market prices of each energy resource through a combination of taxes and phasing out environmentally harmful subsidies (full-cost pricing)?

What Is Net Energy? The Only Energy That Really Counts It takes energy to get energy. For example, oil must be **(1)** found, **(2)** pumped up from beneath the ground or ocean floor, **(3)** transferred to a refinery and converted to useful fuels (such as gasoline, diesel fuel, and heating oil), **(4)** transported to users, and **(5)** burned in furnaces and cars before it is useful to us. Each of these steps uses energy, and the second law of thermodynamics (p. 59) tells us that each time we use high-quality energy (Figure 3-12, p. 53) to perform a task, some of it is always wasted and degraded to lower-quality energy.

The usable amount of *high-quality energy* (Figure 3-12, p. 53) available from a given quantity of an energy resource is its **net energy:** the total amount of energy available from an energy resource minus the energy needed to find, extract, process, and get that energy to consumers. It is calculated by estimating the total energy available from the resource over its lifetime minus the amount of energy **(1)** used (the first law of thermodynamics), **(2)** automatically wasted (the second law of thermodynamics), and **(3)** unnecessarily wasted in finding, processing, concentrating, and transporting the useful energy to users.

Net energy is like your net spendable income (your wages minus taxes and other deductions). For example, suppose that for every 10 units of energy in oil in the ground we have to use and waste 8 units of energy to find, extract, process, and transport the oil to users. Then we have only 2 units of *useful energy* available from every 10 units of energy in the oil.

We can express net energy as the ratio of useful energy produced to the useful energy used to produce it. In the example just given, the *net energy ratio* would be 10/8, or 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 15-17 (p. 354) shows estimated net energy ratios for **(1)** various types of space heating, **(2)** high-temperature heat for industrial processes, and **(3)** transportation. Currently, oil has a high net energy ratio because much of it comes from large, accessible, and cheap-to-use deposits such as those in the Middle East. When those sources are depleted, the net energy ratio of oil will decline and prices will rise. Then more money and high-quality fossil fuel energy will be needed to find, process, and deliver new oil from **(1)** deposits that are small and widely dispersed, buried deep in the earth's crust, and located in remote areas or further and further offshore, and **(2)** extracting and processing shale oil.

Conventional nuclear energy has a low net energy ratio because large amounts of energy are needed to

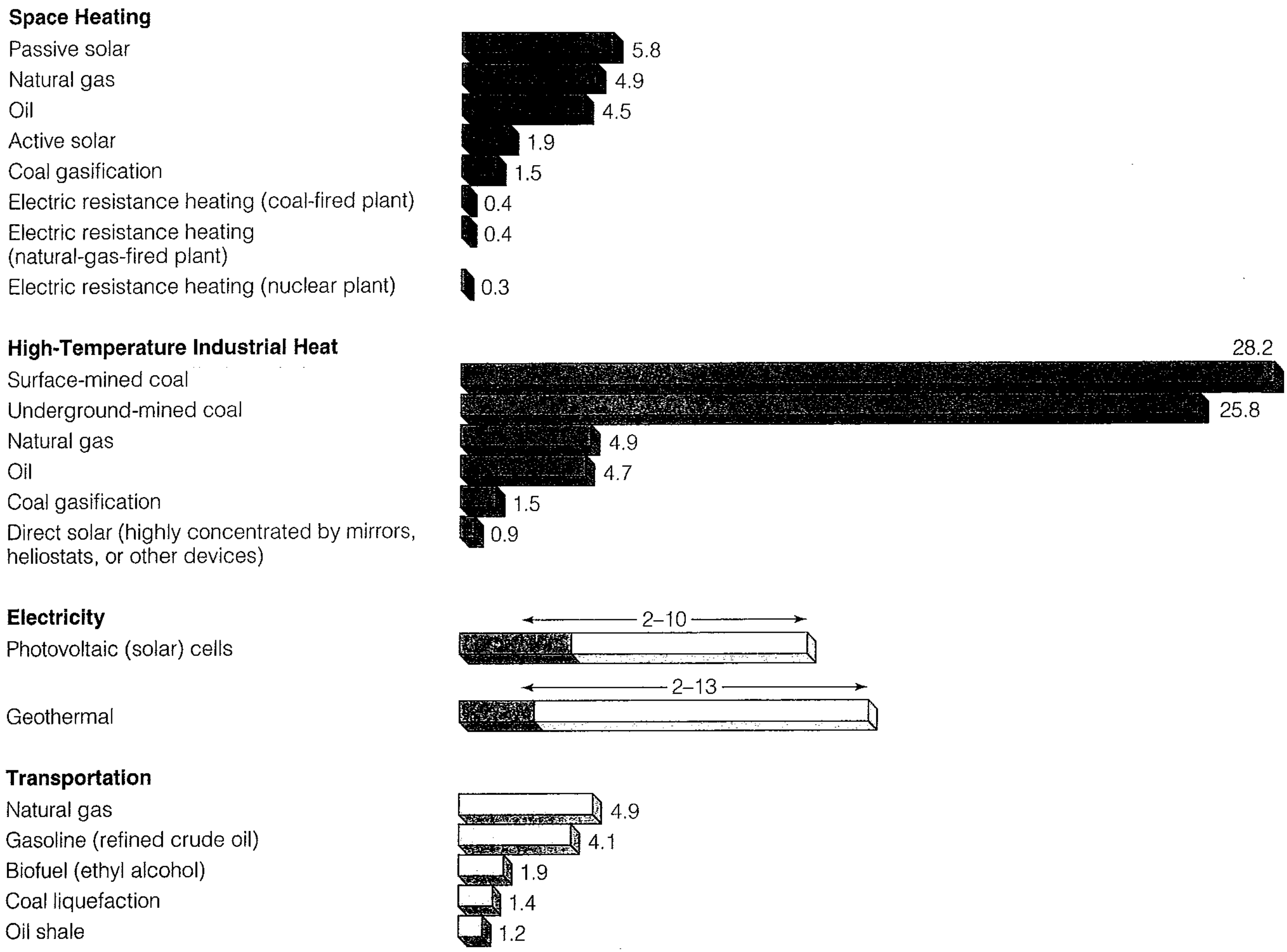


Figure 15-17 *Net energy ratios* for various energy systems over their estimated lifetimes. The higher the net energy ratio, the greater the net energy available. (Data from U.S. Department of Energy and Colorado Energy Research Institute, *Net Energy Analysis*, 1976; and Howard T. Odum and Elisabeth C. Odum, *Energy Basis for Man and Nature*, 3rd ed., New York: McGraw-Hill, 1981)

(1) extract and process uranium ore, **(2)** convert it into a usable nuclear fuel, **(3)** build and operate nuclear power plants, **(4)** dismantle the highly radioactive plants after their 15–60 years of useful life, and **(5)** store the resulting highly radioactive wastes safely for thousands of years.

15-6 OIL

What Is Crude Oil, and How Is It Extracted and Processed? **Petroleum,** or **crude oil** (oil as it comes out of the ground), is a thick liquid consisting of hundreds of combustible hydrocarbons along with small amounts of sulfur, oxygen, and nitrogen impurities. This fossil fuel was produced by the decomposition of dead organic matter from plants (primarily plankton) and animals that were **(1)** buried under lake and ocean sediments 2–140 million years ago and **(2)** subjected to high temperatures and pressures over millions of years as part of the carbon cycle (Figure 4-28, p. 84).

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 15-10). The crude oil is dispersed in pores and cracks in underground rock formations, somewhat like water saturating a sponge. A well can be drilled. Then we can pump out the crude oil that is drawn by gravity out of the rock pores and into the bottom of the well.

On average, producers get only about 35% of the oil out of an oil deposit. They then abandon the well because the remaining *heavy crude oil* is too difficult or expensive to recover. As oil prices rise, it can become economical to remove about 10–25% of this remaining heavy oil by flushing the well with steam and water. But the net energy yield for such recovered oil is lower because it takes the energy in one-third of a barrel of refined oil to retrieve each barrel of heavy crude oil.

Drilling for oil causes only moderate damage to the earth's land because the wells occupy fairly little land area. However, oil drilling always involves **(1)** some oil spills on land and in aquatic systems and **(2)** the harmful environmental effects associated with the extraction, processing, and use of any nonrenewable resource from the earth's crust (Figure 15-6).

Some *good news* is that new drilling technologies allow oil and natural gas producers to **(1)** drill deeper on land and the ocean bottom, **(2)** use fewer drilling rigs (derricks) by using one rig to drill several gas or oil pockets at the same time (multilateral drilling), and **(3)** remove oil or gas from distances as far away as 8 kilometers (5 miles) by drilling at angles of 90 degrees or more (slant drilling). According to oil producers, these improved extraction technologies can increase oil production without despoiling environmentally sensitive areas.

When prices for conventional oil rise and range from $30–40 per barrel, it may become economically feasible to extract enough of the heavy crude oil left in existing wells to increase the world's identified oil reserves by 50%. However, at that price it may be cheaper to depend more on natural gas and other energy resources such as wind and eventually hydrogen (Figure 15-16)

Once crude oil has been extracted, it is transported to a *refinery* by pipeline, truck, or ship (oil tanker). There it is heated and distilled in gigantic columns to separate it into components with different boiling points (Figure 15-18). 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.

Who Has the World's Oil Supplies? Oil *reserves* are identified deposits from which 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 67% of the world's crude oil reserves, which explains why OPEC is expected to have long-term control over world oil supplies and prices.

Saudi Arabia, with 26%, has by far the largest proportion of the world's crude oil reserves, followed by Iraq, Kuwait, Iran, and United Arab Emirates, each with 9–10%.

The remaining global crude oil reserves are found in **(1)** Latin America (9%, mostly in Venezuela and Mexico), **(2)** Africa (7%), **(3)** the former Soviet Union (6%), **(4)** Asia (4%, with 3% in China), **(5)** the United States (3%), and **(6)** western Europe (2%). Figure 15-19

*OPEC was formed in 1960 so developing countries with much of the world's known and projected oil supplies could get a higher price for this resource. Today its members are Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates, and Venezuela.

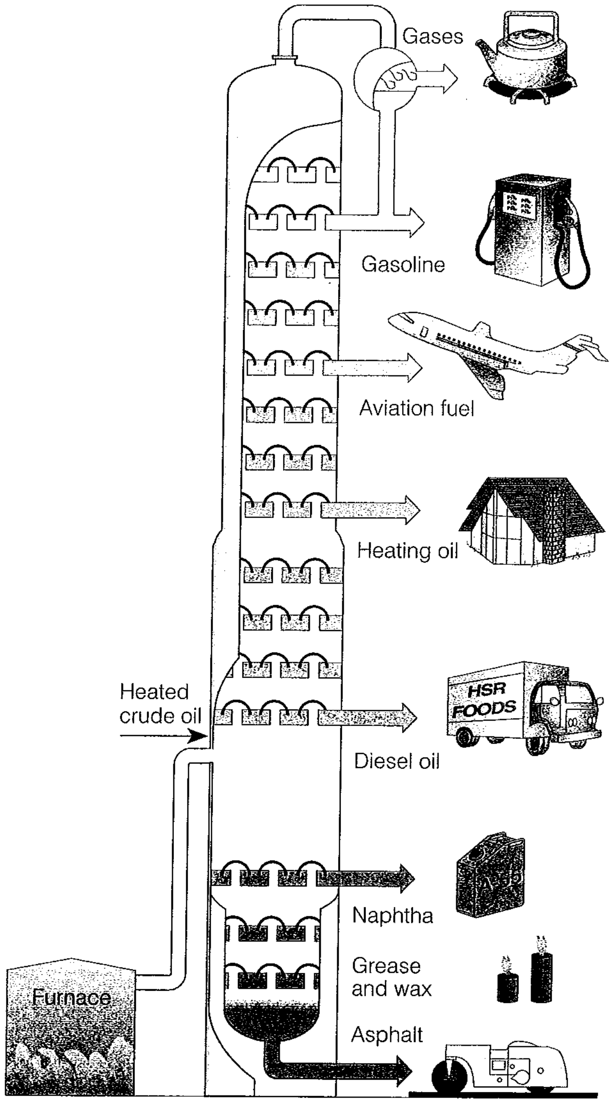


Figure 15-18 Refining crude oil. Based on their boiling points, components are removed at various levels in a giant distillation column. The most volatile components with the lowest boiling points are removed at the top of the column.

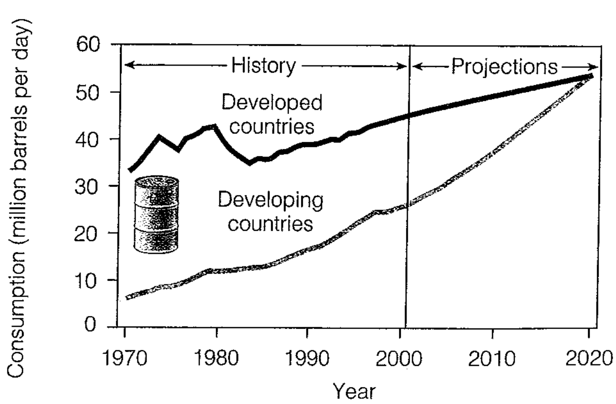


Figure 15-19 Oil consumption in developed and developing regions, 1970–2020. (U.S. Department of Energy)

shows the projected increase in oil consumption in developed and developing countries.

Case Study: Oil Use in the United States Figure 15-20 shows the locations of the major known deposits of fossil fuels (oil, natural gas, and coal) in **(1)** the United States and Canada and **(2)** ocean areas where more crude oil and natural gas might be found. In 2001, about 25% of U.S. domestic oil production came from offshore drilling and 17% from Alaska's North Slope. Currently, about 93% of all U.S. offshore drilling takes place in the Gulf of Mexico, primarily off the coasts of Texas and Louisiana (Figure 15-21).

The United States has only 3% of the world's oil reserves. However, it uses about 26% of the crude oil extracted worldwide each year (68% of it for transportation), mostly because oil is an abundant and convenient fuel to use and is cheap (Figure 15-22). Despite an upsurge in exploration and test drilling, U.S. oil extraction has declined since 1985, and most geologists do not expect a significant increase in domestic supplies (Figure 15-23).

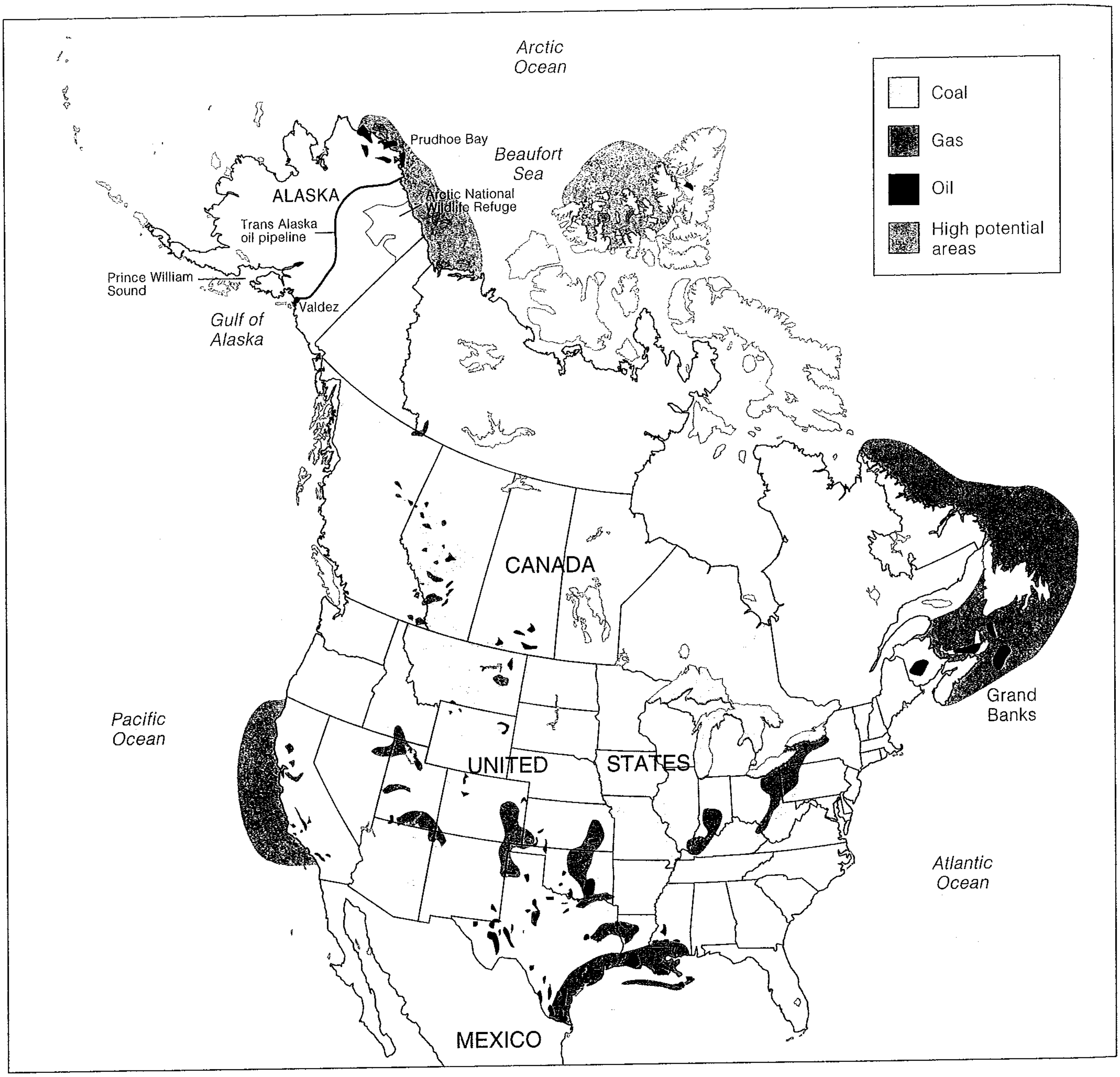


Figure 15-20 Locations of the major known deposits of oil, natural gas, and coal in North America and offshore areas where more crude oil and natural gas might be found. Geologists do not expect to find very much new oil and natural gas in North America. (Data from Council on Environmental Quality and U.S. Geological Survey)

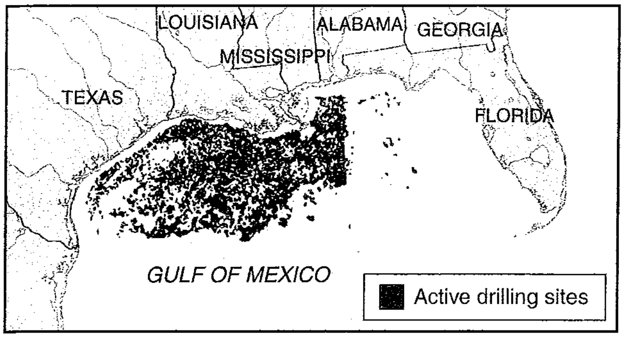


Figure 15-21 Offshore drilling for oil accounts for about 26% of U.S. oil production. About 93% of this oil comes from the Gulf of Mexico where there are 4,000 oil drilling platforms and 53,000 kilometers (33,000 miles) of underwater pipeline. (U.S. Geological Survey)

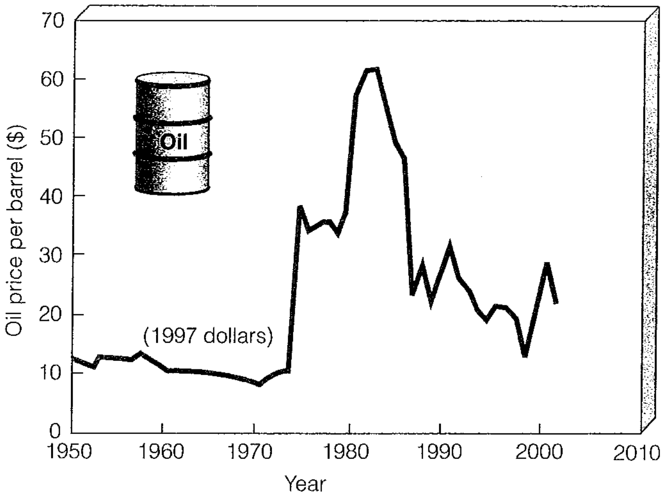


Figure 15-22 Inflation-adjusted price of oil, 1950–2001. When adjusted for inflation, oil costs about the same as it did in 1975. Although low oil prices have stimulated economic growth, they have discouraged **(1)** improvements in energy efficiency and **(2)** increased use of renewable energy resources. (Data from U.S. Department of Energy and Department of Commerce)

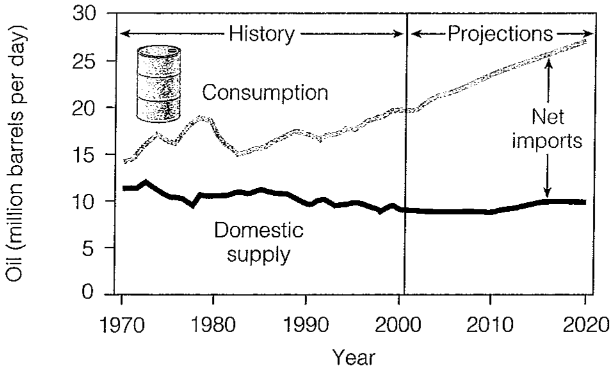


Figure 15-23 U.S. petroleum supply, consumption, and imports, 1970–2000, with projections to 2020. (U.S. Department of Energy)

In 2001, the United States imported about 55% of the oil it used (up from 36% in 1973 during the OPEC oil embargo), mostly because of declining domestic oil reserves, higher production costs for domestic oil than for most sources of imported oil, and increased oil use. About 23% of this oil came from countries in the Persian Gulf, mainly Saudi Arabia (14%), Iraq (7%), and Kuwait (3%); 27% from Canada (15%) and Mexico (12%); and 20% from the OPEC nations of Venezuela (13%) and Nigeria (7%). In 2001, the U.S. bill for oil imports was about $100 billion—an average of $11 million per hour. According to the Department of Energy (DOE), the United States could be importing 61% or more of the oil it uses by 2010 (Figure 15-23).

How Long Will Oil Supplies Last, and What Are the Pros and Cons of Oil? It is important to understand that *we are not currently running out of oil—or natural gas or coal.* Like all nonrenewable resources, the world's oil supplies are eventually expected to decline (Spotlight, p. 359). This will occur gradually when **(1)** affordable supplies of oil decrease as demand exceeds production and prices rise and **(2)** other energy resources become economically and environmentally acceptable substitutes for oil.

Since 1800 the primary energy resource for the world has shifted from wood to coal to oil and is projected to shift to natural gas and perhaps hydrogen by 2100 (Figure 15-16). Each of these shifts has taken at least 50 years so the search for replacements for oil is under way.

In 1999, Mike Bowling, CEO of ARCO Oil said at an energy conference in Houston, Texas, "We are embarked on the beginning of the last days of the Age of Oil." He then went on to discuss the need for the world to shift from a carbon-based to a hydrogen-based energy economy during this century (Figure 15-16).

Production of the world's estimated oil reserves is expected to peak between 2010 and 2030 (Figure 15-24, top, p. 358), and production of estimated U.S. reserves peaked in 1975 (Figure 15-23 and Figure 15-24, bottom).

Identified global reserves of oil should last about 53 years at the current usage rate, and 42 years if usage increases exponentially by about 2% per year. Undiscovered oil that is thought to exist might add another 20–40 years to global oil supplies, probably at higher prices. Thus *known and projected supplies of oil are expected to be 80% depleted within 42–93 years depending on the annual rate of use* (Spotlight, p. 359).

U.S. oil reserves should last about **(1)** 15–24 years (Figure 15-24, bottom) at current consumption rates and **(2)** 10–15 years if consumption increases as projected. However, potential reserves might yield an additional 24 years of production. Thus *U.S. oil supplies are projected to be 80% depleted within 10–48 years, depending on the annual rate of use* (Spotlight, p. 359).

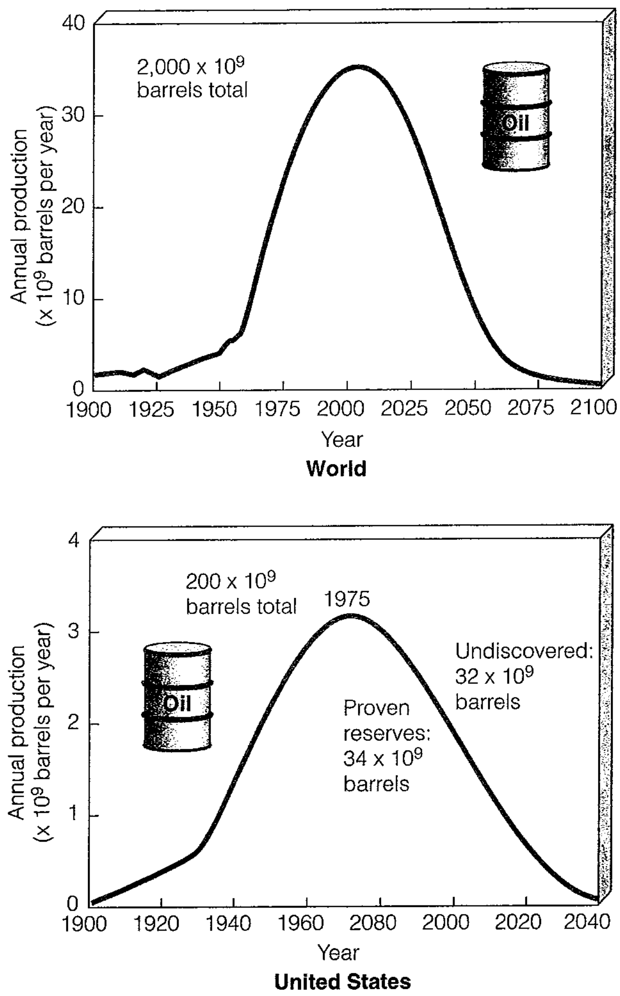


Figure 15-24 Petroleum production curves for the world (top) and the United States (bottom). (Data from U.S. Geological Survey)

Some analysts contend that rising oil prices (when oil consumption exceeds oil production) will stimulate exploration and lead to enough new reserves to meet future demand through the next century or longer. Other analysts argue that such projections ignore the consequences of the high (1–5% per year) exponential growth in oil consumption (Figure 15-19).

Assuming that we use oil at the current rate,

- Saudi Arabia, with the world's largest crude oil reserves, could supply world 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 would met current oil demand for only 1–5 months and U.S. oil demand for 7–24 months (Pro/Con, p. 360).
- Estimated oil reserves on other federal lands on Alaska's North Slope would meet the current world oil demand for 10 days–2 months and U.S. demand for 2–11 months.

In short, to keep using conventional oil at the *current rate*, we must discover global oil reserves equivalent to a new Saudi Arabian supply *every 10 years*.

According to the Bush administration, the United States can reduce its dependence on imported oil and have more control over global oil prices by increasing domestic oil supplies. Most analysts consider this unrealistic because the United States **(1)** has only 3% of the world's oil reserves, **(2)** uses 26% of the world's annual oil production, and **(3)** produces most of its dwindling supply of oil at a high cost of $5–7.50 per barrel compared to production costs of less than $1.50 per barrel in Persian Gulf countries. Thus opening all of the U.S. coastal water, forests, and wild places to drilling would hardly put a dent in world oil prices or meet much of the growing U.S. demand for oil.

Critics also urge the government to force the oil companies to **(1)** stop shorting taxpayers by about $100 million a year on oil royalty payments for oil extracted from public lands and **(2)** pay the several billion dollars they owe in back bills for underpayment of oil royalties. According to sworn government and court evidence, the oil industry shorts taxpayers in annual oil royalty payments by **(1)** falsifying prices, **(2)** using phony bills of sale, and **(3)** deliberately classifying high-quality oil as low-quality oil.

The problem is that the current system allows the oil industry great leeway in deciding **(1)** how to measure the amount of oil removed from public lands and **(2)** how much it should pay the government for the oil. This is like going to a gas station and being allowed to bring your own gauge to measure how much gasoline you pump into your car and then decide how much it is worth.

Burning any carbon-containing fossil fuel releases CO_2 into the atmosphere and thus can promote global warming. Figure 15-25 compares the relative amounts

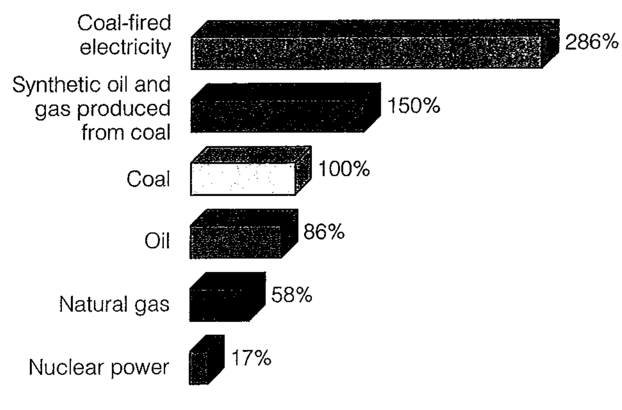


Figure 15-25 CO_2 emissions per unit of energy produced by various fuels, expressed as percentages of emissions produced by coal.

A Brief History of Oil

SPOTLIGHT

In 1859, the world's first commercial oil well was drilled in Titusville, Pennsylvania. This was the beginning of the *Age of Oil*, which now supplies most of the world's energy (Figure 15-12, left). *We are not running out of oil, but many energy experts expect that by* 2059—some 200 years after oil was discovered—we will probably begin shifting to increased dependence on natural gas and possibly hydrogen by 2100 (Figure 15-16).

Here are some milestones in the Age of Oil:

- **1905:** Oil supplies 10% of U.S. energy.
- **1925:** United States produces 71% of the world's oil.
- **1930:** Because of an oil glut, oil sells for 10¢ a barrel.
- **1953:** U.S. oil companies account for about half of the world's oil production and the United States is the world's leading oil exporter.
- **1955:** United States has 20% of the world's estimated oil reserves.
- **1960:** OPEC formed so developing countries, with most of the world's known oil and projected oil supplies, can get a higher price for their oil.
- **1961:** U.S.-proven oil reserves reach a peak and begin to decline.
- **1970:** U.S. oil production peaks and begins to decline.
- **1973:** 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 U.S. because of its support for Israel in the 18-day Yom Kippur War with Egypt and Syria. World oil prices rise sharply (Figure 15-22) and lead to **(1)** double-digit inflation in the United States and many other countries and **(2)** 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:** Iran–Iraq war pushes global oil prices to a historic high (Figure 15-22).
- **1983:** Facing an oil glut, OPEC cuts its oil prices.
- **1985:** U.S. domestic oil production begins to decline. Domestic production is not expected to increase enough to **(1)** affect the global price of oil or **(2)** reduce U.S. dependence on oil imports (unless the demand decreases through a combination of reducing oil waste and shifting to other energy resources).
- **August 1990–June 1991:** United States and its allies fight the Persian Gulf War to protect Saudi Arabia and Kuwait oil supplies after Iraq invades Kuwait.
- **2001:** OPEC has 67% of world oil reserves and produces 40% of the world's oil. U.S. has only 3% of oil reserves, used 26% of the world's oil production, and imported 55% of its oil.
- **2010:** U.S. could be importing at least 61% of the oil it uses as consumption continues to exceed production (Figure 15-23).
- **2010–2030:** Production of oil from the world's estimated oil reserves is expected to peak. Oil prices expected to increase gradually as the demand for oil increasingly exceeds the supply—unless the world decreases demand by **(1)** wasting less energy and **(2)** shifting to other sources of energy.
- **2010–2048:** Domestic U.S. oil supplies projected to be 80% depleted.
- **2042–2083:** Gradual decline in dependence on oil (Figure 15-16) unless the world decreases demand for oil by **(1)** wasting less energy and **(2)** shifting to other sources of energy.

Critical Thinking

What are the three most likely effects of decreased dependence on oil on **(a)** the country where you live, **(b)** your life, and **(c)** the life of any child you might have?

of CO_2 emitted per unit of energy by the major fossil fuels and nuclear power. Currently, burning oil mostly as gasoline and diesel fuel for transportation accounts for 43% of global CO_2 emissions.

Figure 15-26 (p. 361) lists the pros and cons of using conventional crude oil as an energy resource. We are heavily dependent on oil today because it has a high energy content and net energy yield, low cost (as long as supplies exceed demand), and is easy to transport within and between countries.

How Useful Are Heavy Oils from Oil Shale and Tar Sands? *Oil shale* is a fine-grained sedimentary rock (Figure 15-27, left, p. 361) containing a solid combustible organic material called *kerogen.* This material can be distilled from oil shale by heating it in a large container to yield *shale oil* (Figure 15-27, right). Before the thick shale oil can be sent by pipeline to a refinery, it must be **(1)** heated to increase its flow rate and **(2)** processed to remove sulfur, nitrogen, and other impurities.

Some *good news* is that estimated potential global supplies of shale oil are about 240 times larger than estimated global supplies of conventional oil. The *bad news* is most deposits of oil shale are of such a low grade that with current oil prices and technology it

Should Oil and Gas Development Be Allowed in the Arctic National Wildlife Refuge?

PRO/CON

The Arctic National Wildlife Refuge (ANWR) on Alaska's North Slope (Figure 15-20) contains more than one-fifth of all the land in the U.S. National Wildlife Refuge System and has been called the crown jewel of the system. The refuge's coastal plain, its most biologically productive part, is the only stretch of Alaska's arctic coastline not open to oil and gas development.

The Alaskan National Interest Lands Conservation Act of 1980 requires specific authorization from Congress before drilling or other development can take place on this coastal plain. For years, U.S. oil companies have been lobbying Congress to grant them permission to carry out exploratory drilling in the coastal plain because they believe this area might contain oil and natural gas deposits.

Some oil company officials, with the support of the Bush administration and members of the powerful congressional delegation from Alaska (which gets 80% of its general revenue from oil royalties), argue that

- Possible oil and natural gas in ANWR's coastal plain could **(1)** increase U.S. oil and natural gas supplies, **(2)** reduce U.S. dependence on oil imports, and **(3)** lower energy prices.
- They seek to open to oil and gas development on about 800 hectares (2,000 acres) of the coastal plain region.
- They have developed Alaska's Prudhoe Bay oil fields without significant harm to wildlife.
- They can develop this area in an environmentally responsible manner with little lasting environmental impact by using new oil-drilling technology. These advances **(1)** greatly reduce the area covered by gravel drilling pads, buildings, and equipment and **(2)** inject drilling wastes deep into the ground instead of into huge surface pits.

Environmentalists, many biologists, and some economists oppose this proposal. They contend that

- The Department of Interior estimates there is only a 19% chance of finding as much economically recoverable oil in ANWR as the United States consumes every 7–24 months. This will have no effect on oil prices or oil imports because **(1)** the potential supply is too little (no more than 1% of the world's oil for a few years) and **(2)** Persian Gulf oil is much cheaper to produce.
- It would take at least 10 years for any oil or natural gas from the refuge to become available and another 15 years for the field to reach peak production level.
- Improving fuel efficiency is a much faster, cheaper, cleaner, and more secure way to save far more oil. For example, refining the projected peak oil output from ANWR would provide enough gasoline to run only 2% of American cars and light trucks—an amount that could be supplied much more quickly and cheaply from improving the fuel efficiency of these vehicles by only 0.2 kilometers per liter (0.4 miles per gallon). In addition, requiring new SUVs and light trucks used in the United States to have the same average fuel efficiency as new cars would save more oil in 10 years than would ever be produced from the ANWR.
- The 800 hectares (2,000 acres) to be developed would be spread across 35 separate and far-flung drilling sites that would require construction of a network of roads and pipelines, spanning a much larger area.
- Between 1996 and 2001, more than 400 oil spills or oil-related pollution incidents per year have occurred at Alaska's Prudhoe Bay, including the huge 1989 oil spill from the tanker *Exxon Valdez* in Alaska's Prince William Sound. A 2001 study by British Petroleum revealed large and growing maintenance problems and safety valve failures at its giant oil field in Prudhoe Bay.
- The Trans-Alaska Pipeline System and other oil distribution facilities in Alaska are highly vulnerable to sabotage and hard to repair.
- Potential degradation of any portion of this irreplaceable wildlife area is not worth the risk. A 1995 study by the Department of the Interior concluded that long-lasting ecological harm would be caused by oil drilling in the refuge's fragile tundra ecosystem.
- Carrying out any sort of drilling or exploration there will disqualify the refuge from being added to the U.S. wilderness system.
- Even if drilling in the Arctic National Wildlife Refuge posed no environmental threats, it still could not be justified on economic and national security grounds.
- Improvements in slant drilling technology may enable oil companies someday to drill the refuge from outside its boundaries.

Critical Thinking

1. Do you believe oil companies should be allowed to explore and remove oil and natural gas from this wildlife refuge? Why or why not?

2. Use the library or Internet to find out the political fate of this wildlife refuge.

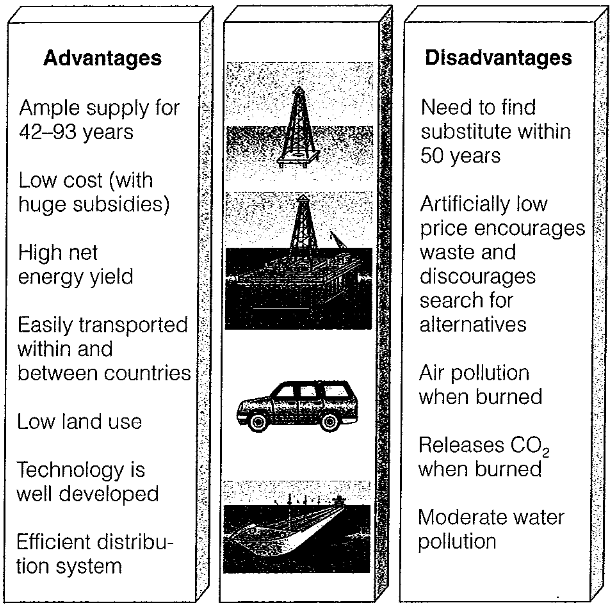


Figure 15-26 Advantages and disadvantages of using conventional oil as an energy resource.

takes more energy and money to mine and convert the kerogen to crude oil than the resulting fuel is worth. However, as oil prices rise it may become economically feasible to exploit reserves of oil shale.

Tar sand (or oil sand) is a mixture of clay, sand, water, and a combustible organic material called *bitumen* (a thick and heavy oil with a high sulfur content). Most deposits are too deep underground to be mined at a profit, but some deposits are close enough to the earth's surface to be removed by surface mining. The bitumen is removed, purified, and chemically upgraded into a synthetic crude oil suitable for refining.

Figure 15-27 Oil shale (left) and the shale oil (right) extracted from it. Big U.S. oil shale projects have been canceled because of excessive cost.

The world's largest known deposits of tar sands, the Athabasca Tar Sands, lie in northern Alberta, Canada. About 10% of these deposits lie close enough to the surface to be surface mined. In Canada, oil has been extracted from tar sands since 1978. Currently, these deposits supply about 21% of Canada's oil needs with prices dropping from $28 per barrel in 1978 to about $11 per barrel today—less than half the current cost of conventional oil.

These deposits could supply all of Canada's projected oil needs for about 33 years at its current consumption rate, but they would last the world only about 2 years. Other large deposits of tar sands are in Utah, Venezuela, Colombia, and Russia. According to the U.S. Department of Energy, exploitation of tar sands could increase the global oil reserves **(1)** by 50% within 25 years if the price of conventional oil rises above $30 per barrel and **(2)** fivefold if the price of oil rises above $40 per barrel.

Figure 15-28 lists the pros and cons of using heavy oil from oil shale and tar sand as energy resources. Because of low net energy yields and the high costs needed to develop and process them, neither of these resources is expected to provide much of the world's energy in the near future. However, as oil prices rise it may become economically feasible to exploit these two sources of heavy oil unless supplies of natural gas and other energy resources cost less to develop and produce fewer harmful environmental effects.

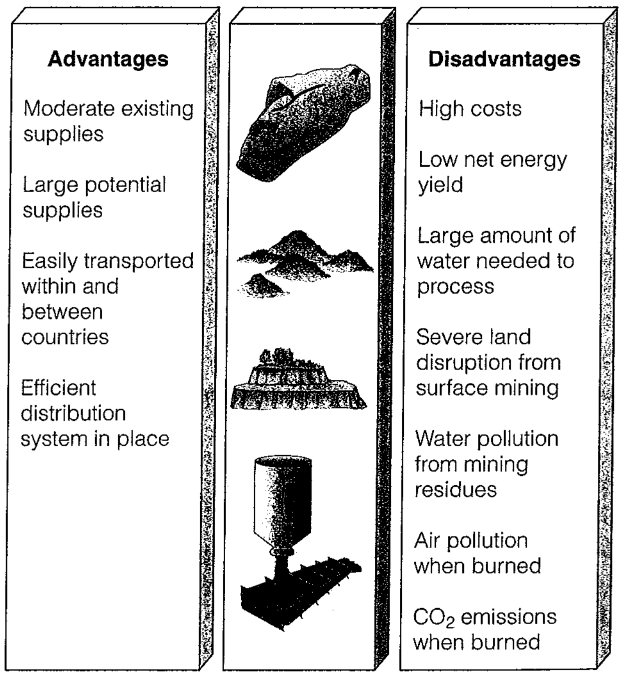


Figure 15-28 Advantages and disadvantages of using heavy oils from oil shale and tar sand as energy resources.

15-7 NATURAL GAS

What Is Natural Gas? In its underground gaseous state, **natural gas** is a mixture of **(1)** 50–90% by volume of methane (CH_4), the simplest hydrocarbon, **(2)** smaller amounts of heavier gaseous hydrocarbons such as ethane (C_2H_6), propane (C_3H_8), and butane (C_4H_{10}), and **(3)** small amounts of highly toxic hydrogen sulfide (H_2S), a by-product of naturally occurring sulfur in the earth.

Conventional natural gas lies above most reservoirs of crude oil and like oil formed from fossil deposits of plants (mostly phytoplankton) and animals buried on the seafloor for millions of years (Figure 15-10). *Unconventional natural gas* is found by itself in other underground sources. One such source is *methane hydrate,* which is composed of small bubbles of natural gas trapped in ice crystals deep under the arctic permafrost and beneath deep-ocean sediments. So far it costs too much to get natural gas from such unconventional sources, but the extraction technology is being developed rapidly.

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 **(1)** dried to remove water vapor, **(2)** cleansed of poisonous hydrogen sulfide and other impurities, and **(3)** pumped into pressurized pipelines for distribution. At a very low temperature of −184°C (−300°F), natural gas can be converted to **liquefied natural gas (LNG).** This highly flammable liquid can then be shipped to other countries in refrigerated tanker ships.

Who Has the World's Natural Gas Supplies? Russia and Kazakhstan have about 42% of the world's natural gas reserves. Other countries with large known natural gas reserves are Iran (15%), Qatar (5%), Saudi Arabia (4%), Algeria (4%), the United States (3%), Nigeria (3%), and Venezuela (3%).

Geologists expect to find more natural gas, especially in unexplored developing countries. Most U.S. natural gas reserves are located in the same places as crude oil (Figures 15-10 and 15-20).

How Long Will Natural Gas Supplies Last? The outlook for natural gas supplies is much better than for oil. *At the current consumption rate, known reserves and undiscovered, potential reserves of conventional natural gas are expected to last the world for 125 years and the United States for 65–80 years.*

Geologists estimate that *conventional* supplies of natural gas, plus *unconventional* supplies available at higher prices, will last at least **(1)** 200 years at the current consumption rate and **(2)** 80 years if usage rates rise 2% per year. Thus *global supplies of conventional and unconventional natural gas should last 205–325 years, depending on how rapidly natural gas is used.*

What Is the Future of Natural Gas? Figure 15-29 lists the pros and cons of natural gas as an energy resource. Energy experts project greatly increased global use of natural gas during this century (Figure 15-16) because of its abundant supply, low production costs, and lower pollution and CO_2 per unit of energy than other fossil fuels.

In *combined-cycle natural gas systems,* natural gas is burned in combustion turbines, which are essentially giant jet engines bolted to the ground. This system can **(1)** produce electricity more efficiently than burning coal or oil or using nuclear power, **(2)** produce much less CO_2 (Figure 15-25) and smog-causing nitrogen oxides per unit of energy than coal-burning power plants, and **(3)** provide backup power for solar energy and wind power systems. Smaller combined-cycle natural gas units being developed could supply the heat and electricity needs of an apartment or office building.

In 2001, natural gas was burned to provide 53% of the heat in U.S. homes and 16% of the country's electricity. By 2020, the DOE projects that natural gas will be burned to produce 32% of the country's electricity. However, this will require considerable expansion of the country's natural gas pipeline distribution system.

A major problem is that U.S. production of natural gas has been declining for a long time, and experts do

Advantages	Disadvantages
Ample supplies (125 years)	Nonrenewable resource
High net energy yield	Releases CO_2 when burned
Low cost (with huge subsidies)	Methane (a greenhouse gas) can leak from pipelines
Less air pollution than other fossil fuels	Difficult to transfer from one country to another
Lower CO_2 emissions than other fossil fuels	Shipped across ocean as highly explosive LNG
Moderate environmental impact	Sometimes burned off and wasted at wells because of low price
Easily transported by pipeline	Requires pipelines
Low land use	
Good fuel for fuel cells and gas turbines	

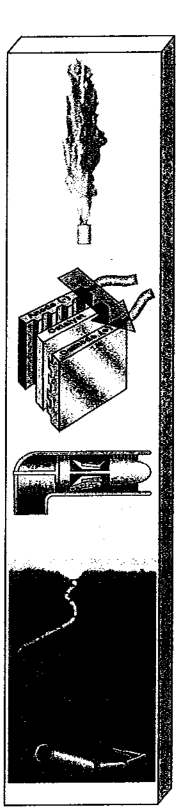


Figure 15-29 Advantages and disadvantages of using conventional natural gas as an energy resource.

not believe this situation will be reversed. More natural gas could be obtained from Canada and Alaska's North Slope. But the pipeline for bringing this gas to the lower 48 states—assuming that it is ever built—will take 7–10 years to complete. More liquified natural gas could be imported by ship. But this requires cooling the gas to −184°C (−300°F), shipping it in special tankers and building special LNG receiving terminals.

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 solar energy and hydrogen over the next 50 years (Figures 15-15 and 15-16).

15-8 COAL

What Is Coal, and How Is It Extracted and Processed? Coal is a solid fossil fuel formed in several stages as 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 15-30). Coal contains **(1)** small amounts of sulfur (released into the atmosphere as SO_2 when coal is burned) and **(2)** trace amounts of mercury and radioactive materials (also released into the atmosphere when coal is burned). Anthracite, about 98% carbon, is the most desirable type of coal because of its high heat content and low sulfur content (Figure 15-30). However, because it takes much longer to form, it is less common and therefore more expensive than other types of coal.

Some coal is extracted underground (Figure 15-5) by miners working in tunnels and shafts. Such mining is one of the world's most dangerous occupations because of accidents and black lung disease (caused by prolonged inhalation of coal dust particles). When coal lies close to the earth's surface, it is extracted by *area strip mining* (Figure 15-4c) on flat terrain and *contour strip mining* (Figure 15-4d) on hilly or mountainous terrain. In some cases, entire mountaintops are removed to expose seams of coal under the mountains.

After coal is removed, it is transported (usually by train) to a processing plant, where it is broken up, crushed, and then washed to remove impurities. The coal is then dried and shipped (again usually by train) to users, mostly power plants and industrial plants.

How Is Coal Used, and Where Are the Largest Supplies? Coal provides about 21% of the world's commercial energy (22% in the United States). It is burned to generate 62% of the world's electricity (52% in the United States) and make 75% of its steel.

About 66% of the world's proven coal reserves and 85% of the estimated undiscovered coal deposits are located in the United States (with 24% of global reserves), Russia, China, and India. Half of global coal consumption takes place in the United States (26%) and China (24%).

How Long Will Coal Supplies Last? Coal is the world's most abundant fossil fuel. *Identified* world reserves of coal should last at least **(1)** 225 years at the current usage rate and **(2)** 65 years if usage rises 2% per year. The world's *unidentified* coal reserves are projected to last about **(1)** 900 years at the current consumption rate and **(2)** 149 years if the usage rate increases 2% per year. Thus *identified and unidentified supplies of coal could last the world for 214–1,125 years, depending on the rate of usage.*

China, with 11% of the world's reserves, has enough coal to last 300 years at its current rate of consumption. Identified U.S. coal reserves should also last about 300 years at the current consumption rate, and unidentified U.S. coal resources could extend those supplies for perhaps 100 years, at a higher cost.

What Is the Future of Coal? Figure 15-31 (p. 364) lists the pros and cons of using coal as an energy resource. Although coal is very abundant it has the highest environmental impact of any

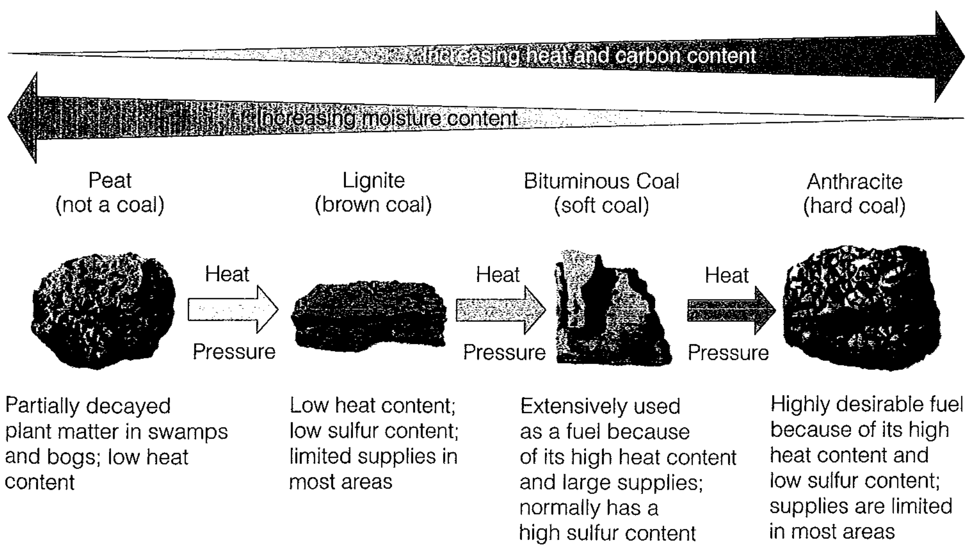


Figure 15-30 Stages in coal formation over millions of years. Peat is a soil material made of moist, partially decomposed organic matter. Lignite and bituminous coal are sedimentary rocks, whereas anthracite is a metamorphic rock (Figure 10-8, p. 210).

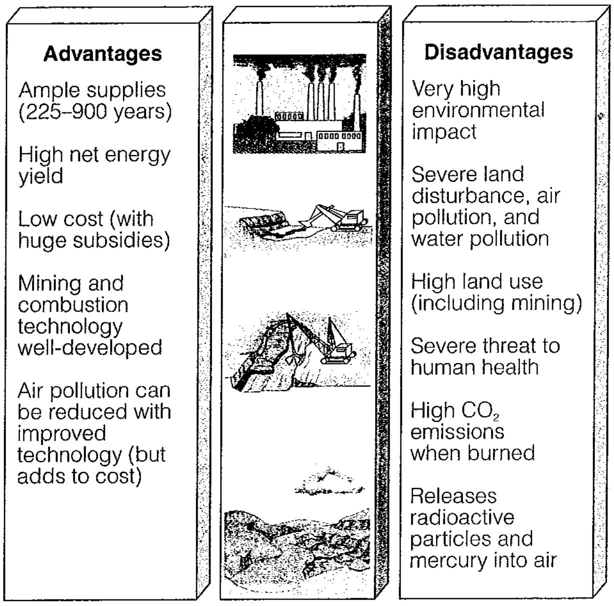


Figure 15-31 Advantages and disadvantages of using coal as an energy resource.

fossil fuel from **(1)** land disturbance (Figures 15-4 and 15-6), **(2)** air pollution, **(3)** CO_2 emissions (Figure 15-25, accounting for about 36% of the world's annual emissions), **(4)** release of particles of toxic mercury when burned, **(5)** release of thousands of times more radioactive particles into the atmosphere per unit of energy produced than a normally operating nuclear power plant, and **(6)** water pollution (Figure 15-7). Each year in the United States alone, air pollutants from coal burning **(1)** kill thousands of people (with estimates ranging from 65,000 to 200,000), **(2)** cause at least 50,000 cases of respiratory disease, and **(3)** result in several billion dollars of property damage.

Coal is also difficult and expensive to transport very far because it is heavy and bulky. Thus most coal is used fairly close to where it is mined—with only about 10% of the coal produced exported compared to 60% of the oil produced.

Energy costs from a new coal power plant in the United States are low (around 4¢ per kilowatt-hour*), mostly because of large governmental subsidies. However, according to a 2001 study by Stanford University researchers, this cost doubles to around 8¢ per kilowatt-hour if health and environmental costs are included. In contrast, the average cost of wind energy in the United States—including its environmental and health costs—is about 4¢ per kilowatt-hour.

New ways, such as *fluidized-bed combustion* (Figure 15-32), and *coal gasification* have been developed to burn coal more cleanly and efficiently. With large government subsidies, these technologies may be phased in over the next several decades. But they do little to reduce CO_2 emissions that are considered the major culprit in projected global warming and a major drawback of coal as an energy resource.

In 2001, the Bush administration **(1)** scuttled U.S. participation in the Kyoto treaty designed to reduce global CO_2 emissions and later proposed that business voluntarily reduce their CO_2 emissions (a policy strongly opposed by supporters of the Kyoto treaty throughout much of the world), **(2)** proposed a $2 billion government subsidy program for research into cleaner coal technologies (such as fluidized-bed combustion and coal gasification), **(3)** supported exemption of older and highly polluting U.S. coal burning plants from the latest Clean Air Act standards for another 10 years, **(4)** allowed already heavily subsidized coal-fired power plants to qualify for government renewable energy subsidies merely by mixing small amounts of biomass such as wood chips or agriculture waste with the coal they burn (called an obvious scam by environmentalists), and **(5)** asked Congress to reduce government research and development subsidies for energy efficiency by 30% and renewable energy by 40%.

What Are the Pros and Cons of Converting Solid Coal into Gaseous and Liquid Fuels? Solid coal can be converted into **synthetic natural gas (SNG)** by **coal gasification** (Figure 15-33) or into a liquid fuel such

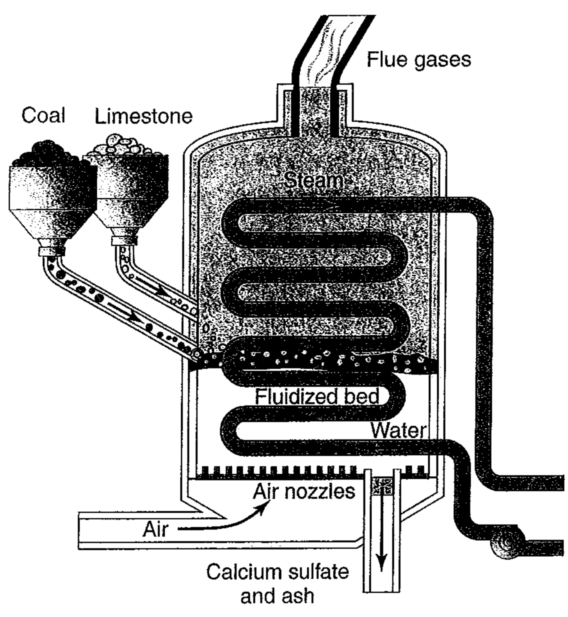


Figure 15-32 *Fluidized-bed coal combustion.* A stream of hot air is blown into a boiler to suspend a mixture of powdered coal and crushed limestone. This method **(1)** removes most of the sulfur dioxide, **(2)** sharply reduces emissions of nitrogen oxides, and **(3)** burns the coal more efficiently and cheaply than conventional combustion methods. However, it does little to reduce CO_2 emissions.

*A *kilowatt-hour* (kwh), a basic unit of electricity, is equal to the energy consumed by a 100-watt lightbulb burning for 10 hours.

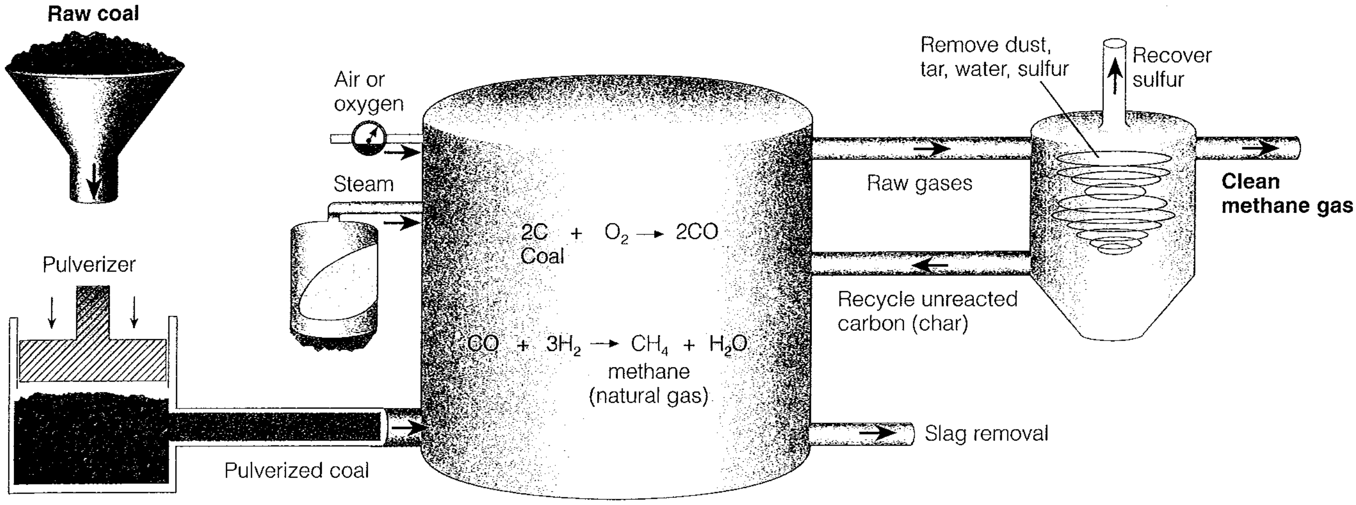


Figure 15-33 *Coal gasification.* Generalized view of one method for converting solid coal into synthetic natural gas (methane).

as methanol or synthetic gasoline by **coal liquefaction.** Figure 15-34 lists the pros and cons of using these *synfuels* produced from coal.

Unless it receives huge government subsidies, most analysts expect coal gasification to play only a minor role as an energy resource in the next 20–50 years mostly because

- **(1)** CO_2 emissions from gasifying coal and burning the gas are higher than those from burning the coal itself or natural gas (Figure 15-25) and **(2)** using wind to produce electricity emits virtually no CO_2 or other pollutants.

- Construction and operating costs per kilowatt are much higher than producing electricity from natural gas, conventional coal, and wind.

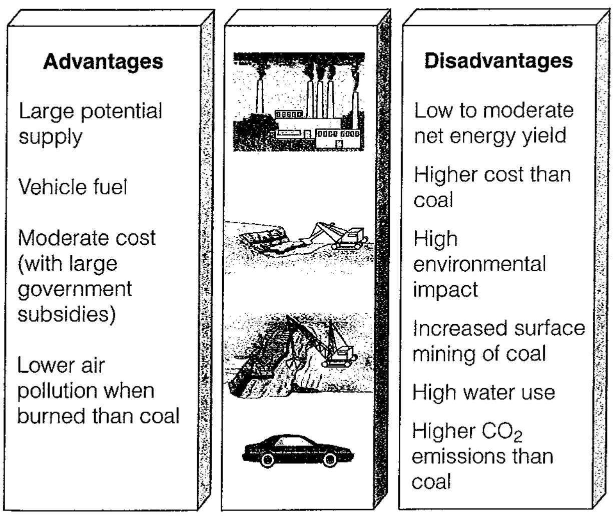


Figure 15-34 Advantages and disadvantages of using synthetic natural gas (SNG) and liquid synfuels produced from coal.

15-9 NUCLEAR ENERGY

How Does a Nuclear Fission Reactor Work? To evaluate the pros and cons of nuclear power, we must know how a conventional nuclear power plant and its accompanying nuclear fuel cycle work. In a nuclear fission chain reaction, neutrons split the nuclei of atoms such as uranium-235 (Figure 3-17, p. 58) and plutonium-239 and release energy mostly as high-temperature heat. In the reactor of a nuclear power plant, the rate of fission is controlled and the heat generated is used to produce high-pressure steam, which spins turbines that generate electricity.

Light-water reactors (LWRs) like the one diagrammed in Figure 15-35 (p. 366) produce about 85% of the world's nuclear-generated electricity (100% in the United States). An LWR has the following key parts:

- *Core,* containing 35,000–70,000 long, thin fuel rods, each packed with fuel pellets. Each pellet is about one-third the size of a cigarette and contains the energy equivalent of 0.9 metric tons (1 ton) of coal.

- *Uranium oxide fuel,* consisting of about 97% nonfissionable uranium-238 and 3% fissionable uranium-235. To create a suitable fuel, the concentration of uranium-235 in the ore is increased (enriched) from 0.7% (its natural concentration in uranium ore) to 3% by removing some of the uranium-238.

- *Control rods,* which are moved in and out of the reactor core to absorb neutrons and thus regulate the rate of fission and amount of power the reactor produces.

- *Moderator,* which slows down the neutrons emitted by the fission process so the chain reaction can be kept going. This is a material such as **(1)** liquid water (75% of the world's reactors, called *pressurized water reactors,*

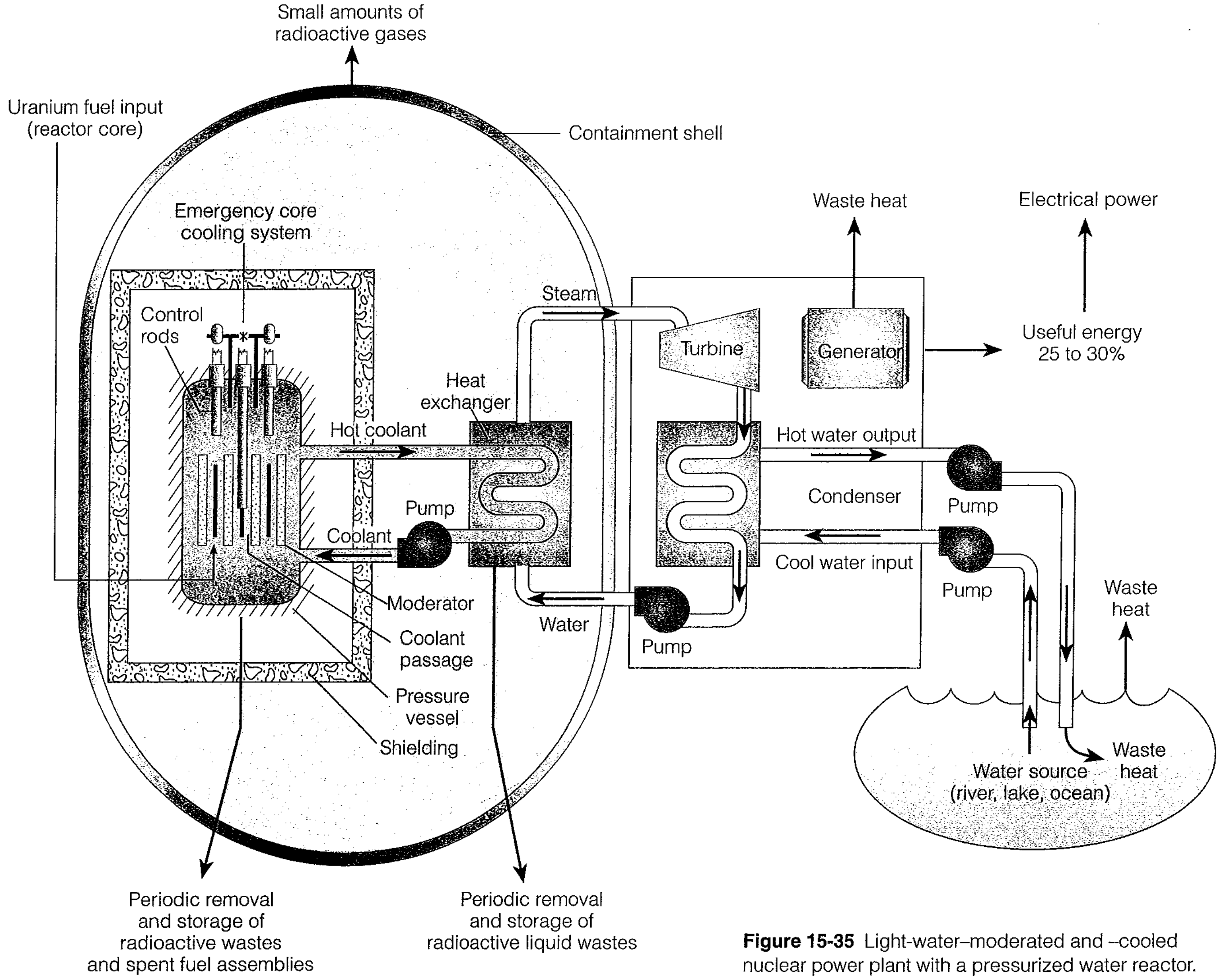


Figure 15-35 Light-water–moderated and –cooled nuclear power plant with a pressurized water reactor.

Figure 15-35), **(2)** solid graphite (20% of reactors), or **(3)** heavy water (D_2O; 5% of reactors). Graphite-moderated reactors can also produce fissionable plutonium-239 for nuclear weapons.

- *Coolant,* usually water, which circulates through the reactor's core to remove heat (to keep fuel rods and other materials from melting) and produce steam for generating electricity.

Nuclear power plants, each with one or more reactors, are only one part of the nuclear fuel cycle (Figure 15-36). *In evaluating the safety and economic feasibility of nuclear power, energy experts and economists caution us to look at this entire cycle, not just the nuclear plant itself.*

What Happened to Nuclear Power? Studies indicate that U.S. utility companies began developing nuclear power plants in the late 1950s for three reasons:

- The Atomic Energy Commission (which had the conflicting roles of promoting and regulating nuclear power) promised utility executives that nuclear power would produce electricity at a much lower cost than coal and other alternatives. Indeed, President Dwight D. Eisenhower declared in a 1953 speech that nuclear power would be "too cheap to meter."
- The government paid about one-fourth of the cost of building the first group of commercial reactors and guaranteed there would be no cost overruns.
- After insurance companies refused to insure nuclear power, Congress passed the Price-Anderson Act to protect the U.S. nuclear industry and utilities from significant liability to the general public in case of accidents.*

In the 1950s, researchers predicted that by the year 2000, at least 1,800 nuclear power plants would supply

*This act limits the nuclear industry's liability in case of an accident to $9.5 billion, with the government (taxpayers) paying most of this. According to the U.S. Nuclear Regulatory Commission, a worst-case accident would cause more than $300 billion in damages.

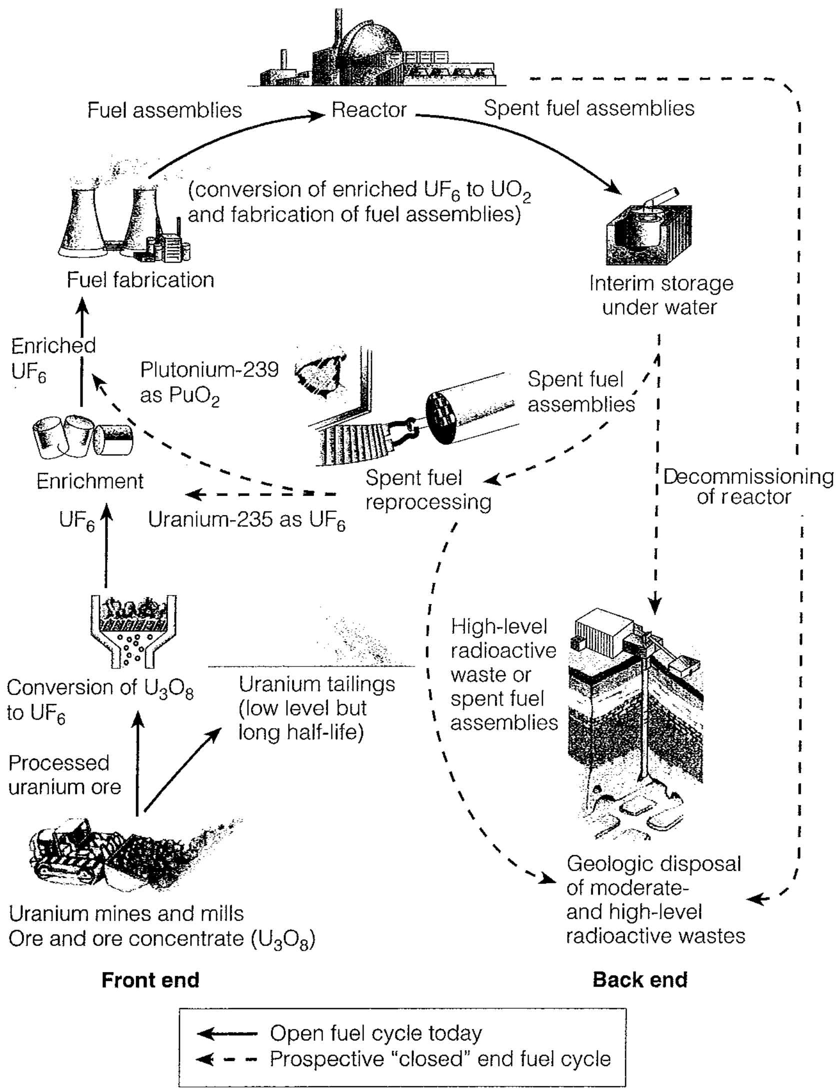


Figure 15-36 The nuclear fuel cycle.

21% of the world's commercial energy (25% in the United States) and most of the world's electricity.

However, after almost 50 years of development, enormous government subsidies, and an investment of $2 trillion, these goals have not been met. Instead,

- By 2001, 436 commercial nuclear reactors in 32 countries were producing 6% of the world's commercial energy and 16% of its electricity.
- Since 1989, the growth in electricity production from nuclear power has essentially leveled off (Figure 15-14, left). The U.S. Department of Energy expect its capacity to decline between 2003 and 2020 as existing plants wear out and are retired (Figure 15-14 and Figure 15-15).
- Germany (with 31% of its electricity from nuclear power) and Sweden (with 39%) plan to phase out nuclear power over the next 20–30 years.
- Nuclear power is losing some of its appeal in France, Japan, and China—all once solid supporters of its increased use. France and China (which has 3 reactors and is building 10 more) have put a moratorium on building new nuclear plants, and France has cut its long-term target for building new reactors in half.
- 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 2001, there were 103 licensed and operating commercial nuclear power reactors in 31 states—most in the eastern half of the country (Figure 15-37, p. 368). These reactors generated about 20% of the country's electricity and 8% of its total energy use. This percentage is expected to decline over the next two decades as existing plants wear out and are retired (decommissioned) (Figure 15-15).

According to energy analysts and economists, the major reasons for the failure of nuclear power to grow as projected are **(1)** multibillion-dollar construction cost overruns, **(2)** stricter government safety regulations, **(3)** higher operating costs and more malfunctions than expected, **(4)** poor management, **(5)** public concerns about safety after the 1986 Chernobyl (p. 338) and 1979 Three Mile Island (Pennsylvania) accidents, and **(6)** investor concerns about the economic feasibility of nuclear power.

What Are the Pros and Cons of Nuclear Power? Figure 15-38 (p. 369) lists the major advantages and disadvantages of nuclear power. Using nuclear power to produce electricity has some important advantages over coal-burning power plants (Figure 15-39, p. 369).

How Safe Are Nuclear Power Plants and Other Nuclear Facilities? *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 accidents at the Chernobyl (p. 338) nuclear power plant in Ukraine and the Three Mile Island plant in Pennsylvania have taught us.

The U.S. Nuclear Regulatory Commission (NRC) estimates there is a 15–45% chance of a complete core meltdown at a U.S. reactor during the next 20 years.

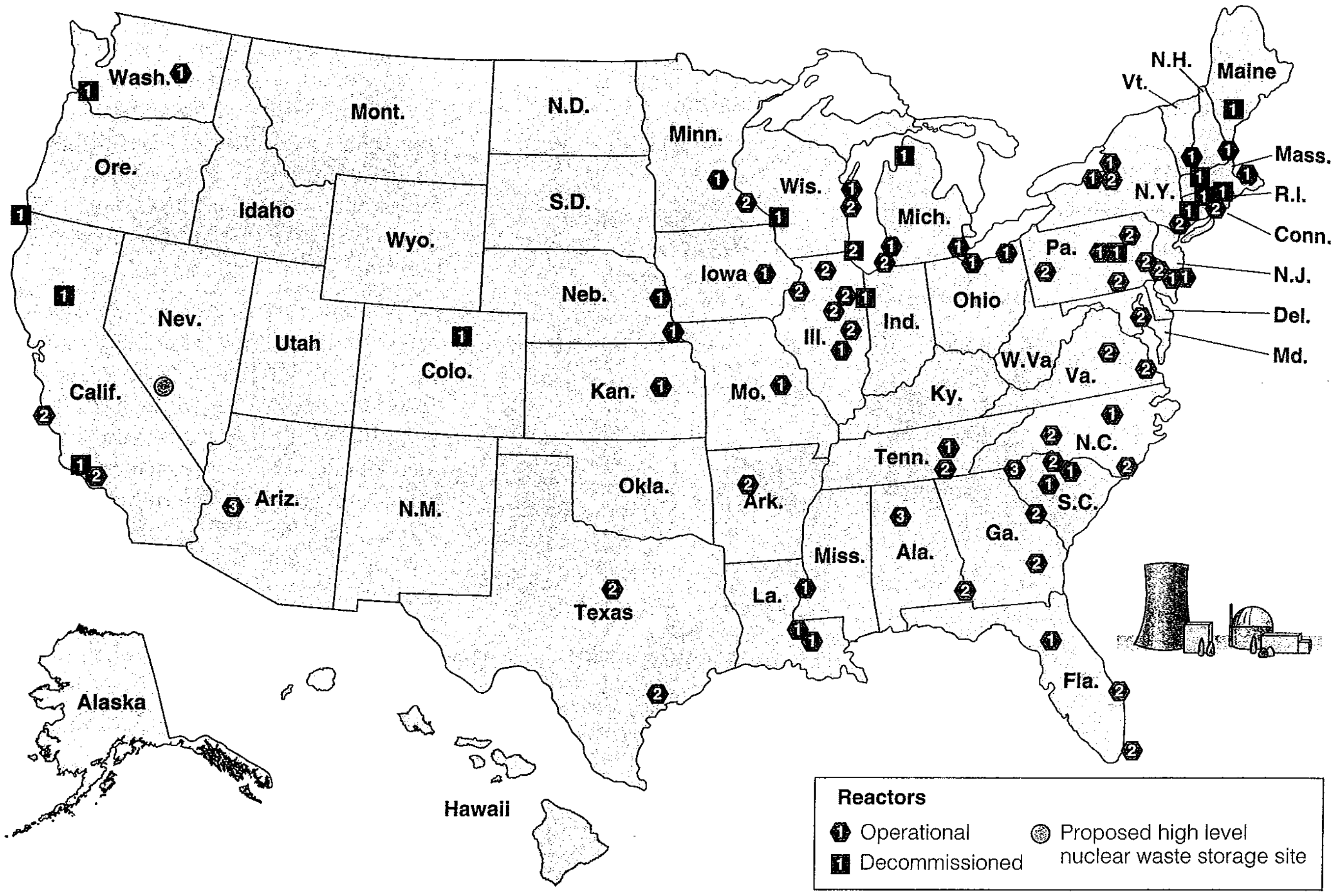


Figure 15-37 Locations in the United States of **(1)** its 103 operating commercial nuclear power plant reactors, **(2)** 13 decommissioned reactors (with highly radioactive used fuel stored on site), and **(3)** the recently approved site in Nevada for storage of highly radioactive used fuel from operating and decommissioned nuclear reactors. Numbers refer to the number of reactors at each nuclear power plant site. (Data from U.S. Nuclear Regulatory Commission and U.S. Department of Energy)

The NRC also found that 39 U.S. reactors have an 80% chance of failure in the containment shell from a meltdown or an explosion of gases inside the containment structures.

In 2002, the NRC found that boric acid, produced as a byproduct in a pressurized water nuclear reactor, had eaten two cavities in the heavy stainless steel device that covers the fuel rods in a reactor near Toledo, Ohio. This head is used for corrosion protection and to help contain the enormous pressure that builds up inside the reactor. The NRC is investigating whether the corrosion could weaken the head enough for it to shatter and create a serious *loss of coolant* accident at the Toledo reactor and 69 similar reactors in the United States.

Another concern is that 27 of 57 operating nuclear power plants in the United States failed mock, ground-based terrorist security tests made by the Nuclear Regulatory Commission prior to 1998. The NRC contends that the security weaknesses revealed by these tests have been corrected. But many nuclear power analysts are unconvinced and note that the government has stopped staging mock attacks on nuclear plants that reveal security shortcomings.

The 2001 destruction of New York City's two World Trade Center towers by terrorist attacks has suggested that a similar attack by a large plane loaded with fuel could **(1)** break open a reactor's containment shell (Figure 15-35) and **(2)** set off a reactor meltdown that could create a major radioactive disaster (p. 338). Nuclear officials believe that U.S. plants could survive such an attack. But a 2002 study by the Nuclear Control Institute found that the plants were not designed to withstand the crash of a large jet traveling at the impact speed of the two highjacked airliners that hit the World Trade Center.

According to 2002 report by Rep. Ed Markey (D-Mass) based on analysis of NRC data,

- Guards at U.S. nuclear plants are underpaid, undertrained, and incapable of repelling a serious ground attack by terrorists.

- Twenty-one U.S. nuclear reactors are within 8 kilometers (5 miles) of an airport.
- A small or large aircraft or ground attack that cut off electrical power to a reactor could cause a core meltdown within about two hours without crashing into the reactor.

In 2002, David Freeman, President Jimmy Carter's energy advisor and CEO of several major power companies, warned that "The danger of penetration into a nuclear reactor—which is difficult but not impossible—is so horrendous that we've got to put out of our minds the building of any more nuclear power plants."

Throughout the world, nuclear scientists and government officials urge the shutdown of 35 poorly designed and poorly operated nuclear reactors in some republics of the former Soviet Union and in eastern Europe. This is unlikely without economic aid from the world's developed countries.

In the United States, there is widespread public distrust in the ability of the NRC and the Department of Energy (DOE) to enforce nuclear safety in commercial (NRC) and military (DOE) nuclear facilities. Congressional hearings in 1987 uncovered evidence that high-level NRC staff members **(1)** destroyed documents and obstructed investigations of criminal wrongdoing by utilities, **(2)** suggested ways utilities could evade commission regulations, and **(3)** provided utilities and their contractors with advance notice of so-called surprise inspections. In 1996, George Galatis, a respected senior nuclear engineer, said, "I believe in nuclear power but after seeing the NRC in action I'm convinced a serious accident is not just likely, but inevitable. . . . They're asleep at the wheel."

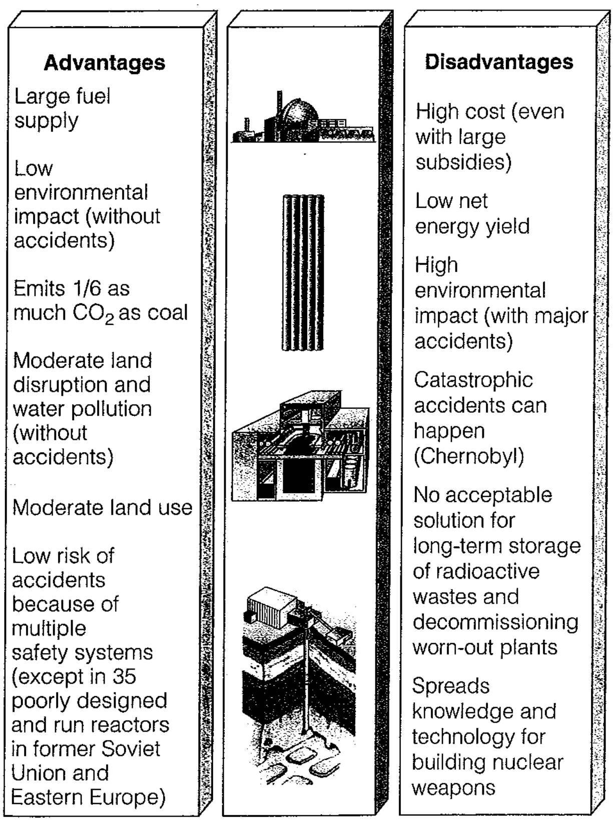


Figure 15-38 Advantages and disadvantages of using nuclear power to produce electricity. This evaluation includes the entire nuclear fuel cycle (Figure 15-36).

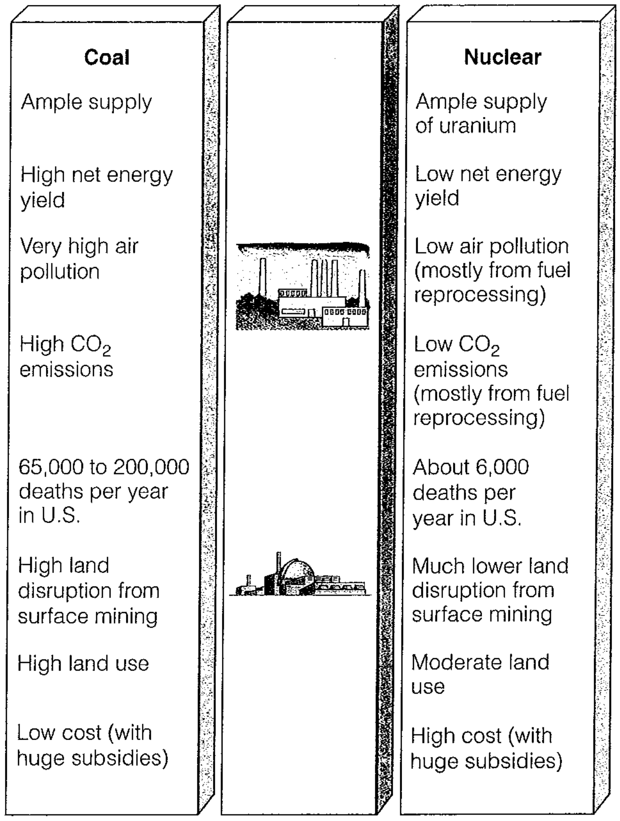


Figure 15-39 Comparison of the risks of using nuclear power and coal-burning plants to produce electricity.

The nuclear power industry claims that nuclear power plants in the United States have not killed anyone and cause far less environmental harm than coal-burning plants (Figure 15-39). However, according to U.S. National Academy of Sciences estimates, U.S. nuclear plants cause 6,000 premature deaths and 3,700 serious genetic defects each year. If correct, this annual death toll is much smaller than the 65,000–200,000 deaths per year caused by coal-burning plants in the United States. But critics point out that the estimated annual deaths from both of these types of plants are unacceptable, given the availability of much less harmful alternatives such as combined-cycle natural gas turbines and wind power and eventually solar cells and hydrogen.

What Do We Do with Low-Level Radioactive Waste? Each part of the nuclear fuel cycle (Figure 15-36) produces low-level and high-level solid, liquid, and gaseous radioactive wastes with various half-lives (Table 3-2, p. 56). Wastes classified as *low-level radioactive wastes* give off small amounts of ionizing radiation and must be stored safely for 100–500 years before decaying to safe levels.

From the 1940s to 1970, most low-level radioactive waste produced in the United States (and most other countries) was put into steel drums and dumped into the ocean; the United Kingdom and Pakistan still dispose of their low-level radioactive wastes in this way.

Today, low-level waste materials from commercial nuclear power plants, hospitals, universities, industries, and other producers in the United States are put in steel drums and shipped to the two remaining regional landfills run by federal and state governments. Attempts to build new regional dumps for low-level radioactive waste using improved technology (Figure 15-40) have met with fierce public opposition.

What Should We Do with High-Level Radioactive Waste? *High-level radioactive wastes* give off large amounts of ionizing radiation (Figure 3-13, p. 56) for a short time and small amounts for a long time. Such wastes must be stored safely for at least 10,000 years and about 240,000 years if plutonium-239 (with a half-life of 24,000 years) is not removed by reprocessing (Figure 15-36).

Most high-level radioactive wastes are **(1)** spent fuel rods from commercial nuclear power plants (now being stored in barrels immersed in pools of water or in dry-storage casks at plant sites; Figure 15-37) and **(2)** an assortment of wastes from plants that produce plutonium and tritium for nuclear weapons. There is concern that some of the pools and casks used to stored spent fuel rods at various nuclear power plants are vulnerable to sabotage by terrorist attacks (Case Study, p. 371).

After 50 years of research, scientists still do not agree on whether there is any safe method of storing these wastes. Some scientists believe the long-term safe storage or disposal of high-level radioactive wastes is technically possible. Others disagree, pointing out it is impossible to demonstrate that any method will work for the 10,000–240,000 years of fail-safe storage needed for such wastes.

Here are some of the proposed methods and their possible drawbacks:

- *Bury it deep underground* (Figure 15-41, p. 372, and Case Study, p. 374). This favored strategy is under study by all countries producing nuclear waste. In 2001, the U.S. National Academy of Sciences concluded that the geological repository option is the only scientifically credible long-term solution for safely isolating such wastes. However, according to an earlier 1990 report by the U.S. National Academy of Sciences, "Use of geological information to pretend to be able to make very accurate predictions of long-term site behavior is scientifically unsound."
- *Shoot it into space or into the sun.* Costs would be very high, and a launch accident, like the explosion of the space shuttle *Challenger*, could disperse high-level radioactive wastes over large areas of the earth's surface. This strategy has been abandoned for now.
- *Bury it under the Antarctic ice sheet or the Greenland ice cap.* The long-term stability of the ice sheets is not known. They could be destabilized by heat from the

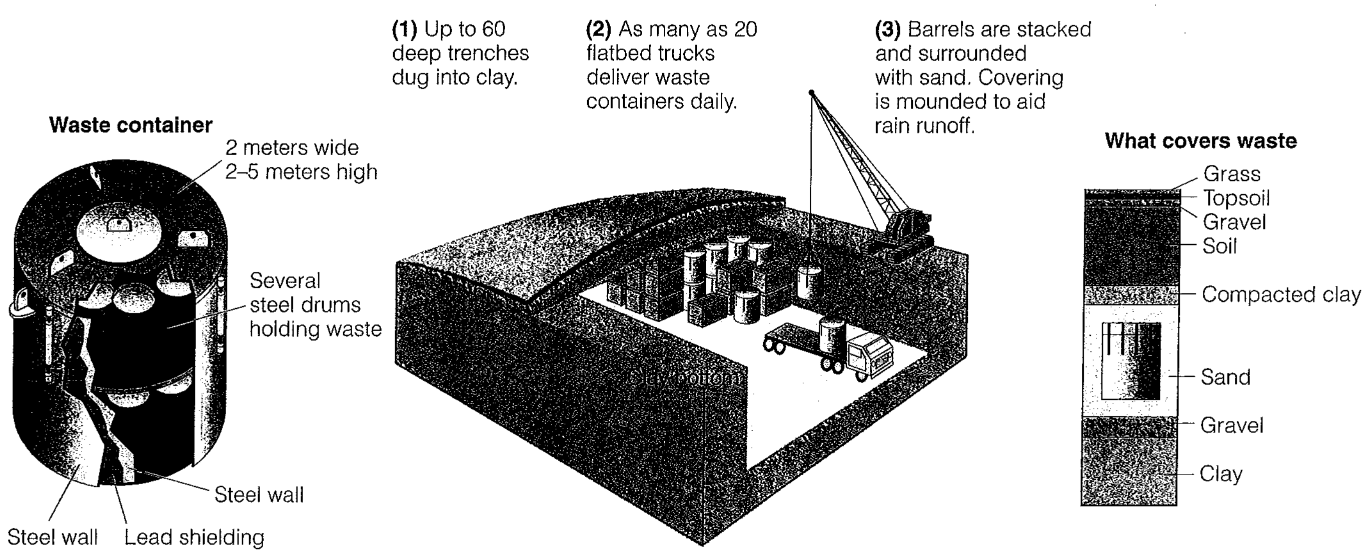


Figure 15-40 Proposed design of a state-of-the-art *low-level radioactive waste landfill.* According to the EPA, all landfills eventually leak. The best designed landfills may not leak for several decades, after which the companies running them would no longer be liable for leaks and problems. Then any problems would be passed on to taxpayers and future generations. (Data from U.S. Atomic Industrial Forum)

How Safe Are Radioactive Wastes Stored at Nuclear Power Plants?

CASE STUDY

Highly radioactive spent-fuel rods are stored underwater and in dry casks at many U.S. nuclear power plants (Figure 15-37). Spent-fuel pools typically hold 5–10 times more long-lived radioactivity than the radioactive core inside a plant's reactor. Unlike the reactor core, many of these pools and dry casks have little protective cover.

At about one-third of U.S. power plants the reactor is in one building and the spent-fuel pool is in a separate building with a thin corrugated metal roof and walls. At the rest of the plants, the spent-fuel pool is in a concrete building attached to the reactor building.

The NRC acknowledges that with enough explosives a spent-fuel pool or a spent-fuel dry cask can be penetrated. If a spent-pool loses its water or a dry storage cask is ruptured, the exposed and thermally hot fuel rods can catch fire, release large amounts of radioactive materials into the atmosphere, and render large areas uninhabitable for generations. These pools have back-up cooling systems to help prevent such a fire but these systems could malfunction or be destroyed by a terrorist attack.

A 1997 report prepared by the Brookhaven National Laboratory for the Nuclear Regulatory Commission estimated that a severe fire in a typical spent-fuel pool could **(1)** render about 487 square kilometers (188 square miles) uninhabitable for decades, **(2)** cause as many as 28,000 premature deaths from radiation-induced cancers, and **(3)** result in up to $59 billion in damages.

According to a 2002 study by the Institute for Resource and Security Studies,

- Ground-level sabotage or a small plane could penetrate or blow up the corrugated buildings that house spent-fuel pools and perhaps destroy the back-up cooling system. This could start a fire and release radioactive material into the environment. After the September 11 attacks in 2001, the Federal Aviation Administration banned small planes from flying over most U.S. nuclear plants, but these restrictions were lifted on November 6, 2001.
- A similar accident could be caused by the crash of a larger plane or jet into a concrete building used to store spent fuel rods.
- An accident or sabotage that released all of radioactive material in the spent-fuel rods in the storage pool at the Millstone Unit 3 reactor in Connecticut would **(1)** put five times more radioactive material into the atmosphere than the 1986 Chernobyl accident (p. 338) and **(2)** make about 145,000 square kilometers (55,900 square miles)—more than the area of New York state—uninhabitable for at least 30 years because of radioactive contamination.
- If all of the fuel in two spent-fuel storage pools at the Sharon Harris Nuclear Plant near Raleigh, North Carolina, burned, enough radioactive material would be released to contaminate an area larger than the entire state for at least 30 years.
- At some nuclear plants, some of the spent-fuel rods have been removed from the pool and stored in lead-lined concrete casks. An explosion or airplane crash could split open the casks and allow the rods to catch fire. However, these casks are probably less vulnerable to such an attack than spent fuel stored in pools.
- Spent fuel is stored away from nuclear plants at some sites which are sometimes guarded by only one person.
- Decommissioned nuclear power plants (Figure 15-37) may be even more vulnerable to sabotage because they store large amounts of spent fuel and have fewer security personnel than operating plants.

Nuclear power officials, **(1)** consider such events to be highly unlikely worst-case scenarios, **(2)** question some of the estimates, **(3)** consider nuclear power facilities to be very safe from such attacks, and **(4)** consider this a reason to store all spent-fuel rods in a national underground storage site as soon as possible.

Other analysts contend that using trucks or trains to make thousands of shipments of spent fuel across much of the United States to a central storage facility in Nevada (Figure 15-37) makes the shipments highly vulnerable to sabotage.

Critical Thinking

You are in charge of security for nuclear power plants and nuclear waste materials stored at such plants in the United States. How would you protect against release of radioactive materials by sabotage from **(1)** spent fuel rods stored in pools or casks at plant sites or **(2)** transportation of dry casks to a central waste storage facility?

wastes, and retrieving the wastes would be difficult or impossible if the method failed. This strategy is prohibited by international law.

- *Dump it into descending subduction zones in the deep ocean* (Figure 10-6, middle, p. 208). However, **(1)** wastes eventually might be spewed out somewhere else by volcanic activity, **(2)** containers might leak and contaminate the ocean before being carried downward, and **(3)** retrieval would be impossible if the method did not work. This strategy is prohibited by international law.
- *Bury it in thick deposits of mud on the deep-ocean floor in areas that tests show have been geologically stable for 65 million years.* The waste containers eventually would corrode and release their radioactive contents. This approach is prohibited by international law.

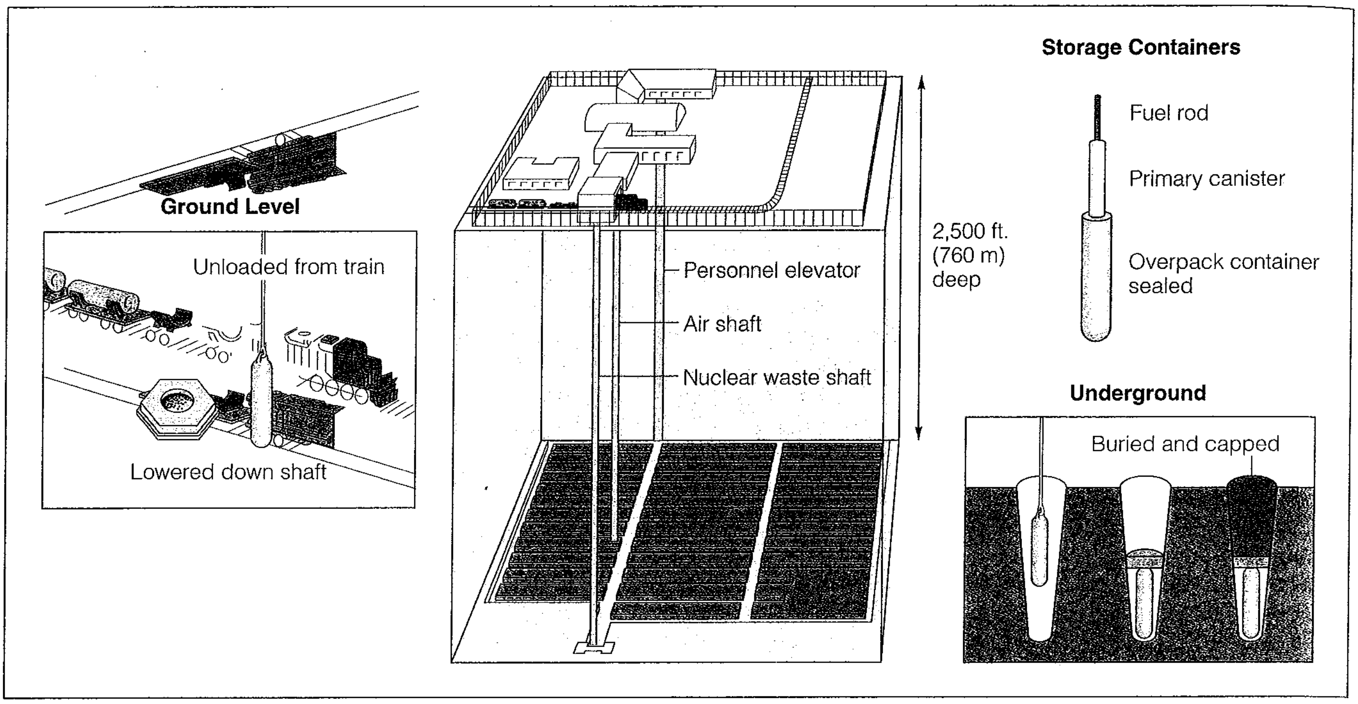


Figure 15-41 Proposed general design for deep underground permanent storage of high-level radioactive wastes from commercial nuclear power plants in the United States. (U.S. Department of Energy)

- *Change it into harmless, or less harmful, isotopes.* Currently no way exists to do this. Even if a method was developed, **(1)** costs probably would be very high, and **(2)** the resulting toxic materials and low-level (but very long-lived) radioactive wastes would still need to be disposed of safely.

How Widespread Are Contaminated Radioactive Sites? In 1992, the EPA estimated that as many as 45,000 sites in the United States may be contaminated with radioactive materials, 20,000 of them belonging to the DOE and the Department of Defense. Since 1992, the DOE has spent $60 billion on cleanups and estimates that the cleanup will cost taxpayers another $200 billion over the next 70 years (with some analysts estimating a cost of $400–900 billion). According to a 2000 DOE report, more than two-thirds of 144 highly contaminated sites used to produce nuclear weapons will never be completely cleaned up and will have to be protected and monitored for centuries. Some critics question spending so much money on a problem ranked by scientific advisers to the EPA as a low-risk ecological problem and not among the top high-risk human health problems (Figure 11-15, p. 246).

The radioactive contamination situation in the United States pales in comparison to the post–Cold War legacy of nuclear waste and contamination in the republics of the former Soviet Union. Land in various parts of the former Soviet Union is dotted with **(1)** areas severely contaminated by nuclear accidents, **(2)** 25 operating nuclear power plants with flawed and unsafe designs, **(3)** nuclear waste dump sites, **(4)** radioactive waste-processing plants, **(5)** contaminated nuclear test sites, and **(6)** coastal waters where nuclear wastes and retired nuclear-powered submarines were dumped.

A 1957 explosion of a nuclear waste storage tank at Mayak, a plutonium production facility in southern Russia, spewed 2.5 times as much radiation into the atmosphere as the Chernobyl accident. Because of radioactive contamination, **(1)** no one can live within about 2,600 square kilometers (1,000 square miles) of the surrounding area, and **(2)** nearby Lake Karachay (which was a dump site for the facility's radioactive wastes between 1949 and 1967) is so radioactive that standing on its shores for about an hour would be fatal.

What Can We Do with Worn-Out Nuclear Plants? After approximately 15–40 years of operation, a nuclear reactor becomes dangerously contaminated with radioactive materials, and many of its parts are worn out. Unless the plant's life can be extended by expensive renovation, it must be *decommissioned* or retired (the last step in the nuclear fuel cycle, Figure 15-36) This can be done by **(1)** dismantling it and storing its large volume of highly radioactive materials in high-level nuclear waste storage facilities which currently do not exist (Figure 15-41), **(2)** putting up a physical barrier and setting up full-time security for 30–100 years before the plant is dismantled, or **(3)** en-closing the entire plant in a tomb that must last for several thousand years.

At least 228 large commercial reactors worldwide (20 in the United States) are scheduled for retirement by 2012. By 2033, all U.S. reactors will have to be retired, based on the life of their original 40-year operating licenses.

Decommissioning costs for large commercial U.S. reactors range from $300–500 million depending on the site. U.S. utilities have been setting aside funds for decommissioning more than 100 reactors, but to date these funds fall far short of the estimated costs. If sufficient funds are not available for decommissioning, the balance of the costs could be passed along to ratepayers and taxpayers.

Some utility companies and the Bush administration have proposed extending the life of current reactors to 50–60 years. By 2000, five U.S. nuclear reactors had obtained 20-year license extensions, and 30 other plants may apply for such extensions by 2005. Opponents contend that extending the life of reactors could increase the risk of nuclear accidents in aging reactors.

What Is the Connection Between Nuclear Reactors and the Spread of Nuclear Weapons? Currently, 60 countries—1 of every 3 in the world—have nuclear weapons or the knowledge and ability to build them. Information and fuel needed to build these nuclear weapons have come mostly from the research and commercial nuclear reactors that the United States and 14 other countries have been giving away and selling in the international marketplace for decades.

Some *good news* is that between 1986 and 2000, the number of nuclear warheads held by the world's five largest nuclear powers declined by 55% and further declines are expected by 2012. The *bad news* is that **(1)** this still leaves enough nuclear weapons to kill everyone in the world at least 30 times and **(2)** greatly increases the amount of bomb-grade plutonium-239 removed from retired nuclear warheads that must be kept secure from use in nuclear weapons.

What Is the Threat From "Dirty" Radioactive Bombs? There is growing concern, especially after the September 11, 2001, terrorist attack in New York City, about threats from explosions of so-called *"dirty" radioactive bombs.* A *dirty bomb* consists of an explosive such as dynamite mixed with some form of radioactive material that is not difficult or expensive to obtain. Such a conventional bomb with a small amount of radioactive material (that often would fit in a coffee cup) is fairly easy to assemble.

Examples of radioactive materials for use in such bombs include **(1)** *irridium-192* (half-life 74 days), **(2)** *cobalt-60* (half-life 5.3 years), **(3)** *cesium-137* (half-life 30 years), and **(4)** *americium-241* (half-life 433 years).

Such materials can be stolen from thousands of loosely guarded and difficult to protect sources or bought on the black market. Sources include **(1)** hospitals, using radioisotopes to treat cancer, diagnose various diseases, and sterilize some types of medical equipment, **(2)** university research labs, **(3)** industries using radioisotopes to detect leaks in underground pipes, irradiate food, examine mail and other materials, and detect flaws in pipe welds, boilers, and concrete, and **(4)** smoke detectors (americium-241).

Detonating a dirty bomb at street level or on a rooftop does not cause a nuclear blast. But depending on the amount of TNT used it could

- Kill a dozen to 1,000 people in densely populated cities from the blast and subsequent cancers.
- Spread radioactive material over several to hundreds of blocks.
- Contaminate buildings and soil in the affected area for up to 10 times the half-life of the isotope used unless areas are cleaned up at great expense (billions of dollars). Cleanup would involve sandblasting or demolishing buildings, digging up asphalt and sidewalks, removing topsoil, and transporting the radioactive material to safe storage sites.
- Require long-term evacuation of affected areas, shut down businesses and government agencies, and discourage businesses and agencies from reopening in such areas.
- Cause intense psychological terror and panic—the primary objective of terrorism.

According to simulations by the Federation of American Scientists and the Center for Strategic and International Studies (a Washington think tank), detonating a dirty bomb

- In Manhattan using a small piece of cobalt-60 stolen from a food irradiation plant would spread contamination over about 300 city blocks, kill up to 1,000 people, and render much of New York City uninhabitable for decades.
- Using 4.5 kilograms (10 pounds) of TNT and containing a pea-size piece of cesium-137 (which is fairly easy to steal from medical equipment) on the mall in Washington, D.C., near the National Gallery of Art would kill about 20 people and contaminate a 1.6-kilometer (1-mile) swath of land that includes the U.S. Capitol, Supreme Court, and Library of Congress buildings.
- Containing 1,800 kilograms (4,000 pounds) of TNT and a small amount of cesium-137 in an empty school bus on Washington's mall would kill several hundred people, contaminate a much larger area, shut down official Washington, close nearby airports, cause immense panic and long-term economic damage, and

Underground Storage of High-Level Radioactive Wastes in the United States

CASE STUDY

In 1985, the U.S. Department of Energy (DOE) announced plans to build a repository for underground storage of high-level radioactive wastes from commercial nuclear reactors on federal land in the Yucca Mountain desert region, 160 kilometers (100 miles) northwest of Las Vegas, Nevada (green dot in Figure 15-37).

By 2002, the federal government had spent about $7 billion evaluating the site as a permanent underground repository. The proposed facility (Figure 15-41), expected to cost at least $58 billion to build (financed by a tax on nuclear power), is scheduled to open by 2010.

Some scientists argue that it should never be allowed to open, mostly because **(1)** rock fractures may allow water to leak into the site and corrode radioactive waste storage casks, **(2)** an active volcano is located nearby, and **(3)** there are 32 active earthquake fault lines running through the site—an unusually high number. 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."

However, in 1999 and 2002, scientists working on the site released a report finding nothing to disqualify the site as a safe place to store high-level radioactive wastes.

Other scientists and energy analysts disagree with this assessment. For example,

- According to a December 2002 report by Congress's General Accounting Office, any decision to officially approve the site would be "premature" because 293 scientific questions about safety have not been answered.
- A January 2002 review by the Nuclear Waste Technical Review Board pointed to numerous scientific uncertainties in basic assumptions and computer models used to project how well the site should protect the wastes. The Board said these uncertainties make it impossible to ensure that the wastes would remain safe for the thousands of years necessary to protect the environment and human health.

Despite such concerns, in January 2002, the U.S. Energy Secretary **(1)** found that the site is scientifically sound and **(2)** recommended to President Bush and Congress that that highly radioactive waste from the nation's nuclear power plants be deposited under Nevada's Yucca Mountain far from population centers. The Secretary cited this as an important way to help protect wastes now stored at nuclear plants from possible terrorist attacks (Case Study, p. 371). However, according to the DOE, the Yucca Mountain site will not solve the nuclear waste storage problem unless its size is doubled. By 2036 when the site is expected to be filled, there will be about as much nuclear waste stored at plant sites as exists today.

This decision raised a storm of protest from Nevada elected officials and citizens (80% of them opposed to the site) and others concerned about the safety of this approach. Critics point out that shipping high-level nuclear waste in casks to the Nevada site by truck or rail from nuclear plants scattered throughout 39 states in the United States (Figure 15-37) poses a much greater security risk than beefing up protection of the wastes at nuclear power plants.

However, nuclear plant officials want to pass on more of their onsite waste storage and security costs to taxpayers. Critics say that this and the desire to restart a de-

probably require the President to declare martial law in Washington.

Since 1986, the NRC has recorded 1,700 incidents in the United States in which radioactive materials used by industrial, medical, or research facilities have been stolen or lost—an average of about 100 incidents per year. Since 1991, the International Atomic Energy Agency (IAEA) has detected 671 incidents of illicit trafficking in dirty-bomb materials.

Can Nuclear Power Reduce Dependence on Oil? Proponents of nuclear power in the United States claim it will help reduce dependence on imported oil. However, other analysts point out that use of nuclear power has little effect on U.S. oil use because **(1)** oil produces only about 2–3% of the electricity in the United States, and **(2)** the major use for oil is in transportation, which would not be affected by increasing nuclear power production.

Can We Afford Nuclear Power? Experience has shown that nuclear power is an expensive way to boil water to produce electricity, even when huge government subsidies partially shield it from free-market competition with other energy sources.

Costs rose dramatically in the 1970s and 1980s because of unanticipated safety problems and stricter regulations after the Three Mile Island and Chernobyl accidents. Estimates of the costs of producing nuclear power vary widely because of different variables used to make such calculations. However, current costs are typically 2–3 times higher per kilowatt-hour than for using coal, natural gas, and wind power to produce electricity.

In 1995, the World Bank said that nuclear power is too costly and risky. *Forbes* business magazine has called the failure of the U.S. nuclear power program "the largest managerial disaster in U.S. business history, involving $1 trillion in wasted investment and $10 billion in direct losses to stockholders."

clining industry are major reasons why the nuclear power industry donated $13.8 million to candidates from both parties for federal office in the 2000 elections and spent another $25 million in 2000 to lobby elected officials.

Drawing lines between each reactor site and the Nevada site reveals that at least 56,000 truckloads (or rail car loads) of nuclear waste will be traveling over much of the United States, especially in the eastern half where most nuclear reactors are found (Figure 15-37). This amounts to an average of six shipments a day for 30 years. According to the DOE, possible highway and rail routes will pass through 109 cities of 100,000 population or more—with Atlanta, Georgia, bearing much of the waste traffic.*

Nevada's Senator Harry Reid, calls a truck carrying waste to the site "a dirty nuclear bomb on 18 wheels waiting to happen." Others call such trucks or rail cars "rolling Chernobyls."

The DOE estimates that a nuclear waste shipment accident could cost $20–50 billion in damages and cleanup costs and lead to an unknown number of premature cancer deaths from exposure to radioactivity. The DOE and nuclear power proponents say the risks of an accident are negligible. Opponents believe the risks are underestimated, especially after the events of September 11, 2001.

Opponents contend that *the waste site should not be opened because it greatly decreases national security* by **(1)** making about 56,000 shipments of wastes over much of the country for 30 years in trucks and rail cars that are extremely difficult to protect and **(2)** still having about the same amount of wastes stored in pools and casks at the country's nuclear plant sites because the plants will be producing new wastes about as fast as the old wastes are shipped out.

The National Academy of Sciences and collaboration between Harvard and University of Tokyo scientists urge the government to slow down and rethink the nuclear waste storage process. They contend that storing spent-fuel rods in dry-storage casks in well-protected buildings at nuclear plant sites is an adequate solution for a number of decades in terms of safety and security. This would buy time **(1)** to carry out more research on this complex problem and **(2)** to evaluate other sites that might be more acceptable scientifically and politically.

Despite many objections from scientists and citizens, during the summer of 2002, Congress approved Yucca Mountain as the official site for the country's commercial nuclear wastes.

*Anyone can go to the website, www.mapscience.org, type in an address, and view a map showing how close that area is to probable nuclear waste transportation routes to be used for at least 36 years after the site opens.

Critical Thinking

1. What do you believe should be done with high-level radioactive wastes? Explain.

2. Would you favor having high-level nuclear waste transported by truck or train through the area where you live to the Yucca Mountain site? Explain. Use the website in the footnote (left) to see how close such shipments might come to the area where you live for at least 36 years after the site is opened.

In recent years, the operating cost of many U.S. nuclear power plants has dropped mostly because of less downtime. However, environmentalists and economists point out that the cost of nuclear power must be based on the entire nuclear fuel cycle, not merely the operating cost of individual plants. This includes mining and producing nuclear fuel, nuclear waste disposal, and decommissioning of worn-out plants. When these costs are included, the overall cost of nuclear power is very high (even with huge government subsidies) compared to many other energy alternatives.

Can We Develop New and Safer Types of Nuclear Reactors? The U.S. nuclear industry hopes to persuade the federal government and utility companies to build hundreds of smaller second-generation plants using standardized designs, which they claim are safer and can be built more 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. 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."

One proposed new design is called a *pebble bed modular reactor* (*PBMR*) (Figure 15-42, p. 376). About 10,000 uranium oxide fuel particles, each the size of a pencil point, are encapsulated into a microsphere ball (Figure 15-42). Designers say the balls are meltdown-proof. To make this reactor affordable, they contend there is no need for an emergency core cooling system and an airtight containment dome used in light-water reactors (Figure 15-35). Germany, South Africa, and China have built small-scale pebble bed reactors to help evaluate and improve this technology.

Edwin Lyman and several other nuclear physicists oppose the pebble bed reactor. They contend that

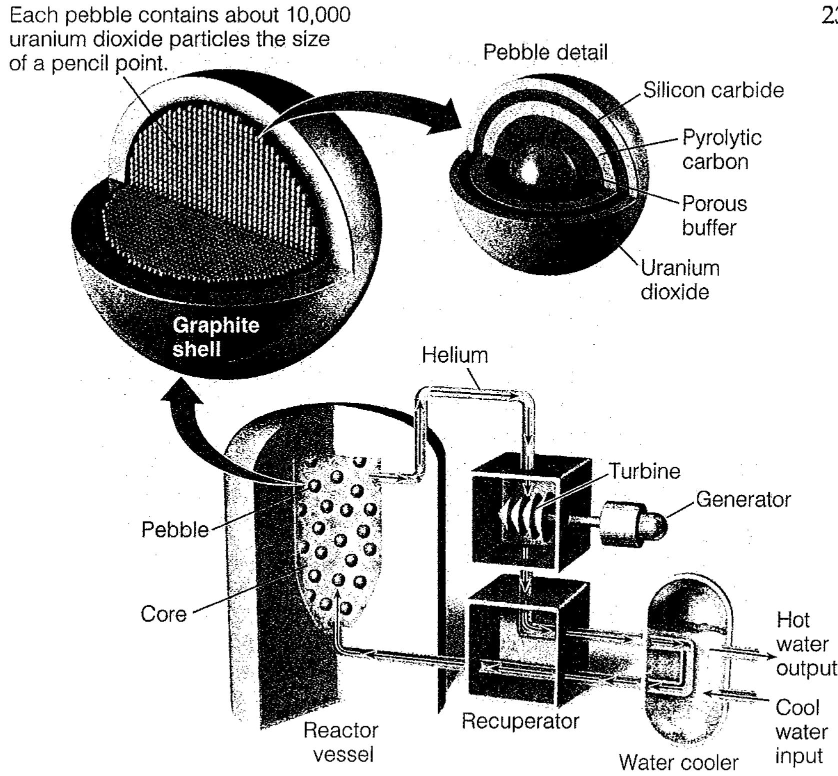


Figure 15-42 *Pebble bed modular reactor (PBMR).* This is one of several new and smaller reactor designs that some nuclear engineers say should improve the safety of nuclear power and reduce its costs. This design reduces chances of a runaway chain reaction by encapsulating uranium fuels in tiny heat-resistant ceramic spheres instead of packing large numbers of fuel pellets into long metal rods.

- A crack in the reactor could expose the graphite protective coatings to air. At a high temperature the graphite could burn and release massive amounts of radioactivity—similar to what happened at Chernobyl (Figure 15-1).

- It is an old design that has been rejected in England and Germany for safety reasons.

- This technology would create about 10 times the volume of high-level radioactive waste per unit of electricity as a conventional nuclear reactor.

- A lack of a containment shell would make it easier for terrorists to enter such reactor facilities and **(1)** steal nuclear fuel material that could be used to make nuclear weapons or **(2)** blow it up to release large amounts of radioactivity.

- This approach does not eliminate the expense and hazards of long-term radioactive waste storage and power plant decommissioning.

Is Breeder Nuclear Fission a Feasible Alternative? 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. Because breeders would use more than 99% of the uranium in ore deposits, the world's known uranium reserves would last at least 1,000 years, and perhaps several thousand years.

However, if the safety system of a breeder reactor fails, the reactor could lose some of its liquid sodium coolant, which ignites when exposed to air and reacts explosively if it comes into contact with water. This could cause 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 particulate matter. Leaks of flammable liquid sodium can also cause fires, which has happened with all experimental breeder reactors built so far.

In addition, existing experimental breeder reactors produce plutonium so slowly, it would take 100–200 years for them to produce enough to fuel a significant number of other breeder reactors. In 1994, the United States ended government-supported research for breeder technology after providing about $9 billion in research and development funding.

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, other countries have abandoned their plans to build full-size commercial breeder reactors.

Is Nuclear Fusion a Feasible Alternative? 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 3-18, p. 58).

After 50 years of research and huge expenditures of mostly government funds, controlled nuclear fusion is still in the laboratory stage. None of the approaches tested so far have produced more energy than they use.

In 1989, two chemists claimed to have achieved deuterium–deuterium (D–D) nuclear fusion at room temperature using a simple apparatus, but subsequent experiments have not substantiated their claim. Some scientists still hope to develop low-temperature nuclear fusion, but most nuclear physicists are skeptical that it can be done.

If researchers can eventually get more energy out of nuclear fusion than they put in, the next step would be to build a small fusion reactor and then scale it up to commercial size. This is an extremely difficult engineering problem. The estimated cost of a commercial fusion reactor is several times that of a comparable conventional fission reactor.

Proponents contend that with greatly increased federal funding, a commercial nuclear fusion power plant might be built by 2030. However, many energy experts do not expect nuclear fusion to be a significant energy source until 2100, if then.

What Should Be the Future of Nuclear Power in the United States? Since 1948, nuclear energy (fission and fusion) has received about 58% of all federal energy research and development funds in the United States (compared to 22% for fossil fuels, 11% for renewable energy, and 8% for energy efficiency and conservation). Some analysts call for **(1)** phasing out all or most government subsides and tax breaks for nuclear power and **(2)** using such funds to subsidize and accelerate the development of promising newer energy technologies.

To these analysts, nuclear power is a complex, expensive, inflexible, and centralized way to produce electricity that is too vulnerable to terrorist attack. They believe it is a technology whose time has passed in a world where electricity will increasingly be provided by small, decentralized, easily expandable power plants such as natural gas turbines, wind turbines, arrays of solar cells, and fuel cells. According to investors and World Bank economic analysts, nuclear power simply cannot compete in today's increasingly open and unregulated energy market.

Proponents of nuclear power, including the Bush administration, argue that governments should continue funding research and development and pilot plant testing of potentially safer and cheaper reactor designs (Figure 15-42) along with breeder fission and nuclear fusion. They argue that we need to keep these nuclear options available for use in the future if natural gas turbines, improved energy efficiency, hydrogen-powered fuel cells, wind turbines, and other renewable energy options fail to **(1)** keep up with electricity demands and **(2)** reduce CO_2 emissions to acceptable levels.

The question is not whether there will be an energy revolution. It is already under way. The only questions are how rapidly it will unfold, whether it will move fast enough to prevent climate change from getting out of hand, and who will benefit most from the transition.

LESTER R. BROWN

REVIEW QUESTIONS

1. Define the boldfaced terms in this chapter.

2. Describe the causes and effects of the 1986 Chernobyl nuclear power plant accident in the former Soviet Union.

3. Distinguish between a *mineral resource* and an *ore*. Distinguish among *identified resources, undiscovered resources, reserves,* and *other resources*. List two factors that can increase the reserves of a mineral resource.

4. Describe how mineral deposits are formed by *magma flows, hydrothermal processes, sedimentary sorting, precipitation,* and *rock weathering*.

5. List seven ways mining companies find mineral deposits. Distinguish among **(a)** *overburden* and *spoils*, **(b)** *surface mining* and *subsurface mining*, and **(c)** *open-pit mining, dredging, area strip mining,* and *contour strip mining*.

6. List five major environmental impacts of mining, processing, and using mineral resources. Describe the life cycle of a metal resource. Distinguish among *ore mineral, gangue,* and *tailings*. What is *smelting*, and what are its major environmental impacts? What three environmental limits are associated with extracting and using mineral resources?

7. What is *economic depletion* of a mineral resource? When such depletion occurs, what five choices are available? Distinguish between *depletion time* and the *reserve-to-production ratio* for a mineral resource. How can the estimated depletion time for a resource be extended?

8. Explain how a competitive free market should increase supplies of a scarce mineral resource. List three reasons why this idea may not be effective under today's economic conditions.

9. Describe the basic features of the 1872 Mining Law in the United States and list its pros and cons.

10. List the pros and cons of allowing more mineral exploration and mining on public lands in the United States.

11. List the pros and cons of increasing supplies of mineral resources by **(a)** mining lower-grade ores, **(b)** mining the oceans, and **(c)** finding substitutes for scarce nonrenewable mineral resources.

12. List the pros and cons of **(a)** current methods used to mine gold in developed and developing countries and **(b)** using bacteria to extract metals from ores.

13. What supplies 99% of the energy we use? What percentage of the remaining 1% of the energy we use comes from nonrenewable and from renewable energy in **(a)** the world, and **(b)** the United States?

14. Summarize the trends since 1950 in the global use of **(a)** coal, **(b)** oil, **(c)** natural gas, **(d)** nuclear power to produce electricity, and **(e)** wood to provide heat and cook food in developing countries.

15. How long does it usually take to phase in a new energy alternative to the point where it accounts for 10–20% of total energy use? What seven questions should we try to answer about each energy resource?

16. What is *net energy*, and why is it important in evaluating an energy resource? Why is the net energy for oil from the Middle East high and that for nuclear power low?

17. What is *petroleum*, or *crude oil*? How is oil extracted from the earth's crust?

18. What happens to crude oil at a refinery? What are *petrochemicals*?

19. Summarize the history of the Age of Oil.

20. Who has most of the world's oil reserves? What percentage of the world's oil reserves is found in the United States? What percentage of the world's oil does the United States use? What percentage of the oil used in the United States is imported?

21. How long are known and projected supplies of conventional oil expected to last in **(a)** the world and **(b)** the United States? List the pros and cons of drilling for oil and natural gas in Alaska's Arctic National Wildlife Refuge.

22. What are the pros and cons of using conventional oil as an energy resource?

23. What are the pros and cons of using heavy oil from shale oil and tar sand as energy resources?

24. What is *natural gas*? Who has most of the world's reserves of natural gas? What is *methane hydrate*? Distinguish between *liquefied petroleum gas (LPG)* and *liquefied natural gas (LNG)*.

25. How long are known and projected supplies of natural gas expected to last in **(a)** the world and **(b)** the United States? What is a *combined-cycle natural gas turbine system*, and why is its use rising rapidly?

26. What are the pros and cons of using natural gas as an energy resource?

27. What is *coal*, and how is it formed? Distinguish among *lignite*, *bituminous*, and *anthracite* coal. How is coal extracted from the earth's crust? How is coal used? What four countries have the largest coal reserves?

28. How long are known and projected supplies of coal expected to last **(a)** in the world and **(b)** in the United States?

29. What are the pros and cons of using coal as an energy resource? What are the pros and cons of converting solid coal into gaseous and liquid fuels?

30. Describe how a *nuclear fission reactor* works. What are the five major components of a *light-water nuclear reactor*, and what role does each play? What is the *nuclear fuel cycle*?

31. List three reasons why commercial nuclear power plants were developed in the United States after World War II. List six factors that have contributed to the leveling off of the use of nuclear power plants to produce electricity.

32. List the major advantages and disadvantages of using conventional nuclear fission to produce electricity. Compare the advantages and disadvantages of using nuclear power and burning coal to produce electricity.

33. How safe are nuclear power plants?

34. What is being done with *low-level radioactive waste* produced by the nuclear fuel cycle? What are the options for dealing with *high-level radioactive waste*? Describe the threat from terrorist attacks on high-level radioactive wastes stored in pools of water or in dry casks at most nuclear power plants in the United States.

35. List the pros and cons of the proposed site for storing high-level nuclear wastes at Yucca Mountain in Nevada. How widespread are contaminated radioactive waste sites in **(a)** the United States and **(b)** the former Soviet Union?

36. What are the three options for retiring (decommissioning) worn-out nuclear power plants?

37. What is the relationship between the development of commercial nuclear power and the spread of nuclear weapons throughout much of the world? Describe the threat from terrorists stealing or buying radioactive materials used in medicine, industry, and research facilities and using the materials to make dirty radioactive bombs.

38. How useful is nuclear power in reducing U.S. dependence on oil imports?

39. What are the pros and cons of new reactor designs such as the pebble bed nuclear reactor?

40. What are the pros and cons of using **(a)** breeder nuclear fission and **(b)** nuclear fusion as an energy resource? What are the pros and cons of continuing large-scale government subsidies for research and development of conventional nuclear power, breeder fission, and nuclear fusion?

CRITICAL THINKING

1. Use the second law of thermodynamics (p. 59) to analyze the scientific and economic feasibility of each of the following processes: **(a)** extracting most minerals dissolved in seawater, **(b)** mining increasingly lower-grade deposits of minerals, **(c)** using inexhaustible solar energy to mine minerals, and **(d)** continuing to mine, use, and recycle minerals at increasing rates.

2. 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 lands in the United States 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.

3. List the pros and cons of including the environmental and health costs caused by mining, processing, and producing mineral resources (Figure 15-6) in the prices of metals to manufacturers and in the prices of consumer products. Do you favor including environmental costs in the prices of products? Explain. How would you institute such a policy?

4. Just 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 a new Saudi Arabia supply (the world's largest) *every 10 years*. Do you believe this is possible? If not, what effects might this have on your life and on the life of a child or grandchild you might have?

5. If you were trying to find new deposits of oil, would you search primarily in formations of igneous rock, sedimentary rock, or metamorphic rock? Explain.

6. List five actions you can take to reduce your dependence on oil and resources such as gasoline and most plastics derived from oil (see website material for this chapter). Which of these things do you actually plan to do?

7. The United States now imports 55% of the oil it uses and could be importing at least 61% of its oil by 2010. Explain why you are for or against continuing to increase oil imports. What do you believe are the three best ways to reduce dependence on oil imports?

8. Explain why you agree or disagree with the following proposals by various energy analysts 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 nuclear power, and **(d)** phase out all nuclear power plants by 2020.

9. Explain why you agree or disagree with each of the following proposals made by the U.S. nuclear power industry: **(a)** provide at least $100 billion in government subsidies to build a large number of better designed nuclear fission power plants (Figure 15-42) to reduce dependence on imported oil and slow global warming, **(b)** prevent the public from participating in hearings for licensing nuclear power plants and the Yucca Mountain high-level waste depository (Figure 15-41) and on safety issues at the nation's nuclear reactors, **(c)** restore government subsidies to develop a breeder nuclear fission reactor program, and **(d)** greatly increase federal subsidies for developing nuclear fusion.

10. If you had to choose, would you rather live next door to a coal-fired power plant or a nuclear plant? Explain.

11. Should the United States and other developed countries provide economic and technical aid for closing 35 poorly designed and poorly operated nuclear reactors in some republics of the former Soviet Union and in eastern Europe? Explain.

PROJECTS

1. What mineral resources are extracted in your local area? What mining methods are used, and what have been their environmental impacts? How has mining these resources benefited the local economy?

2. How is the electricity in your community produced? How has the cost of that electricity changed since 1970 compared to general inflation?

3. Write a two-page scenario of what your life might be like without oil. Compare and discuss the scenarios developed by members of your class.

4. Use the library or the Internet to find out information about the accident that took place at the Three Mile Island (TMI) nuclear power plant near Harrisburg, Pennsylvania, in 1979. According to the nuclear power industry, the TMI accident showed that its safety systems work because the accident caused no known deaths. Other analysts dispute this claim and argue the accident was a wake-up call about the potential dangers of nuclear power plants that led to tighter and better safety regulations. Use the information you find to determine which of these positions you support, and defend your choice.

5. Use the library or the Internet to find bibliographic information about *Ann Dorr* and *Lester R. Brown,* whose quotes appear at the beginning and end of this chapter.

6. Make a concept map of this chapter's major ideas, using the section heads and subheads and the key terms (in boldface). Look on the website for this book for information about making concept maps.

INTERNET STUDY RESOURCES AND RESOURCES FOR FURTHER READING AND RESEARCH

The website for this book contains helpful study aids and many ideas for further reading and research. Log on to

www.info.brookscole.com/miller13

and click on the Chapter-by-Chapter area. Choose Chapter 15 and select a resource:

- Flash Cards allows you to test your mastery of the Terms and Concepts to Remember for this chapter.
- Tutorial Quizzes provides a multiple-choice practice quiz.
- Student Guide to InfoTrac will lead you to Critical Thinking Projects that use InfoTrac College Edition as a research tool.
- References lists the major books and articles consulted in writing this chapter.
- Hypercontents takes you to an extensive list of sites with news, research, and images related to individual sections of the chapter.

INFOTRAC COLLEGE EDITION

Improve your skills with InfoTrac College Edition, a searchable online database of articles from more than 700 periodicals. Log on to

http://www.infotrac-college.com

or access InfoTrac through the website for this book. Try to find the following articles:

1. Geiselman, B. 2002. Yucca Mountain foes quake over plan; Tremor won't dissuade energy officials. (Brief article) *Waste News* 8: 1. *Keywords:* "Yucca Mountain" and "earthquake." Nevada's proposed Yucca Mountain nuclear waste repository has been controversial for a number of years, but as the government prepares to make the site the official US nuclear waste dump, the area's geologic stability is being questioned.

2. Kerlin, K. 2001. Diamonds aren't forever. *E* 12: 54. *Keywords:* "diamonds" and "environmental problems." Diamonds, gold, and other precious materials often come from not-so-friendly places and at high environmental costs.

16 ENERGY EFFICIENCY AND RENEWABLE ENERGY

The Coming Energy-Efficiency and Renewable-Energy Revolution

Energy experts Hunter and Amory Lovins (Guest Essay, p. 384) have built a large, passively heated, superinsulated, partially earth-sheltered home and office in Snowmass, Colorado (Figure 16-1), where winter temperatures can drop to −40°C (−40°F).

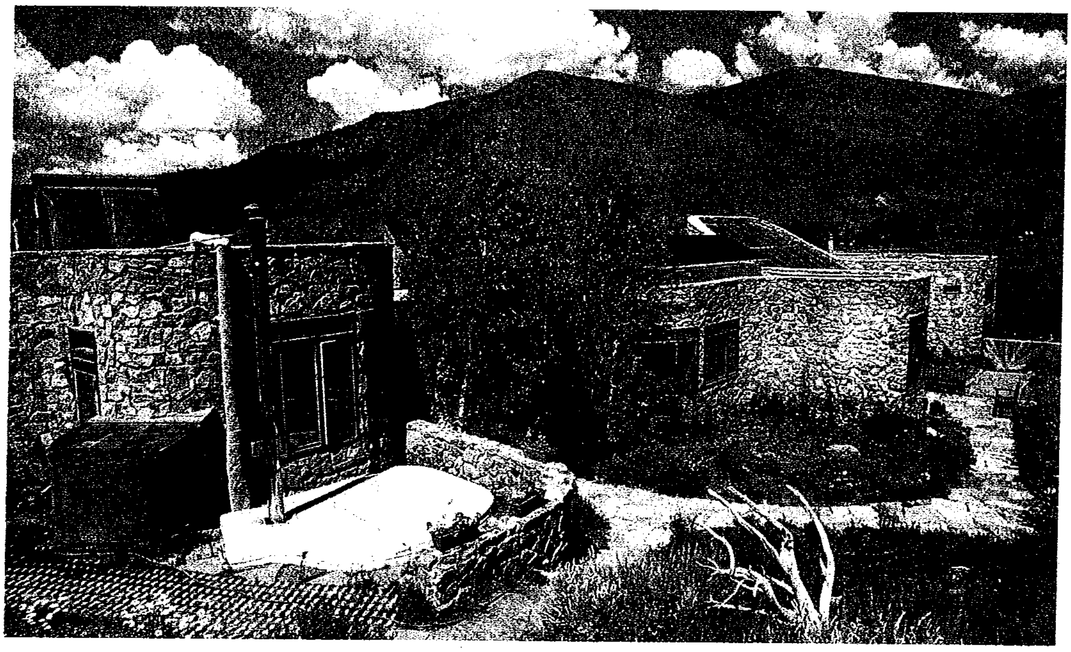
This structure, which also houses the research center for the Rocky Mountain Institute, an office used by 40 people, **(1)** gets 99% of its space and water heating and 95% of its daytime lighting from the sun and **(2)** uses one-tenth the usual amount of electricity for a structure of its size.

With today's superinsulating windows a house can have large numbers of windows without much heat loss in cold weather or heat gain in hot weather. Thinner insulation material now being developed will allow roofs and walls to be insulated far better than in today's best superinsulated houses.

A small but growing number of people in developed and developing countries are getting their electricity from *solar cells* that convert sunlight directly into electricity. They can be attached like shingles to a roof, used as a roof material, or applied to window glass as a coating. Solar-cell prices are high but are falling.

Many scientists and executives of oil and automobile companies believe we are in the beginning stages of a *solar–hydrogen revolution* to be phased in during this century as the Age of Oil begins winding down (Spotlight, p. 359, and Figure 15-16, p. 353). Electricity produced by large banks of solar cells or farms of wind turbines could be passed through water to make hydrogen gas (H_2), which could be used to fuel vehicles, industries, and buildings. Another solution is to burn hydrogen in energy-efficient *fuel cells* that produce electricity to **(1)** run cars and appliances, **(2)** heat water, and **(3)** heat and cool buildings.

Burning hydrogen made by decomposing water produces water vapor and no carbon dioxide (CO_2). Thus shifting to hydrogen as our primary energy resource during this century would eliminate most of the world's air pollution and greatly slow global warming—as long as the hydrogen is produced from water and not fossil fuels or other carbon-containing compounds.



Robert Millman/Rocky Mountain Institute

Figure 16-1 The Rocky Mountain Institute in Colorado. This facility is a home and a center for the study of energy efficiency and sustainable use of energy and other resources. It is also an example of energy-efficient passive solar design.

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.

AMORY B. LOVINS

This chapter addresses the following questions:

- What are the advantages and disadvantages of improving energy efficiency?
- What are the advantages and disadvantages of using solar energy to **(1)** heat buildings and water and **(2)** produce electricity?
- What are the advantages and disadvantages of using flowing water (hydropower) to produce electricity?
- What are the advantages and disadvantages of using wind to produce electricity?
- What are the advantages and disadvantages of burning plant material (biomass) to **(1)** heat buildings and water, **(2)** produce electricity, and **(3)** propel vehicles (biofuels)?
- What are the advantages and disadvantages of producing hydrogen gas and using it to **(1)** produce electricity, **(2)** heat buildings and water, and **(3)** propel vehicles?
- What are the advantages and disadvantages of extracting heat from the earth's interior (geothermal energy)?
- What are the advantages and disadvantages of using smaller, decentralized micropower sources to heat buildings and water, produce electricity, and propel vehicles?
- How can we make a transition to a more sustainable energy future?

16-1 THE IMPORTANCE OF IMPROVING ENERGY EFFICIENCY

What Is Energy Efficiency? Doing More with Less **Energy efficiency** is the percentage of total energy input into an energy conversion device or system that **(1)** does useful work and **(2)** is not converted to low-quality, essentially useless heat. Improving the energy efficiency of a car motor, home heating system, or other energy conversion device involves using less energy to do more useful work.

How Much Energy Do We Waste? You may be surprised to learn that *84% of all commercial energy used in the United States is wasted* (Figure 16-2). About 41% of this energy is wasted automatically because of the degradation of energy quality imposed by the second

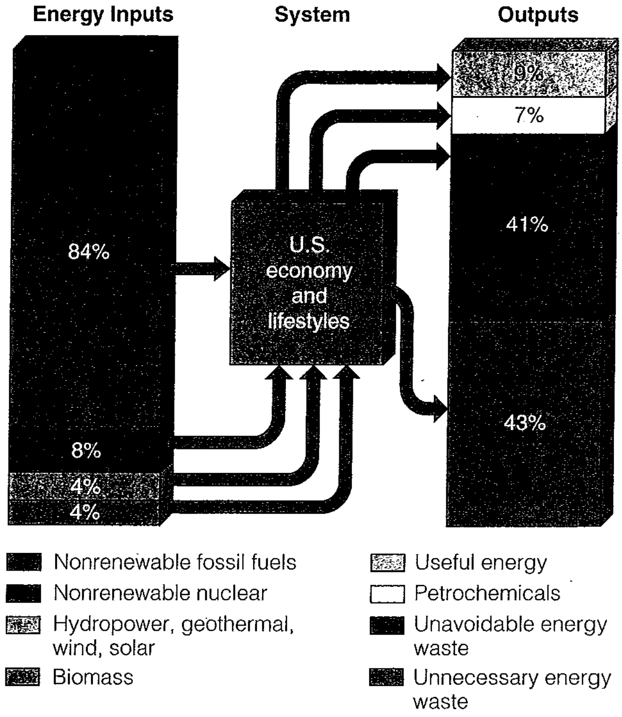


Figure 16-2 Flow of commercial energy through the U.S. economy. Note that only 16% of all commercial energy used in the United States ends up performing useful tasks or being converted to petrochemicals; the rest is either automatically and unavoidably wasted because of the second law of thermodynamics (41%) or wasted unnecessarily (43%).

law of thermodynamics (p. 59). However, about 43% is wasted unnecessarily, mostly by **(1)** using fuel-wasting motor vehicles, furnaces, and other devices and **(2)** living and working in leaky, poorly insulated, poorly designed buildings (Guest Essay, p. 384).

According to the U.S. Department of Energy (DOE), the United States unnecessarily wastes as much energy as two-thirds of the world's population consumes. Improvements in energy efficiency since the OPEC oil embargo in 1973 (Figure 2-9, p. 31, and Spotlight, p. 359) have cut U.S. energy bills by $275 billion a year. But unnecessary energy waste still costs the United States about $300 billion per year—an average of $570,000 per minute. Reducing energy waste has a number of economic and environmental advantages (Figure 16-3, p. 382).

What Are the Energy Efficiencies of Common Devices? The energy conversion devices we use vary in their energy efficiencies (Figure 16-4, p. 382). We can save energy and money by buying more energy-efficient cars, lighting, heating systems, water heaters, air conditioners, and appliances. Some energy-efficient models may cost more initially, but in the long

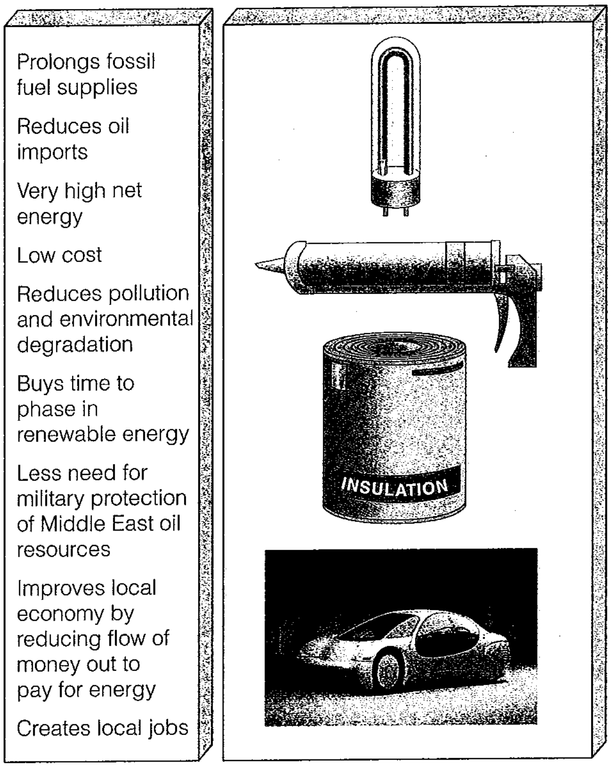


Figure 16-3 Advantages of reducing energy waste. Global improvements in energy efficiency could save the world about $1 trillion per year—an average of $11.4 million per hour.

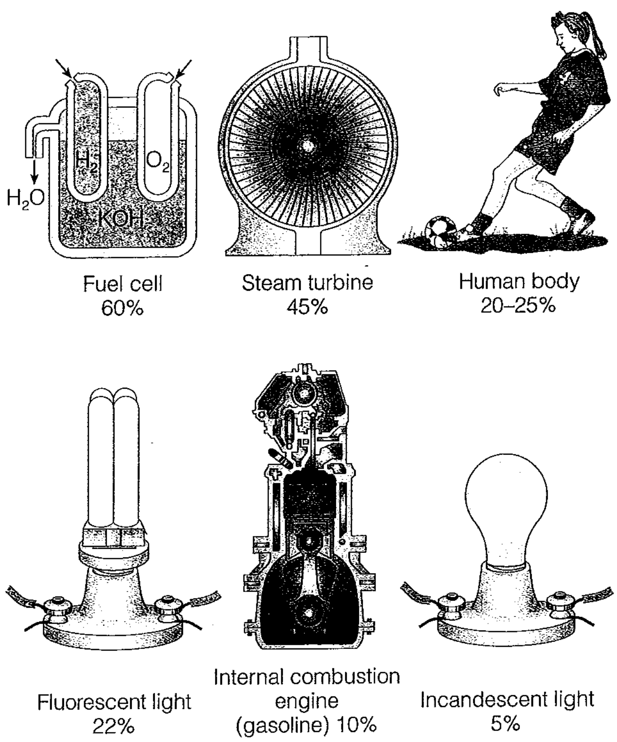


Figure 16-4 Energy efficiency of some common energy conversion devices.

run they usually save money by hav
cycle cost: initial cost plus lifetime ope

Perhaps the three least efficie devices in widespread use today are lightbulbs (which waste 95% of the **(2)** vehicles with internal combustior waste 86–90% of the energy in **(3)** nuclear power plants producing ele heating or water heating (which w energy in their nuclear fuel and pro the energy needed to deal with radioa retired nuclear plants is included). Er for us to replace these devices or grea energy efficiency over the next few de

Coal-burning power plants alsc wasters. About 34% of the energy in typical electric power plant is used t tricity, and the remaining 66% ends that flows into the environment. As a burning power plants throw away as the energy used by Japan.

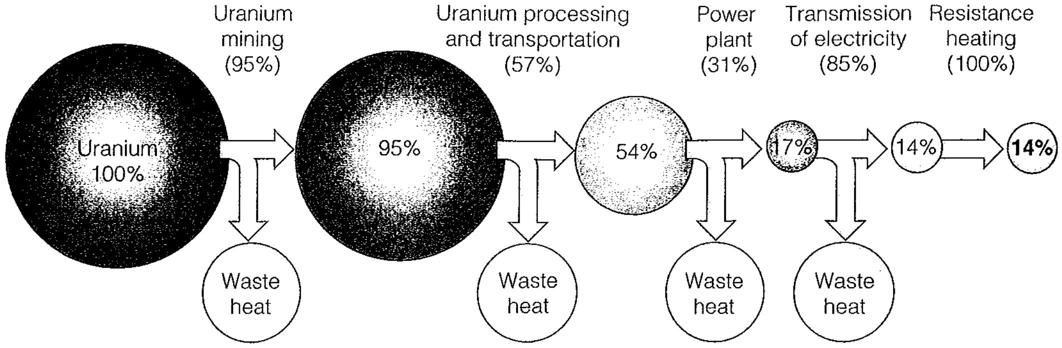
What Is Net Energy Efficiency? only energy that really counts is *net er net energy efficiency* of the entire process for a space heater, water heat mined by the efficiency of each step i version process.

Figure 16-5 shows the net ener heating two well-insulated homes, (tricity produced at a nuclear power p by wire to the home, and convertec resistance heating) and **(2)** the other with an input of direct solar energ efficiency windows facing the sun, w heat-absorbing materials for slow rel

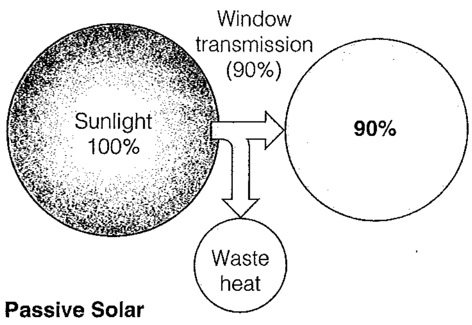
This analysis shows that the proc ing the high-quality energy in nucl quality heat at several thousand deg plant, **(2)** converting this heat to high- **(3)** transmitting the electricity to us the electricity to provide low-quality a house to only about 20°C (68°F) is high-quality energy (Figure 3-12, p. 5 any fossil fuel at a power plant to sup transmitting it long distances to heat also inefficient.

This example illustrates two gen saving energy:

- *Keep the number of steps in an energ process as low as possible.* Each time w from one form to another or transmi energy is lost.
- *Strive to have the highest possible en each step in an energy conversion proces*



Electricity from Nuclear Power Plant



Passive Solar

Figure 16-5 Comparison of net energy efficiency for two types of space heating. The cumulative net efficiency is obtained by multiplying the percentage shown inside the circle for each step by the energy efficiency for that step (shown in parentheses). Because of the second law of thermodynamics, in most cases the greater the number of steps in an energy conversion process, the lower its net energy efficiency. About 86% of the energy used to provide space heating by electricity produced at a nuclear power plant is wasted. If the additional energy needed to deal with nuclear wastes and to retire highly radioactive nuclear plants after their useful life is included, then the net energy yield for a nuclear plant is only about 8% (or 92% waste). By contrast, with passive solar heating, only about 10% of incoming solar energy is wasted.

16-2 WAYS TO IMPROVE ENERGY EFFICIENCY

How Can We Use Waste Heat? Could we save energy by recycling energy? No. The second law of thermodynamics (p. 59) tells us that we cannot recycle energy. But we can slow the rate at which waste heat flows into the environment when high-quality energy is degraded.

For a house, the best way to do this is to **(1)** insulate it thoroughly, **(2)** eliminate air leaks (Figure 16-6), and **(3)** equip it with an air-to-air heat exchanger to prevent buildup of indoor air pollutants.

In office buildings and stores, waste heat from lights, computers, and other machines can be collected and distributed to reduce heating bills during cold weather. During hot weather, the collected heat can be vented outdoors to reduce cooling bills or to

VANSCAN® Continuous Mobile Thermogram by Daedalus Enterprises, Inc.

Figure 16-6 An infrared photo (thermogram) 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 in most 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.

Technology Is the Answer (But What Was the Question?)

GUEST ESSAY

Amory B. Lovins

Physicist and energy consultant Amory B. Lovins is one of the world's most respected experts on energy strategy. In 1989, he received the Delphi Prize for environmental work; in 1990, the Wall Street Journal *named him one of the 39 people most likely to change the course of business in the 1990s. He is research director at Rocky Mountain Institute, a nonprofit resource policy center that he and Hunter Lovins founded in Snowmass, Colorado, in 1982. He has served as a consultant to more than 200 utilities, private industries, and international organizations, and to many national, state, and local governments. He is active in energy affairs in more than 35 countries and has published several hundred papers and a dozen books on energy strategies and policies.*

It is fashionable to suppose that we're running out of energy and ask how can we get more of it. However, the more important questions are **(1)** How much energy do we need and **(2)** What are the cheapest and least environmentally harmful ways to meet these needs?

How much energy it takes to make steel, run a car, or keep ourselves comfortable in our houses depends on how cleverly we use energy. For example, it is now cheaper to double the efficiency of most industrial electric motor drive systems than to fuel existing power plants to make electricity. Just this one saving can more than replace the entire U.S. nuclear power program. We know how to make **(1)** lights five times as efficient as those currently in use and **(2)** household appliances that give us the same work as now but use one-fifth as much energy (saving money in the process).

There are at least 50 good-sized, peppy, safe prototype cars averaging 30–60 kpl (70–140 mpg) on the market. Within a decade automakers could have cars getting 64–128 kpl (150–300 mpg) on the road if consumers demanded such cars.

We know today how to make new buildings (and many old ones) so heat-tight (but still well ventilated) that they need essentially no outside energy to maintain comfort year-round, even in severe climates. In fact, I live and work in one [Figure 16-1].

These energy-saving measures are all cheaper than going out and getting more energy. However, the old view of the energy problem included a worse mistake than forgetting to ask how much energy we needed: It sought more energy, in any form, from any source, at any price, as if all kinds of energy were alike.

Just as there are different kinds of food, so there are many different forms of energy whose different prices and qualities suit them to different uses [Figure 3-12, p. 53]. After all, there is no demand for energy as such; nobody wants raw kilowatt-hours or barrels of sticky black goo. People instead want energy services: comfort, light, mobility, hot showers, cold beverages, and the ability to cook food and make cement. In developing energy resources we should start by asking, "What tasks do we want energy for, and what amount, type, and source of energy will do each task most cheaply?"

The real question is, "What is the cheapest way to do low-temperature heating and cooling?" The answer is weather-stripping, insulation, heat exchangers, greenhouses, superwindows (which have as much insulating value as the outside wall of a typical house), roof overhangs, trees, and so on. These measures generally cost the equivalent of buying electricity at about 0.5¢–2¢ per kilowatt-hour, the lowest-cost way by far to supply energy.

If we need more electricity, we should get it from the cheapest sources first. In approximate order of increasing price, these include

- Converting to efficient lighting equipment. This would save the United States electricity equal to the output of 120 large power plants, plus $30 billion a year in fuel and maintenance costs.
- Using more efficient electric motors to save up to half the energy used by motor systems. This would save electricity equal to the output of another 150 large power plants and repay the cost in about a year.

drive a type of air conditioner called an *absorption chiller.*

How Can We Save Energy in Industry? Here are three important ways to save energy and money in industry:

- **Cogeneration,** or *combined heat and power (CHP)* systems, in which two useful forms of energy (such as steam and electricity) are produced from the same fuel source. These systems **(1)** have an efficiency of up to 80% (compared to about 30–40% for coal-fired boilers and nuclear power plants) and **(2)** emit two-thirds less CO_2 per unit of energy produced than conventional coal-fired boilers. Cogeneration has been widely used in western Europe for years. Its use in the United States (now producing only 9% of the country's electricity) and China is growing. In Germany, small cogeneration units that run on natural gas or liquefied petroleum gas (LPG) supply restaurants, apartment buildings, and houses with all their energy. In 6–8 years, they pay for themselves in saved fuel and electricity.

- *Replacing energy-wasting electric motors.* Running electric motors (mostly in industry) consumes about half of the electricity produced in the United States. Most of these motors are inefficient because they run

- Displacing the electricity now used for water heating and for space heating and cooling with good architecture, weatherization, insulation, and mostly passive solar techniques.
- Improving the energy efficiency of appliances, smelters, and the like.

Just these four measures can quadruple U.S. electrical efficiency, making it possible to run today's economy with no changes in lifestyles and using no power plants, whether old or new or fueled with oil, gas, coal, uranium, or solar energy. We would need only the present hydroelectric capacity, readily available small-scale hydroelectric projects, and a modest amount of wind power.

If we still wanted more electricity, the next cheapest sources would include **(1)** cogenerating electricity and heat in industrial plants and power plants, **(2)** using low-temperature heat engines run by industrial waste heat or by solar ponds, **(3)** filling empty turbine bays and upgrading equipment in existing big dams, **(4)** using modern wind turbines or small-scale hydroelectric turbines in good sites, **(5)** using combined-cycle natural gas turbines, and perhaps **(6)** using recently developed more efficient solar cells when their price is reduced by mass production.

Only after exhausting all these cheaper opportunities should we even consider building a new central power station of any kind—the slowest and costliest known way to get more electricity (or to save oil).

To emphasize the importance of starting with energy end uses rather than energy sources, consider a story from France. In the mid-1970s, energy conservation planners in the French government found that their biggest need for energy was to heat buildings and that even with good heat pumps, electricity would be the costliest way to do this. So they had a fight with their government-owned and -run utility company; they won, and electric heating was supposed to be discouraged or even phased out because it was so wasteful of money and fuel.

Meanwhile, down the street, the energy supply planners (who were far more numerous and influential in the French government) said, "Look at all that nasty imported oil coming into our country. We must replace that oil with some other source of energy. Voilà! Nuclear reactors can give us energy, so we'll build them all over the country." However, they paid little attention to who would use that extra energy and no attention to relative prices.

Thus, these two groups of the French energy establishment went on with their respective solutions to two different, indeed contradictory, French energy problems: *more energy of any kind* versus *the right kind to do each task in the most inexpensive way*. It was only in 1979 that these conflicting perceptions collided. The supply-side planners suddenly realized that the only thing they would be able to sell all that nuclear electricity for would be electric heating, which they had just agreed not to do.

Every industrial country is in this embarrassing position. Supply-oriented planners think the problem boils down to whether to build coal or nuclear power stations (or both). Energy-use planners realize that *no* kind of new power station can be an economic way to meet the needs for using electricity to provide low- and high-temperature heat and for the vehicular liquid fuels that are 92% of our energy problem.

So if we want to provide energy services at the lowest cost, we need to begin by determining what we need the energy for!

Critical Thinking

1. The author argues that building more nuclear, coal, or other electrical power plants to supply electricity for the United States is unnecessary and wasteful of energy and money. List your reasons for agreeing or disagreeing with this viewpoint.

2. Explain why you agree or disagree that increasing the supply of energy, instead of improving energy efficiency, is the wrong answer to our energy problems.

only at full speed with their output throttled to match the task. 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 new adjustable-speed drive motors would **(1)** be paid back in about 1 year and **(2)** save an amount of energy equal to that generated by 150 large (1,000-megawatt) power plants.

- *Switching to high-efficiency lighting.*

How Can We Save Energy in Transportation? According to most energy analysts, the best way to save energy (especially oil) and money in transportation is to *increase the fuel efficiency of motor vehicles.*

Some *good environmental news* is that between 1973 and 1985, the average fuel efficiency rose sharply for new cars sold in the United States and to a lesser degree for pickup trucks, minivans, and sport utility vehicles (SUVs) (Figure 16-7, p. 386). This occurred because of the government-mandated *Corporate Average Fuel Economy* (*CAFE*) standards.

Some *bad environmental news* is that between 1985 and 2001, the average fuel efficiency for new motor vehicles sold in the United States leveled off or declined slightly (Figure 16-7). This occurred because of **(1)** the increased popularity of energy-inefficient sport utility

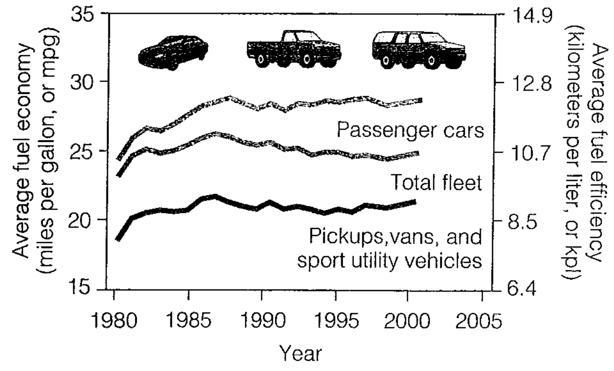


Figure 16-7 Average fuel economy of new vehicles sold in the United States, 1975–2001. (Data from U.S. Environmental Protection Agency and National Highway Traffic Safety Administration)

vehicles (SUVs), minivans, light trucks, and large autos that also produce about 20% of U.S. emissions of CO_2 and **(2)** failure of elected officials to raise CAFE standards because of opposition from automakers.

According to a 2001 study by the American Council for an Energy-Efficient Economy (ACEEE), increasing the fuel economy of new vehicles in the United States by just 5% a year for 10 years would **(1)** save 10–20 times more oil than the projected supply from the Arctic National Wildlife Refuge (Pro/Con, p. 360) and **(2)** more than three times the oil in the nation's current proven oil reserves.

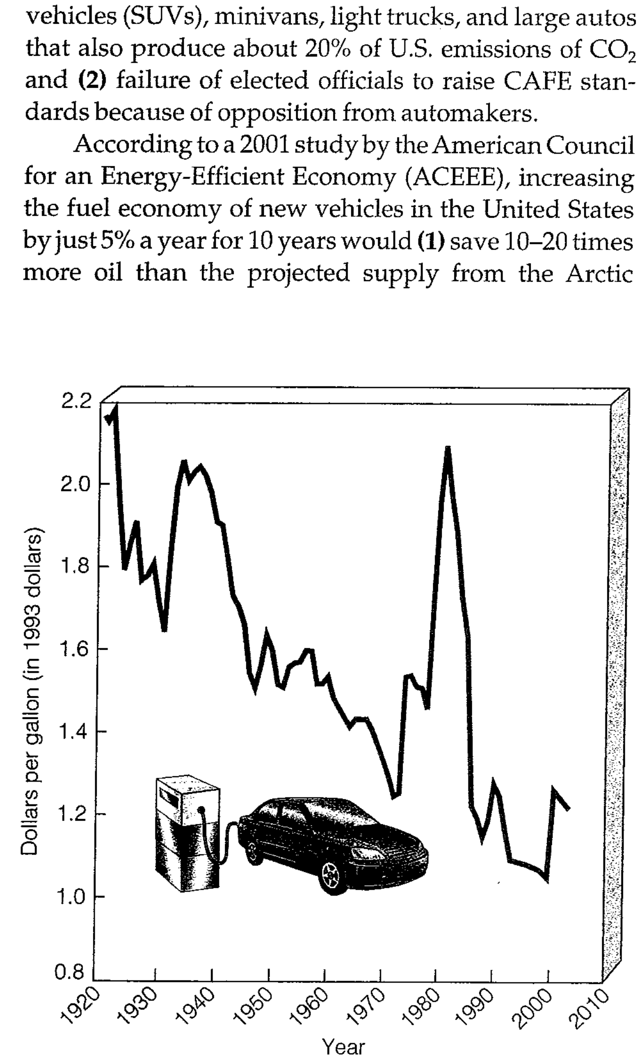


Figure 16-8 Real price of gasoline (in 1993 dollars) in the United States, 1920–2001. The 225 million motor vehicles in the United States use about 40% of the world's gasoline. Gasoline is one of the cheapest items American consumers buy and is less expensive than bottled water. (U.S. Department of Energy)

Suppose that in 1991 the first Bush administration and Congress had established a policy of requiring that the average car in the United States get 14 kilometers per liter (32 miles per gallon) by 2001. According to energy analysts, doing this would have saved enough oil to eliminate all current oil imports to the United States from the Persian Gulf. A similar action by the second Bush administration and Congress could significantly reduce U.S. dependence on imported oil within 10 years.

There are about 50 models of cars that get more than 15 kpl (35 mpg) on the market in the United States. However, they account for less than 1% of all car sales mostly because **(1)** the inflation-adjusted price of gasoline today in the United States is low (Figure 16-8 and Connections, p. 388), and **(2)** two-thirds of U.S. consumers prefer SUVs, pickup trucks, minivans, and other large, inefficient vehicles.

In Europe, where gasoline costs 80¢–$1.30 per liter ($3–5 per gallon), small subcompact cars are in much greater use—especially for urban trips. For example, Volkswagen has a four-seater subcompact car that gets 33 kpl (78 mpg) and has begun producing a smaller model that gets 100 kpl (235 mpg).

According to a 2001 study by the Natural Resources Defense Council (NRDC), a well-designed small car can be safer than a large gas guzzler. For example, U.S. government safety authorities gave **(1)** the General Motors Jimmy SUV an overall safety rating of only one star and the smaller Honda Accord five stars and **(2)** the Jeep Cherokee three stars in side-impact collisions and the much smaller Volkswagen Beetle five stars.

Are Hybrid-Electric Cars the Answer? There is rapidly growing interest in developing *superefficient cars* that could eventually get 34–128 kpl (80–300 mpg). One type of highly efficient car uses **(1)** a small *hybrid-electric internal combustion engine* that runs on gasoline, diesel fuel, or natural gas and **(2)** a small battery (recharged by the internal combustion engine) to provide the energy needed for acceleration and hill climbing (Figure 16-9).

In 2002, fuel-efficient hybrid-engine cars included the **(1)** *Toyota Prius* (a five-seater) that gets 21 kpl (49 mpg), **(2)** *Honda Insight* (a two-seater) that gets 29 kpl (67 mpg), and **(3)** *Honda Civic Hybrid* (a five-seater) that gets 21 kpl (49 mpg). These cars, priced at about $20,000, are selling well, and new buyers can get a federal tax deduction of up to $2,000 through 2003.

Carmakers are projected to introduce up to 20 hybrid models, including cars, trucks, SUVs, and vans, in the next 4–5 years. Sales are expected to reach 500,000 a year by 2006.

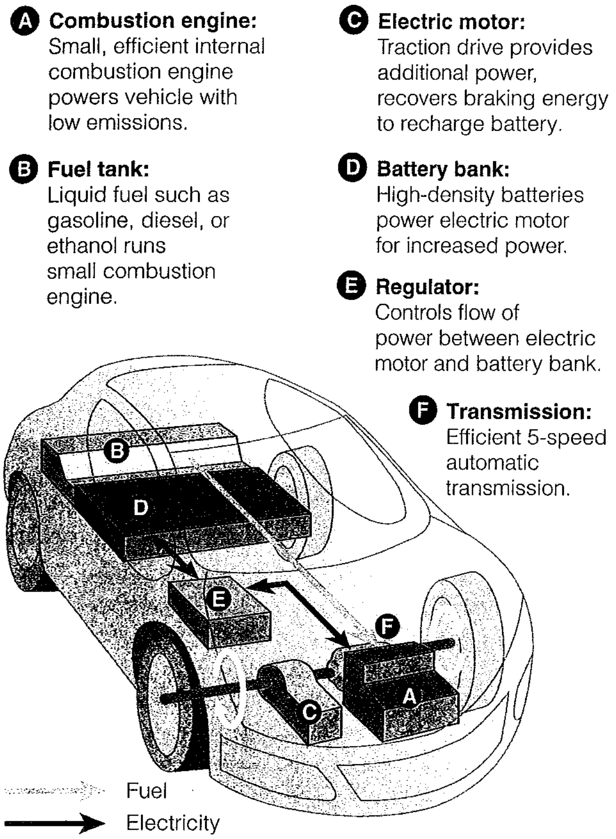
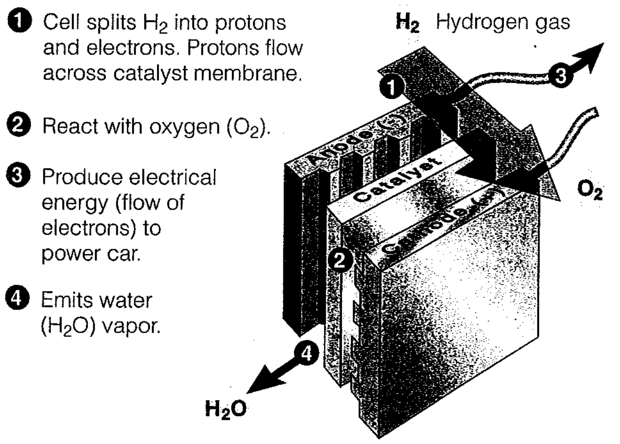


Figure 16-9 General features of a car powered by a *hybrid gas–electric engine.* A small internal combustion engine recharges the batteries, thus reducing the need for heavy banks of batteries and solving the problem of the limited range of conventional electric cars. The bodies of future models of such cars probably will be made of lightweight composite plastics that **(1)** offer more protection in crashes, **(2)** do not need to be painted, **(3)** do not rust, **(4)** can be recycled, and **(5)** have fewer parts than conventional cars. (Concept information from DaimlerChrysler, Ford, Honda, and Toyota)

Are Fuel-Cell Cars the Answer? Another type of superefficient car is an electric vehicle that uses a *fuel cell* that burns hydrogen (H_2) fuel to produce the electricity (Figure 16-10). In the cell, the hydrogen fuel (H_2) combines with oxygen (O_2) in the air to produce **(1)** electrical energy to power the car and **(2)** water vapor (H_2O), which is emitted into the atmosphere.

Most major automobile companies have developed prototype fuel-cell cars and hope to begin marketing them within a few years using several different approaches:

- An *onboard liquid reformer system* that strips hydrogen from available carbon-containing fuels such as gasoline, methanol, or natural gas. However, the use of carbon-containing fuels to produce the hydrogen adds CO_2 to the atmosphere. The amount of CO_2 emitted per kilometer traveled varies with the carbon



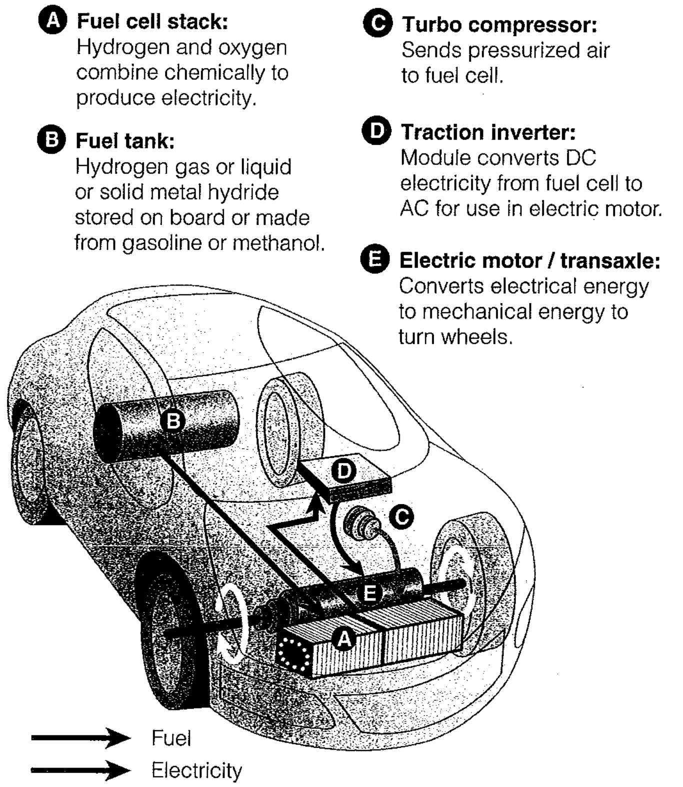


Figure 16-10 General features of an electric car powered by a *fuel cell* running on hydrogen gas. The hydrogen can be produced **(1)** onboard the vehicle from gasoline or methanol **(2)** or offboard for transfer to the vehicle from natural gas or by using renewable energy sources such as solar cells or wind turbines to decompose water into hydrogen and oxygen gas. Several automobile companies have developed prototypes and are working to get costs down. Early models could be on the road by 2003–2004. (Concept information from DaimlerChrysler, Ford, Ballard, Toyota, and Honda)

The Real Cost of Gasoline in the United States

CONNECTIONS

Economists and environmentalists point out that gasoline costs U.S. consumers much more than it appears. This is because the real cost of gasoline is not paid directly at the pump.

According to a 1998 study by the International Center for Technology Assessment, the hidden costs of gasoline to U.S. consumers is about \$1.30–3.70 per liter (\$5–14 per gallon), depending on how the costs are estimated. These hidden costs include the following:

- Government subsidies and tax breaks for oil companies and road builders.
- Pollution cleanup.
- Military protection of oil supplies in the Middle East.
- Environmental, health, and social costs such as increased medical bills and insurance premiums, time wasted in traffic jams, noise pollution, increased mortality from air and water pollution, urban sprawl, and harmful effects on wildlife species and habitats.

Economists point out that if these harmful costs were included as taxes in the market price of gasoline, we would have much more energy-efficient and less polluting cars. However, gasoline and car companies benefit financially by being able to pass these hidden costs on to consumers and future generations.

This is basically an education and political problem. Most consumers are unaware that they are paying these harmful costs and do not connect them with gasoline use. Also, politicians running on a platform of raising gasoline prices in the United States 3–11-fold would be committing political suicide.

Critical Thinking

Some economists have suggested that U.S. consumers might be willing to pay much more for gasoline if **(1)** they understood they are already paying these hidden costs indirectly and **(2)** the tax revenues from gasoline sales were used to reduce taxes on wages, income, and wealth and provide a safety net for low- and middle-class consumers. Would you support or oppose such a proposal? Explain.

compounds used to produce the hydrogen fuel (Figure 16-11).

- DamlierChrysler has developed a prototype minivan fueled with an *onboard* system that converts *solid sodium borohydride* into a mixture of borax (a nontoxic compound used in laundry detergent), water, and hydrogen gas (used to power a fuel cell). When the vehicle is refueled with sodium borohydride, the borax solution can be pumped out and discarded or recycled to make more sodium borohydride. This system does not require a large fuel tank to store hydrogen or a large, hot, dirty reformer and does not emit CO_2. In addition, the sodium borohydride fuel is not flammable.

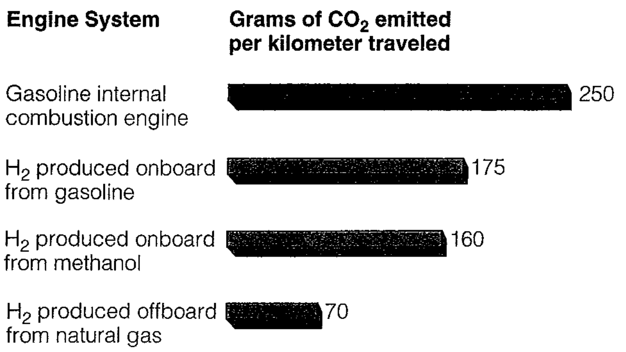


Figure 16-11 Comparison of CO_2 emissions from a conventional gasoline-powered internal combustion engine (red bar) and a hydrogen-powered fuel-cell engine, with the hydrogen produced from various options (green bars). (Data from Pembina Institute, Drayton Valley, Alberta, Canada)

- General Motors and Honda use a chemical process to store hydrogen fuel produced *offboard* in a *solid metal hydride* compound that can be heated to provide H_2 and replaced as needed at fueling stations.

Which is best: hybrid-electric or fuel-cell cars? It is too early to know. The answer will depend primarily on **(1)** how rapidly the technologies for both systems are developed, **(2)** the amount automobile and fuel-cell companies are willing to invest in developing each approach, **(3)** the comparative costs of each type of vehicle, and **(4)** the amount of government research and development subsidies and tax breaks that are available for each approach. Currently, fuel cells are very expensive but automakers hope to bring the costs down.

A 2001 MIT study tentatively concluded that

- In the short run, gasoline-powered hybrid-electric cars are expected to have better fuel economies and lower CO_2 and air pollution emissions than fuel-cell cars producing their hydrogen fuel from carbon-based gasoline, methanol, or natural gas (methane).
- After 2020, fuel-cell cars may have fuel economy and environmental advantages if their hydrogen fuel can be produced economically by using various forms of renewable energy to decompose water molecules into hydrogen and oxygen gas. Cars would be fueled from a network of hydrogen fueling stations. Because of the potential of these new technologies, William Ford, CEO of Ford Motor Company, said in 1998 that he expects to preside over the demise of the conventional internal combustion engine.

How Can Electric Bicycles and Scooters Reduce Energy Use and Waste? For urban trips, some people may begin using *electric bicycles* powered by a small electric motor. These bicycles, now being sold by several companies, **(1)** cost $500–1,100, **(2)** travel at up to 32 kilometers per hour (20 miles per hour), **(3)** go about 48 kilometers (30 miles) without pedaling on a full electric charge, and **(4)** produce no pollution during operation (and only a small amount for the electricity used in recharging them).

In 2003, an electric bicycle powered by a small fuel cell became available for about $1,500–2000. A small metal container (similar to a propane gas container) that can be easily disconnected and refilled within seconds supplies the hydrogen.

Another alternative is an *electric scooter*. One model, the Nova Cruz Voloci, has a range of about 81 kilometers (50 miles), can travel at a top speed of 48 kph (30 mph), and costs about $2,500.

How Can We Save Energy in Buildings? Atlanta's 13-story Georgia Power Company building 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, blocking out the higher summer sun to reduce air conditioning costs but allowing warming by the lower winter sun. Energy-efficient lights focus on desks rather than illuminating entire rooms.

If phased in over 2–3 decades, the Georgia Power model and other existing cost-effective commercial building technologies could **(1)** reduce energy use by 75% in U.S. buildings, **(2)** cut CO_2 emissions in half, and **(3)** save more than $130 billion per year in energy bills—an average of $15 million an hour.

A number of ways are available to improve the energy efficiency of houses, some of them discussed in the opening of this chapter (p. 380). One is a *superinsulated house* (Figure 16-12). Such houses typically cost 5% more to build than conventional houses of the same size. But this extra cost is paid back by energy savings within about 5 years and can save a home owner $50,000–100,000 over a 40-year period.

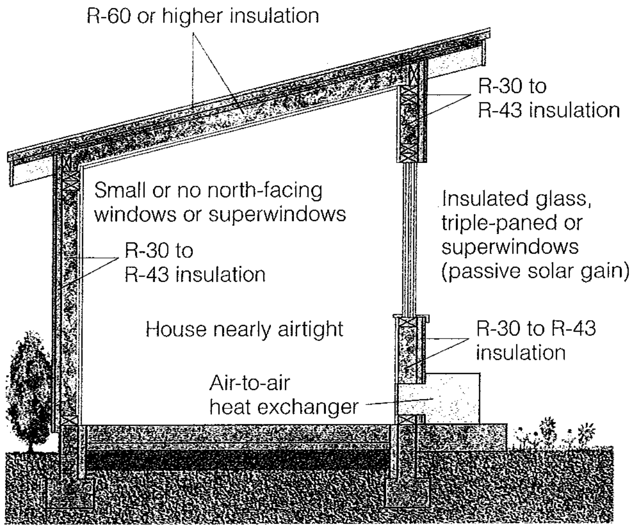


Figure 16-12 Major features of a *superinsulated house.* Such a house is so heavily insulated and so airtight that it can be warmed by heat from direct sunlight, appliances, and human bodies, with little or no need for a backup heating system. An air-to-air heat exchanger prevents buildup of indoor air pollution.

Since the mid-1980s there has been growing interest in building superinsulated houses called *strawbale houses.* Their walls consist of compacted bales of certain types of straw (available at a low cost almost everywhere) covered with plaster or adobe (Figure 16-13). By 2002, more than 1,200 such homes had been built or were under construction in the United States (Guest Essay, p. 390). Using straw, an


Alison Gannett


Alison Gannett

Figure 16-13 An energy-efficient, environmentally healthy, and affordable Victorian-style *strawbale house* designed and built by Alison Gannett in Crested Butte, Colorado. The left photo is during construction, and the right photo is the completed house. Depending on the thickness of the bales, plastered strawbale walls have an insulating value of R-35–R-60, compared to R-12–R-19 in a conventional house. (The R-value is a measure of resistance to heat flow.)

Living Lightly on the Earth at Round Mountain Organics

GUEST ESSAY

Nancy Wicks

Nancy Wicks is an eco-pioneer trying to live her ideals. She grew up in a small town in Iowa and did undergraduate studies in a village in Nepal. Both of these life experiences inspired her to live more sustainably by creating Round Mountain Organics, an organic garden at an altitude of 1.6 kilometers (8,500 feet) in the Rocky Mountains near Crested Butte, Colorado. Nancy lives in a passive solar strawbale house, which is powered by the wind and sun. She is a fanatic reuser, recycler, and composter. She received the "Sustainable Business of the Year 2000" award from the High Country Citizen's Alliance.

After studying in Nepal, where sustainability is a do or die situation, I have tried to incorporate as many sustainable practices into my life as possible at my house and organic garden business called Round Mountain Organics. This includes being a member of a buying coop (where buying in bulk not only saves resources but also saves money), reusing everything from plastic and paper bags to trays and pots for garden plants, and composting food waste (which saves money on trash bills and fertilizes the soil).

After moving onto the land that is now home to Round Mountain Organics, I spent 4 years planning and building an octagonal strawbale house with a stucco exterior—the first such house to be built in the county. I chose to build with straw because **(1)** straw is a natural building material and renewable resource, **(2)** there is a surplus of straw after harvesting grains such as wheat (which I used), oats, barley, and rice, **(3)** its insulation value of R-54 comes in handy when you live in an area where winter temperatures can dip to 40°F below zero, and **(4)** they are easy to build (with only 1 week needed to put up the strawbale walls). Since the 1980s strawbale houses have also been built in Arizona and New Mexico to beat the heat.

I used a passive solar design by orienting the house to the south to take advantage of Colorado's abundant sunshine. During the day the insulated window covers are drawn up and the sun shines onto flagstone tiles covering a cement slab that stores and releases heat slowly to keep the house comfortably warm or cool regardless of outside conditions. At night the window covers are let down to hold the heat in.

Because I live in one of the world's sunniest places, I decided not to get hooked up to the electrical grid and instead get my electricity from a small wind turbine and panels of solar cells. The electricity is stored in a bank of 12 batteries and an inverter converts the stored direct current (DC) electricity to ordinary 120-volt alternating current (AC).

If it's cloudy and not windy for a couple of days (which is rare), I fire up a small gas generator to charge the batteries. I also use some propane to provide hot water with a small on-demand water heater. Only a small pilot light stays lit until the hot water faucet is turned on. Then a large flame is ignited that the water is piped through. This way, I do not use energy to keep a tank of water hot around the clock.

I use many energy-saving devices. They include compact florescent lightbulbs, an oversized pressure tank so the well pump does not have to kick on every time the faucet turns on, and a superinsulated energy-efficient DC refrigerator.

I use organic gardening to grow flowers, herbs, and vegetables for my own use and for sale to local residents and restaurants. I incorporate some pioneering organic gardening techniques such as Rudolph Steiner's biodynamics (developed in 1924) and Bill Mollison's permaculture (developed in 1978).

Insect pests are picked off by hand and beneficial insects such as ladybugs are used to eat harmful insects such as aphids. Compost, aged animal manure, and cover crops that are plowed in as green manure are used to add nutrients to the soil. Crop rotation is used so as not to deplete the soil of nutrients.

Cold frames (a type of mini-greenhouse) are used to extend the growing season to 150 days in the cold climate where there are only about 90 days without a killing frost. Recently I built a passively heated strawbale greenhouse to extend the short growing season further and raise heat-loving plants such as tomatoes, cucumbers, and zucchinis. The chicken coop is in the northeast corner of the greenhouse, with the heat given off by the chickens helping to warm the greenhouse.

Now I am working on starting a nonprofit, Round Mountain Institute, Inc., to educate people on how they can live in harmony with the earth.

Critical Thinking

Would you like to live a lifestyle similar to that of Nancy Wicks? Explain. Why do you think more people do not try to live more sustainably, as she does? List three ways to help encourage people to adopt such a lifestyle.

annually renewable agricultural residue often burned as a waste product, for the walls reduces the need for wood and thus slows deforestation. The main problem is getting banks and other moneylenders to recognize the potential of this and other unconventional types of housing and provide home owners with con-struction loans.

Eco-roofs covered with plants have been used i[n] Germany and in other parts of Europe for about 2[…] years. These plant-covered roof gardens **(1)** provid[e]

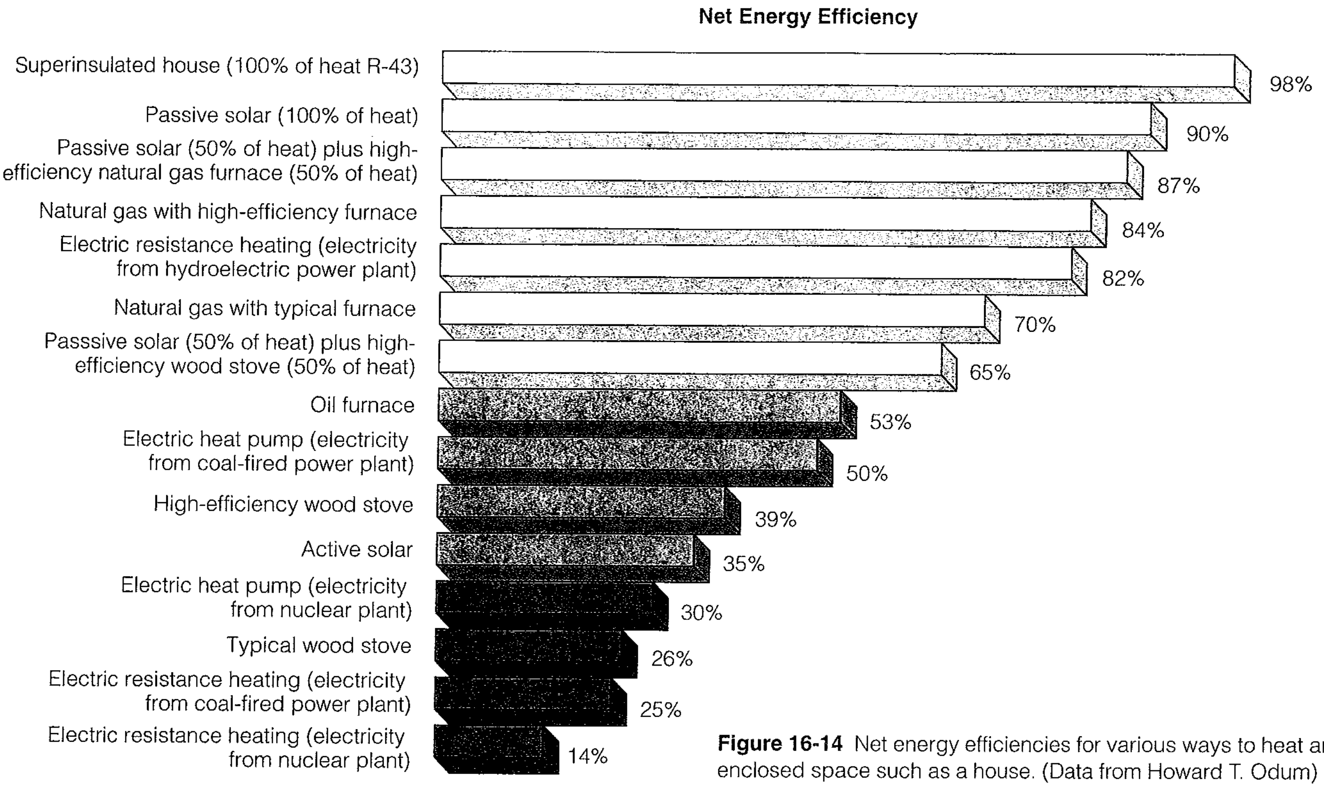


Figure 16-14 Net energy efficiencies for various ways to heat an enclosed space such as a house. (Data from Howard T. Odum)

good insulation, **(2)** absorb storm water, and **(3)** outlast conventional roofs.

Another way to save energy is to *use the most energy-efficient ways to heat houses* (Figure 16-14). The most energy-efficient ways to heat space are **(1)** a superinsulated house, **(2)** passive solar heating, **(3)** heat pumps in warm climates (but not in cold climates because at low temperatures they automatically switch to costly electric resistance heating), and **(4)** a high-efficiency (85–98%) natural gas furnace. The most wasteful and expensive way is to use electric resistance heating with the electricity produced by a coal-fired or nuclear power plant.

The energy efficiency of existing houses and buildings can be improved significantly by **(1)** *adding insulation,* **(2)** *plugging leaks, and* **(3)** *installing energy-saving windows and lighting.* About one-third of heated air in U.S. homes and buildings escapes through closed windows and holes and cracks (Figure 16-6)—equal to the energy in all the oil flowing through the Alaska pipeline every year. During hot weather these windows and cracks also let heat in, increasing the use of air conditioning.

Replacing all windows in the United States with low-E (low-emissivity) windows would cut these expensive losses by two-thirds and reduce CO_2 emissions. Widely available superinsulating windows insulate as well as 8–12 sheets of glass. Although they cost 10–15% more than double-glazed windows, this cost is paid back rapidly by the energy they save. Even better windows will reach the market soon.

Simply wrapping a water heater in a $20 insulating jacket can save $45 a year and reduce CO_2 emissions. Leaky ducts 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 ducts inside the home's thermal envelope so that escaping hot or cool air leaks into the living space.

An energy-efficient way to heat hot water for washing and bathing is to use *tankless instant water heaters* (about the size of a small suitcase) fired by natural gas or LPG (Guest Essay, p. 390). These devices, widely used in many parts of Europe, **(1)** heat water instantly as it flows through a small burner chamber, **(2)** provide hot water only when it is needed, and **(3)** use about 20% less energy than traditional water heaters.*

A well-insulated, conventional natural gas or LPG water heater is fairly efficient. But all conventional natural gas and electric resistance heaters **(1)** waste energy by keeping a large tank of water hot all day and night and **(2)** can run out after a long shower or two.

Using electricity produced by any type of power plant is the most inefficient and expensive way to heat

*They work great. I used them in a passive solar office and living space for 15 years. Models are available for $500–1,000 from companies such as Rinnai, Bosch, Takagi, and Envirotech.

water for washing and bathing. A $425 electric water heater can cost $5,900 in energy over its 20-year life, compared to about $4,000 for a comparable natural gas water heater over the same period.

Cutting off lights, computers, TVs, and other appliances when they are not needed can make a big difference in energy use and bills. At 9 P.M. one weekday evening, major TV stations in Bangkok, Thailand, cooperated with the government in showing a dial that gave the city's current use of electricity. When viewers were asked to turn off unnecessary lights and appliances, they watched the dial register a 735 megawatt drop in electricity use—a drop equal to the output of two medium-sized coal-burning power plants. This visual experience showed individuals that reducing their unnecessary electricity use could cut their bills and collectively close down power plants.

Setting higher energy-efficiency standards for new buildings would also save energy. Building codes could require that all new houses use 60–80% less energy than conventional houses of the same size, as has been done in Davis, California. Because of tough energy-efficiency standards, the average Swedish home consumes about one-third as much energy as the average American home of the same size.

Another way to save energy is to *buy the most energy-efficient appliances and lights.* Since 1978, the Department of Energy (DOE) has set federal energy-efficiency standards for more than 20 appliances used in the United States. A 2001 study by the National Academy of Sciences found that **(1)** between 1978 and 2000, the $7 billion spent by the DOE on this program saved consumers more than $30 billion in energy costs and provided environmental benefits valued conservatively at $60–80 billion, and **(2)** the program is expected to save U.S. consumers another $46 billion in energy costs between 2000 and 2020.* Programs like these exist in 43 other countries.

Energy-efficient lighting could save U.S. businesses and homes about $30 billion per year in electricity bills. Replacing a standard incandescent bulb with an energy-efficient compact fluorescent bulb (Figure 16-15) saves about $48–70 per bulb over its 10-year life. Thus replacing 25 incandescent bulbs (in a house or building) with energy-efficient fluorescent bulbs saves $1,250–1,750. Students in Brown University's environmental studies program showed that the school could save more than $40,000 per year just by replacing the incandescent lightbulbs in exit signs with compact fluorescent bulbs.

*Each year the American Council for an Energy-Efficient Economy (ACEEE) publishes a list of the most energy-efficient major appliances mass produced for the U.S. market. A copy can be obtained from the council at 1001 Connecticut Avenue NW, Suite 801, Washington, DC 20036, or on their website at http://www.aceee.org/consumerguide/index.htm.

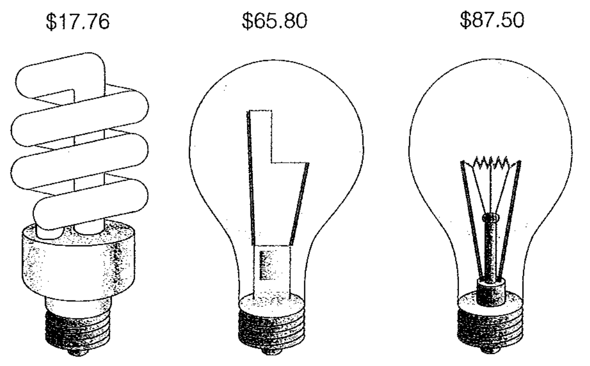


Figure 16-15 Cost of electricity for comparable lightbulbs used for 10,000 hours. Because conventional incandescent bulbs are only 5% efficient and last only 1,500 hours, they waste enormous amounts of energy and money and add to the heat load of houses during hot weather. Socket-type fluorescent lights use one-fourth as much electricity as conventional bulbs. Although these bulbs cost $6–15 per bulb, they last up to 100,000 hours (60–70 times longer than conventional incandescent bulbs and 25 times longer than halogen bulbs), saving a lot of money (compared with less efficient incandescent and halogen bulbs) over their long life. Between 1998 and 2001, global sales of compact fluorescent bulbs rose from 45 million to 606 million per year—with 80% of them made in China. (Data from Electric Power Research Institute)

Despite their advantages, less than 10% of U.S. homes use these energy- and money-saving bulbs, which pay for themselves in 2–4 years. Reasons for their low use are **(1)** their high initial cost, **(2)** lack of information and education about life-cycle costing, **(3)** initial lack of suitable light fixtures for these larger bulbs (light fixtures and smaller bulbs are now available), and **(4)** dissatisfaction with the color and intensity of the light produced compared with incandescent bulbs (corrected with newer bulbs).

In 2001, researchers at the Lawrence Berkeley National Laboratory developed a very efficient high-intensity fluorescent table lamp. It uses two independently controllable and fully dimmable compact fluorescent bulbs, one directed downward and the other upward. The lamp can eliminate the need for overhead room lighting, provide down lighting for reading and other tasks, and help decrease use of highly inefficient halogen bulbs (which can also start fires and increase air conditioning needs because of the intense heat they produce). In 2002, scientists at Sandia National Laboratories developed a new type of incandescent lightbulb that raises the efficiency of such bulbs from 5% to about 60%.

If all households in the United States used the most efficient frost-free refrigerator now available,

Using the Internet to Save Energy and Paper and Reduce Global Warming

CONNECTIONS

According to a 2000 report by researchers at the Center for Energy and Climate Solutions, increasing use of the Internet is saving energy and material resources by

- Allowing more employees to work at home.
- Allowing a reduction in retail, manufacturing, warehouse, and commercial office space. Some online companies keep no merchandise in warehouses and have it shipped to customers directly from manufacturers. For example, Amazon.com uses 1/16 as much energy per unit of floor space to sell a book as a regular store.
- Using less energy to get products from sellers to consumers. Sending a package by overnight air uses about 40% less fuel than driving round trip to the mall to get the product. Shipping by rail saves even more energy. However, shipping a larger number of packages to individuals instead of bulk shipments to businesses causes a huge increase in packaging.
- Reducing the energy, paper, and materials used to produce, package, and market consumer items such as computer software and music CDs by downloading them.
- Reducing energy used in transporting goods by using Internet-based systems to auction off empty shipping space on trucks, aircraft, and trains.

The resulting energy savings also reduce air pollution and CO_2 emissions by reducing fossil fuel use. Paper production (a highly energy- and resource-intensive industry) is expected to decrease as **(1)** consumers use the Internet to download software and view magazines, newspapers, research articles, telephone directories, encyclopedias, and books, **(2)** consumers and businesses send more e-mail and less mail and reports by using envelopes and packages, and **(3)** easily updated online catalogs replace paper catalogs.

Although this book is printed on paper, I used no paper in preparing it for the publisher. Instead, the manuscript was sent to the publisher electronically as attachments to e-mail messages. Copyediting of the manuscript was also done via e-mail attachments.

This and other books are still being printed on paper. However, we can envision a day not too far away when we can read and interact with most textbooks on websites maintained by book publishers or individual authors.

Critical Thinking

What types of environmental harm might be increased by greatly expanded use of the Internet to sell more and more goods in the global marketplace?

18 large (1,000-megawatt) power plants could close. Microwave ovens can cut electricity use for cooking by 25–50% (but not if used for defrosting food). Clothes dryers with moisture sensors cut energy use by 15%, and front-loading washers use 50% less energy than top-loading models but cost about the same. Increased use of the Internet for business and shopping transactions reduces energy use and decreases emissions of CO_2 and other air pollutants (Connections, above).

Why Are We Not Doing More to Reduce Energy Waste? According to Amory Lovins (Guest Essay, p. 384), energy-efficient improvements since 1975 now save the United States each year energy equal to **(1)** more than five times the country's annual domestic oil production, **(2)** two times the energy in all current oil imports, and **(3)** twelve times the energy in all oil imported from the Persian Gulf. Even though improving energy efficiency is the country's cheapest energy option, its potential has barely been tapped.

With such an impressive array of benefits (Figure 16-3), why isn't there more emphasis on improving energy efficiency? The major reasons are as follows:

- A glut of low-cost oil (Figure 15-22, p. 357) and gasoline (Figure 16-8). As long as energy is cheap, people are more likely to waste it and not make investments in improving energy efficiency.
- Lack of sufficient tax breaks and other economic incentives for consumers and businesses to invest in improving energy efficiency.
- Lack of information about the availability of energy-saving devices and the amount of money such items can save consumers by using *life cycle cost* analysis.

16-3 USING SOLAR ENERGY TO PROVIDE HEAT AND ELECTRICITY

What Are the Major Advantages and Disadvantages of Solar Energy? Figure 16-16 (p. 394) lists some of the advantages and disadvantages of making a shift to greatly increased use of direct solar energy and indirect forms of solar energy such as wind. Like fossil fuels and nuclear power (Chapter 15), each renewable energy alternative has a mix of advantages and disadvantages, as discussed in the remainder of this chapter.

Advantages	Disadvantages
Save money (wind)	Making solar cells produces toxic chemicals
Reduce air pollution (99% less than coal)	Solar systems last only 30–40 years
Greatly reduce CO_2 emissions	Solar cells and solar thermal take large amounts of land because of diffuse nature of sunlight
Reduce dependence on imported oil	Can damage fragile desert ecosystems used to collect solar energy
Last as long as coal and nuclear plants (30–40 years)	Need backup systems at night and during cloudy and rainy weather
Land use less than for coal	Solar cells and solar thermal systems still too costly
Low land use with new solar cell and window glass system	
Backup and storage devices available (such as gas turbines, batteries, and flywheels)	
Backup need reduced by distributing and storing solar-produced hydrogen gas	

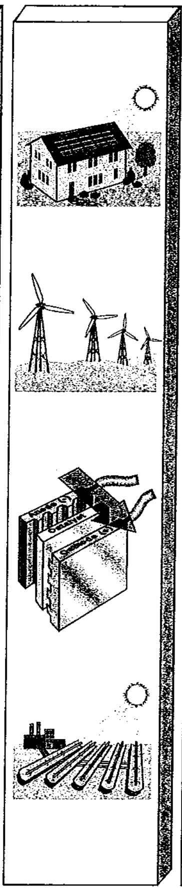


Figure 16-16 Major advantages and disadvantages of using direct and indirect solar energy systems to produce heat and electricity. Specific advantages and disadvantages of different direct and indirect solar and other renewable energy systems are discussed in this chapter.

Here is some *good news* about the increased use of renewable energy:

- In 2001, the European Union (EU) adopted a law requiring its member countries to get 12% of their total energy and 22% of their electricity from renewable energy by 2010.
- A 2001 joint study by the American Council for an Energy Efficient Economy, the Tellus Institute, and the Union of Concerned Scientists showed how renewable energy could provide 20% of U.S. energy and save consumers $440 billion by 2020.
- In 2001, voters overwhelmingly approved a $100 million bond issue aimed at **(1)** making San Francisco, California, the nation's top urban producer of solar power and wind power and **(2)** using these renewable forms of energy to supply about 25% of the energy used by the city's schools and government buildings.
- According to Royal Dutch Shell International Petroleum, renewable energy could account for 50% of the world's energy production by 2050.

The *bad news* is that solar and wind power currently provide only about 1% of the world's commercial energy—mostly because they have received and continue to receive much lower government tax breaks, subsidies, and research and development funding than fossil fuels and nuclear power.

How Can We Use Solar Energy to Heat Houses and Water? Buildings and water can be heated by solar energy using two methods: passive and active (Figure 16-17). A **passive solar**

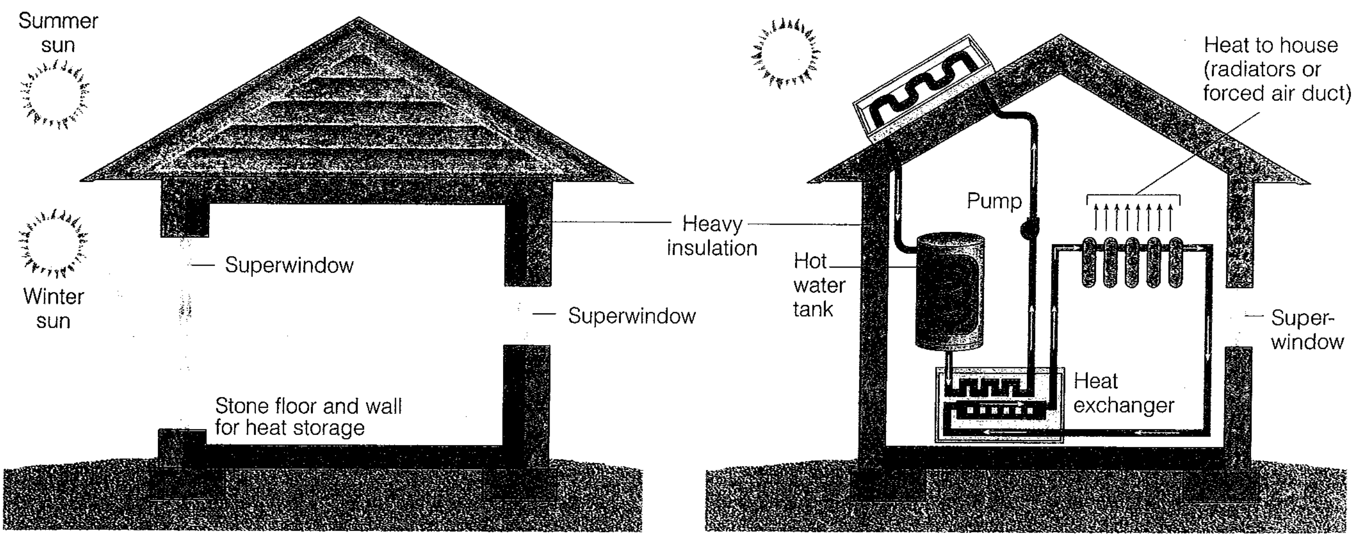


Figure 16-17 Passive and active solar heating for a home.

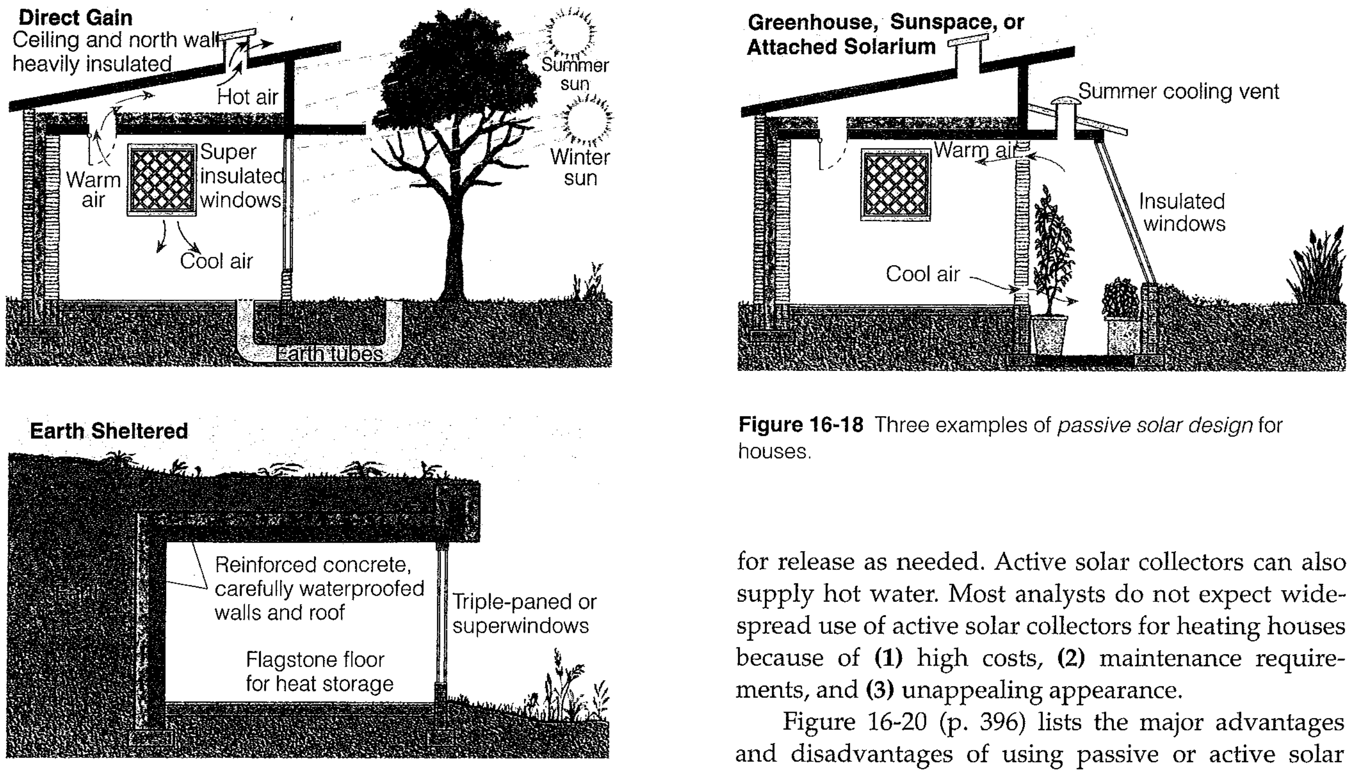


Figure 16-18 Three examples of *passive solar design* for houses.

heating system absorbs and stores heat from the sun directly within a structure (Figure 16-1, Figure 16-17, left, Figure 16-18, and Guest Essay, p. 390).

Energy-efficient windows and attached greenhouses face the sun to collect solar energy by direct gain. Walls and floors of concrete, adobe, brick, stone, salt-treated timber, and water in metal or plastic containers 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.

On a life cycle cost basis, good passive solar and superinsulated design is the cheapest way to heat a home or small building in regions where ample sunlight is available during the daytime (Figure 16-19, p. 396). Such a system usually adds 5–10% to the construction cost, but the life cycle cost of operating such a house is 30–40% lower. The typical payback time for passive solar features is 3–7 years.

In an **active solar heating system,** collectors absorb solar energy, and a fan or a pump supplies part of a building's space-heating or water-heating needs (Figure 16-17, right). Several connected collectors usually are mounted on the roof with an unobstructed exposure to the sun. Some of the heat can be used directly, and the rest can be stored in insulated tanks containing rocks, water, or a heat-absorbing chemical for release as needed. Active solar collectors can also supply hot water. Most analysts do not expect widespread use of active solar collectors for heating houses because of **(1)** high costs, **(2)** maintenance requirements, and **(3)** unappealing appearance.

Figure 16-20 (p. 396) lists the major advantages and disadvantages of using passive or active solar energy for heating buildings. Passive solar cannot be used to heat existing homes and buildings **(1)** not oriented to receive sunlight and **(2)** whose access to sunlight is blocked by other buildings and structures.

How Can We Cool Houses Naturally? Ways to make a building cooler include the following:

- Using superinsulation and superinsulating windows.
- Blocking the high summer sun with deciduous trees, window overhangs, or awnings (Figure 16-18, top left).
- Using windows and fans to take advantage of breezes and keep air moving.
- Suspending reflective insulating foil in an attic to block heat from radiating down into the house.
- Placing plastic *earth tubes* 3–6 meters (10–20 feet) underground where the earth is cool year round and using a tiny fan to pipe cool and partially dehumidified air into an energy-efficient house (Figure 16-18, top left).*
- Using solar-powered evaporative air conditioners (which work well only in dry climates and cost too much for residential use).

*They work. I used them in a passively heated and cooled office and home for 15 years. People allergic to pollen and molds should add an air purification system, but this is also necessary with a conventional cooling system.

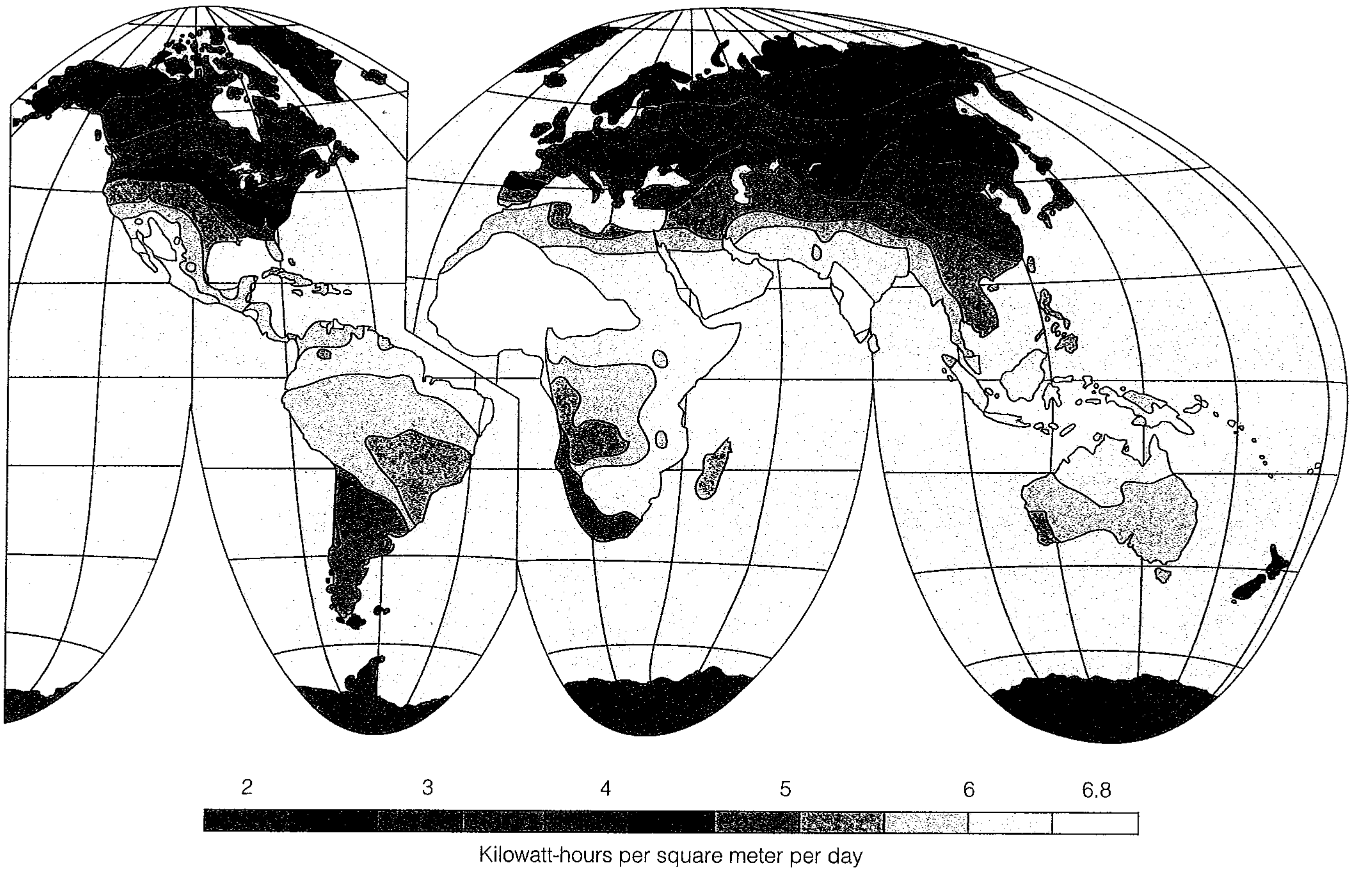


Figure 16-19 Map of *global solar energy availability.* Areas with more than 3.5 kilowatt-hours per square meter per day (see scale) are good candidates for passive and active solar heating systems and use of solar cells to produce electricity. (Data from U.S. Department of Energy)

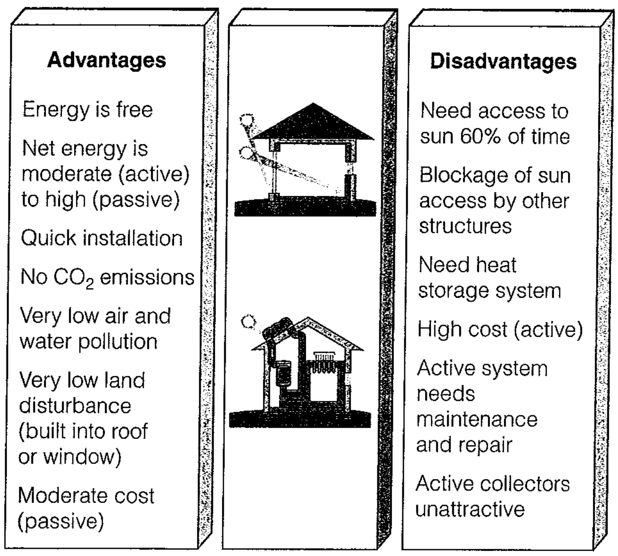
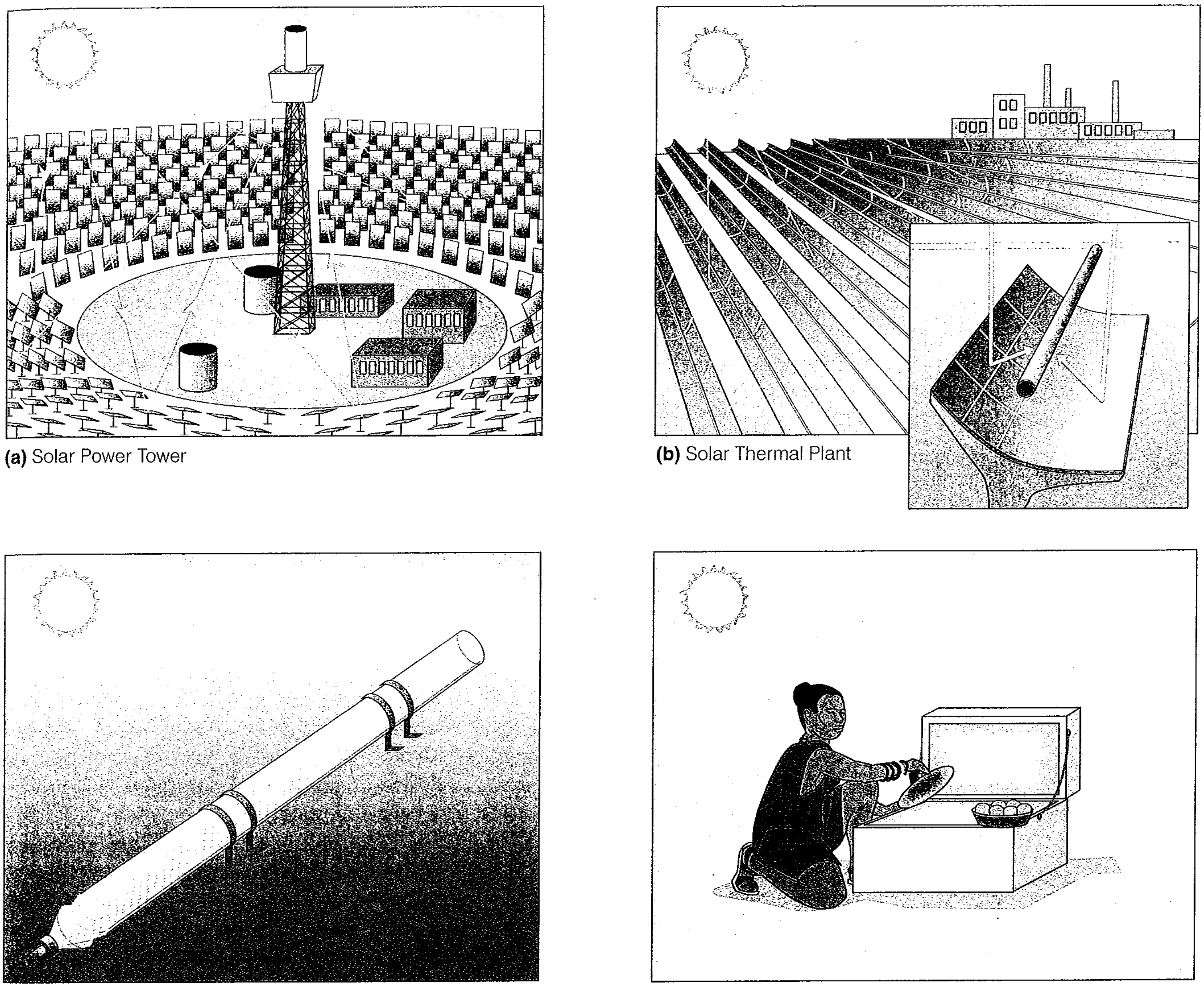


Figure 16-20 Advantages and disadvantages of heating a house with passive or active solar energy.

How Can We Use Solar Energy to Generate High-Temperature Heat and Electricity? Several so-called *solar thermal systems* collect and transform radiant energy from the sun into high-temperature thermal energy (heat), which can be used directly or converted to electricity (Figure 16-21). Examples include the following:

- A *central receiver system,* called a *power tower,* in which huge arrays of computer-controlled mirrors called *heliostats* track the sun and focus sunlight on a central heat collection tower (Figure 16-21a).
- A *solar thermal plant* or *distributed receiver system,* in which sunlight is collected and focused on oil-filled pipes running through the middle of curved solar collectors (Figure 16-21b). This concentrated sunlight can generate temperatures high enough for industrial processes or for producing steam to run turbines and generate electricity. At night or on cloudy days, high-efficiency combined-cycle natural gas turbines can supply backup electricity as needed.
- A distributed receiver system which uses *parabolic dish collectors* (which look somewhat like TV satellite



(a) Solar Power Tower

(b) Solar Thermal Plant

(c) Nonimaging Optical Solar Concentrator

(d) Solar Cooker

Figure 16-21 Several ways to collect and concentrate solar energy to produce high-temperature heat and electricity. Because of their high costs (except for solar ovens), such systems are not expected to provide much of the world's energy.

dishes) instead of parabolic troughs. These collectors can track the sun along two axes and generally are more efficient than troughs. A pilot plant is being built in northern Australia. The DOE projects that within 10–20 years, parabolic dishes with a natural gas turbine backup should be able to produce electrical power costing about the same as that from coal-burning plants.

- A *nonimaging optical solar concentrator* which intensifies incoming solar energy about 80,000 times (Figure 16-21c).
- Inexpensive *solar cookers*, which can focus and concentrate sunlight and cook food, especially in rural villages in sunny developing countries. They can be made by fitting an insulated box big enough to hold three or four pots with a transparent, removable top (Figure 16-21d). Solar cookers reduce **(1)** deforestation for fuelwood, **(2)** the time and labor needed to collect firewood, and **(3)** indoor air pollution from smoky fires.

Figure 16-22 (p. 398) lists the advantages and disadvantages of concentrating solar energy to produce high-temperature heat or electricity. Most analysts do not expect widespread use of such technologies over the next few decades because of **(1)** their high costs, **(2)** lack of sufficient tax breaks and government research and development funding, and **(3)** the availability of much cheaper ways to produce electricity such as combined-cycle natural gas turbines and wind turbines.

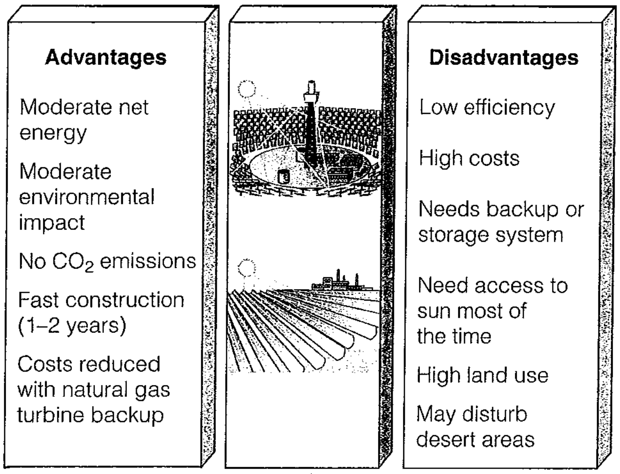


Figure 16-22 Advantages and disadvantages of using solar energy to generate high-temperature heat and electricity.

How Can We Produce Electricity with Solar Cells? Solar energy can be converted directly into electrical energy by **photovoltaic (PV) cells,** commonly called **solar cells** (Figure 16-23). A solar cell is a transparent wafer containing a *semiconductor* material with a thickness ranging from less than that of a human hair to that of a sheet of paper. Sunlight energizes and causes electrons in the semiconductor to flow, creating an electrical current.

Because a single solar cell produces only a tiny amount of electricity, many cells are wired together in modular panels to produce the amount of electricity needed. The resulting direct current (DC) electricity can be **(1)** stored in batteries and used directly or **(2)** converted to conventional alternating-current (AC) electricity by a separate inverter or an inverter built into the cells (Guest Essay, p. 390).

Traditional-looking solar-cell roof shingles and roofing material (developed in Japan) reduce the cost of solar-cell installations by saving on roof costs (Figure 16-23). Glass walls and windows of buildings can also have built-in solar cells. With this technology, the roof and glass walls and windows become a building's power plant.

Easily expandable banks of solar cells can be used to **(1)** provide electricity for 1.7 billion people in rural villages of developing countries who have no electricity, **(2)** produce electricity at a small power plant, using combined-cycle natural gas turbines to provide backup power when the sun is not shining, and **(3)** convert water to hydrogen gas that can be distributed to energy users by pipeline, as natural gas is. With financing from the World Bank, India (the world's number-one market for solar cells) is installing solar-cell systems in 38,000 villages, and Zimbabwe is bringing solar electricity to 2,500 villages.

Oberlin College in Ohio recently built a new environmental studies center incorporating major elements of *green design,* including use of passive solar energy and solar cells (Figure 16-24). David Orr (head of Oberlin's environmental studies program) designed the building with the help of more than 250 students, faculty, and townspeople.

Figure 16-25 (p. 400) lists the advantages and disadvantages of solar cells. By 2001, about 1 million homes in the world (200,000 in the United States) were getting some or all of their electricity from solar cells. About 700,000 of these homes were located in villages in developing countries.

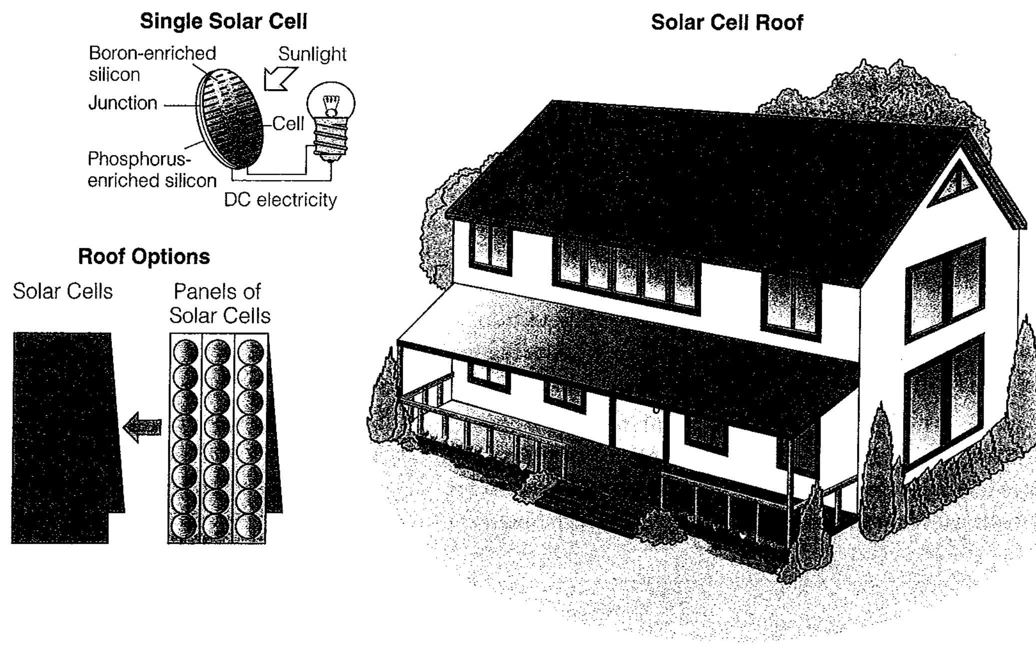


Figure 16-23 Photovoltaic (PV) (solar) cells can provide electricity for a house or building using new solar-cell roof shingles or PV panel roof systems that look like metal roofs. Small and easily expandable arrays of such cells can provide electricity for urban villages throughout the world without large power plants or power lines. Large banks of such cells can also produce electricity at a small power plant for direct use or for converting water to hydrogen fuel. As the price of such electricity drops, usage is expected to increase dramatically.

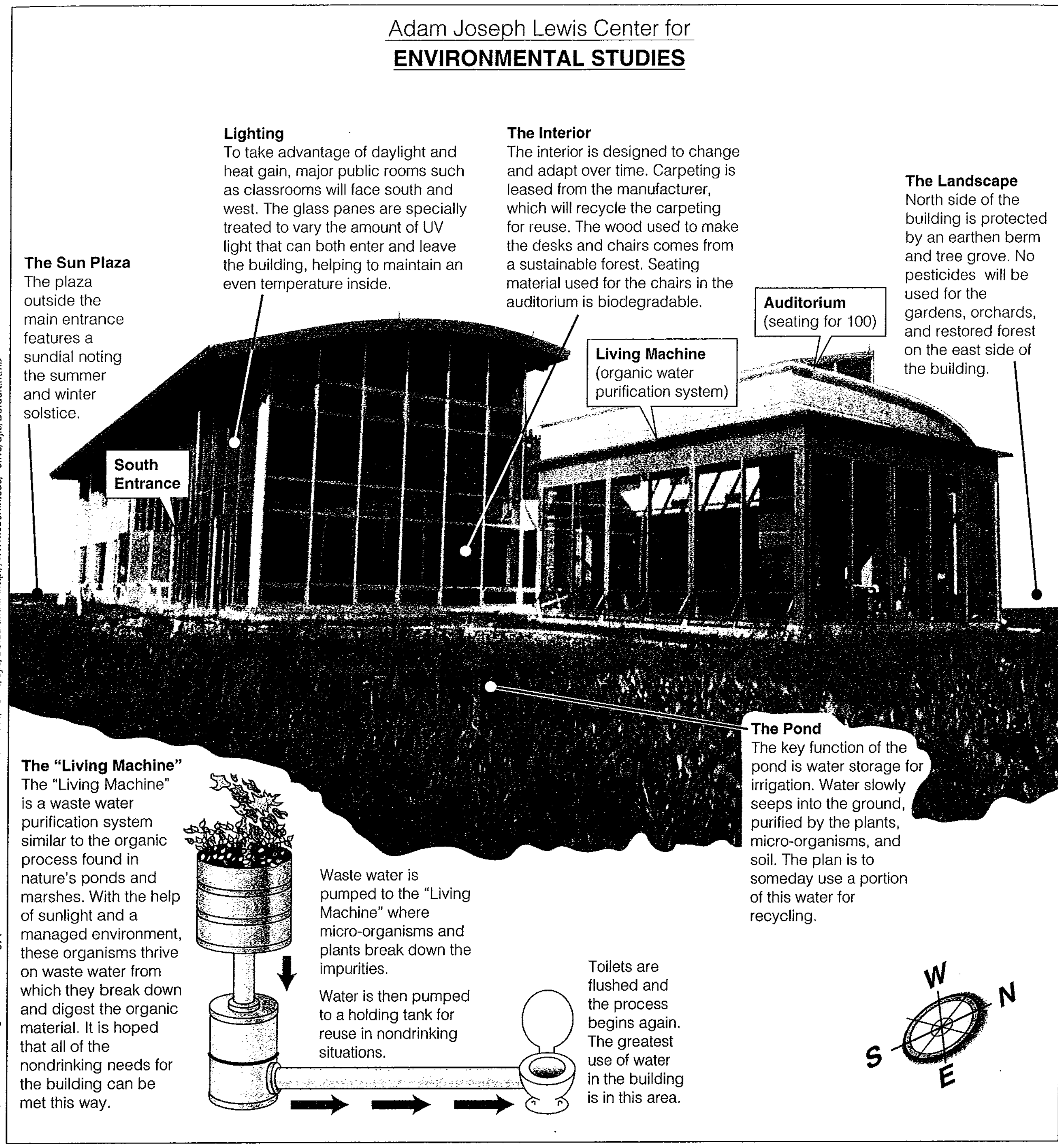


Figure 16-24 Major elements of green design in the Adam Joseph Lewis Center for Environmental Studies at Oberlin College in Ohio. There were no waste products as a result of the construction and no use of toxic materials. The building is the brainchild of David Orr (head of Oberlin's Environmental Studies program) and a number of students, faculty, and townspeople. In North Carolina, Catawba College's Center for the Environment is also a model of green design.

Current costs of producing electricity from solar cells are high, but costs are expected to drop because of **(1)** greatly increased research by major corporations and many governments in solar-cell design (based on use of very thin films of cheap amorphous silicon and possibly carbon-based polymers) and manufacturing technology and **(2)** savings from mass production of solar cells. Researchers are developing ways to make solar cells out of thin and flexible plastic materials that can be stuck on windows and and can be mixed and painted onto houses, cars, and other surfaces.

Currently solar cells supply less than 1% of the world's electricity. With a strong push from governments and private investors, by 2050 they could

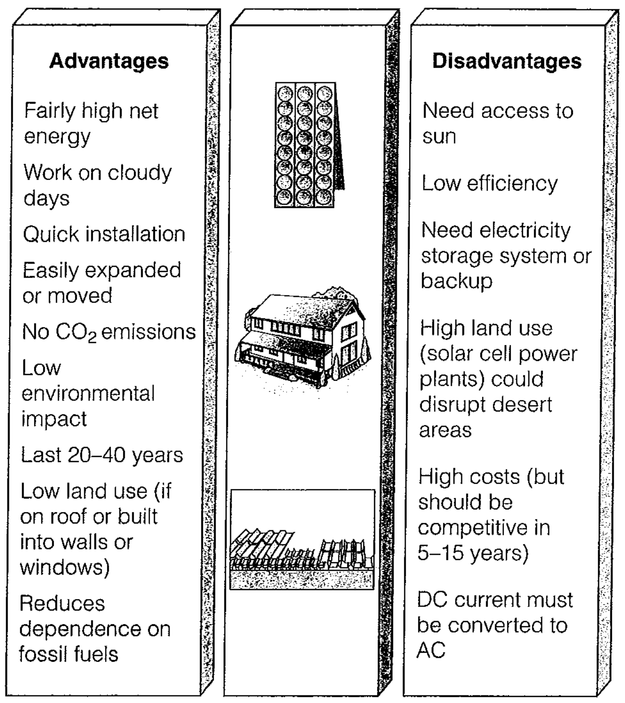


Figure 16-25 Advantages and disadvantages of using solar cells to produce electricity.

provide up to 25% of the world's electricity (at least 35% in the United States). If such projections are correct, the production, sale, and installation of solar cells could become one of the world's largest and fastest growing businesses.

Critics of solar energy contend that producing electricity using large banks of solar cells, solar thermal plants (Figure 16-21b), and wind farms (see photo in table of contents, p. xx) uses too much land. However, these three ways of producing electricity use less land per unit of electricity produced than coal (including the land disrupted from coal mining), the most widely used method for producing electricity (Figure 16-26).

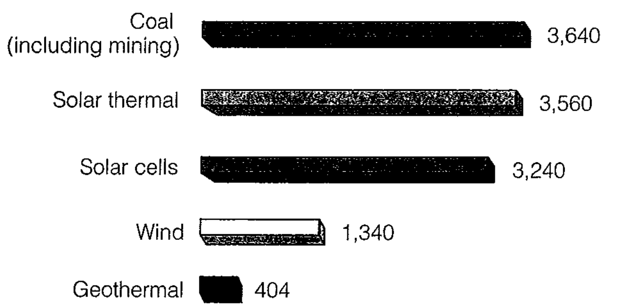


Figure 16-26 Approximate land use of various systems for producing electricity in the United States. Numbers give the land occupied in square meters per gigawatt-hour of electricity produced for 30 years. (Data from Worldwatch Institute).

16-4 PRODUCING ELECTRICITY FROM MOVING WATER AND FROM HEAT STORED IN WATER

How Can We Produce Electricity Using Hydropower Plants? Electricity can be produced from flowing water by

- *Large-scale hydropower,* in which a high dam is built across a large river to create a reservoir (Figure 14-9, p. 319). Some of the water stored in the reservoir is allowed to flow through huge pipes at controlled rates, spinning turbines and producing electricity.
- *Small-scale hydropower,* in which a low dam with no reservoir (or only a small one) is built across a small stream, and the stream's flow of water is used to spin turbines and produce electricity.
- *Pumped-storage hydropower,* in which pumps using surplus electricity from a conventional power plant pump water from a lake or a reservoir to another reservoir at a higher elevation. When more electricity is needed, water in the upper reservoir is released, flows through turbines, and generates electricity on its return to the lower reservoir.

Hydropower supplies about **(1)** 6% of the world's total commercial energy (3–4% in the United States), **(2)** 20% of the world's electricity (10% in the United States but about 63% of the power used along the West Coast), and **(3)** 99% of the electricity in Norway, 75% in New Zealand, 50% in developing countries, and 25% in China.

Figure 16-27 lists the advantages and disadvantages of using large-scale hydropower plants to produce electricity. According to the United Nations, only about 13% of the world's technically exploitable potential for hydropower has been developed, with much of this untapped potential in South Asia (especially China, Case study, p. 320), South America, and parts of the former Soviet Union.

Because of increasing concern about the harmful environmental and social consequences of large dams (Figure 14-9, p. 319), there has been growing pressure on the World Bank and other development agencies to stop funding new large-scale hydropower projects. In 2000, the World Commission on Dams published a study indicating that hydropower is a major emitter of greenhouse gases. This occurs because reservoirs that power the dams can trap rotting vegetation, which can emit greenhouse gases such as CO_2 and CH_4.

Small-scale hydropower projects eliminate most of the harmful environmental effects of large-scale projects, but they can **(1)** threaten recreational activities and aquatic life, **(2)** disrupt the flow of wild and

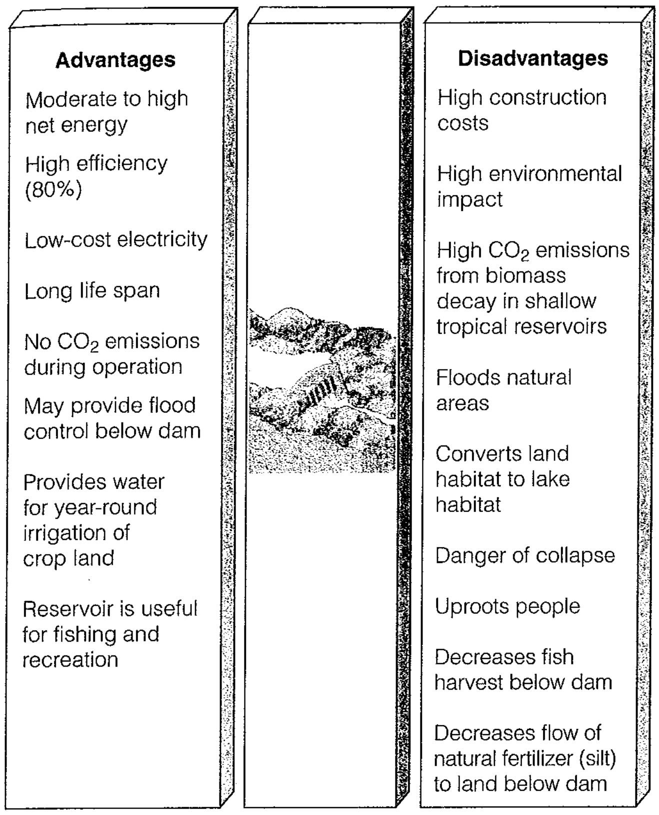


Figure 16-27 Advantages and disadvantages of using large dams and reservoirs to produce electricity.

scenic rivers, and **(3)** destroy wetlands. In addition, their electrical output can vary with seasonal changes in stream flow.

Is Producing Electricity from Tides and Waves a Useful Option? Twice a day in high and low tides, water that flows into and out of coastal bays and estuaries can spin turbines to produce electricity. Two large tidal energy facilities are currently operating, one at La Rance in France and the other in Canada's Bay of Fundy. However, most analysts expect tidal power to make only a tiny contribution to world electricity supplies because of a lack of suitable sites and high construction costs.

The kinetic energy in ocean waves, created primarily by wind, is another potential source of electricity. Most analysts expect wave power to make little contribution to world electricity production, except in a few coastal areas with the right conditions (such as western England).

How Can We Produce Electricity from Heat Stored in Water? Japan and the United States have been evaluating the use of the large temperature differences (between the cold deep waters and the sun-warmed surface waters) of tropical oceans for producing electricity. If economically feasible, this would be done in *ocean thermal energy conversion* (*OTEC*) plants anchored to the bottom of tropical oceans in suitable sites. However, most energy analysts believe the large-scale extraction of energy from ocean thermal gradients may never compete economically with other energy alternatives.

Saline solar ponds, usually located near inland saline seas or lakes in areas with ample sunlight, can be used to produce electricity. Heat accumulated during the day in the denser bottom layer can be used to produce steam that spins turbines, generating electricity. A small experimental saline solar pond power plant on the shore of the Israeli side of the Dead Sea operated for several years but was closed in 1989 because of high operating costs.

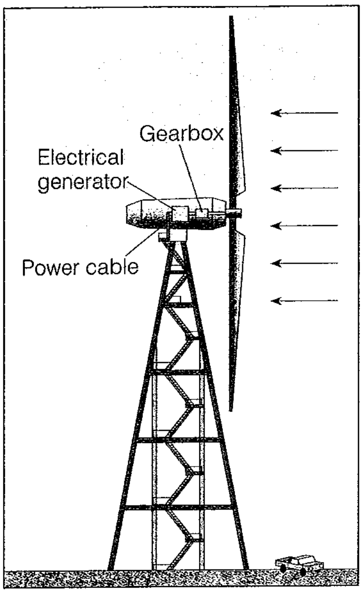
Freshwater solar ponds can be used to heat water and space. A shallow hole is dug and lined with concrete. A number of large black plastic bags, each filled with several centimeters of water, are placed in the hole and then covered with fiberglass insulation panels. The panels let sunlight in but keep most of the heat stored in the water during the daytime from being lost to the atmosphere. When the water in the bags has reached its peak temperature in the afternoon, a computer turns on pumps to transfer hot water from the bags to large insulated tanks for distribution.

Saline and freshwater solar ponds **(1)** use no energy storage and backup systems, **(2)** emit no air pollution, and **(3)** have a moderate net energy yield. Freshwater solar ponds can be built in almost any sunny area and have moderate construction and operating costs. However, saline and freshwater solar ponds are expected to make little contribution to global energy supplies in the foreseeable future.

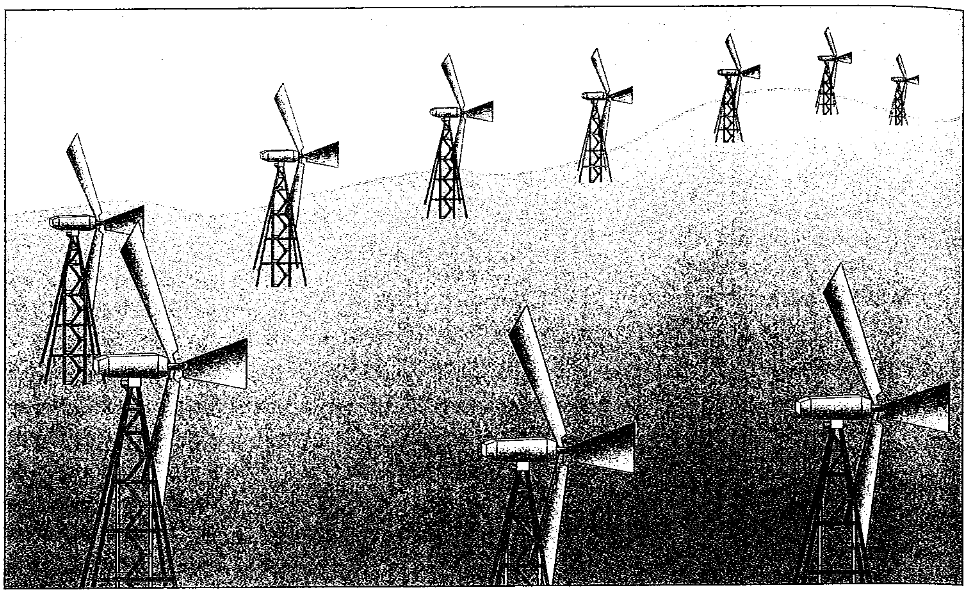
16-5 PRODUCING ELECTRICITY FROM WIND

What Is the Status of Wind Power? In 2001, wind turbines (Figure 16-28, p. 402) worldwide produced almost 25,000 megawatts of electricity, enough to meet the needs of about 7 million homes. About 70% of the world's wind power is produced in Europe, especially in Germany, Spain, and Denmark.

In 2001, the price of electricity produced by wind at prime sites in the United States was about 4¢ per kilowatt-hour (down from 38¢ per kilowatt-hour in the early 1980s). This is **(1)** almost equal to the cost of electricity produced by new coal-fired power plants and half the cost if coal's health and environmental costs are included and **(2)** about half the cost of nuclear power if all nuclear fuel cycle costs (Figure 15-36, p. 367) are taken into account.



Wind Turbine



Wind Farm

Figure 16-28 Wind turbines can be used to produce electricity individually or in clusters called wind farms. Since 1990, wind power has been the world's fastest growing source of energy.

The global wind power industry was a $7 billion business in 2001. Increased investments in wind power by governments and large corporation should reduce its costs further from technological innovations and savings from mass production of wind turbines.

Figure 16-29 shows the potential areas for use of wind power in the United States. The DOE calls the midwestern United States the "Saudi Arabia of wind." The Dakotas and Texas alone have enough wind resources to meet all the nation's electricity needs.

What Areas Have the Greatest Potential for Wind Power? In 2001, Western European countries produced 2% of their electricity from wind (18% in Denmark). These countries expect to get at least 10% of their electricity from onshore and offshore wind turbines within 10 years. The German government plans to get 25% of its electricity from wind power by 2025, much of it from building offshore wind farms in the Baltic and the North Sea.

Wind power also is being developed rapidly in India (the world's number-two market for wind energy), and China could easily double its wind-generating capacity.

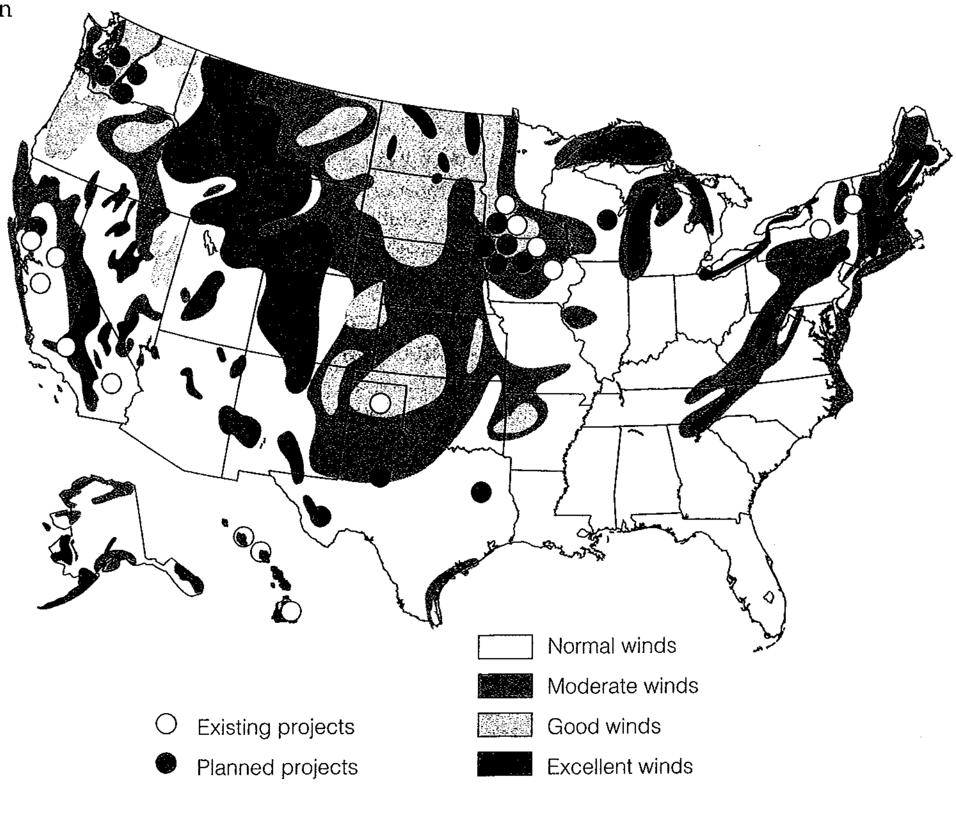


Figure 16-29 Potential for use of wind power in the United States. In principle, exploiting the wind potential of just three states—North Dakota, South Dakota, and Texas—could provide all the power needs of the United States. (Data from U.S. Department of Energy)

A growing number of U.S. farmers and ranchers are boosting their income by leasing some of their cropland or ranchland for wind turbines while still growing crops or grazing cattle around the turbines. Currently, a U.S. farmer or rancher who leases 0.10 hectare (0.25 acre) of cropland or rangeland to the local utility as a site for a wind turbine can easily get $2,000 a year in royalties from providing the local community with electricity worth $100,000. Some are making more money by leasing their land for wind power production than from growing crops or raising cattle. This explains why many U.S. farmers and ranchers are joining environmentalists and wind industry executives in urging political leaders to increase government research and development and tax breaks for wind power. Because most money from wind power stays in local communities, using this resource can boost the economies of rural areas in the United States and elsewhere.

In the 1980s, the United States led the world in the development of wind power. But the country frittered away its lead by meager government research and development funds and tax credits compared to most Western European countries and to those available for fossil fuels and nuclear power. In 2001, wind produced only 0.3% of U.S. electricity. A modest wind power tax credit enacted by the U.S. Congress expired at the end of 2001 and has not been renewed. In addition, the Bush administration proposed cutting already modest federal research and development funds for wind power in 2002 and 2003 in half while greatly increasing research funds and tax breaks for coal and nuclear power.

What Are the Major Advantages and Disadvantages of Wind Power? Figure 16-30 lists the advantages and disadvantages of using wind to produce electricity. Some critics have alleged that wind turbines suck large numbers of birds into their wind stream. However, studies have shown that much larger numbers of birds die when they **(1)** are sucked into jet engines, **(2)** crash into skyscrapers, plate glass windows, communications towers, and car windows and **(3)** are killed by domesticated and feral cats. As long as wind farms are not located along bird migration routes most birds learn to fly around them.

In addition, much larger numbers of birds, fish, and other forms of wildlife are killed by oil spills, air pollution, water pollution, and release of toxic wastes from use of fossil fuels such as coal and oil. The key questions are **(1)** which types of energy resources lead to the lowest loss of wildlife and **(2)** how loss of wildlife from use of any energy resource can be minimized.

In the long run, electricity from large wind farms in remote areas might be used to make hydrogen gas from water during off-peak periods—thus storing electricity from excess wind capacity in a useful fuel. The hydrogen could then be fed into a pipeline and storage system for fuel cells or gas turbines used to power cars, homes, and buildings.

Advantages

Moderate to high net energy

High efficiency

Moderate capital cost

Low electricity cost (and falling)

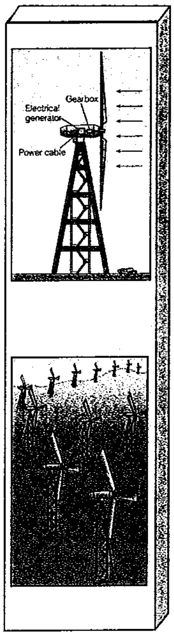
Very low environmental impact

No CO_2 emissions

Quick construction

Easily expanded

Land below turbines can be used to grow crops or graze livestock



Disadvantages

Steady winds needed

Backup systems needed when winds are low

High land use for wind farm

Visual pollution

Noise when located near populated areas

May interfere in flights of migratory birds and kill birds of prey

Figure 16-30 Advantages and disadvantages of using wind to produce electricity. Wind power experts project that 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.

Increasingly, many governments and corporations are recognizing that wind is a vast, climate-benign, renewable energy resource that can supply both electricity and hydrogen fuel at an affordable cost. If its current growth rate continues, wind power could produce 10% of the world's electricity by 2020.

16-6 PRODUCING ENERGY FROM BIOMASS

How Useful Is Burning Solid Biomass? Biomass is plant materials and animal wastes used as sources of energy. Biomass comes in many forms and can be burned directly as a solid fuel or converted into gaseous or liquid **biofuels** (Figure 16-31, p. 404).

Most biomass is burned **(1)** directly for heating, cooking, and industrial processes or **(2)** indirectly to drive turbines and produce electricity. Burning wood and manure for heating and cooking supplies about 11% of the world's energy and about 30% of the energy used in developing countries. Almost 70% of the people living in developing countries heat their homes and cook their food by burning wood or charcoal. However, about 2.7 billion people in these countries cannot find or are too poor to buy enough fuelwood to meet their needs.

In the United States, biomass is used to supply about 4% of the country's commercial energy and 2%

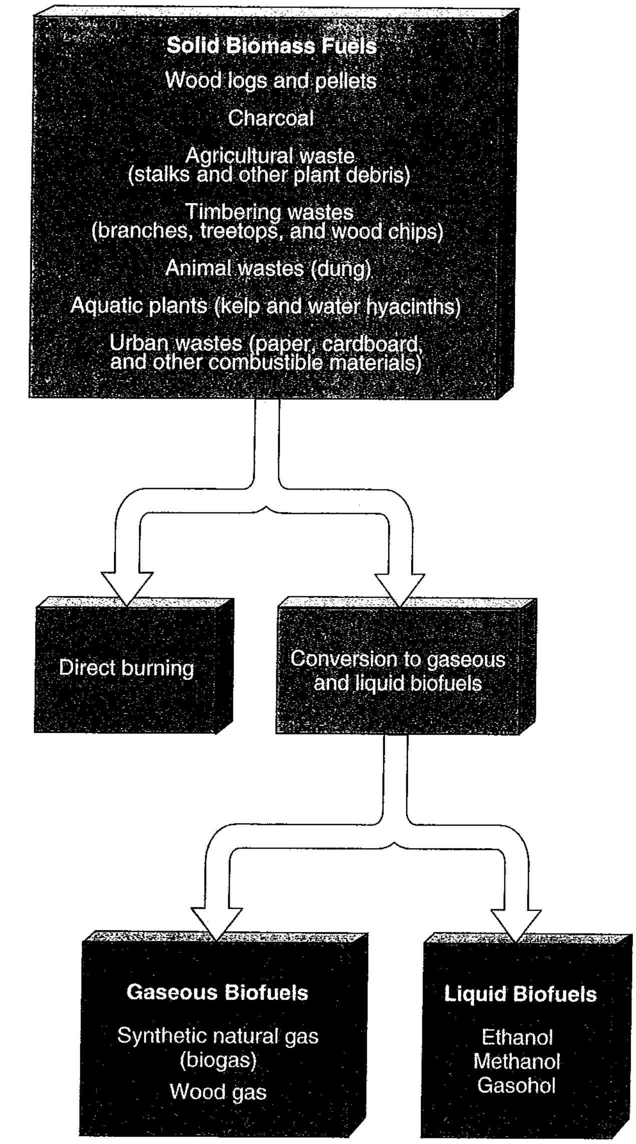


Figure 16-31 Principal types of biomass fuel.

of its electricity (produced by about 350 biomass power plants). The U.S. government has a goal of increasing the use of biomass energy to 9% of the country's total commercial energy by 2010.

One way to produce biomass fuel is to plant, harvest, and burn large numbers of **(1)** fast-growing trees (especially cottonwoods, poplars, sycamores, willows, and leucaenas), **(2)** shrubs, **(3)** perennial grasses (such as switchgrass), and **(4)** water hyacinths in *biomass plantations.*

In agricultural areas, *crop residues* (such as sugarcane residues, rice husks, cotton stalks, and coconut shells) and *animal manure* can be collected and burned or converted into biofuels. According to a 1999 study by the Union of Concerned Scientists, energy crops and crop wastes from the Midwest alone could theoretically provide about 16% of the electricity used in the United States, without irrigation and without competing with food crops for land. Some ecologists argue that it makes more sense to use animal manure as a fertilizer and crop residues to feed livestock, retard soil erosion, and fertilize the soil.

Figure 16-32 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.

Is Producing Gaseous and Liquid Fuels from Solid Biomass a Useful Option? Bacteria and various chemical processes can convert some forms of biomass into gaseous and liquid biofuels (Figure 16-31). Examples include **(1)** *biogas,* a mixture of 60% methane and 40% CO_2, **(2)** *liquid ethanol* (ethyl, or grain, alcohol), and **(3)** *liquid methanol* (methyl, or wood alcohol).

In China, anaerobic bacteria in more than 6 million *biogas digesters* convert plant and animal wastes into methane fuel for heating and cooking. These simple devices can be built for about $50 including labor. After the biogas has been separated, the solid residue is used as fertilizer on food crops or, if contaminated, on trees. When they work, biogas digesters are very

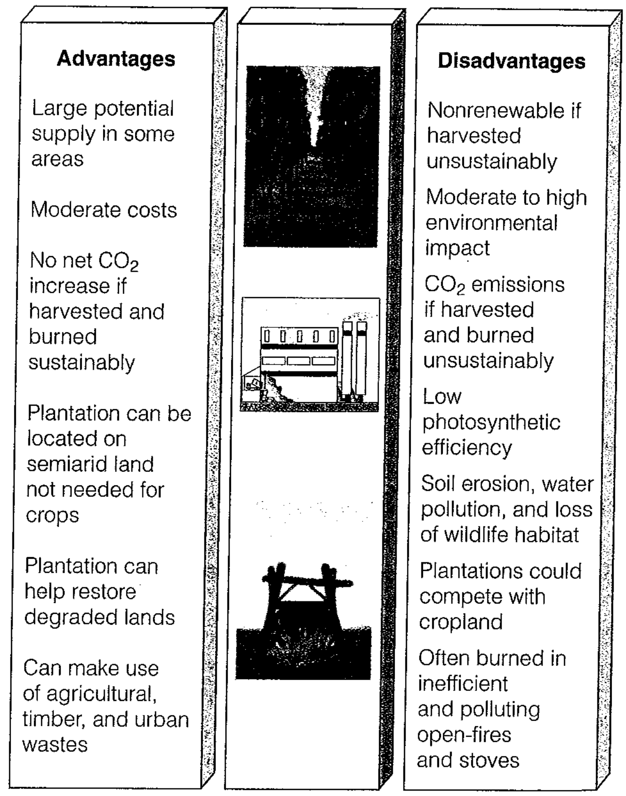


Figure 16-32 General advantages and disadvantages of burning solid biomass as a fuel.

efficient. However, they are also slow and unpredictable, a problem that could be corrected by developing more reliable models.

Some analysts believe liquid ethanol and methanol produced from biomass could replace gasoline and diesel fuel when oil becomes too scarce and expensive. *Ethanol* can be made from sugar and grain crops (sugarcane, sugar beets, sorghum, sunflowers, and corn) by fermentation and distillation. Gasoline mixed with 10–23% pure ethanol makes *gasohol,* which can be burned in conventional gasoline engines and is sold as super unleaded or ethanol-enriched gasoline.

Another alcohol, *methanol,* is made mostly from natural gas but also can be produced at a higher cost from wood, wood wastes, agricultural wastes (such as corncobs), sewage sludge, garbage, and coal. Some of the first generation of cars using hydrogen-powered fuel cells (Figure 16-10) will use reformers to convert carbon-containing natural gas, gasoline, or methanol to hydrogen. The advantages and disadvantages of using ethanol, methanol, and several other fuels as alternatives to gasoline are summarized in Table 16-1, p. 406. According to a 1997 analysis by David Pimentel and two other researchers, "Large-scale biofuel production is not an alternative to the current use of oil and is not even an advisable option to cover a significant fraction of it."

16-7 THE SOLAR–HYDROGEN REVOLUTION

What Can We Use to Replace Oil? Goodbye Oil and Smog, Hello Hydrogen When oil is gone (or when what is left costs too much to use), how will we fuel vehicles, industry, and buildings? Many scientists and executives of major oil companies and automobile companies say the fuel of the future is hydrogen gas (H_2) (Table 16-1, p. 406)—envisioned in 1874 by science fiction writer Jules Verne in his book *The Mysterious Island.*

When hydrogen gas burns in air, it combines with oxygen gas in the air and produces nonpolluting water vapor ($2H_2 + O_2 \longrightarrow 2H_2O$).* Widespread use of this fuel would **(1)** eliminate most of the air pollution problems we face today and **(2)** greatly reduce the threats from global warming by emitting no CO_2 (as long as the hydrogen is not produced from fossil fuels or other carbon-containing compounds).

The *bad news* is that although hydrogen is all around us it is chemically locked up in water and organic compounds such as methane and gasoline. But the *good news* is that we can produce it from something we have plenty of: *water.* Water can be split by electricity (electrolysis) or high temperatures (thermolysis) into gaseous hydrogen and oxygen (Figure 16-33, p. 407). Hydrogen can also be produced **(1)** by *reforming,* in which high temperatures and chemical processes are used to separate hydrogen from carbon atoms in organic chemicals (hydrocarbons) found in conventional carbon-containing fuels such as natural gas, gasoline, or methanol, **(2)** from gasification of coal (Figure 15-33, p. 365) or biomass, and **(3)** by some types of algae and bacteria (Spotlight, p. 408). These various sources of hydrogen could become, as some scientists put it, "tomorrow's oil" and be used to provide most of the energy need to run an economy (Figure 16-34, p. 407).

What Is the Catch? If you think using H_2 as our major energy source sounds too good to be true, you are right. Several problems must be solved to make hydrogen one of our primary energy resources, but scientists are making rapid progress in finding solutions to these challenges.

One problem is that it takes energy (and thus money) to produce this fuel. We could burn coal to produce high-temperature heat or use electricity from coal-burning and nuclear power plants to split water and produce hydrogen. However, doing this **(1)** subjects us to the harmful environmental effects associated with using these fuels (Figure 15-31, p. 364; Figure 15-38, p. 369; and Figure 15-39, p. 369), and **(2)** costs more than the hydrogen fuel is worth. We can also produce hydrogen by coal gasification or from carbon-containing methane (natural gas), gasoline, or methanol, but this adds CO_2 to the atmosphere.

Most proponents of using hydrogen gas believe that if we are to get its very low pollution benefits, the energy needed to produce H_2 by decomposing water must come from renewable energy, probably in the form of electricity generated by solar cells, wind farms, hydropower, and geothermal energy (p. 409) or by bacteria and algae through *biolysis* (Spotlight, p. 408). The type of renewable energy used would vary in different parts of the world depending on its local and regional availability.

If scientists and engineers can learn how to use various forms of direct and indirect solar energy to decompose water cheaply enough, they will set in motion a *solar–hydrogen revolution* over the next 50 years and change the world as much as the agricultural and industrial revolutions did. In effect, the world would shift from carbon-based *fossil fuel economies* (Figure 15-12, p. 351) to decarbonized *hydrogen economies* powered increasingly by using solar energy to produce hydrogen gas from water (Figure 15-16, p. 353). By using renewable solar energy, such an economy would

*Water vapor is a potent greenhouse gas. However, because there is already so much of it in the atmosphere, human additions of this gas are insignificant.

Table 16-1 Evaluation of Alternatives to Gasoline

Advantages	Disadvantages
Compressed Natural Gas	
Fairly abundant, inexpensive domestic and global supplies Low hydrocarbon, CO, and CO_2 emissions Vehicle development advanced; well suited for fleet vehicles Reduced engine maintenance	Large fuel tank needed; one-fourth the range Expensive engine modification needed ($2,000) New filling stations needed Nonrenewable resource
Electricity	
Renewable if not generated from fossil fuels or nuclear power Zero vehicle emissions Electric grid in place Efficient and quiet	Limited range and power Batteries expensive Slow refueling (6–8 hours) Power plant emissions if generated from coal or oil
Reformulated Gasoline (Oxygenated Fuel)	
No new filling stations needed Low to moderate CO emissions reduction No engine modification needed	Nonrenewable resource Dependence on imported oil perpetuated No CO_2 emission reduction Higher cost Groundwater contaminated by leakage and spills (especially by MTBE, a possible human carcinogen) No longer needed because of improved emission control system
A-55 (55% water, 45% naphtha)	
Can be sold in conventional filling station Much lower emissions of nitrogen oxide and particulates than diesel fuel Cannot explode or catch fire Lower cost (25–50%) Naphtha produces 90% less pollution at refineries than gasoline or diesel fuel Low-cost engine modification ($300 for cars, $1,000 for trucks and buses) Modified engine can run A-55, gasoline, or diesel	Not yet widely available Independent tests needed to verify pollution reduction claims Refineries may limit supply or drive up price of less-profitable naphtha (Figure 15-18, p. 355) Large amounts of water needed to produce
Methanol	
High octane Reduction of CO_2 emissions (total amount depends on method of production) Reduced total air pollution (30–40%) Can be made from natural gas	Large fuel tank needed; one-half the range Corrosive to metal, rubber, plastic Increased emissions of potentially carcinogenic formaldehyde High CO_2 emissions if generated by coal High capital cost to produce Hard to start in cold weather
Ethanol	
High octane Reduction of CO_2 emissions (total amount depends on distillation process and efficiency of crop growing) Reduction of CO emissions Potentially renewable	Large fuel tank needed; lower range Cannot be shipped in multifuel pipelines Much higher cost Corn supply limited Competition with food growing for cropland Higher emissions of smog-forming compounds Higher emissions of NO Corrosive Hard to start in cold weather
Solar–Hydrogen	
Renewable if produced using solar energy High-energy fuel Lower flammability than gasoline Potentially unlimited supply if produced from water Virtually emission-free No emissions of CO_2 Nontoxic	Nonrenewable if generated by fossil fuels or nuclear power Large fuel tank needed No distribution system in place Engine redesign needed Currently expensive

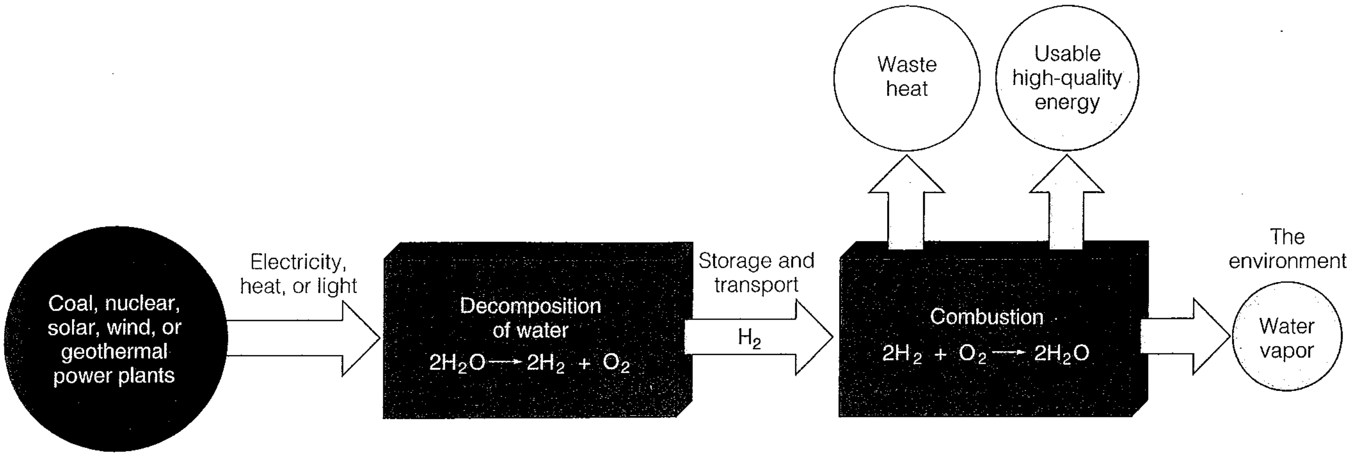


Figure 16-33 Hydrogen gas as an energy source. Producing hydrogen gas takes electricity, heat, or solar energy to decompose water, thus leading to a negative net energy yield. However, hydrogen is a clean-burning fuel that can replace oil, other fossil fuels, and nuclear energy. Using solar energy (probably solar cells and wind turbines) to produce hydrogen from water could eliminate most air pollution and greatly reduce the threat of global warming.

follow the first of the four principles of sustainability based on observing how the earth sustains itself (Solutions, p. 201).

Methane from natural gas may be used to produce hydrogen in the transition to a true renewable hydrogen system because of its **(1)** large supply (p. 362) and **(2)** lower production of air pollutants and CO_2 (Figure 15-25, p. 358) compared to other fossil fuels.

How Can We Store Hydrogen? Once produced, H_2 can be stored (Figure 16-34)

- In *compressed gas storage tanks,* either above or below ground or aboard motor vehicles. The technology is available, but the costs of tanks and compression are high. Storage tanks are too heavy and large for use in cars but can be used in buses and large trucks.
- As *liquid hydrogen.* Condensing hydrogen gas into more dense liquid form allows a larger quantity of hydrogen to be stored in stationary containers or aboard motor vehicles. However, the liquid hydrogen must be stored at very low temperatures below −250°C (−420°F), which is costly, takes a large input of energy (as much as 30% of the hydrogen's original fuel energy), and requires a large amount of insulation. Liquid hydrogen could be transported in refrigerated tankers from one country to another, just as liquefied propane gas (LPG) is today.

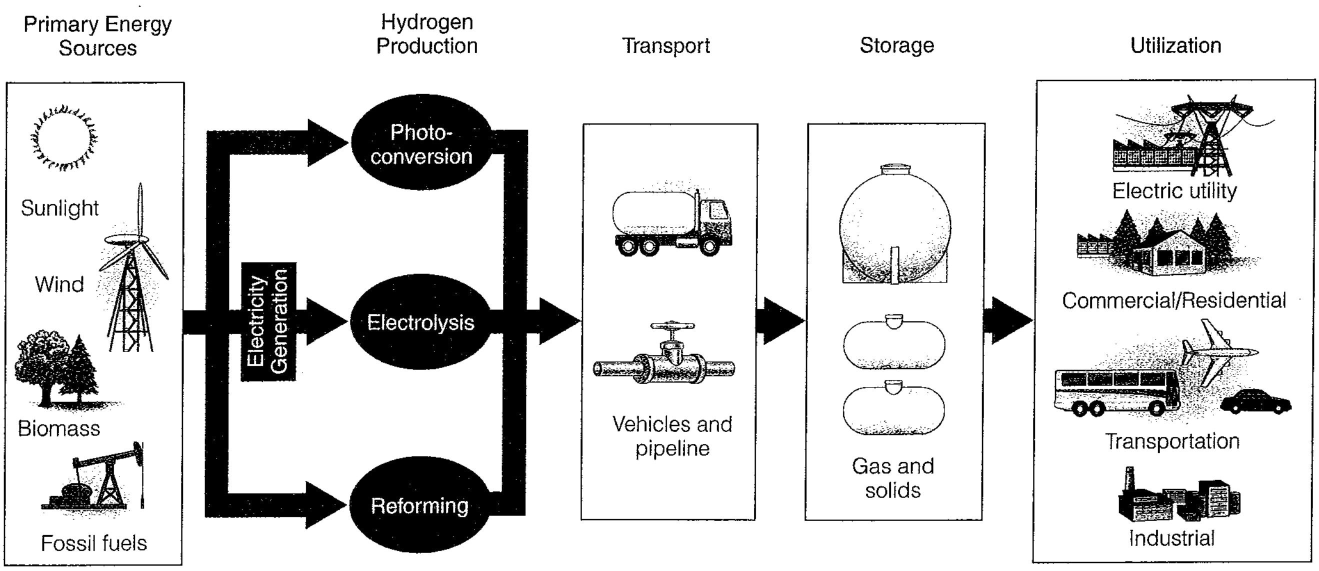


Figure 16-34 A hydrogen energy system. (Data from U.S. Department of Energy and the Worldwatch Institute)

SPOTLIGHT

Producing Hydrogen from Green Algae Found in Pond Scum

In a few decades we may be able to use large-scale cultures of green algae to produce hydrogen gas. This simple plant grows all over the world and is commonly found in pond scum.

When living in ordinary air and sunlight, green algae carry out photosynthesis like other plants and produce carbohydrates and oxygen gas. However, in 2000, Tasios Melis, a researcher at the University of California at Berkeley, found a way to make these algae produce bubbles of hydrogen rather than oxygen.

First, he grew cultures of hundreds of billions of the algae in the normal way with plenty of sunlight, nutrients, and water. Then he cut off their supply of two key nutrients: sulfur and oxygen. Within 20 hours, the plant cells underwent a metabolic change and switched from an oxygen-producing to a hydrogen-producing metabolism, allowing the researcher to collect hydrogen gas bubbling from the culture.

Melis believes he can increase the efficiency of this hydrogen-producing process tenfold. If so, sometime in the future a biological hydrogen plant might cycle a mixture of algae and water through a system of clear tubes exposed to sunlight to produce hydrogen. The gene responsible for producing the hydrogen might even be transferred to other plants to produce hydrogen.

Critical Thinking

What might be some ecological problems related to the widespread use of this method for producing hydrogen?

- *As solid metal hydride compounds.* When cooled, the metal absorbs and chemically bonds the hydrogen in the metal's latticework of atoms and when heated releases the hydrogen. This is a safe and efficient way to store hydrogen. However, current metal hydrides are costly, heavy, and require energy to release the hydrogen.
- *By absorption on activated charcoal or graphite nanofibers,* which when heated release hydrogen gas. Like hydrides, this is a safe and efficient way to store hydrogen, but an input of energy is needed to release the hydrogen.
- *Inside glass microspheres.* Currently, tiny glass spheres are being developed for this purpose.

Some *good news* is that metal hydrides (including sodium borohydride), charcoal powders, graphite nanofibers, and glass microspheres containing hydrogen will not explode or burn if a vehicle's tank is ruptured in an accident.

The *bad news* is that so far it is difficult to store enough hydrogen gas in a car as a compressed gas, liquid, or a solid for it to run very far. Scientists and engineers are seeking solutions to this problem.

What Is the Role of Fuel Cells in the Solar-Hydrogen Revolution? In a *fuel cell* (Figures 16-4 and 16-10), hydrogen and oxygen gas combine to produce electrical current. Various versions of such cells can be used to power a car or bus and meet the heating, cooling, and electrical needs of buildings.

Fuel cells **(1)** have energy efficiencies of 65–95% (several times the efficiency of conventional gasoline-powered engines and electric cars and at least twice the efficiency of coal-burning and nuclear power plants), **(2)** have no moving parts, **(3)** are quiet, **(4)** emit only water and heat but some CO_2 if the hydrogen is produced from carbon-containing substances such as gasoline, natural gas, propane, or methanol, and **(5)** are more reliable than the traditional electricity grid because they are not as susceptible to lightning strikes, fallen trees, and terrorist or military attacks.

Some fuel cells are tiny enough to fit into a cellular phone. Others are big enough to power a large building or factory and are currently used to provide electricity for buildings such as a police station in New York City's Central Park and a postal facility in Alaska. Smaller fuel cells can power bicycles, vacuum cleaners, laptop computers, lawn mowers, leaf blowers, and other devices.

With hydrogen-powered fuel cells, people would have their own personal power plant to run their lights, appliances, and car and to heat and cool their house. Progress toward this goal is being made:

- A number of prototype fuel-cell systems for cars, buses, homes, and buildings are being tested and evaluated.
- Buses are a good choice for hydrogen-powered fuel cells because they can **(1)** carry large and heavy fuel cells, **(2)** store large amounts of compressed hydrogen gas in roof-mounted tanks, and **(3)** be refueled at centralized facilities. Fleets of such buses are running in various cities of the world in the United States (Dearborn, Michigan, and Las Vegas, Nevada), Germany (Munich), Iceland (Reykjavik), Italy (Milan), and Japan (Osaka and Takamatsu).
- In 1999, DaimlerChrysler, Royal Dutch Shell, and Norsk Hydro announced government-approved plans to turn the tiny country of Iceland into the world's first "hydrogen economy" by 2030–2040—the brain-

child of chemist Bragi Árnason, known as "Professor Hydrogen." The country's abundant renewable geothermal energy, hydropower, and offshore winds will be used to produce hydrogen from seawater with the H_2 used to run its buses, passenger cars, fishing vessels, and factories. Royal Dutch Shell is already opening hydrogen filling stations in parts of Europe and plans to open a chain of such stations in Iceland.

The key problem with fuel cells so far is cost. For widespread use the price of fuel cells must be sharply reduced by improved technology and mass production. With greatly increased private and government-funded research and tax breaks, some analysts see this happening within 10 years. They envision fuel cells being used first by electric utilities, followed in order by midsize buildings, homes and small buildings, and motor vehicles.

What Are the Pros and Cons of Hydrogen as an Energy Resource? Figure 16-35 lists the pros and cons of using hydrogen as an energy resource. The U.S. Department of Energy has a goal of hydrogen energy providing 10% of all U.S. energy consumption by 2025.

Citizens and local and state officials can promote the transition to a hydrogen economy by creating *hydrogen cities* and regional *hydrogen utility districts.* Emphasis would be on **(1)** converting municipal buses and fleets of taxis, police vehicles, and other government vehicles to run on hydrogen, **(2)** establishing hydrogen refueling facilities along heavily traveled routes, and **(3)** using stationary fuel cells to power local schools, airports, and police stations and other government buildings.

Advantages	Disadvantages
Can be produced from water	Not found in nature
Low environmental impact	Energy is needed to produce fuel
No CO_2 emissions	Negative net energy
Good substitute for oil	Nonrenewable if generated by fossil fuels or nuclear power
Competitive price if environmental and social costs are included in cost comparisons	High costs (but expected to come down)
Easier to store than electricity	Short driving range for current fuel cell cars
Safer than gasoline and natural gas	No distribution system in place
High efficiency (65–95%) in fuel cells	

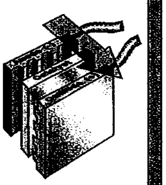


Figure 16-35 Advantages and disadvantages of using hydrogen as a fuel for vehicles and for providing heat and electricity.

16-8 GEOTHERMAL ENERGY

How Can We Tap the Earth's Internal Heat? Heat contained in underground rocks and fluids is an important source of energy. Over millions of years, this **geothermal energy** from the earth's mantle (Figure 10-3, p. 205, and Figure 10-4, p. 206) has been transferred to underground reservoirs of **(1)** *dry steam* (steam with no water droplets), **(2)** *wet steam* (a mixture of steam and water droplets), and **(3)** *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

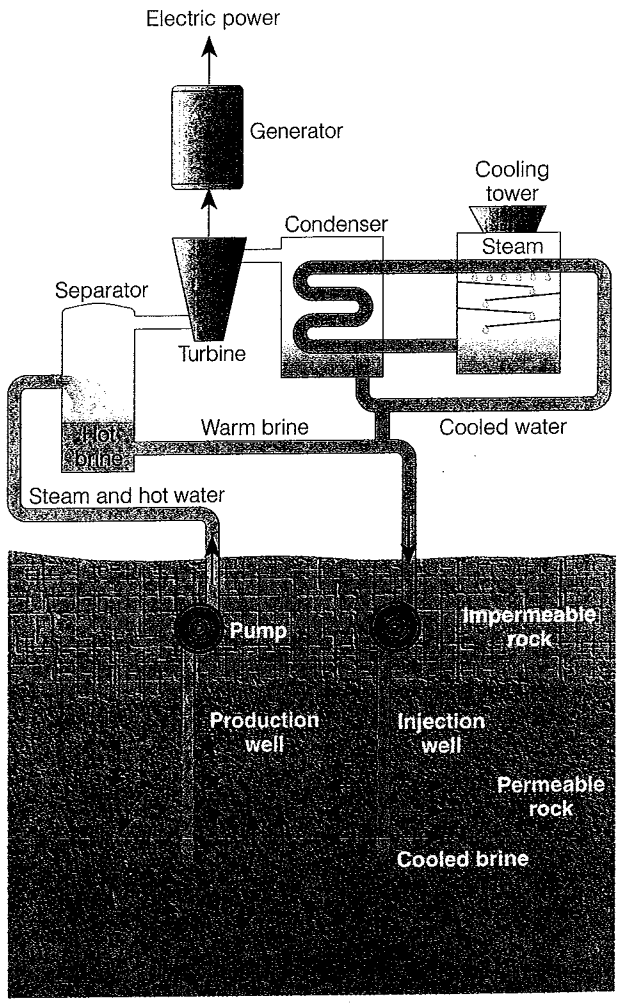


Figure 16-36 Tapping the earth's internal heat or *geothermal energy* in the form of wet steam to produce electricity.

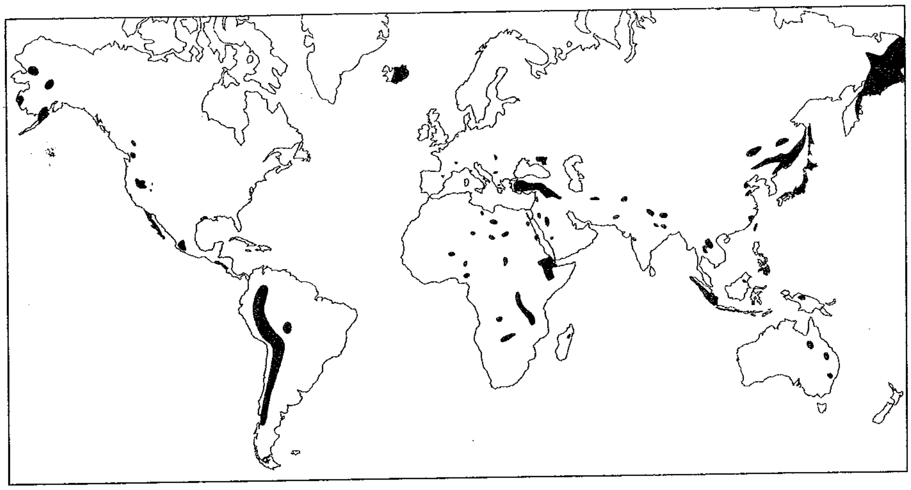


Figure 16-37 Known global reservoirs of moderate- to high-temperature geothermal energy. (Data from Canadian Geothermal Resources Council)

(Figure 16-36), or hot water. This thermal energy can be used to heat homes and buildings and to produce electricity. For example, geothermal energy is used to heat about 85% of Iceland's buildings.

Figure 16-37 shows the locations of the world's known reservoirs of moderate- to high-temperature geothermal energy. Currently, about 22 countries (most of them in the developing world) are extracting energy from geothermal sites to produce about 1% of the world's electricity. Japan, with an abundance of geothermal energy, could get an estimated 30% of its electricity from this energy resource.

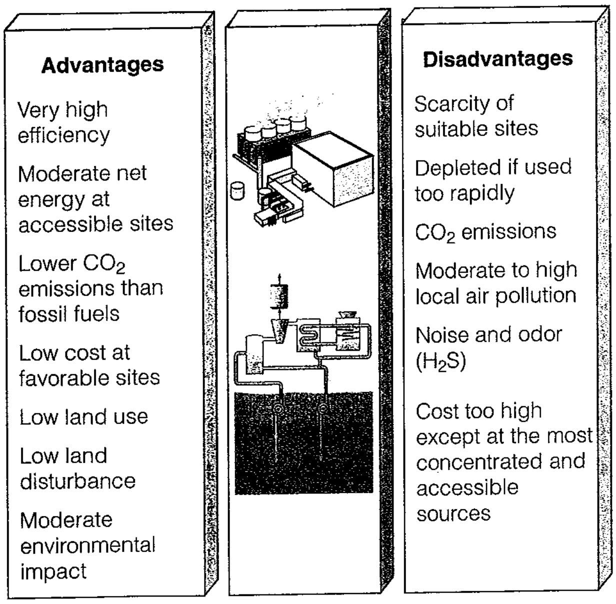


Figure 16-38 Advantages and disadvantages of using geothermal energy for space heating and to produce electricity or high-temperature heat for industrial processes.

However, geothermal reservoirs can be depleted if heat is removed faster than natural processes renew it. Thus geothermal resources can be nonrenewable on a human time scale, but the potential supply is so vast that it is usually classified as a renewable energy resource.

Geothermal electricity meets the electricity needs of 6 million Americans and supplies 6% of California's electricity. The world's largest operating geothermal system, called *The Geysers,* extracts energy from a dry steam reservoir north of San Francisco, California. But heat is being withdrawn from this geothermal site about 80 times faster than it is being replenished, converting this potentially renewable resource to a nonrenewable source of energy. In 1999, Santa Monica, California, became the first city in the world to get all its electricity from geothermal energy.

Three other nearly nondepletable sources of geothermal energy are **(1)** *molten rock* (magma), **(2)** *hot dry-rock zones,* where molten rock that has penetrated the earth's crust heats subsurface rock to high temperatures, and **(3)** low- to moderate-temperature *warm-rock reservoir deposits,* which could be used to preheat water and run heat pumps for space heating and air conditioning. Research is being carried out in several countries to see whether hot dry-rock zones, which can be found almost anywhere about 8–10 kilometers (5–6 miles) below the earth's surface, can provide affordable geothermal energy.

Figure 16-38 lists the pros and cons of using geothermal energy. Currently, the cost of tapping geothermal energy is too high for all but the most concentrated and accessible sources. In 2000, the U.S. Department of Energy launched a program to have geothermal energy produce 10% of the electricity used in the western United States by 2020.

16-9 ENTERING THE AGE OF DECENTRALIZED MICROPOWER

What Is Micropower? According to the director of energy supply policy for the Edison Electric Institute, Chuck Linderman, the era of big central power plant systems (Figure 16-39) is over. Most energy analysts believe the chief feature of electricity production over the next few decades will be *decentralization* to dispersed, small-scale, **micropower systems** that generate 1–10,000 kilowatts of power (Figure 16-40). This shift

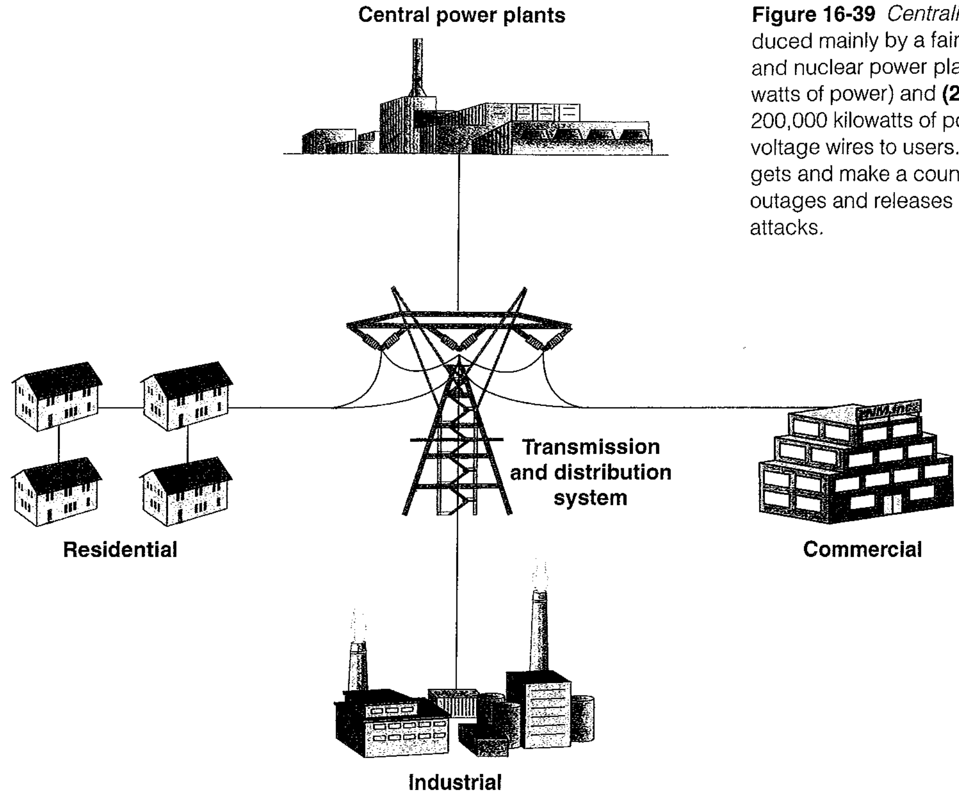


Figure 16-39 *Centralized power system* in which electricity produced mainly by a fairly small number of **(1)** large coal-burning and nuclear power plants (producing 600,000–1 million kilowatts of power) and **(2)** natural gas turbines (producing about 200,000 kilowatts of power) is distributed by a system of high-voltage wires to users. Such centralized systems are easy targets and make a country more vulnerable to widespread power outages and releases of radioactivity from terrorist or military attacks.

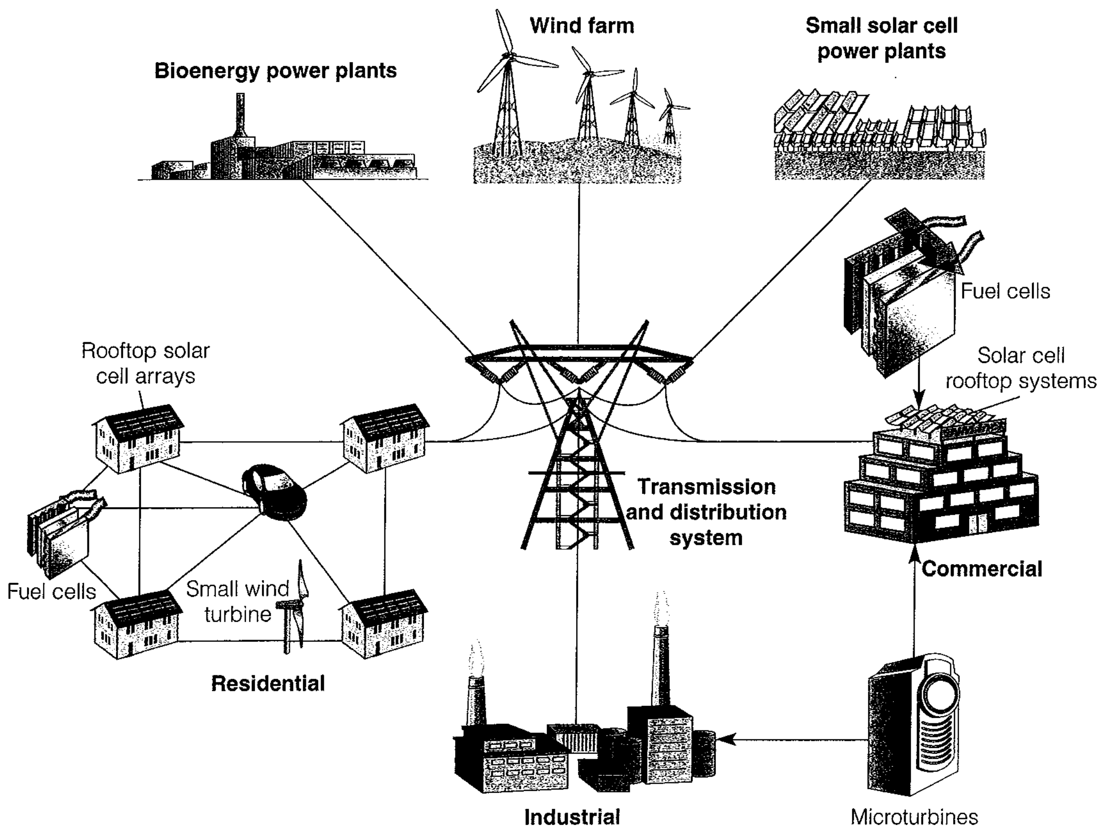


Figure 16-40 *Decentralized power system* in which electricity is produced by a large number of dispersed, small-scale *micro-power systems* (producing 1–10,000 kilowatts of power). Some would produce power on site and others would feed the power they produce into a conventional electrical distribution system. Over the next few decades, many energy and financial analysts expect a shift to this type of power system.

from centralized *macropower* to dispersed *micropower* is analogous to the computer industry's shift from large centralized mainframes to increasingly smaller, widely dispersed PCs, laptops, and handheld computers.

Examples of micropower systems include energy-efficient **(1)** natural gas–burning *microturbines* for commercial buildings and residences (5–10,000 kilowatts), **(2)** *wind turbines* (1–3,000 kilowatts), **(3)** *Stirling engines* (0.1–100 kilowatts), **(4)** *fuel cells* (1–10,000 kilowatts), and **(5)** household *solar panels and solar roofs* (1–1,000 kilowatts; Figures 16-23 and 16-24). Figure 16-41 lists some of the advantages of decentralized micropower systems over traditional macropower systems.

The potential for financial gain by companies and investors in micropower systems is huge, with a $10-trillion market projected for the global energy supply between 2000 and 2020. Decentralized micropower systems could also allow 2 billion people in isolated villages in developing countries to leapfrog over more expensive centralized power systems.

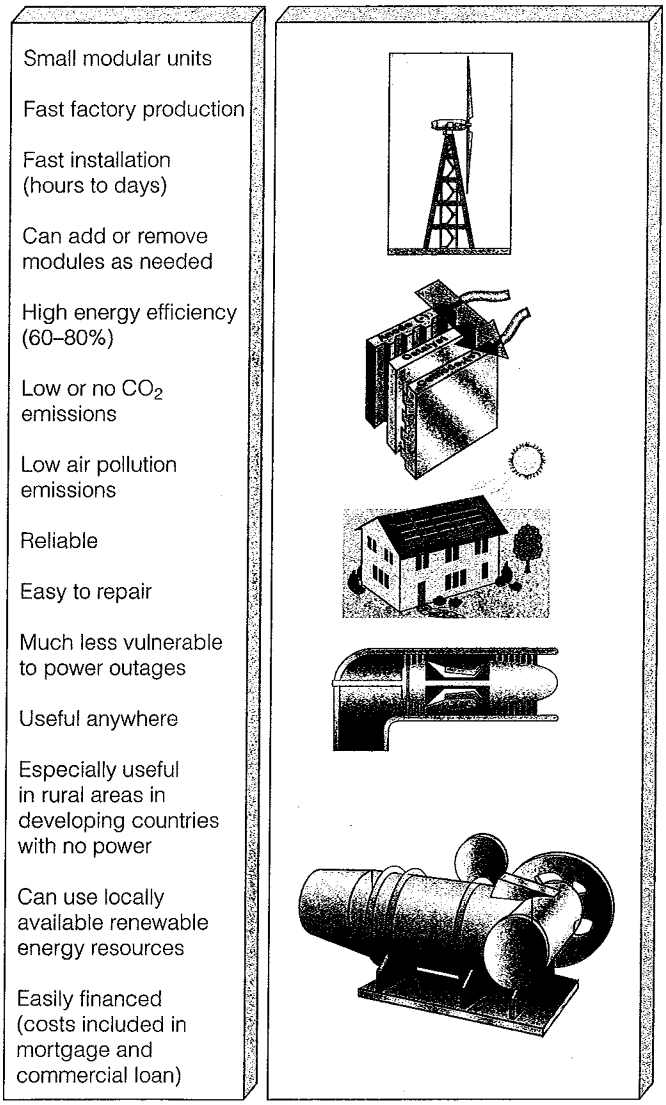


Figure 16-41 Some advantages of micropower systems.

16-10 SOLUTIONS: A SUSTAINABLE ENERGY STRATEGY

What Are the Best Energy Alternatives? Many scientists and energy experts who have evaluated energy alternatives have come to the following general conclusions:

- *We are not running out of energy and we have a variety of available nonrenewable and renewable energy resources,* each with certain advantages and disadvantages.
- *There will be a gradual shift from centralized macropower systems* (Figure 16-39) *to smaller, decentralized micropower systems* (Figures 16-40 and 16-41).
- *The best alternatives are a combination of improved energy efficiency and using natural gas as a fuel to make the transition to increased use of a variety of small-scale, decentralized, locally available renewable energy resources.*
- *Because not enough money is available to develop all energy alternatives, governments and private companies must choose carefully which alternatives to support.*
- *Over the next 50 years, the choice is not between using nonrenewable fossil fuels and various types of renewable energy.* Because of their supplies and low prices, fossil fuels will continue to be used in large quantities (Figure 15-15, p. 352, and Figure 15-16, p. 353). The key questions are **(1)** how we can reduce the harmful environmental impacts of widespread fossil fuel use (especially to reduce air pollution and slow projected global warming) and **(2)** what roles improving energy efficiency and depending more on some forms of renewable energy can play in achieving these goals.

What Role Does Economics Play in Energy Resource Use? To most analysts the key to making a shift to more sustainable energy resources and societies is not technology but economics and politics. Governments can use three basic economic and political strategies to help stimulate or dampen the short-term and long-term use of a particular energy resource:

- *Allowing all energy resources to compete in a free market without any government interference.* This is rarely politically feasible because of well-entrenched government intervention into the marketplace in the form of subsidies, taxes, and regulations. Furthermore, the free-market approach, with its emphasis on short-term profit, can inhibit development of new energy resources, which can rarely compete economically in their early stages without government support.

- *Trying to keep energy prices artificially low to encourage use of selected energy resources.* This is done mostly by **(1)** providing research and development subsidies and tax breaks and **(2)** enacting regulations that help stimulate the development and use of energy resources receiving such support. For decades, this approach has been used to help stimulate the development and use of fossil fuels and nuclear power in the United States (Figure 16-42) and most other developed countries. This has created an uneven economic playing field that **(1)** encourages energy waste and rapid depletion of a nonrenewable energy resource and **(2)** discourages the development of energy alternatives such as energy efficiency and renewable energy (Figures 16-42 and 16-43) that are not getting at least the same level of subsidies and tax breaks.
- *Keeping energy prices artificially high to discourage use of a resource.* Governments can raise the price of an energy resource by **(1)** withdrawing existing tax breaks and other subsidies, **(2)** enacting restrictive regulations, or **(3)** adding taxes on its use. This **(1)** increases government revenues, **(2)** encourages improvements in energy efficiency, **(3)** reduces dependence on imported energy, and **(4)** decreases use of an energy resource that has a limited future supply.

Many economists favor *increasing taxes on fossil fuels* as a way to reduce air and water pollution and slow global warming. The tax revenues would be used to **(1)** reduce income taxes on wages and profits, **(2)** improve energy efficiency, **(3)** encourage use of renewable energy resources, and **(4)** provide energy assistance to the poor and lower middle class. Some economists believe the public might accept these higher taxes if income and payroll taxes were lowered as gasoline or other fossil fuel taxes were raised.

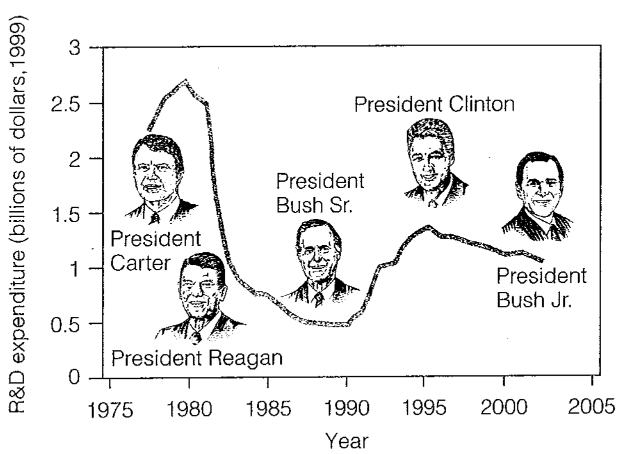


Figure 16-43 U.S. government research and development (R & D) spending on renewable energy and energy efficiency, 1978–2002. (Data from U.S. Department of Energy and Worldwatch Institute)

How Can We Develop a More Sustainable Energy Future? Figure 16-44 (p. 414) lists strategies for making the transition to a more sustainable energy future over the next few decades.

Energy experts estimate that implementing policies such as those shown in Figure 16-44 over the next 20–30 years could **(1)** save money, **(2)** create a net gain in jobs, **(3)** reduce greenhouse gas emissions, **(4)** sharply reduce air and water pollution, and **(5)** increase national security by reducing dependence on imported oil and decreasing dependence on large nuclear power and coal plants that are vulnerable to terrorist attacks.

Some *great news* is that we have technology, creativity, and wealth to make the transition to a more sustainable energy future. The *challenging news* is that making this happen depends primarily on politics—which depends largely on pressure individuals put on elected officials. See this chapter's website for actions you can take to promote this transition.

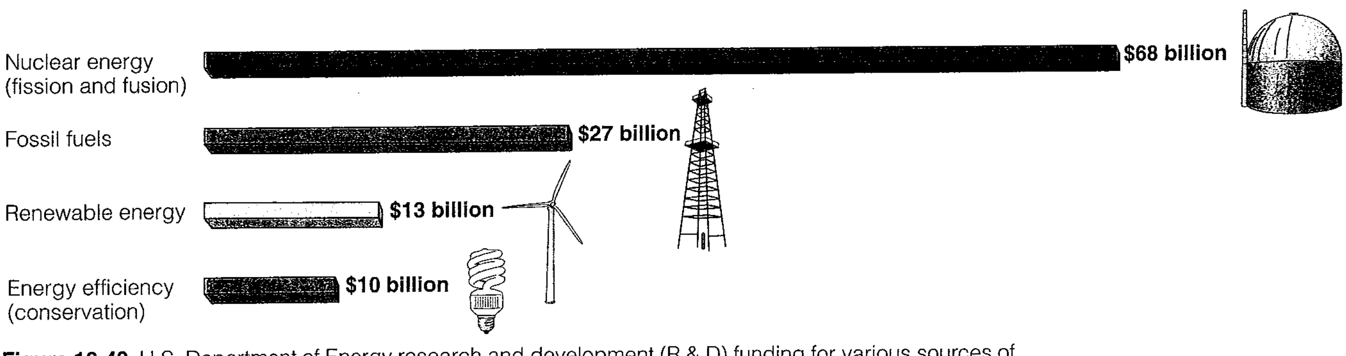


Figure 16-42 U.S. Department of Energy research and development (R & D) funding for various sources of energy, 1948–1998. If other government subsidies and tax breaks were included, the figures for nuclear power and fossil fuels would be much higher. (Data from Congressional Research Office)

Improve Energy Efficiency

Increase fuel-efficiency standards for vehicles, buildings, and appliances

Mandate government purchases of efficient vehicles and other devices

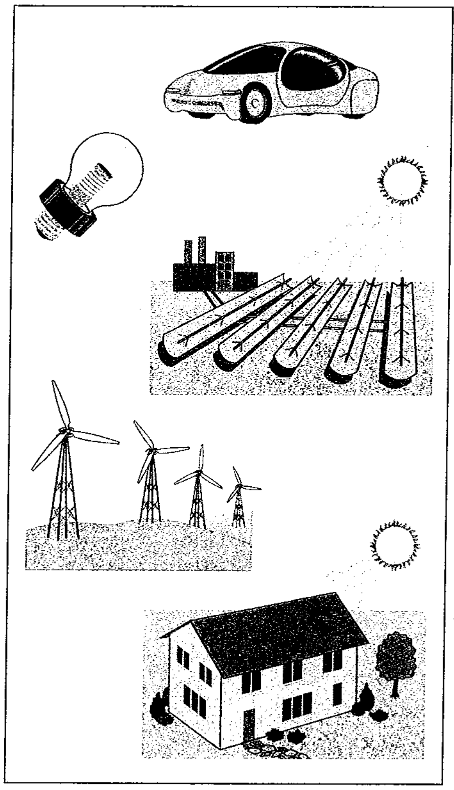
Provide large tax credits for buying efficient cars, houses, and appliances

Offer large tax credits for investments in efficiency

Reward utilities for reducing demand

Encourage independent power producers

Greatly increase efficiency research and development



More Renewable Energy

Increase renewable energy to 20% by 2020 and 50% by 2050

Provide large subsidies and tax credits for renewable energy

Use full-cost accounting and least-cost analysis for comparing all energy alternatives

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 or put it on hold until 2020

Phase out nuclear power subsidies

Figure 16-44 *Solutions:* suggestions of various analysts to help make the transition to a more sustainable energy future.

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. Define the boldfaced terms in this chapter.

2. What is *energy efficiency?* How much of the energy used in the United States is wasted? What percentage is wasted because of the second law of thermodynamics, and what percentage is wasted unnecessarily? What is *life cycle cost?* What are three of the least efficient energy-using devices?

3. Explain why we cannot recycle energy. List three ways to slow down the flow of heat from **(a)** a house and **(b)** an office building.

4. What are the advantages of saving energy?

5. What is *cogeneration,* and how efficient is it compared with producing electricity by a conventional coal-burning or nuclear power plant? List two other ways to save energy in industry.

6. What do most experts believe is the best way to save energy in transportation?

7. List the pros and cons of using **(a)** hybrid cars, **(b)** fuel-cell cars, and **(c)** electric bicycles.

8. Describe how we can save energy in homes by using **(a)** superinsulated houses and **(b)** strawbale houses. What are the four most efficient ways to heat a house? Describe ways to make an existing house more energy efficient. What are the most efficient and least efficient ways to heat water for washing and bathing? List the pros and cons of switching from inefficient incandescent and halogen lightbulbs to efficient compact fluorescent lightbulbs.

9. Describe how using the Internet can save energy and help reduce CO_2 emissions.

10. List three reasons why there is little emphasis on saving energy in the United States, despite its important benefits.

11. What are the major advantages and disadvantages of relying more on direct and indirect renewable energy from the sun?

12. Distinguish between a *passive solar heating system* and an *active solar heating system,* and list the pros and cons of each system.

13. Describe three ways to cool houses naturally.

14. Distinguish among the following solar systems used to generate high-temperature heat and electricity: **(a)** power tower, **(b)** solar thermal plant, **(c)** parabolic dish collection system, and **(d)** nonimaging optical solar concentrator. List the advantages and disadvantages of concentrating solar energy to produce high-temperature heat or electricity.

15. What is a *solar cell?* List the advantages and disadvantages of using solar cells to produce electricity.

16. Distinguish among *large-scale hydropower, small-scale-hydropower,* and *pumped-storage hydropower* systems. List the advantages and disadvantages of using hydropower to produce electricity.

17. List the advantages and disadvantages of using the following systems for storing heat in water to produce electricity: **(a)** ocean thermal energy conversion (OTEC), **(b)** saline solar ponds, and **(c)** freshwater solar ponds.

18. List the advantages and disadvantages of using wind to produce electricity.

19. List the advantages and disadvantages of **(a)** burning solid biomass as a source of energy and **(b)** producing gaseous and liquid fuels from solid biomass.

20. What is the *solar–hydrogen revolution?* What is a *fuel cell,* and what are the advantages and disadvantages of using this technology? List the advantages and disadvantages of using hydrogen as a source of energy.

21. What is *geothermal energy?* Describe three types of geothermal reservoirs. List the advantages and disadvantages of using geothermal energy to produce heat and electricity.

22. What is *micropower,* and what are its advantages over macropower electricity systems? Describe five types of micropower systems.

23. What five conclusions have energy experts reached about possible future energy alternatives?

24. Summarize the three different economic approaches that can be used to stimulate or dampen the use of a particular energy resource. List the pros and cons of each approach.

25. What major ways have various analysts suggested to help make the transition to a more sustainable energy future?

CRITICAL THINKING

1. A home builder installs electric baseboard heat and claims "it is the cheapest and cleanest way to go." Apply your understanding of the second law of thermodynamics to evaluate this claim.

2. Someone tells you we can save energy by recycling it. How would you respond?

3. Should the Corporate Average Fuel Economy (CAFE) standards for motor vehicles used in the United States be increased, left at 1985 levels (the current situation), or eliminated? Explain. Should the CAFE standards for light trucks, vans, and sport utility vehicles be increased to the same level as for cars? Explain. List the positive and negative effects on your health and lifestyle if CAFE standards are **(a)** increased or **(b)** eliminated.

4. What are the five most important actions an individual can take to save energy at home and in transportation (see website for this chapter)? Which, if any, of these do you currently do? Which, if any, do you plan to do?

5. Congratulations! You have won $250,000 to build a house of your choice anywhere you want. What type of house would you build? Where would you locate it? What types of materials would you use? What types of materials would you *not* use? How would you heat and cool your house? How would you heat your water? Considering fuel and energy efficiency, what sort of lighting, stove, refrigerator, washer, and dryer would you use? Which of these appliances could you do without?

6. Explain why you agree or disagree with the following proposals by various energy analysts: **(a)** federal subsidies for all energy alternatives should be eliminated so 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, coal), synthetic natural gas and oil, and nuclear power (fission and fusion) 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, and **(c)** development of solar, wind, and hydrogen energy should be left to private enterprise and receive little or no help from the federal government, but nuclear energy and fossil fuels should continue to receive large federal subsidies.

7. Explain why you agree or disagree with the proposals suggested in Figure 16-44 as ways to promote a more sustainable energy future.

8. Congratulations! You are in charge of the world. List the five most important features of your energy policy.

PROJECTS

1. Make a study of energy use in your school and use the findings to develop an energy-efficiency improvement program. Present your plan to school officials.

2. Learn how easy it is to produce hydrogen gas from water using a battery, some wire for two electrodes, and a dish of water. Hook a wire to each of the poles of the battery, immerse the electrodes in the water, and observe bubbles of hydrogen gas being produced at the negative electrode and bubbles of oxygen at the positive electrode. Carefully add a small amount of battery acid to the water and notice that this increases the rate of hydrogen production.

3. Use the library or the Internet to find bibliographic information about *Amory B. Lovins* and *Mohamed El-Ashry,* whose quotes appear at the beginning and end of this chapter.

4. Make a concept map of this chapter's major ideas, using the section heads and subheads and the key terms (in boldface). Look on the website for this book for information about making concept maps.

INTERNET STUDY RESOURCES AND RESOURCES FOR FURTHER READING AND RESEARCH

The website for this book contains helpful study aids and many ideas for further reading and research. Log on to

www.info.brookscole.com/miller13

and click on the Chapter-by-Chapter area. Choose Chapter 16 and select a resource:

- Flash Cards allows you to test your mastery of the Terms and Concepts to Remember for this chapter.
- Tutorial Quizzes provides a multiple-choice practice quiz.
- Student Guide to InfoTrac will lead you to Critical Thinking Projects that use InfoTrac College Edition as a research tool.
- References lists the major books and articles consulted in writing this chapter.
- Hypercontents takes you to an extensive list of sites with news, research, and images related to individual sections of the chapter.

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http://www.infotrac-college.com

or access InfoTrac through the website for this book. Try to find the following articles:

1. Nanney, J. 2002. How motor efficiencies affect system designs. *Plant Engineering* 56: 46. *Keywords:* "motor efficiencies" and "system designs." Electric motors are ubiquitous in America's manufacturing plants. They are also notoriously inefficient. This article describes how revamping the motors in a manufacturing plant can help the "watts per part" of a company's bottom line.

2. Fairley, P. 2002. Wind power for pennies: A lightweight wind turbine is finally on the horizon and it just might be the breakthrough needed to give fossil fuels a run for their money. *Technology Review* 105: 40. *Keywords:* "wind power" and "fossil fuels." Using the wind as a way to generate electricity seems to be always just out of reach on a large scale, but advances in turbine design may make wind power a windfall for electricity users.