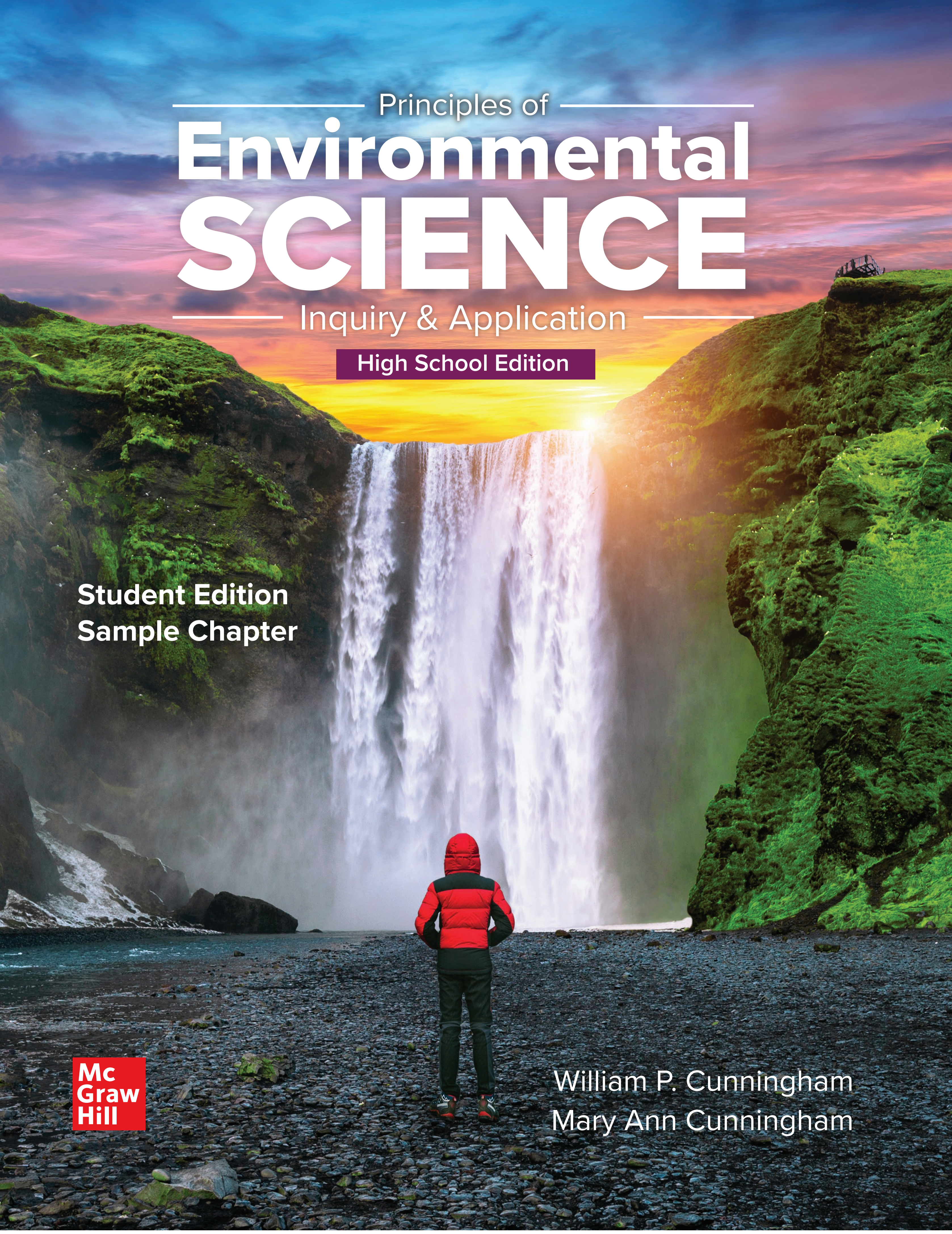

Principles of

Environmental SCIENCE

Inquiry & Application

High School Edition

Student Edition
Sample Chapter

William P. Cunningham
Mary Ann Cunningham

McGraw Hill

PRINCIPLES OF Environmental SCIENCE

Inquiry & Application

High School Edition

William P. Cunningham
University of Minnesota

Mary Ann Cunningham
Vassar College

McGraw Hill

About the cover: A visitor enjoys the view of the Skogafoss waterfall in Iceland.
Front Cover: Guitar photographer/Shutterstock

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Courtesy Tom Finkle

William P. Cunningham is an emeritus professor at the University of Minnesota. In his 38-year career at the university, he taught a variety of biology courses, including Environmental Science, Conservation Biology, Environmental Health, Environmental Ethics, Plant Physiology, General Biology, and Cell Biology. He is a member of the Academy of Distinguished Teachers, the highest teaching award granted at the University of Minnesota. He was a member of a number of interdisciplinary programs for international students, teachers, and nontraditional students. He also carried out research or taught in Sweden, Norway, Brazil, New Zealand, China, and Indonesia.

Professor Cunningham has participated in a number of governmental and nongovernmental organizations over the past 40 years. He was chair of the Minnesota chapter of the Sierra Club, a member of the Sierra Club national committee on energy policy, vice president of the Friends of the Boundary Waters Canoe Area, chair of the Minnesota governor's task force on energy policy, and a citizen member of the Minnesota Legislative Commission on Energy.

In addition to environmental science textbooks, Professor Cunningham edited three editions of Environmental Encyclopedia published by Thompson-Gale Press. He has also authored or co-authored about 50 scientific articles, mostly in the fields of cell biology and conservation biology as well as several invited chapters or reports in the areas of energy policy and environmental health. His Ph.D. from the University of Texas was in botany.

His hobbies include birding, hiking, gardening, traveling, and video production. He lives in St. Paul, Minnesota, with his wife, Mary. He has three children (one of whom is co-author of this book) and seven grandchildren.

MARY ANN CUNNINGHAM

Courtesy Tom Finkle

Mary Ann Cunningham is a professor of geography at Vassar College, in New York's Hudson Valley. A biogeographer with interests in landscape ecology, geographic information systems (GIS), and land use change, she teaches environmental science, natural resource conservation, and land use planning, as well as GIS and spatial data analysis. Field research methods, statistical methods, and scientific methods in data analysis are regular components of her teaching. As a scientist and educator, she enjoys teaching and conducting research with both science students and non-science liberal arts students. As a geographer, she likes to engage students with the ways their physical surroundings and social context shape their world experience. In addition to teaching at a liberal arts college, she has taught at community colleges and research universities. She has participated in Environmental Studies and Environmental Science programs and has led community and college field research projects at Vassar.

Mary Ann has been writing in environmental science for nearly two decades, and she is also co-author of Environmental Science: A Global Concern, now in its fourteenth edition. She has published work on habitat and landcover change, on water quality and urbanization, and other topics in environmental science. She has also done research with students and colleagues on climate change, its impacts, and carbon mitigation strategies.

Research and teaching activities have included work in the Great Plains, the Adirondack Mountains, and northern Europe, as well as in New York's Hudson Valley, where she lives and teaches. In her spare time she loves to travel, hike, and watch birds. She holds a bachelor's degree from Carleton College, a master's degree from the University of Oregon, and a Ph.D. from the University of Minnesota.

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Preface

UNDERSTANDING CRISIS AND OPPORTUNITY

Environmental science often emphasizes that while we are surrounded by challenges, we also have tremendous opportunities. We face critical challenges in biodiversity loss, clean water protection, climate change, population growth, sustainable food systems, and many other areas. But we also have tremendous opportunities to take action to protect and improve our environment. By studying environmental science, you have the opportunity to gain the tools and the knowledge to make intelligent choices on these and countless other questions.

Because of its emphasis on problem solving, environmental science is often a hopeful field. Even while we face burgeoning cities, warming climates, looming water crises, we can observe solutions in global expansion in access to education, health care, information, even political participation and human rights. Birth rates are falling almost everywhere, as women's rights gradually improve. Creative individuals are inventing new ideas for alternative energy and transportation systems that were undreamed of a generation ago. We are rethinking our assumptions about how to improve cities, food production, water use, and air quality. Local action is rewriting our expectations, and even economic and political powers feel increasingly compelled to show cooperation in improving environmental quality.

Sustainability, also a central idea in this book, has grown from a fringe notion to a widely shared framework for daily actions (recycling, reducing consumption) and civic planning (building energy-efficient buildings, investing in public transit and bicycle routes). Sustainability isn't just about the environment anymore. Increasingly we know that sustainability is also smart economics and that it is essential for social equity. Energy efficiency saves money. Alternative energy can reduce our reliance on fuel sources in politically unstable regions. Healthier food options reduce medical costs. Accounting for the public costs and burdens of pollution and waste disposal helps us rethink the ways we dispose of our garbage and protect public health. Growing awareness of these co-benefits helps us understand the broad importance of sustainability.

WHAT SETS THIS BOOK APART?

High school design and pedagogy: This book combines the authors' decades of experience in the field and classroom, its up-to-date data, and a new unique design specifically for the high school market. The student edition and supporting teacher materials make it easy for teachers to guide students through a scaffolded approach to the content, without sacrificing the real-life data and scientific rigor.

Demystifying science: We make science accessible by showing how and why data collection is done and by giving examples, practice, and exercises that demonstrate central principles. Exploring Science readings empower students by helping them understand how scientists do their work. These readings give examples of technology and methods in environmental science.

Quantitative reasoning: Students need to become comfortable with graphs, data, and comparing numbers. We provide focused discussions on why scientists answer questions with numbers, the nature of statistics, of probability, and how to interpret the message in a graph. We give accessible details on population models, GIS (mapping and spatial analysis), remote sensing, and other quantitative techniques. In-text applications and online, testable Data Analysis questions give students opportunities to practice with ideas, rather than just reading about them.

Up-to-date concepts and data: Throughout the text we introduce emerging ideas and issues such as ecosystem services, cooperative ecological relationships, epigenetics, and the economics of air pollution control, in addition to basic principles such as population biology, the nature of systems, and climate processes. Current approaches to climate change mitigation, campus sustainability, sustainable food production, and other issues give students current insights into major issues in environmental science and its applications. We introduce students to current developments such as ecosystem services, coevolution, strategic targeting of Marine Protected Areas, impacts of urbanization, challenges of REDD (reducing emissions through deforestation and degradation), renewable energy development in China and Europe, fertility declines in the developing world, and the impact of global food trade on world hunger.

Active learning: Learning how scientists approach problems can help students develop habits of independent, orderly, and objective thought. But it takes active involvement to master these skills. This book integrates a range of learning aids—Math Practice exercises, Critical Thinking and Discussion questions, and Data Analysis exercises—that push students to think for themselves. Data and interpretations are presented not as immutable truths but rather as evidence to be examined and tested, as they should be in the real world. Taking time to look closely at figures, compare information in multiple figures, or apply ideas in text is an important way to solidify and deepen understanding of key ideas.

Hands-on learning: Pair this book with the printed *Environmental Science Laboratory Manual,* written specifically for the high school classroom. This manual contains 33 lab activities that can be conducted in any classroom. The labs include modeling exercises, experiments, and simulations. Students can build their skills with the Guided Inquiry labs, and master them with Open Inquiry labs.

Synthesis: Students come to environmental science from a multitude of fields and interests. We emphasize that most of our pressing problems, from global hunger or climate change to conservation of biodiversity, draw on sciences and economics and policy. This synthesis shows students that they can be engaged in environmental science, no matter what their interests or career path.

Key concepts: In each chapter this section draws together compelling illustrations and succinct text to create a summary "take-home" message. These key concepts draw together the major ideas, questions, and debates in the chapter but give students a central idea on which to focus. These can also serve as starting points for lectures, student projects, or discussions.

Positive perspective: All the ideas noted here can empower students to do more effective work for the issues they believe in. While we don't shy away from the bad news, we highlight positive ways in which groups and individuals are working to improve their environment. What Can You Do? features in every chapter offer practical examples of things everyone can do to make progress toward sustainability.

Thorough coverage: No other book in the field addresses the multifaceted nature of environmental questions such as climate policy, sustainability, or population change with the thoroughness this book has. We cover not just climate change but also the nature of climate and weather systems that influence our day-to-day experience of climate conditions. We explore both food shortages and the emerging causes of hunger—such as political conflict, biofuels, and global commodity trading—as well as the relationship between food insecurity and the growing pandemic of obesity-related illness. In these and other examples, this book is a leader in in-depth coverage of key topics.

Student empowerment: Our aim is to help students understand that they can make a difference. From campus sustainability assessments to public activism we show ways that student actions have led to policy changes on all scales. In all chapters we emphasize ways that students can take action to practice the ideas they learn and to play a role in the policy issues they care about. What Can You Do? boxed features give steps students can take to make a difference.

Unparalleled teacher resources: *Principles of Environmental Science: Inquiry and Application* is accompanied by a print teacher manual. This manual includes invaluable resources such as pacing guides, a suggested approach, classroom activities with differentiated instruction, and support for English language learners.

Exceptional online support: Online resources integrated with readings encourage students to pause, review, practice, and explore ideas, as well as to practice quizzing themselves on information presented. McGraw Hill's online Environmental Science course gives students the means to better connect with their coursework, with their teachers, and with the important concepts that they will need to know for success now and in the future. Valuable assets such as SmartBook, an interactive ebook, Data Analysis exercises, and Google Earth exercises are all available online.

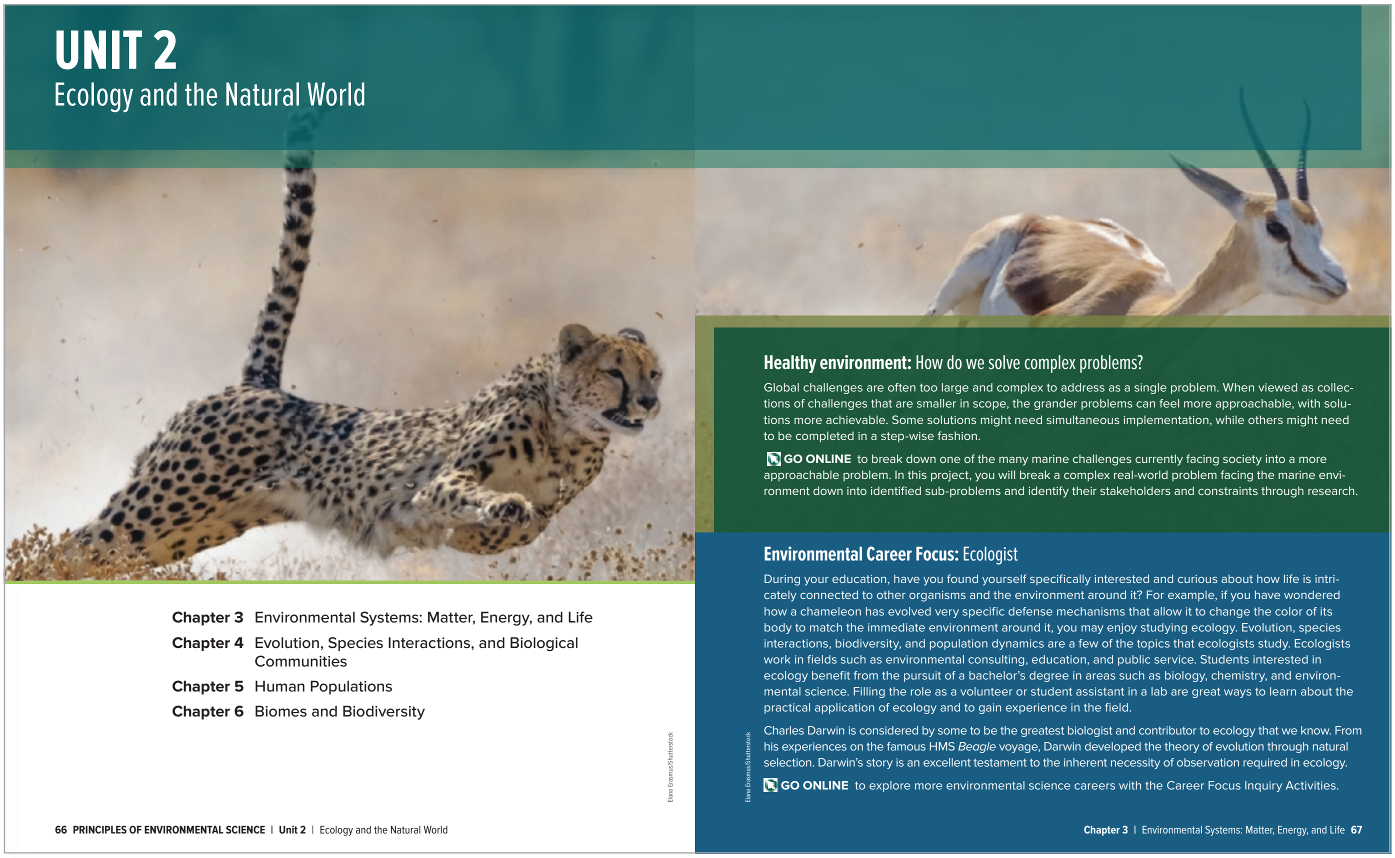
Guided Tour

Designed for for Introductory Environmental Science

Crafted specifically for a high school environmental science course, *Principles of Environmental Science: Inquiry and Application* is true to its title with an up-to-date, introductory view of the essential themes of the course and numerous opportunities for students to practice scientific thinking and active learning. Accessible pedagogical tools lead students to apply science and engineering practices, work with real data, and better understand environmental science and all of its complexities.

The high school edition has been organized into four **units**. Each Unit Opener outlines the chapters and topics covered.

Unit Projects are an opportunity for students to apply the engineering practices to real-life problems related to environmental science to understand the impacts on their own lives and how scientists study complex problems.



UNIT 2

Ecology and the Natural World

Chapter 3 Environmental Systems: Matter, Energy, and Life

Chapter 4 Evolution, Species Interactions, and Biological Communities

Chapter 5 Human Populations

Chapter 6 Biomes and Biodiversity

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Healthy environment: How do we solve complex problems?

Global challenges are often too large and complex to address as a single problem. When viewed as collections of challenges that are smaller in scope, the grander problems can feel more approachable, with solutions more achievable. Some solutions might need simultaneous implementation, while others might need to be completed in a step-wise fashion.

GO ONLINE to break down one of the many marine challenges currently facing society into a more approachable problem. In this project, you will break a complex real-world problem facing the marine environment down into identified sub-problems and identify their stakeholders and constraints through research.

Environmental Career Focus: Ecologist

During your education, have you found yourself specifically interested and curious about how life is intricately connected to other organisms and the environment around it? For example, if you have wondered how a chameleon has evolved very specific defense mechanisms that allow it to change the color of its body to match the immediate environment around it, you may enjoy studying ecology. Evolution, species interactions, biodiversity, and population dynamics are a few of the topics that ecologists study. Ecologists work in fields such as environmental consulting, education, and public service. Students interested in ecology benefit from the pursuit of a bachelor's degree in areas such as biology, chemistry, and environmental science. Filling the role as a volunteer or student assistant in a lab are great ways to learn about the practical application of ecology and to gain experience in the field.

Charles Darwin is considered by some to be the greatest biologist and contributor to ecology that we know. From his experiences on the famous HMS *Beagle* voyage, Darwin developed the theory of evolution through natural selection. Darwin's story is an excellent testament to the inherent necessity of observation required in ecology.

GO ONLINE to explore more environmental science careers with the Career Focus Inquiry Activities.

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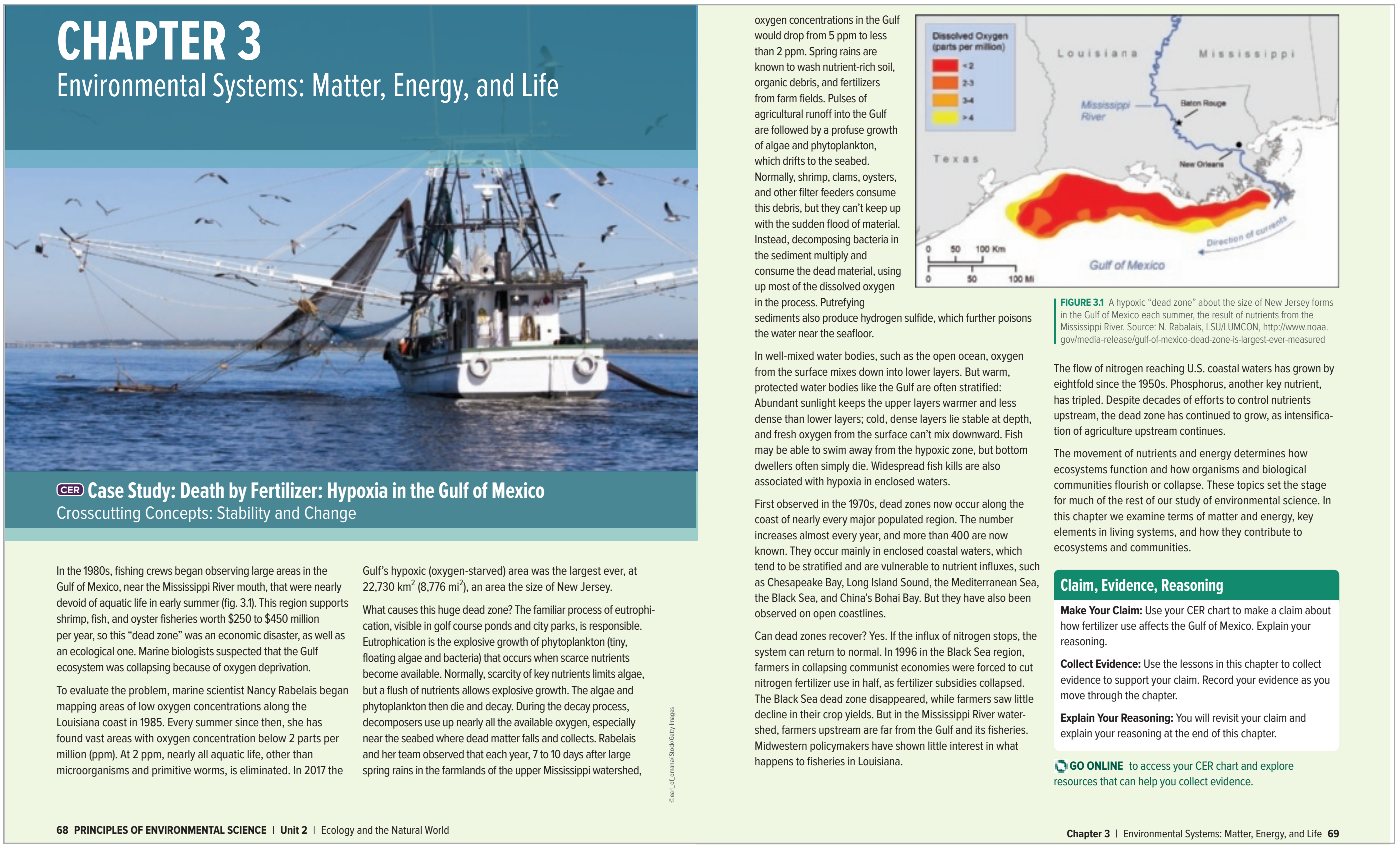
Environmental Career Focus features invite students to explore career options related to environmental science. Online focus activities allow students to explore career options in more depth.

Enhanced Pedagogy and Student Support

Each chapter begins with a **Case Study**. These allow students to encounter a phenomenon related to the chapter at hand, links to an online claim, evidence, reasoning chart, and is revisited as part of the Chapter Review. As part of the Case Study, students are asked to make a claim, collect evidence, and explain their reasoning using their online **Claim, Evidence, Reasoning** chart.



CHAPTER 3

Environmental Systems: Matter, Energy, and Life

CER Case Study: Death by Fertilizer: Hypoxia in the Gulf of Mexico

Crosscutting Concepts: Stability and Change

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In the 1980s, fishing crews began observing large areas in the Gulf of Mexico, near the Mississippi River mouth, that were nearly devoid of aquatic life in early summer (fig. 3.1). This region supports shrimp, fish, and oyster fisheries worth $250 to $450 million per year, so this "dead zone" was an economic disaster, as well as an ecological one. Marine biologists suspected that the Gulf ecosystem was collapsing because of oxygen deprivation.

To evaluate the problem, marine scientist Nancy Rabelais began mapping areas of low oxygen concentrations along the Louisiana coast in 1985. Every summer since then, she has found vast areas with oxygen concentration below 2 parts per million (ppm). At 2 ppm, nearly all aquatic life, other than microorganisms and primitive worms, is eliminated. In 2017 the Gulf's hypoxic (oxygen-starved) area was the largest ever, at 22,730 km^2 (8,776 mi^2), an area the size of New Jersey.

What causes this huge dead zone? The familiar process of eutrophication, visible in golf course ponds and city parks, is responsible. Eutrophication is the explosive growth of phytoplankton (tiny, floating algae and bacteria) that occurs when scarce nutrients become available. Normally, scarcity of key nutrients limits algae, but a flush of nutrients allows explosive growth. The algae and phytoplankton then die and decay. During the decay process, decomposers use up nearly all the available oxygen, especially near the seabed where dead matter falls and collects. Rabelais and her team observed that each year, 7 to 10 days after large spring rains in the farmlands of the upper Mississippi watershed, oxygen concentrations in the Gulf would drop from 5 ppm to less than 2 ppm. Spring rains are known to wash nutrient-rich soil, organic debris, and fertilizers from farm fields. Pulses of agricultural runoff into the Gulf are followed by a profuse growth of algae and phytoplankton, which drifts to the seabed. Normally, shrimp, clams, oysters, and other filter feeders consume this debris, but they can't keep up with the sudden flood of material. Instead, decomposing bacteria in the sediment multiply and consume the dead material, using up most of the dissolved oxygen in the process. Putrefying sediments also produce hydrogen sulfide, which further poisons the water near the seafloor.

In well-mixed water bodies, such as the open ocean, oxygen from the surface mixes down into lower layers. But warm, protected water bodies like the Gulf are often stratified: Abundant sunlight keeps the upper layers warmer and less dense than lower layers; cold, dense layers lie stable at depth, and fresh oxygen from the surface can't mix downward. Fish may be able to swim away from the hypoxic zone, but bottom dwellers often simply die. Widespread fish kills are also associated with hypoxia in enclosed waters.

First observed in the 1970s, dead zones now occur along the coast of nearly every major populated region. The number increases almost every year, and more than 400 are now known. They occur mainly in enclosed coastal waters, which tend to be stratified and are vulnerable to nutrient influxes, such as Chesapeake Bay, Long Island Sound, the Mediterranean Sea, the Black Sea, and China's Bohai Bay. But they have also been observed on open coastlines.

Can dead zones recover? Yes. If the influx of nitrogen stops, the system can return to normal. In 1996 in the Black Sea region, farmers in collapsing communist economies were forced to cut nitrogen fertilizer use in half, as fertilizer subsidies collapsed. The Black Sea dead zone disappeared, while farmers saw little decline in their crop yields. But in the Mississippi River watershed, farmers upstream are far from the Gulf and its fisheries. Midwestern policymakers have shown little interest in what happens to fisheries in Louisiana.

FIGURE 3.1 A hypoxic "dead zone" about the size of New Jersey forms in the Gulf of Mexico each summer, the result of nutrients from the Mississippi River. Source: N. Rabalais, LSU/LUMCON, http://www.noaa.gov/media-release/gulf-of-mexico-dead-zone-is-largest-ever-measured

The flow of nitrogen reaching U.S. coastal waters has grown by eightfold since the 1950s. Phosphorus, another key nutrient, has tripled. Despite decades of efforts to control nutrients upstream, the dead zone has continued to grow, as intensification of agriculture upstream continues.

The movement of nutrients and energy determines how ecosystems function and how organisms and biological communities flourish or collapse. These topics set the stage for much of the rest of our study of environmental science. In this chapter we examine terms of matter and energy, key elements in living systems, and how they contribute to ecosystems and communities.

Claim, Evidence, Reasoning

Make Your Claim: Use your CER chart to make a claim about how fertilizer use affects the Gulf of Mexico. Explain your reasoning.

Collect Evidence: Use the lessons in this chapter to collect evidence to support your claim. Record your evidence as you move through the chapter.

Explain Your Reasoning: You will revisit your claim and explain your reasoning at the end of this chapter.

GO ONLINE to access your CER chart and explore resources that can help you collect evidence.

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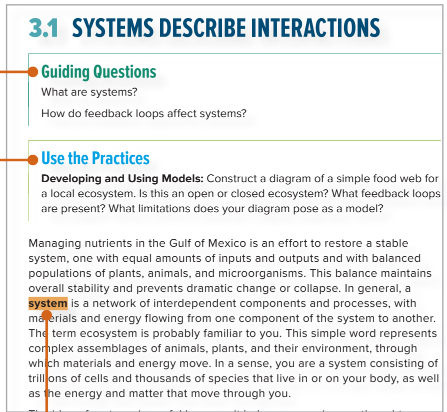
Each chapter section begins with **Guiding Questions** which pinpoint the key takeaways of the section. These are closely linked to the section and end-of-chapter assessments.

Use the Practices are activities that allow students to apply the science and engineering practices such as using models, asking questions, or analyzing data, to the content of each textbook section.



3.1 SYSTEMS DESCRIBE INTERACTIONS

Guiding Questions

What are systems?

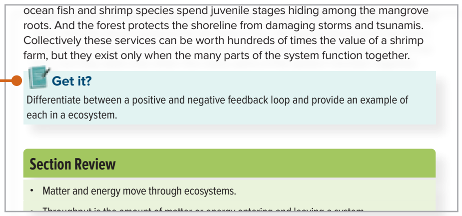
How do feedback loops affect systems?

Use the Practices

Developing and Using Models: Construct a diagram of a simple food web for a local ecosystem. Is this an open or closed ecosystem? What feedback loops are present? What limitations does your diagram pose as a model?

Managing nutrients in the Gulf of Mexico is an effort to restore a stable system, one with equal amounts of inputs and outputs and with balanced populations of plants, animals, and microorganisms. This balance maintains overall stability and prevents dramatic change or collapse. In general, a **system** is a network of interdependent components and processes, with materials and energy flowing from one component of the system to another. The term ecosystem is probably familiar to you. This simple word represents complex assemblages of animals, plants, and their environment, through which materials and energy move. In a sense, you are a system consisting of trillions of cells and thousands of species that live in or on your body, as well as the energy and matter that move through you.

Get it? questions are found throughout the chapter and serve as reading checks.



ocean fish and shrimp species spend juvenile stages hiding among the mangrove roots. And the forest protects the shoreline from damaging storms and tsunamis. Collectively these services can be worth hundreds of times the value of a shrimp farm, but they exist only when the many parts of the system function together.

Get it?

Differentiate between a positive and negative feedback loop and provide an example of each in a ecosystem.

Section Review

- Matter and energy move through ecosystems.

Vocabulary terms are highlighted within the text at point of first use to support ELL instruction.

Real-World Connections

Several boxed feature strands make science accessible through the presentation of how and why data is collected, examples of technology and methods, and additional information that demystifies central principles. These features augment the main chapter content by exploring a pressing environmental issue, discussing current scientific research, or visually exploring a core idea and give students realistic steps for applying their knowledge.

What Do You Think? presents students with challenging environmental studies that offer an opportunity to consider contradictory data, special interest topics, and conflicting interpretations within a real scenario.

What Do You Think?

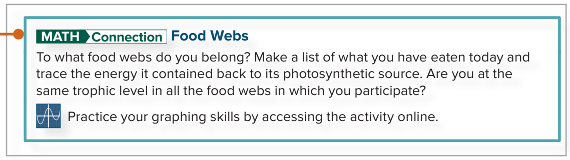
Gene Editing

Humans have known for centuries that selective breeding can improve the characteristics of domestic plants and animals. But selective breeding is slow and rather unpredictable. The development of molecular genetics, inserting pieces of DNA from one species into another, dramatically improved our ability to tailor organisms, but this process is difficult and prone to errors. The discovery of a bacterial system for editing genes, however, may unleash a gold rush in genetic engineering.

CRISPR This gene editing system is called CRISPR, short for "clustered regularly interspaced short palindromic repeats." CRISPR uses short sequences (palindromic repeats) of genetic material to attach to specific sections of DNA in a cell; it then uses an enzyme to cut the DNA in specific places. Bacteria use this process to cut and disable the DNA of invading viruses. But geneticists have realized that this bacterial process could be used to recognize and modify, or "edit," genes in higher plants and animals. Just as bacteria target the DNA of an invading virus, CRISPR uses molecules synthesized to bind to and cut any gene we want to edit. When a target DNA sequence is identified and cut, it can inactivate the gene. This gives us important information about the gene's functions or expressions. Alternatively, as the cell tries to repair broken DNA, CRISPR can supply a template for new versions of the target gene, to replace the original sequence. Think of this as a molecular version of the search and replace function in your word processor.

The tool is being used in the lab to make human cells impervious to HIV, to correct a mutation that leads to blindness, and to cure mice of muscular dystrophy, cataracts, and a hereditary liver disease (fig. 1). It has been used to improve wheat, rice, soybeans, tomatoes, and oranges. Libraries of tens of thousands of DNA sequences are now available to target and activate, or silence, specific genes. One of the most exciting features of CRISPR is that it can modify multiple genes at the same time in a single cell. This may make it possible to study and eventually treat complex diseases, such as Alzheimer's or Parkinson's, that are regulated by many genes.

In 2017, scientists tried editing a gene inside a living human, in an attempt to permanently cure an inherited metabolic disorder called Hunter syndrome. In this syndrome, cells cannot produce an enzyme needed to break down complex sugars, so these sugar molecules accumulate in cells, blood, and tissues. Consequences can include nerve degeneration



MATH Connection **Food Webs**

To what food webs do you belong? Make a list of what you have eaten today and trace the energy it contained back to its photosynthetic source. Are you at the same trophic level in all the food webs in which you participate?

Practice your graphing skills by accessing the activity online.

Math Connection features encourage students to practice their quantitative reasoning skills and apply their understanding of newly learned concepts and to propose possible solutions.

Exploring Science

Who Cares About Krill?

Krill are small, shrimplike animals of immense importance in marine ecology. They occur in all the oceans of the world, but they are especially abundant in the Southern Ocean around Antarctica. Krill are considered one of the most abundant species in the world. Although each individual is tiny, their combined biomass is estimated to exceed that of any other species on the planet. The supply has seemed inexhaustible, but now marine biologists are concerned that a combination of overfishing and climate change could decimate the krill population—and the entire Antarctic ecosystem.

Krill flourish in the cold, nutrient-rich waters of Antarctica, where they subsist on photosynthetic algae under and around the ice. Directly or indirectly, they support all higher trophic levels, including penguins, seals, fish, squid, seabirds, and whales. A single blue whale can eat as much as 4 tons of krill per day. But Antarctic krill are also increasingly sought as a source of protein and oil for farmed seafood, poultry, pets, and livestock. Krill are rich in protein (40 percent or more) and lipids (up to 20 percent). You probably won't find krill on your menu, but their high levels of omega-3 fatty acids make them a popular source of "fish oil" supplements and health products. And if you eat farmed salmon, there is a good chance it was fed with krill or krill-consuming fish. That would make you a top consumer in a krill-based ecosystem.

Between 1970 and 1990 the world catch of Antarctic krill grew from almost nothing to as much as half a million tons per year. The Soviet Union was the first nation to establish large-scale commercial krill harvests. After the demise of the USSR in 1991 the Soviet fishery collapsed, but other nations, notably Norway, South Korea, and China, have developed extensive krill fisheries. The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) was created in 1982 in an effort to manage this obscure fishery and to prevent overfishing.

The proposed CCAMLR catch limit for the Scotia Sea (around Antarctica) is 5.6 million tons per year, but biologists fear that even the current annual harvest of nearly 300,000 tons is unsustainable. They estimate that krill populations have dropped 80 percent since the 1970s.

Krill are also threatened by the loss of floating ice shelves, the habitat for algae on which they feed. As the climate warms, ice has been declining, even while heavy fishing is depleting krill populations. At the same time, the ocean is becoming more acidic, as it absorbs CO_2 from the atmosphere, and acid conditions are likely to diminish krill reproduction. As krill have disappeared, other species far up the food web, such as Emperor and Adelie penguins, have shown corresponding declines.

Protecting Krill Remarkably, this species is finally gaining legal protection with the establishment of the world's largest marine protected area. Following years of impasses, a 2016 agreement protected 1.5 million km^2 of the Ross Sea, including 1.1 million km^2 where fishing is banned altogether. The agreement allows the same levels of fishing as previously, but it bans fishing in critical habitat near the Antarctic continent, where

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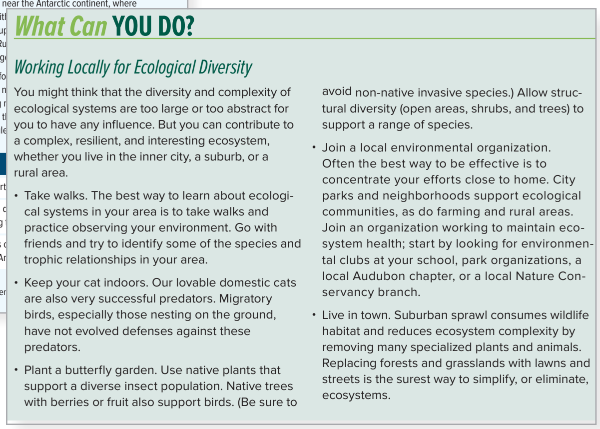
Exploring Science presents current environmental issues that exemplify the principles of scientific observation and data-gathering techniques to promote scientific literacy.



What Can YOU DO?

Working Locally for Ecological Diversity

You might think that the diversity and complexity of ecological systems are too large or too abstract for you to have any influence. But you can contribute to a complex, resilient, and interesting ecosystem, whether you live in the inner city, a suburb, or a rural area.

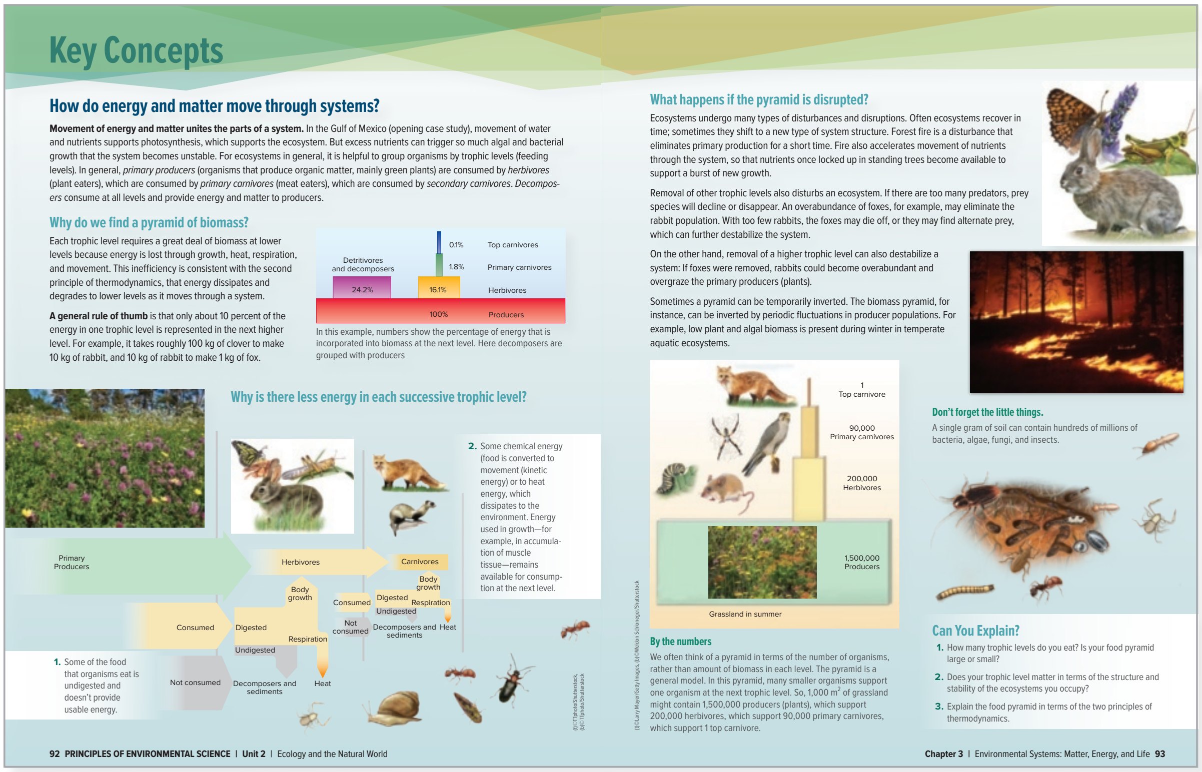
- Take walks. The best way to learn about ecological systems in your area is to take walks and practice observing your environment. Go with friends and try to identify some of the species and trophic relationships in your area.
- Keep your cat indoors. Our lovable domestic cats are also very successful predators. Migratory birds, especially those nesting on the ground, have not evolved defenses against these predators.
- Plant a butterfly garden. Use native plants that support a diverse insect population. Native trees with berries or fruit also support birds. (Be sure to avoid non-native invasive species.) Allow structural diversity (open areas, shrubs, and trees) to support a range of species.
- Join a local environmental organization. Often the best way to be effective is to concentrate your efforts close to home. City parks and neighborhoods support ecological communities, as do farming and rural areas. Join an organization working to maintain ecosystem health; start by looking for environmental clubs at your school, park organizations, a local Audubon chapter, or a local Nature Conservancy branch.
- Live in town. Suburban sprawl consumes wildlife habitat and reduces ecosystem complexity by removing many specialized plants and animals. Replacing forests and grasslands with lawns and streets is the surest way to simplify, or eliminate, ecosystems.

What Can You Do? asks students to employ practical ideas to make positive differences in our environment.

Engaging Visuals

Realistic, three-dimensional, and instructional figures provide depth and orientation to help students visualize complex structures and processes and to support visual learners.

Key Concepts are beautifully displayed, two-page features which guide students through an often complex network of issues. These features highlight the takeaway ideas from the chapter in a visually appealing way.



Key Concepts

How do energy and matter move through systems?

Movement of energy and matter unites the parts of a system. In the Gulf of Mexico (opening case study), movement of water and nutrients supports photosynthesis, which supports the ecosystem. But excess nutrients can trigger so much algal and bacterial growth that the system becomes unstable. For ecosystems in general, it is helpful to group organisms by trophic levels (feeding levels). In general, *primary producers* (organisms that produce organic matter, mainly green plants) are consumed by *herbivores* (plant eaters), which are consumed by *primary carnivores* (meat eaters), which are consumed by *secondary carnivores*. *Decomposers* consume at all levels and provide energy and matter to producers.

Why do we find a pyramid of biomass?

Each trophic level requires a great deal of biomass at lower levels because energy is lost through growth, heat, respiration, and movement. This inefficiency is consistent with the second principle of thermodynamics, that energy dissipates and degrades to lower levels as it moves through a system.

A general rule of thumb is that only about 10 percent of the energy in one trophic level is represented in the next higher level. For example, it takes roughly 100 kg of clover to make 10 kg of rabbit, and 10 kg of rabbit to make 1 kg of fox.

In this example, numbers show the percentage of energy that is incorporated into biomass at the next level. Here decomposers are grouped with producers

Why is there less energy in each successive trophic level?

1. Some of the food that organisms eat is undigested and doesn't provide usable energy.

2. Some chemical energy (food is converted to movement (kinetic energy) or to heat energy, which dissipates to the environment. Energy used in growth—for example, in accumulation of muscle tissue—remains available for consumption at the next level.

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What happens if the pyramid is disrupted?

Ecosystems undergo many types of disturbances and disruptions. Often ecosystems recover in time; sometimes they shift to a new type of system structure. Forest fire is a disturbance that eliminates primary production for a short time. Fire also accelerates movement of nutrients through the system, so that nutrients once locked up in standing trees become available to support a burst of new growth.

Removal of other trophic levels also disturbs an ecosystem. If there are too many predators, prey species will decline or disappear. An overabundance of foxes, for example, may eliminate the rabbit population. With too few rabbits, the foxes may die off, or they may find alternate prey, which can further destabilize the system.

On the other hand, removal of a higher trophic level can also destabilize a system: If foxes were removed, rabbits could become overabundant and overgraze the primary producers (plants).

Sometimes a pyramid can be temporarily inverted. The biomass pyramid, for instance, can be inverted by periodic fluctuations in producer populations. For example, low plant and algal biomass is present during winter in temperate aquatic ecosystems.

By the numbers

We often think of a pyramid in terms of the number of organisms, rather than amount of biomass in each level. The pyramid is a general model. In this pyramid, many smaller organisms support one organism at the next trophic level. So, 1,000 m^2 of grassland might contain 1,500,000 producers (plants), which support 200,000 herbivores, which support 90,000 primary carnivores, which support 1 top carnivore.

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Don't forget the little things.

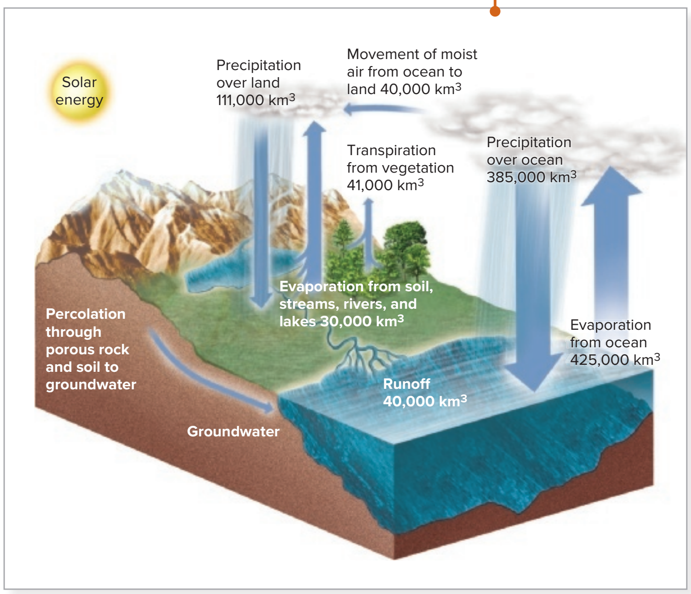
A single gram of soil can contain hundreds of millions of bacteria, algae, fungi, and insects.

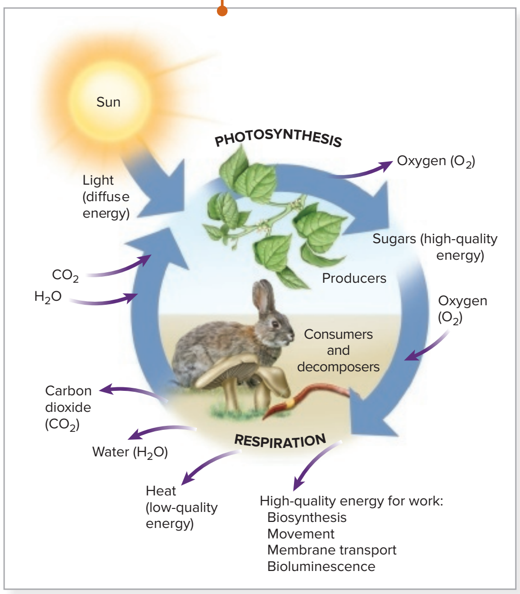
Can You Explain?

1. How many trophic levels do you eat? Is your food pyramid large or small?
2. Does your trophic level matter in terms of the structure and stability of the ecosystems you occupy?
3. Explain the food pyramid in terms of the two principles of thermodynamics.

Chapter 3 | Environmental Systems: Matter, Energy, and Life 93

Informational graphics are beautifully displayed, two-page features which guide students through an often complex network of issues.





Section and Chapter Review

End-of-chapter reviews provide an excellent opportunity for students to reinforce their learning, revisit any content or concepts they may have missed, and make connections across the various chapter activities.

Math Connection and **Writing Connection** questions allow students to improve literacy and computational skills.

Section Review

- Key elements cycle continuously through living and nonliving systems.
- Carbon cycles through all living organisms, the atmosphere, and the oceans.
- Nitrogen, a key to life, is abundant but not easily captured.

1. In what ways is the hydrologic cycle a part of the other nutrient cycles discussed in this section?
2. WRITING Connection This section begins with a quote from naturalist John Muir: "When one tugs at a single thing in nature, he finds it attached to the rest of the world." Using examples from the text, as well as from your own experiences, elaborate on the validity of what John Muir was expressing.

Each section ends with a **Section Review**, which includes a bulleted summary of the content and concepts covered and short-answer assessment questions to check for understanding.

Chapter Review

3.1 Systems Describe Interactions

Guiding Questions

What are systems?

How do feedback loops affect systems?

Vocabulary

system	equilibrium
open systems	positive feedback loop
closed system	negative feedback loop
throughput	

3.2 Elements of Life

Guiding Questions

Explain the importance of nitrogen, oxygen, carbon, and hydrogen to life.

Why are cells the basic unit of life?

Vocabulary

matter	molecule
conservation of matter	acid
element	base
atom	pH
atomic number	organic compound
isotope	deoxyribonucleic acid (DNA)
compound	cell

3.3 Energy and Living Systems

Guiding Questions

Explain the first and second laws of thermodynamics.

Explain the processes of photosynthesis and respiration.

Vocabulary

energy	second law of thermodynamics
kinetic energy	entropy
potential energy	primary producer
chemical energy	chemosynthesis
heat	photosynthesis
first law of thermodynamics	cellular respiration

3.4 From Species to Ecosystems

Guiding Questions

Ecologists say there is no "away" to throw things to, and that everything in the universe tends to slow down and fall apart. What do they mean?

Why are big, fierce animals rare?

Vocabulary

species	trophic level
population	consumer
biological community	herbivore
ecosystem	carnivore
producer	omnivore
productivity	scavenger
biomass	decomposer
food web	detritivore

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The **Chapter Review** summarizes each section including the guiding questions and vocabulary terms.

Powerful Assessment

The end-of-chapter assessments help students master the content and practices included in each chapter. Multiple-choice and free-response questions ask students to recall and synthesize information covered in the course. The Data Analysis Lab allows students to apply what they've learned to real-world scenarios using current scientific data.

3.5 Biogeochemical Cycles and Life Processes

Guiding Questions

What qualities make water so unique and essential for life as we know it?

How and why do elements such as carbon, nitrogen, phosphate and sulfur cycle through ecosystems?

Vocabulary

carbon cycle nitrogen cycle

CER Revisit the Case Study

How Does Fertilizer Use Affect the Gulf of Mexico?

Recall the Case Study at the beginning of this chapter (p. 68). You read about how fertilizer run-off from farming operations impacted the Gulf of Mexico. Throughout the chapter, you read about essential nutrients like nitrogen are moved through environments. Now, it is time to revisit your claim, summarize your evidence, and analyze what you have learned.

Claim, Evidence, Reasoning

Revisit Your Claim: Review your CER chart where you recorded your claim about how fertilizer use affects the Gulf of Mexico.

Summarize Your Evidence: Summarize the evidence you gathered from your investigations and research and finalize your Summary Table.

Explain Your Reasoning: Does your evidence support your claim? Explain why your evidence supports your claim. If it does not, revise your claim.

Review Questions

1. When a system is balanced or stable, it is said to be in what state?
   a. open c. closed
   b. equilibrium d. at threshold
2. Which category do lipids, carbohydrates, proteins, and nucleic acids that form the basic structure of cells and other components of living things belong to?
   a. fertilizers c. organic compounds
   b. metals d. toxic elements
3. Which of the following best describes the structure of DNA?
   a. short chains of base-paired organic compounds bound together in the form of a single-stranded spiral
   b. long chains of base-paired hydrocarbons bound together in the form of a double helix two-stranded spiral
   c. short chains of base-paired nucleotides bound together in the form of a single-stranded spiral
   d. long chains of base-paired nucleotides bound together in the form of a double helix two-stranded spiral
4. Which form of energy is stored in the food you eat?
   a. chemical energy c. light energy
   b. kinetic energy d. electrical energy
5. In a food web such as in figure 3.16, what do the arrows represent?
   a. The arrows indicate how many times each consumer feeds during any given period.
   b. The arrows indicate which consumers are able to feed at any trophic level.
   c. The arrows indicate the direction in which matter and energy are transferred through feeding relationships.
   d. The arrows indicate which organisms are herbivores, omnivores, or carnivores for each trophic level.
6. Which … acidit… critica…
   a. sul…
   b. ca…
7. What … of Me…
   a. ph…
   b. ph…
   c. nit…
   d. nit…

Chapter 3

Students are invited to **Revisit the Case Study** that was introduced at the beginning of the chapter, and fill out their online CER chart with evidence they've gathered while reading.

Review Questions include both multiple choice and short answer questions.

Chapter Review Continued

Critical Thinking

1. Describe what a system is and how feedback loops regulate them.
2. Explain why water is considered to be essential to life and describe two properties that support your explanation.
3. Differentiate between high-quality and low-quality energy and the benefits of each.
4. Explain how the processes of photosynthesis and cellular respiration work together to provide organisms energy for life.
5. Using the food web in figure 3.16, explain which organisms would be negatively affected and why if the Acacia primary producer went extinct.

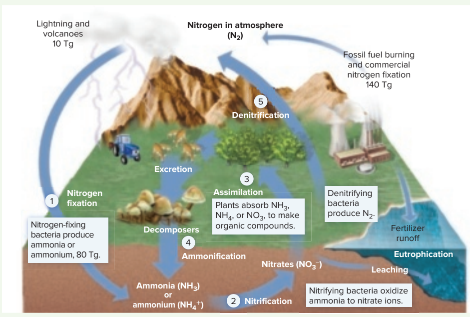
Go Further: Data Analysis Lab

How does the nitrogen cycle link different ecosystems? Nitrogen is an essential nutrient for life. It is a component of proteins, nucleic acids, and other important molecules. Nitrogen exists as part of many inorganic molecules, many of which are inaccessible for plants or animals to use.

Data and Observations: Observe the diagram of the nitrogen cycle shown below and use it to answer the following questions.

Analyze and Interpret Data

1. Which forms of N do plants take up? How is N_2 captured, or fixed, from the air into the food web?
2. Most of the processes are hard to quantify, but the figure shown below gives approximate amounts for fossil fuel burning and commercial N fixation, and for N fixing by bacteria. What do these terms mean? What is the magnitude of each? What is the difference?
3. If anthropogenic processes introduce increasing amounts of atmospheric N to the biosphere and hydrosphere, where does that N go? (Hint: Refer to the opening case study.)
4. In marine systems, N is often a limiting factor. What is a "limiting factor"? What is a consequence of increasing the supply of N in a marine system?



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Critical Thinking questions ask students to apply the skills and knowledge they've obtained from the full course thus far.

The **Data Analysis Lab** gives students an opportunity to work with real data and relates directly back to the chapter Case Study.

Best in Class
Digital Resources

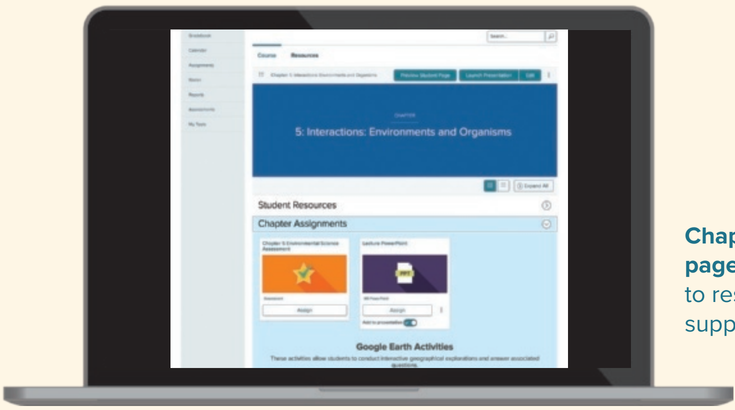
***Principles of Environmental Science:* Inquiry and Application is enriched with multimedia content including art and animations that enhance the teaching and learning experience both inside and outside of the classroom.**

Developed with the world's leading subject matter experts and organized by chapter level, the resources provide students with multiple opportunities to contextualize and apply their understanding. Teachers can save time, customize lessons, monitor student progress, and make data-driven decisions in the classroom with the flexible, easy-to-navigate instructional tools.

Intuitive Design

Resources are organized at the chapter level. To enhance the core content, teachers can add assignments, activities, and instructional aids to any lesson. The chapter landing page gives students access to:

- assigned activities,
- customizable, auto-graded assessments,
- interactive eBook,
- adaptive *SmartBook*® assignments,
- animation activities and virtual labs.



Chapter landing page links students to resources that support success.

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Access to course content on-the-go is easier and more efficient than ever before with the *ReadAnywhere* mobile app.

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SMARTBOOK® is the assignable, adaptive study tool. The interactive features engage students and personalize the learning experience with self-guided tools that:

- assess a student's proficiency and knowledge,
- track which topics have been mastered,
- identify areas that need more study,
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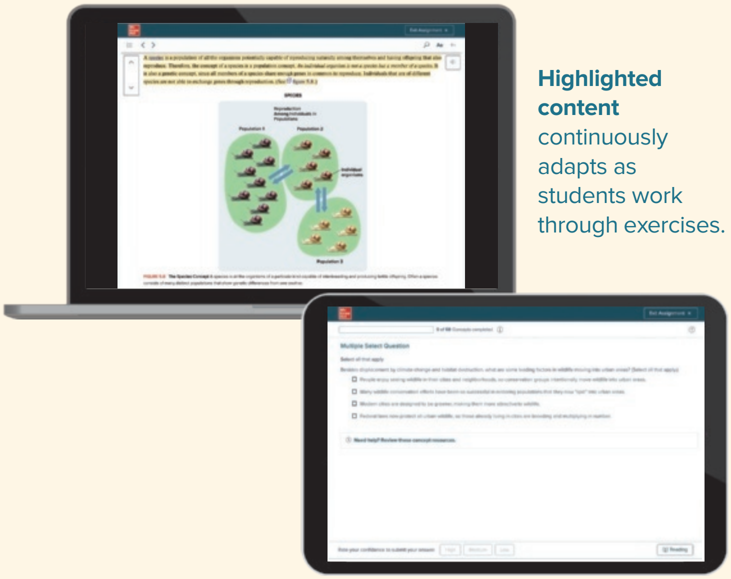

Highlighted content continuously adapts as students work through exercises.

Practice questions measure depth of understanding and present a personalized learning path based on student responses.

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Teachers have access to the interactive eBook, adaptive *SmartBook*®, plus a wealth of customizable chapter resources and powerful gradebook tools.

Resources include:

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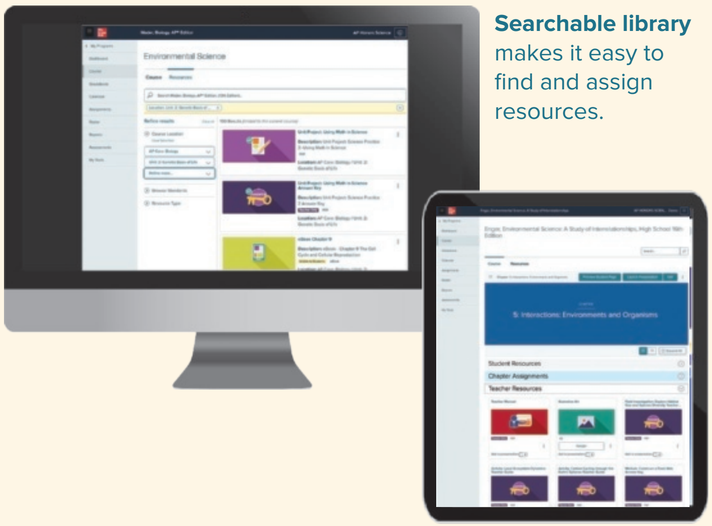
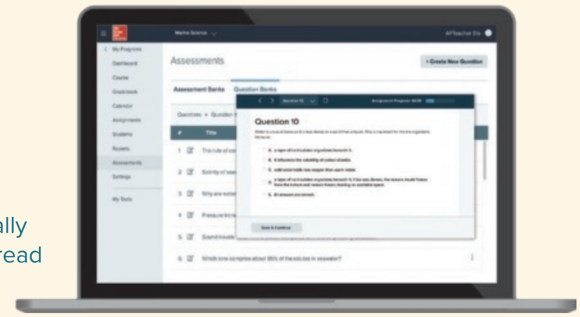


Searchable library makes it easy to find and assign resources.



Customizable assignments and quiz banks are automatically graded and populate easy-to-read reports.

Harness technology, unlock success with the digital resources for *Principles of Environmental Science: Inquiry and Application* **Visit my.mheducation.com**

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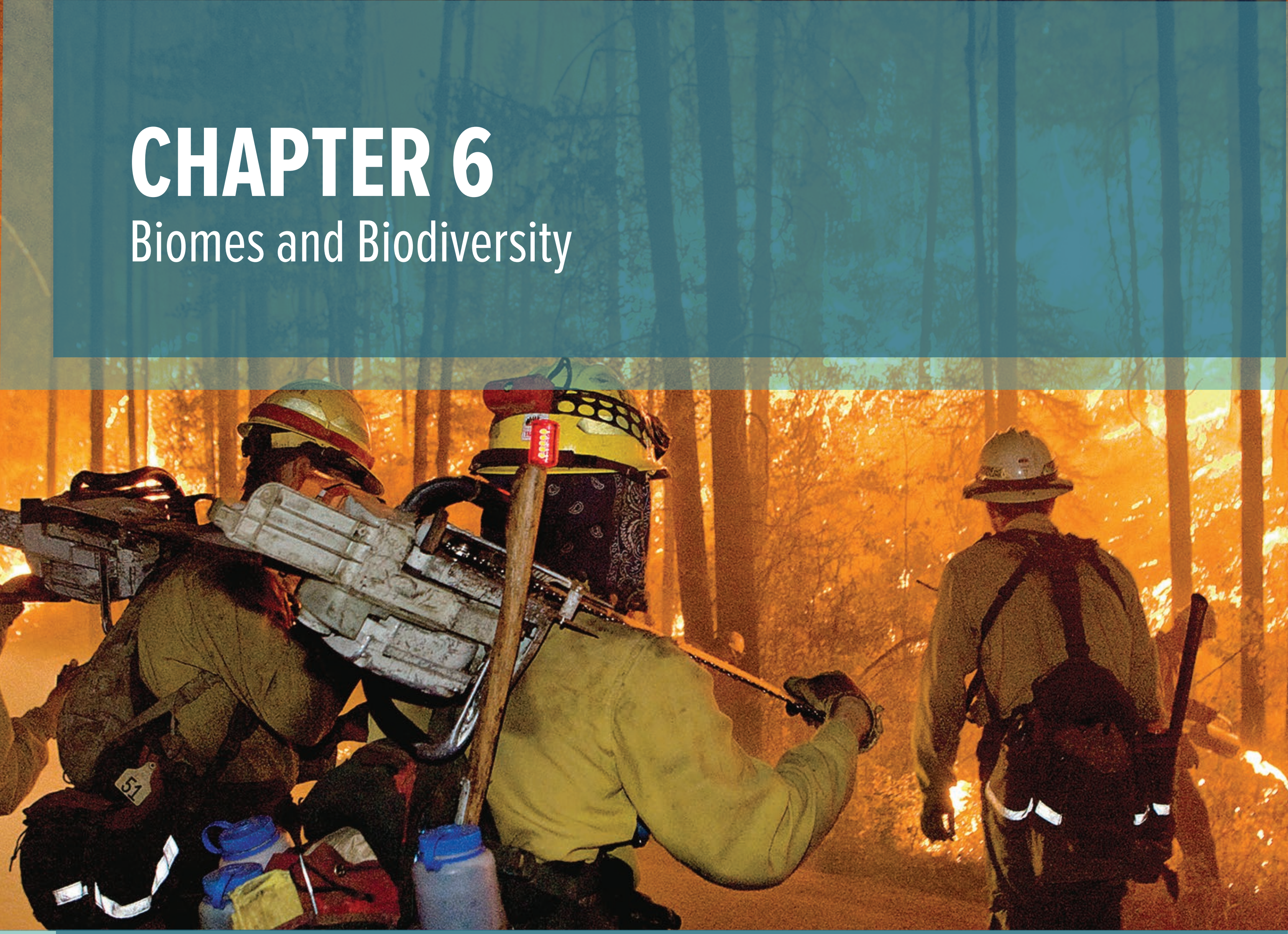
CHAPTER 6
Biomes and Biodiversity



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CER Case Study: Ecosystems in Transition
Crosscutting Concepts: Stability and Change

Recent years have seen the most extensive—and most expensive—forest fire seasons ever in the American West. The fire season has lengthened by nearly 3 months, and fires have become larger and more intense. They are also more expensive, rising from around $250 million in 1985 to nearly $2.5 billion in 2017. What has caused the changes? A combination of factors, including longer, hotter summers and drought. On top of these is the explosive growth of billions of tiny beetles, the size of a grain of rice, that have been blamed for damaging or destroying nearly 17 million ha (42 million acres) of western forests. All of these factors are a natural part of western ecosystems. The question is, as all of them accelerate with climate change, what will become of the region's vast forests?

Fires are common in the region, periodically burning patches of spruce, fir, and pine forests in hot, dry summers and allowing young trees to emerge in aging stands. After a fire the forest in a particular area may grow for decades or centuries before burning again. Fire doesn't necessarily kill trees—prolonged or repeated drought is the more important cause of tree mortality. Many trees survive and grow, with bark gradually covering over scars from multiple fires.

Also common are bark beetles, mainly species of the genus *Dendroctonus* and the genus *Ips,* which burrow below the bark of conifers to consume the living inner bark, or phloem, and deposit their eggs. Bark beetles are especially attracted to damaged or drought-stressed trees: These cannot defend themselves, as a

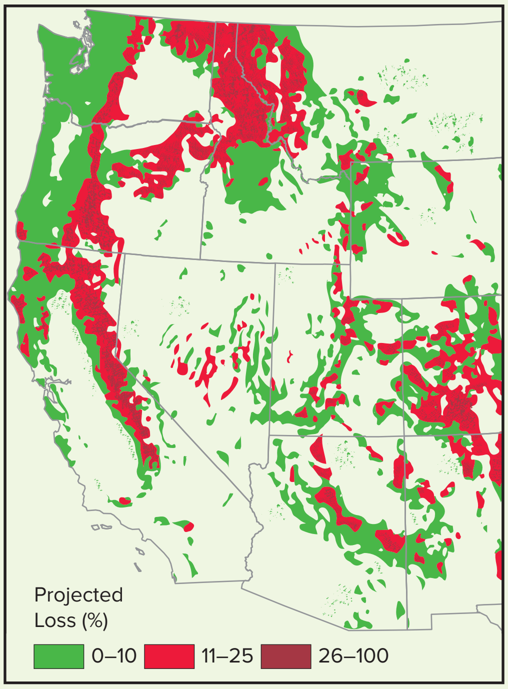

FIGURE 6.1 Projected forest losses from bark beetles and other insect pests by 2027. Source: Data from US Forest Service

healthy tree can, by overwhelming the insects with oozing sap. Normally, long and intensely cold winters kill off many of the beetle larvae, so widespread destruction is infrequent.

In recent decades longer and hotter summers have allowed beetles to thrive. Larvae develop more rapidly in hot weather, and several generations may now occur in a summer. More beetles survive the shorter, milder winters. Outbreaks are now far more extensive and more devastating than western states have seen in the past, and the pests are moving north. Ever-larger areas of forest have become standing dry tinder, waiting for the next lightning strike for ignition (fig 6.1).

Forests can recover from periodic disturbance, but increasingly ecologists are warning that a growing frequency and severity of beetle outbreaks and of fires, both driven by climate warming, are likely to lead to a state transition. What we have known as a forested western landscape is likely to transition to something new in many areas (fig. 6.2). Perhaps former forests will become patchy savannahs, shrublands, or even grasslands. It depends on how much a given area warms and how patterns of rain, snow, and below-freezing temperatures change.

To an ecologist, a transition from forest to some other type of ecosystem makes sense. Temperature and precipitation determine the general type of biome that occurs in an area, often aided by related factors such as insect pests. We have usually considered biome regions stable but shifting patterns of temperature and precipitation should cause a different type of ecosystem to develop in a place. So as climate regions change in coming decades, we can expect that the map of biomes and ecological regions will shift. Where will shifts occur, and how dramatic will they be? That remains to be seen.

To residents of the West, a state transition may mean serious disruption. Much of the region is defined by its forested mountain landscapes. Economies depend on historically reliable forest resources, from timber to the scenery that supports tourism. Ecosystem services, especially provision of drinking water and irrigation from forested watersheds, support cities and farms throughout the region. A shift from abundant forests to another biome type could have dramatic impacts on the lives and livelihoods of people in the region.

In this chapter we examine some of the factors that help us understand why ecosystems and biomes look and function as they do. Understanding these factors can help us understand why the environments we live in look as they do, and what changes we are likely to see in these systems where we live.

FIGURE 6.2 Projected forest losses from bark beetles and other insect pests by 2027. Source: Data from US Forest Service

6.1 TERRESTRIAL BIOMES

Guiding Questions

What are nine major terrestrial biomes, and what environmental conditions control their distribution?

Use the Practices

Obtaining, Evaluating, and Communicating Information: What terrestrial biome are you located in? Create a graphic organizer to show which biome(s) you are located in and closest to, the climatic conditions of the biome or biomes, and the most common species found in the biome.

Biological communities are strongly shaped by temperature ranges and the availability of moisture. As we evaluate potential effects of environmental change, it's useful to start by examining how these factors influence general patterns of plant and animal distribution. **Biome** is a term we use to describe these broad classes of biological communities. If we know the range of temperature and precipitation in a particular place, we can generally predict what kind of biome is likely to occur there, in the absence of human disturbance (fig. 6.3).

An important characteristic of each biome is its **biodiversity**, or the number and variety of biological species that live there. Species not only create much of the structure and functions of an ecosystem but, as we discussed in chapter 3, also

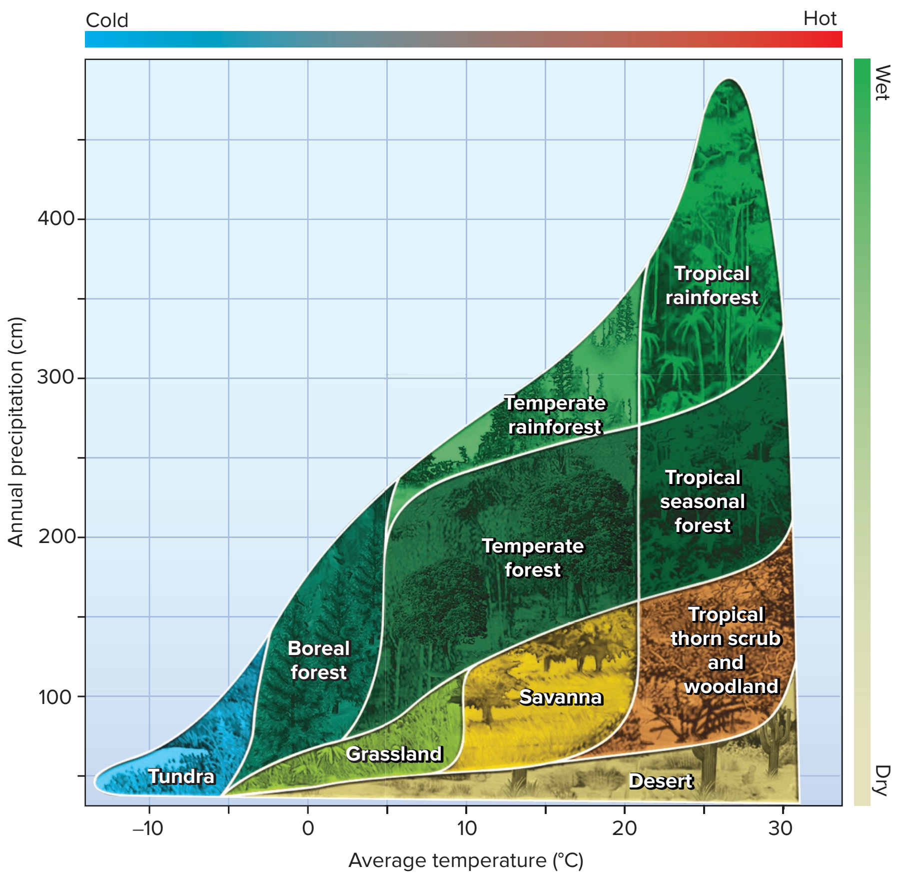

FIGURE 6.3 Biomes most likely to occur in the absence of human disturbance or other disruptions, according to average annual temperature and precipitation. Changes in temperature or precipitation could shift a region into a different place on this chart. Note that this diagram does not consider soil type, topography, wind speed, or other important environmental factors.

Benchmark Data	
Among the ideas and values in this chapter, the following are a few worth remembering	
200 mm	Annual precipitation in tropical rainforests
< 50 mm	Annual precipitation in deserts
> 5,000	Number of mammal species
21%	Mammal species endangered
> 280,000	Number of flowering plant species
73%	Flowering plant species threatened
2 million	Number of reptiles imported illegally into the United States per year

TABLE 6.1 Benchmark Data

generate emergent properties, such as productivity, homeostasis, and resilience. Productivity, the rate at which plants produce biomass, varies a great deal from warm to cold climates, and from wet to dry environments. The amount of resources we can extract, such as timber, fish, or crops, depends largely on a biome's biological productivity. Similarly, homeostasis (stability) and resilience (the ability to recover from disturbance) also depend on biodiversity and productivity. Clear-cut forests, for example, regrow very quickly in the warm, moist Amazon but slowly, if at all, in northern Canada's harsh cold, dry climate.

In the sections that follow, you will learn about nine major biome types. These nine can be further divided into smaller classes: For example, some temperate forests have mainly cone-bearing trees (conifers), such as pines or fir, while others have mainly broad-leaf trees, such as maples or oaks (fig. 6.4).

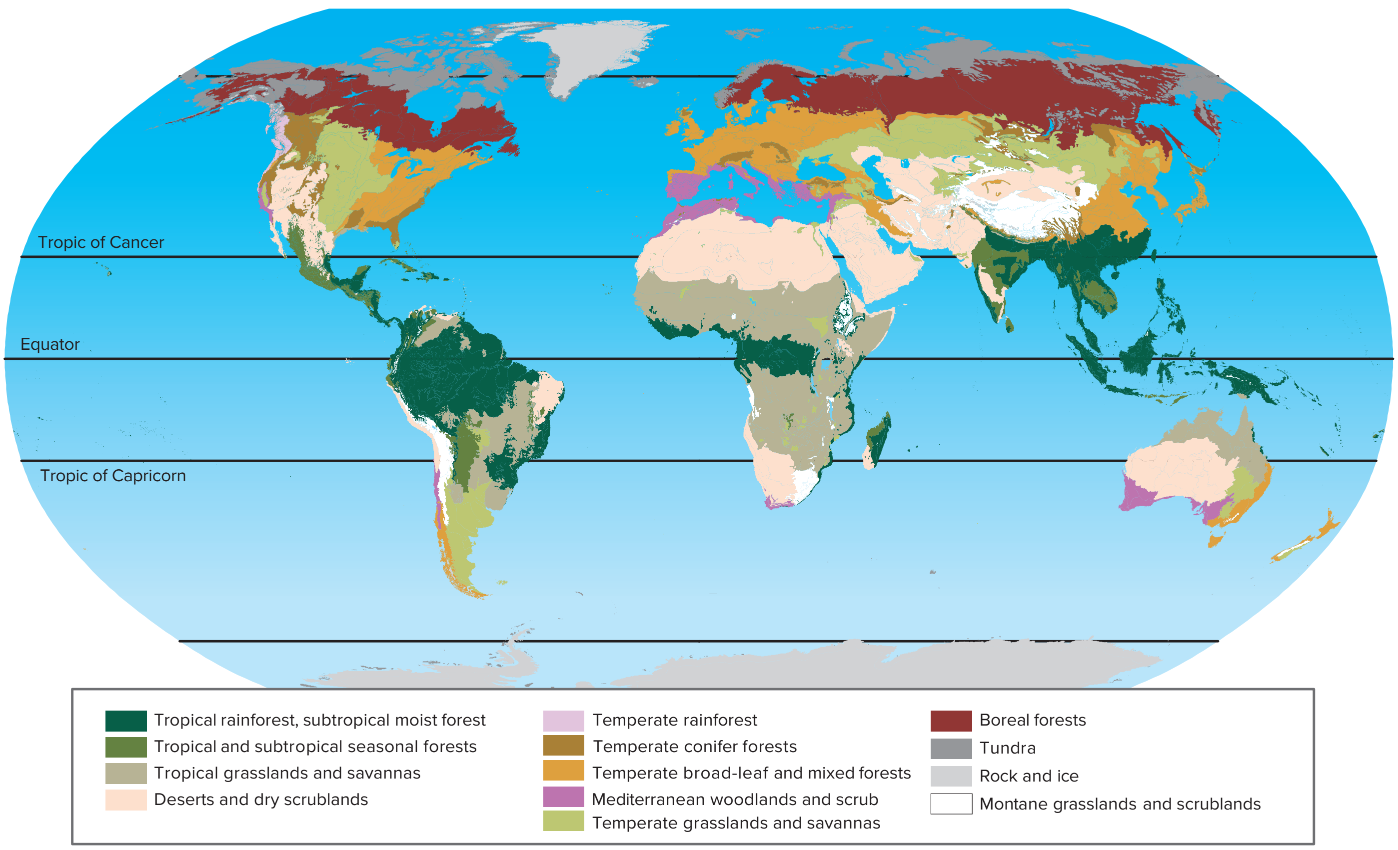

FIGURE 6.4 Major world biomes. Compare this map with figure 6.3 for generalized temperature and moisture conditions that control biome distribution. Also compare it with the satellite image of biological productivity (see fig. 6.15). Source: WWF Ecoregions.

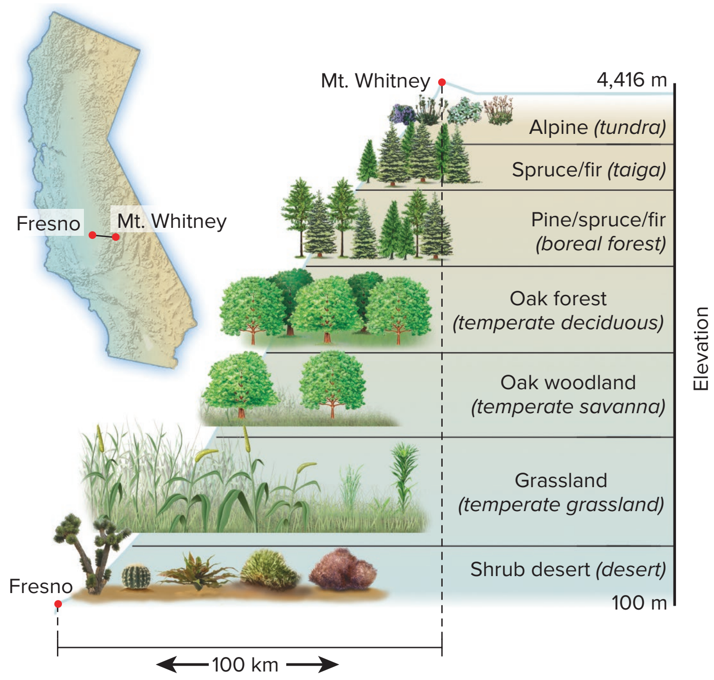

FIGURE 6.5 Vegetation changes with elevation because temperatures are lower and there is more precipitation high on a mountainside. A 100-km transect from Fresno, California, to Mt. Whitney (California's highest point) crosses vegetation zones similar to about seven different biome types.

Many temperature-controlled biomes occur in latitudinal bands. A band of boreal forest crosses Canada, Europe, and Siberia; tropical forests occur near the equator; and expansive grasslands lie near—or just beyond—the tropics. Some biomes are named for their latitudes: Tropical rainforests occur between the Tropic of Cancer (23° north) and the Tropic of Capricorn (23° south); arctic tundra lies near or above the Arctic Circle (66.6° north).

Temperature and precipitation change with elevation as well as with latitude. In mountainous regions, temperatures are cooler and precipitation is usually greater at high elevations. Mountains are cooler, and often wetter, than low elevations. **Vertical zonation** is a term applied to vegetation zones defined by altitude. A 100-km transect from California's Central Valley up to Mt. Whitney, for example, crosses as many vegetation zones as you would find on a journey from southern California to northern Canada (fig. 6.5).

As you consider the terrestrial biomes, compare the climatic conditions that help shape them. To begin, examine the three climate graphs in figure 6.6. These graphs show annual trends in temperature and precipitation (rainfall and snowfall). They also indicate the relationship between potential evaporation, which depends on temperature, and precipitation. When evaporation exceeds precipitation, dry conditions result (marked yellow). Moist climates may vary in precipitation rates, but evaporation rarely exceeds precipitation. Months above freezing temperature (marked brown) have most evaporation. Comparing these climate graphs helps us understand the different seasonal conditions that control plant and animal growth in the different biomes.

Get it?

Explain why it is important to understand productivity and climate of a biome.

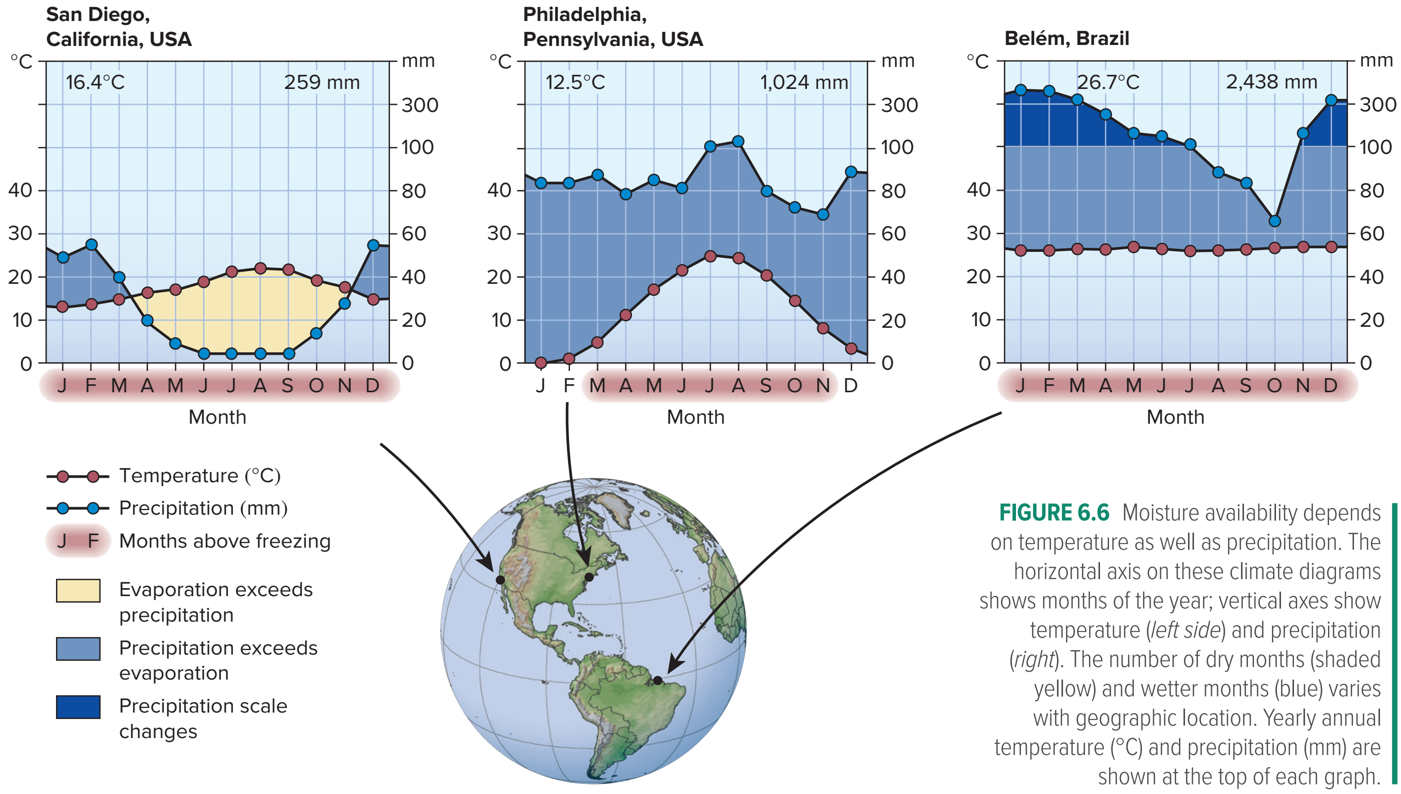

FIGURE 6.6 Moisture availability depends on temperature as well as precipitation. The horizontal axis on these climate diagrams shows months of the year; vertical axes show temperature (*left side*) and precipitation (*right*). The number of dry months (shaded yellow) and wetter months (blue) varies with geographic location. Yearly annual temperature (°C) and precipitation (mm) are shown at the top of each graph.

MATH Connection **Comparing Biome Climates**

Look back at the climate graphs for San Diego, California, an arid region, and Belém, Brazil, in the Amazon rainforest (see fig. 6.6). How much colder is San Diego than Belém in January? in July? Which location has the greater range of temperature through the year? How much do the two locations differ in precipitation during their wettest months?

Compare the temperature and precipitation in these two places with those in the other biomes shown in the pages that follow. How wet are the wettest biomes? Which biomes have distinct dry seasons? How do rainfall and length of warm seasons explain vegetation conditions in these biomes?

Tropical moist forests are warm and wet year-round

The humid tropical regions support one of the most complex and biologically rich biome types in the world (fig. 6.7). Although there are several kinds of moist tropical forests, all have ample rainfall and uniform temperatures. Cool **cloud forests** are found high in the mountains where fog and mist keep vegetation wet all the time. **Tropical rainforests** occur where rainfall is abundant—more than 200 cm (80 in.) per year—and temperatures are warm to hot year-round.

The soil of both these tropical moist forest types tends to be thin, acidic, and nutrient-poor, yet the number of species present can be mind-boggling. For example, the number of insect species in the canopy of tropical rainforests has been estimated to be in the millions! It is thought that one-half to two-thirds of all species of terrestrial plants and insects live in tropical forests.

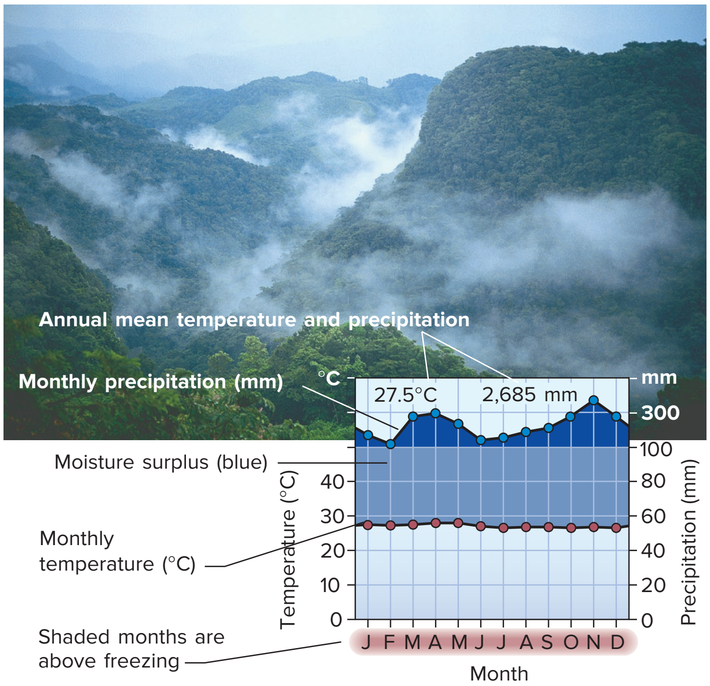

FIGURE 6.7 Tropical rainforests have luxuriant and diverse plant growth. Heavy rainfall in most months, shown in the climate graph, supports this growth.

The nutrient cycles of these forests also are distinctive. About 90 percent of all the nutrients in the rainforest are contained in the bodies of the living organisms. This is a striking contrast to temperate forests, where nutrients are held within the soil and made available for new plant growth. The luxuriant growth in tropical rainforests depends on rapid decomposition and recycling of dead organic material. Leaves and branches that fall to the forest floor decay and are incorporated almost immediately back into living biomass.

When the forest is removed for logging, agriculture, and mineral extraction, the thin soil cannot support continued cropping and cannot resist erosion from the abundant rains. Recovery of the forest could take centuries.

Tropical seasonal forests have annual dry seasons

Many tropical regions are characterized by distinct wet and dry seasons, although temperatures remain hot year-round. These areas support **tropical seasonal forests**: drought-tolerant forests that look brown and dormant in the dry season but burst into vivid green during rainy months. These forests are often called dry tropical forests because they are dry much of the year; however, there must be some periodic rain to support plant growth. Many of the trees and shrubs in a seasonal forest are drought-deciduous: They lose their leaves and cease growing when no water is available. Seasonal forests are often open woodlands that grade into savannas.

Get it?

What factors determine the level of moisture in a biome?

Tropical dry forests are generally more attractive than wet forests for human habitation and have, therefore, suffered greater degradation from settlement. Clearing a dry forest with fire is relatively easy during the dry season. Soils of dry forests often have higher nutrient levels and are more agriculturally productive than those of a rainforest. Finally, having fewer insects, parasites, and fungal diseases than a wet forest makes a dry or seasonal forest a healthier place for humans to live. Consequently, these forests are highly endangered in many places. Less than 1 percent of the dry tropical forests of the Pacific coast of Central America or the Atlantic coast of South America, for instance, remain in an undisturbed state.

Tropical savannas and grasslands are dry most of the year

Where there is too little rainfall to support forests, we find open **grasslands** or grasslands with sparse tree cover, which we call **savannas** (fig. 6.8). Like tropical seasonal forests, most tropical savannas and grasslands have a rainy season, but generally the rains are less abundant or less dependable than in a forest. During dry seasons, fires can sweep across a grassland, killing off young trees and keeping the landscape open. Savanna and grassland plants have many adaptations to survive drought, heat, and fires. Many have deep, long-lived roots that seek groundwater and that persist when leaves and stems above the ground die back. After a fire or drought, fresh, green shoots grow quickly from the roots. Migratory grazers, such as wildebeest, antelope, or bison, thrive on this new growth. Grazing pressure from domestic livestock is an important threat to both the plants and the animals of tropical grasslands and savannas.

Deserts are hot or cold, but always dry

You may think of deserts as barren and biologically impoverished. Their vegetation is sparse, but it can be surprisingly diverse, and most desert plants and animals are highly adapted to survive long droughts, extreme heat, and often extreme cold. **Deserts** occur where precipitation is sporadic and low, usually with less than 30 cm of rain per year. Adaptations to these conditions include water-storing leaves and stems, thick epidermal layers to reduce water loss, and salt tolerance. As in other dry environments, many plants are drought-deciduous. Most desert plants also bloom and set seed quickly when rain does fall.

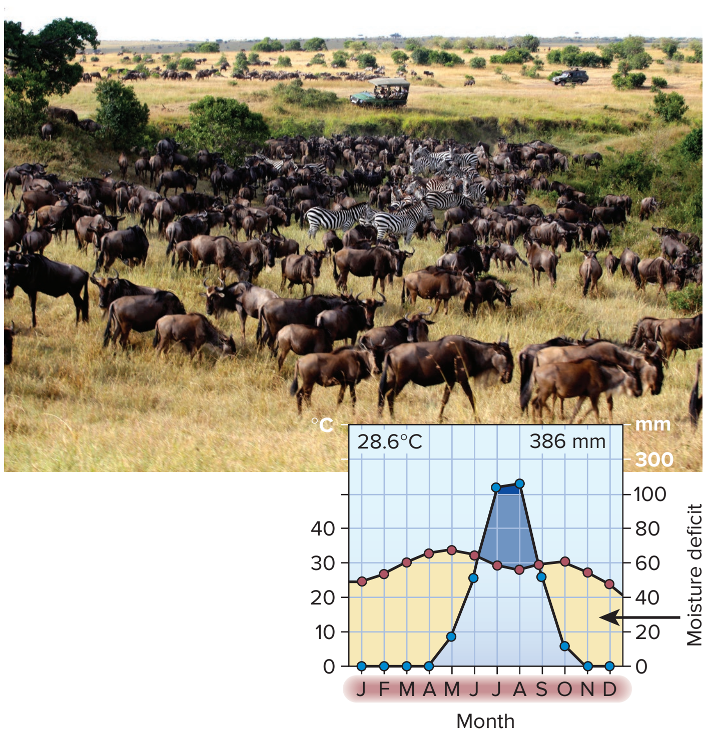

FIGURE 6.8 Tropical savannas and grasslands experience annual drought and rainy seasons and year-round warm temperatures. Thorny acacias and abundant grazers thrive in this savanna. Yellow areas show moisture deficit.

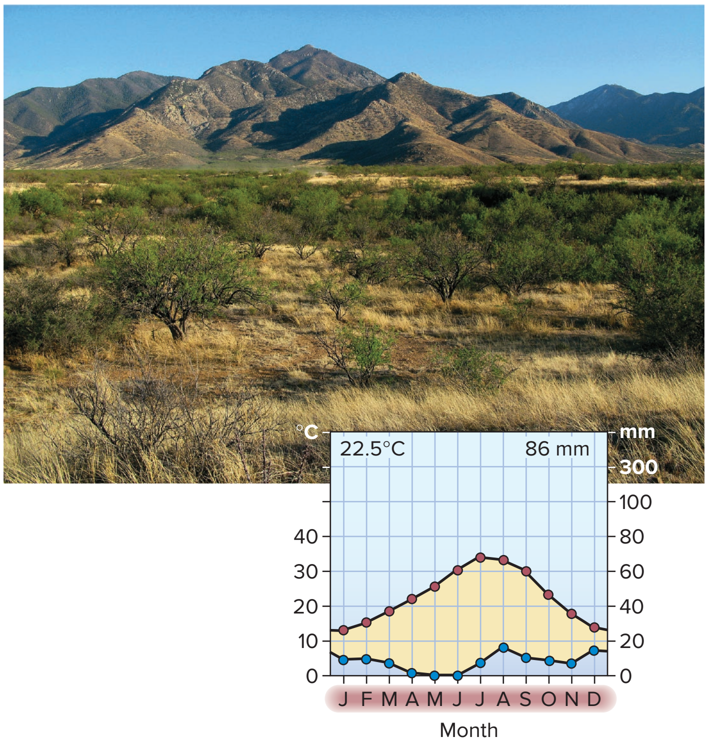

FIGURE 6.9 Deserts generally receive less than 300 mm (30 cm) of precipitation per year. Hot deserts, as in the American Southwest, endure year-round drought and extreme heat in summer.

Warm, dry, high-pressure climate conditions (see chapter 7) create desert regions at about 30° north and south. Extensive deserts occur in continental interiors (where rain is rare and evaporation rates are high) of North America, Central Asia, Africa, and Australia (fig. 6.9). The rain shadow of the Andes produces the world's driest desert in coastal Chile. Deserts can also be cold. Most of Antarctica is a desert; some inland valleys apparently get almost no precipitation at all.

Like plants, animals in deserts are specially adapted. Many are nocturnal, spending their days in burrows to avoid the sun's heat and desiccation. Pocket mice, kangaroo rats, and gerbils can get most of their moisture from seeds and plants. Desert rodents also have highly concentrated urine and nearly dry feces, which allow them to eliminate body waste without losing precious moisture.

Deserts are more vulnerable than you might imagine. Sparse, slow-growing vegetation is quickly damaged by off-road vehicles. Desert soils recover slowly. Tracks left by army tanks practicing in California deserts during World War II can still be seen today.

Deserts are also vulnerable to overgrazing. In Africa's vast Sahel (the southern edge of the Sahara Desert), livestock are destroying much of the plant cover. Bare, dry soil becomes drifting sand, and restabilization is extremely difficult. Without plant roots and organic matter, the soil loses its ability to retain what rain does fall, and the land becomes progressively drier and barer. Similar degradation of dryland vegetation is happening in many desert areas, including Central Asia, India, and the American Southwest and Plains states.

Temperate grasslands have rich soils

As in tropical latitudes, temperate (midlatitude) grasslands occur where there is enough rain to support abundant grass but not enough for forests (fig. 6.10). Usually, grasslands are a complex, diverse mix of grasses and flowering

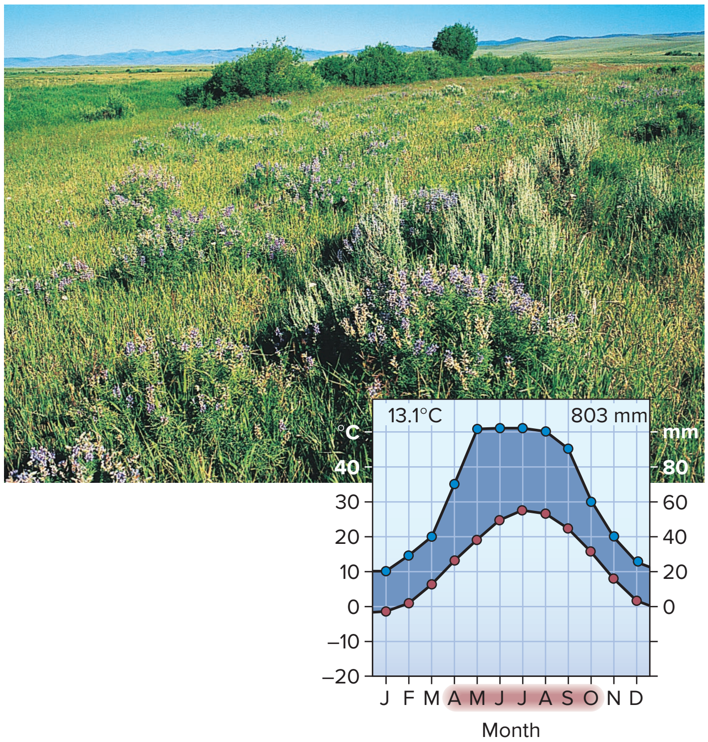

FIGURE 6.10 Grasslands occur at midlatitudes on all continents. Kept open by extreme temperatures, dry conditions, and periodic fires, grasslands can have surprisingly high plant and animal diversity.

herbaceous plants, generally known as forbs. Myriad flowering forbs make a grassland colorful and lovely in summer. In dry grasslands, vegetation may be less than a meter tall. In more humid areas, grasses can exceed 2 m. Where scattered trees occur in a grassland, we call it a savanna.

Deep roots help plants in temperate grasslands and savannas survive drought, fire, and extreme heat and cold. These roots, together with an annual winter accumulation of dead leaves on the surface, produce thick, organic-rich soils in temperate grasslands. Because of this rich soil, many grasslands have been converted to farmland. The legendary tallgrass prairies of the central United States and Canada are almost completely replaced by corn, soybeans, wheat, and other crops. Most remaining grasslands in this region are too dry to support agriculture, and their greatest threat is overgrazing. Excessive grazing eventually kills even deep-rooted plants. As ground cover dies off, soil erosion results, and unpalatable weeds, such as cheatgrass or leafy spurge, spread.

Temperate scrublands have summer drought

Often, dry environments support drought-adapted shrubs and trees, as well as grass. These mixed environments can be highly variable. They can also be very rich biologically. Such conditions are often described as Mediterranean (where the hot season coincides with the dry season, producing hot, dry summers and cool, moist winters). Evergreen shrubs with small, leathery, sclerophyllous (hard, waxy) leaves form dense thickets. Scrub oaks, drought-resistant pines, or other small trees often cluster in sheltered valleys. Periodic fires burn fiercely in this fuel-rich plant assemblage and are a major factor in plant succession. Annual spring flowers often bloom profusely, especially after fires. In California this landscape is called **chaparral**, Spanish for thicket. Resident animals are drought-tolerant species, such as jackrabbits, kangaroo rats, mule deer, chipmunks, lizards, and many bird species. Very similar landscapes are found along the

Mediterranean coast as well as southwestern Australia, central Chile, and South Africa. Although this biome doesn't cover a very large total area, it contains a high number of unique species and is often considered a "hot-spot" for biodiversity. It also is highly desired for human habitation, often leading to conflicts with rare and endangered plant and animal species.

Get it?

Differentiate between climates of a temperate grassland and temperate scrubland and the effects these climates have on vegetation.

Temperate forests can be evergreen or deciduous

Temperate, or midlatitude, forests occupy a wide range of precipitation conditions but occur mainly between about 30° and 55° latitude (see fig. 6.4). In general, we can group these forests by tree type, which can be broad-leaf **deciduous** (losing leaves seasonally) or evergreen **coniferous** (cone-bearing).

Deciduous Forests Broad-leaf forests occur throughout the world where rainfall is plentiful. In midlatitudes, these forests are deciduous and lose their leaves in winter. The loss of green chlorophyll pigments can produce brilliant colors in these forests in autumn (fig. 6.11). At lower latitudes broad-leaf forests may be evergreen or drought-deciduous. Southern live oaks, for example, are broad-leaf evergreen trees.

Although these forests have a dense canopy in summer, they have a diverse understory that blooms in spring, before the trees leaf out. Spring ephemeral (short-lived) plants produce lovely flowers, and vernal (springtime) pools support amphibians and insects. These forests also shelter a great diversity of songbirds.

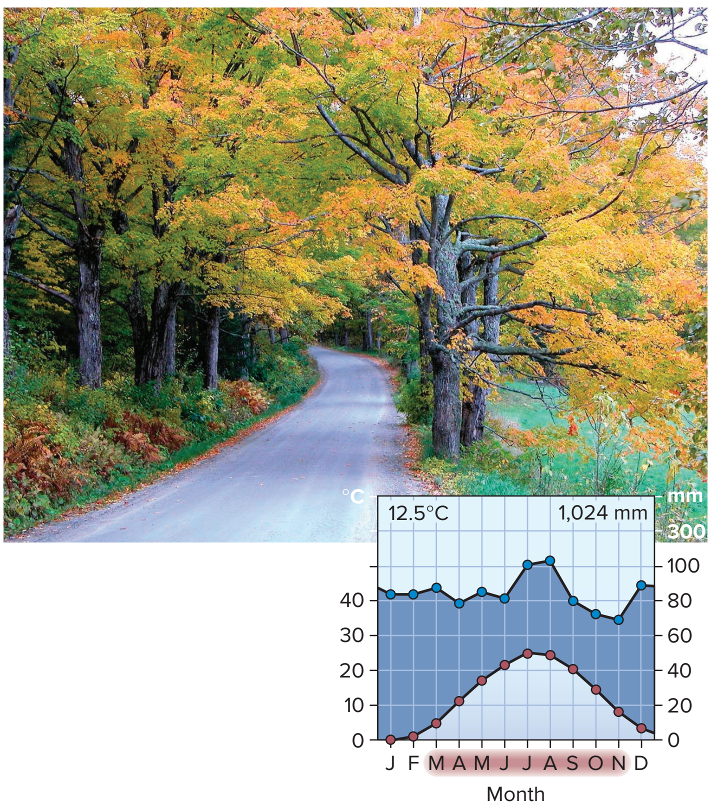

FIGURE 6.11 Temperate deciduous forests have year-round precipitation and winters near or below freezing.

North American deciduous forests once covered most of what is now the eastern half of the United States and southern Canada. Most of western Europe was once deciduous forest but was cleared a thousand years ago. When European settlers first came to North America, they quickly settled and cut most of the eastern deciduous forests for firewood, lumber, and industrial uses, as well as to clear farmland. Many of those regions have now returned to deciduous forest, though the dominant species may have changed.

Deciduous forests can regrow quickly because they occupy moist, moderate climates. But most of these forests have been occupied so long that human impacts are extensive, and most native species are at least somewhat threatened. The greatest current threat to temperate deciduous forests is in eastern Siberia, where deforestation is proceeding rapidly. Siberia may have the highest deforestation rate in the world. As forests disappear, so do Siberian tigers, bears, cranes, and a host of other endangered species.

Coniferous Forests Evergreen forests of pines, spruce, fir, and other species grow in a wide range of environmental conditions. Often they occur where moisture is limited: In cold climates, moisture is unavailable (frozen) in winter; hot climates may have seasonal drought; sandy soils hold little moisture, and they are often occupied by conifers. Thin, waxy leaves (needles) help these trees reduce moisture loss. Coniferous forests provide most wood products in North America. Dominant wood production regions include the southern Atlantic and Gulf coast states, the mountain West, and the Pacific Northwest (northern California to Alaska), but coniferous forests support forestry in many regions. However, climate change, insects, and other stressors, as described in the opening case study for this chapter, can degrade or dramatically change these forests.

The coniferous forests of the Pacific coast grow in extremely wet conditions. The wettest coastal forests are known as **temperate rainforests**, a cool, rainy forest often enshrouded in fog (fig. 6.12). Condensation in the canopy (leaf drip) is a major form of precipitation in the understory. Mild year-round temperatures and

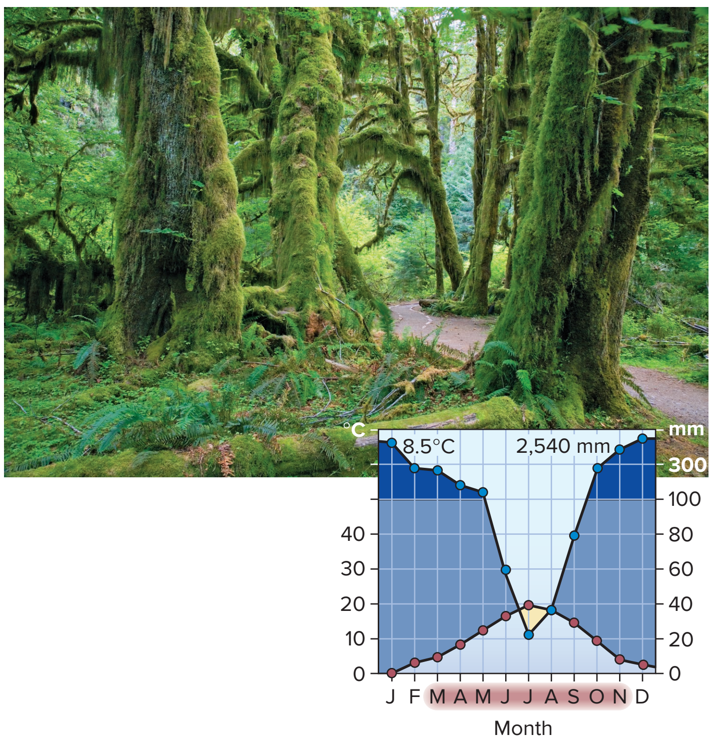

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FIGURE 6.12 Temperate rainforests have abundant but often seasonal precipitation that supports magnificent trees and luxuriant understory vegetation. Often these forests experience dry summers.

abundant rainfall, up to 250 cm (100 in.) per year, result in luxuriant plant growth and giant trees such as the California redwoods, the largest trees in the world and the largest aboveground organism ever known to have existed. Redwoods once grew along the Pacific coast from California to Oregon, but logging has reduced their range to a few small fragments of those areas.

Boreal forests lie north of the temperate zone

Because conifers can survive winter cold, they tend to dominate the **boreal forest**, or northern forests, that lies between about 50° and 60° north (fig. 6.13). Mountainous areas at lower latitudes may also have many characteristics and species of the boreal forest. Dominant trees are pines, hemlocks, spruce, cedar, and fir. Some deciduous trees are also present, such as maples, birch, aspen, and alder. These forests are slow-growing because of the cold temperatures and short frost-free growing season, but they are still an expansive resource. In Siberia, Canada, and the western United States, large regional economies depend on boreal forests. They are favorite places for hunting, fishing, and recreation as well as extractive resource use. If those forests disappear as a result of global warming, both human uses and the unique species, such as moose, lynx, and otter, that depend on that biome will be sorely missed.

Get it?

Explain why trees in a coniferous forest can grow very large in diameter but in a boreal forest trees are usually very small in diameter.

The extreme, ragged edge of the boreal forest, where forest gradually gives way to open tundra, is known by its Russian name, **taiga**. Here extreme cold and short summer limit the growth rate of trees. A 10-cm-diameter tree may be over 200 years old in the far north.

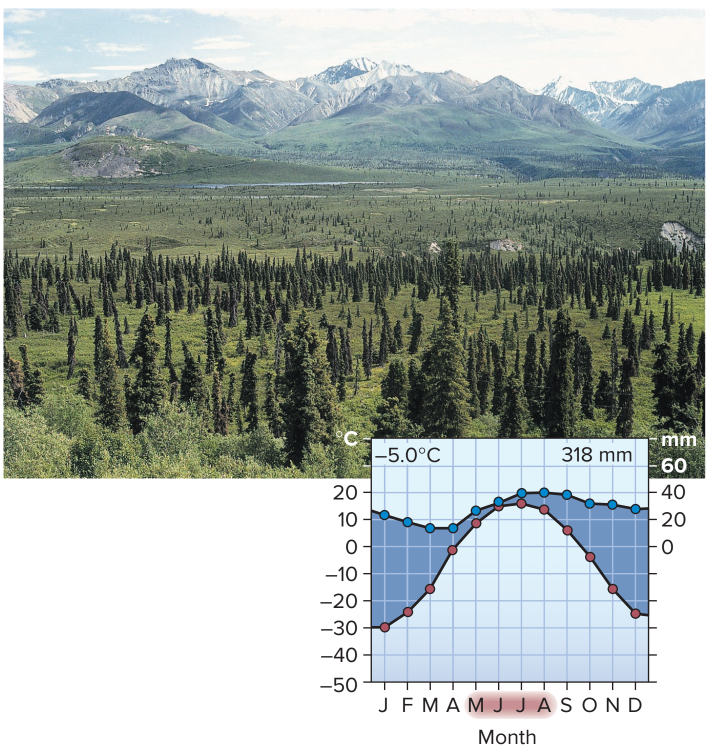

FIGURE 6.13 Boreal forests have moderate precipitation but are often moist because temperatures are cold most of the year. Cold-tolerant and drought-tolerant conifers dominate boreal forests and taiga, at the forest fringe.

Tundra can freeze in any month

Where temperatures are below freezing most of the year, only small, hardy vegetation can survive. **Tundra**, a treeless landscape that occurs at high latitudes or on mountaintops, has a growing season of only 2 to 3 months, and it may have frost any month of the year. Some people consider tundra a variant of grasslands because it has no trees; others consider it a very cold desert because water is unavailable (frozen) most of the year.

Arctic tundra is an expansive biome that has low productivity because it has a short growing season. During midsummer, however, 24-hour sunshine supports a burst of plant growth and an explosion of insect life. Tens of millions of waterfowl, shorebirds, terns, and songbirds migrate to the Arctic every year to feast on the abundant invertebrate and plant life and to raise their young on the brief bounty. These birds then migrate to wintering grounds, where they may be eaten by local predators—effectively, they carry energy and protein from high latitudes to low latitudes. Arctic tundra is essential for global biodiversity, especially for birds.

Alpine tundra, occurring on or near mountaintops, has environmental conditions and vegetation similar to arctic tundra (fig. 6.14). These areas have a short, intense growing season. Often one sees a splendid profusion of flowers in alpine tundra; everything must flower at once in order to produce seeds in a few weeks before the snow comes again. Many alpine tundra plants also have deep pigmentation and leathery leaves to protect against the strong ultraviolet light in the thin mountain atmosphere.

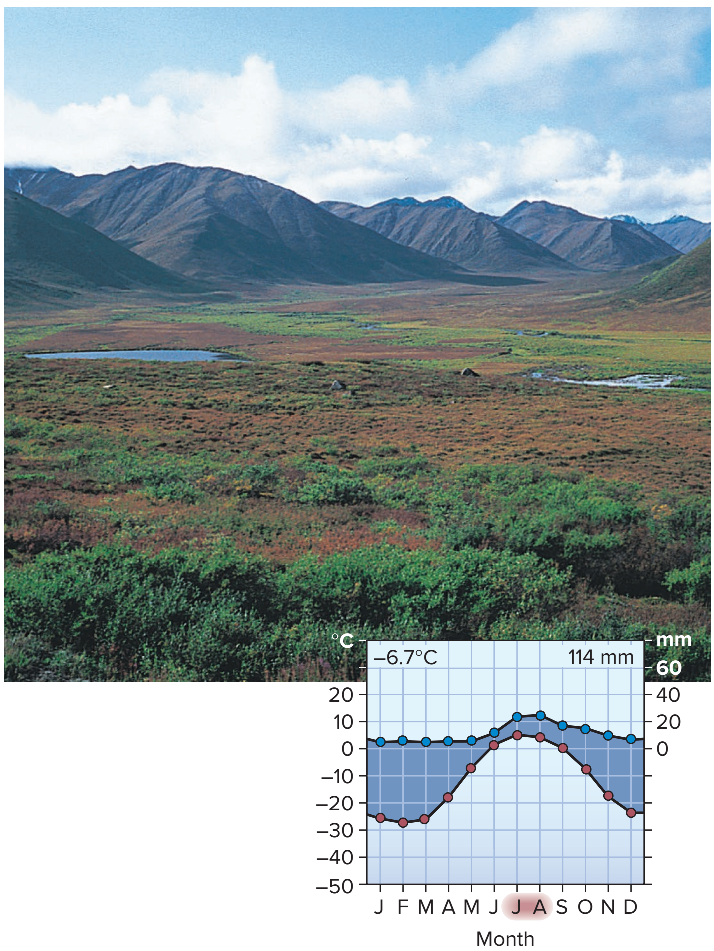

FIGURE 6.14 This landscape in Canada's Northwest Territories has both alpine and arctic tundra. Plant diversity is relatively low, and frost can occur even in summer.

Compared to other biomes, tundra has relatively low diversity. Dwarf shrubs, such as willows, sedges, grasses, mosses, and lichens, tend to dominate the vegetation. Migratory musk ox, caribou, or alpine mountain sheep and mountain goats can live on the vegetation because they move frequently to new pastures.

Because these environments are too cold for most human activities, they are not as badly threatened as other biomes. There are important problems, however. Global climate change may be altering the balance of some tundra ecosystems, and air pollution from distant cities tends to accumulate at high latitudes (see chapter 7). In eastern Canada, coastal tundra is being badly depleted by overabundant populations of snow geese, whose numbers have exploded due to winter grazing on the rice fields of Arkansas and Louisiana. Oil and gas drilling—and associated truck traffic—threatens tundra in Alaska and Siberia. Clearly, this remote biome is not independent of human activities at lower latitudes.

Section Review

- Biomes are broad categories of living systems defined mainly by climate.
- Biomes vary in biodiversity, productivity, and structure.

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1. What are the two main factors that differentiate biomes?
2. Compare and contrast deserts, tundras, and tropical rainforests.

6.2 MARINE ENVIRONMENTS

Guiding Questions

How does vertical stratification differentiate life zones in oceans?

Use the Practices

Asking Questions and Defining Problems: What questions would you ask about a marine ecosystem before categorizing it? Why may marine ecosystems be harder to categorize than terrestrial ones?

The biological communities in oceans and seas are poorly understood, but many are as diverse and complex as terrestrial biomes. In this section we will explore a few facets of these fascinating environments. Oceans cover nearly three-fourths of the earth's surface, and they contribute in important, although often unrecognized, ways to terrestrial ecosystems. Like land-based systems, most marine communities depend on photosynthetic organisms. Often it is algae or tiny, free-floating photosynthetic plants (**phytoplankton**) that support a marine food web, rather than the trees and grasses we see on land. In oceans, photosynthetic activity tends to be greatest near coastlines, where nitrogen, phosphorus, and other nutrients wash offshore and fertilize primary producers. Ocean currents also contribute to the distribution of biological productivity, as they transport nutrients and phytoplankton far from shore (fig. 6.15).

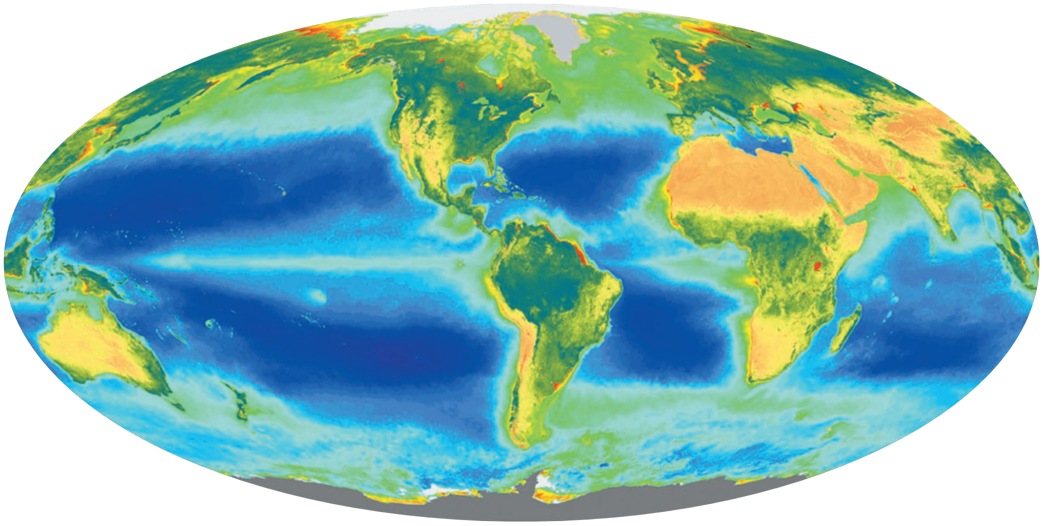

FIGURE 6.15 Biological productivity, from satellite measurements of chlorophyll concentrations. In oceans, productivity is highest (red to green) near coastlines and where currents carry nutrients. Mid-ocean basins have low productivity. On land, dark greens show high productivity; yellow-orange is low. Source: Sea

As plankton, algae, fish, and other organisms die, they sink toward the ocean floor. Deep-ocean ecosystems, consisting of crabs, filter-feeding organisms, strange phosphorescent fish, and many other life-forms, often rely on this "marine snow" as a primary nutrient source. Surface communities also depend on this material. Upwelling currents circulate nutrients from the ocean floor back to the surface. Along the coasts of South America, Africa, and Europe, these currents support rich fisheries.

Vertical stratification is a key feature of aquatic ecosystems. Light decreases rapidly with depth, and communities below the photic zone (light zone, often reaching about 20 m deep) must rely on energy sources other than photosynthesis to persist. Temperature also decreases with depth. Deep-ocean species often grow slowly, in part because metabolism is reduced in cold conditions. In contrast, warm, bright, near-surface communities, such as coral reefs and estuaries, are among the world's most biologically productive environments. Temperature also affects the amount of oxygen and other elements that can be absorbed in water. Cold water holds abundant oxygen, so productivity is often high in cold oceans, as in the North Atlantic, North Pacific, and Antarctic.

Get it?

How does temperature impact the ability of an organism to survive in the ocean at different depths?

MATH Connection Examining Climate Graphs

Among the nine types of terrestrial biomes you've just read about, one of the important factors is the number of months when the average temperature is below freezing (0°C). This is because most plants photosynthesize most actively when daytime temperatures are well above freezing—and when water is fluid, not frozen (see chapter 3). Among the biome examples shown, how many sites have fewer than 3 months when the average temperature is above 0°? How many sites have all months above freezing? Look at figure 6.3. Do all deserts have average yearly temperatures above freezing? Now look at figure 6.4. Which biome do you live in? Which biome do most Americans live in?

Open ocean communities vary from surface to hadal zone

Ocean systems can be described by depth and proximity to shore (fig. 6.16). In general, **benthic** communities occur on the bottom, and **pelagic** (sea in Greek) zones are the water column. The epipelagic zone (epi = on top) has photosynthetic organisms. Below this are the mesopelagic (meso = medium) and bathypelagic (bathos = deep) zones. The deepest layers are the abyssal zone (to 4,000 m) and hadal zone (deeper than 6,000 m). Shorelines are known as littoral zones, and the area exposed by low tides is known as the intertidal zone. Often there is a broad, relatively shallow region along a continent's coast, which may reach a few kilometers or hundreds of kilometers from shore. This undersea area is the continental shelf.

We know relatively little about marine ecosystems and habitats, and much of what we know we have learned only recently. The open ocean has long been known as a biological desert, because it has relatively low productivity, or biomass production. Fish and plankton abound in many areas, however. Sea mounts, or undersea mountain chains and islands, support many commercial fisheries and much newly discovered biodiversity. In the equatorial Pacific and Antarctic oceans, currents carry nutrients far from shore, supporting biological productivity. The Sargasso Sea, a large region of the Atlantic near Bermuda, is known for its free-floating mats of brown algae. These algae mats support a phenomenal diversity of animals, including sea turtles, fish, and other species. Eels that hatch amid the algae eventually migrate up rivers along the Atlantic coasts of North America and Europe.

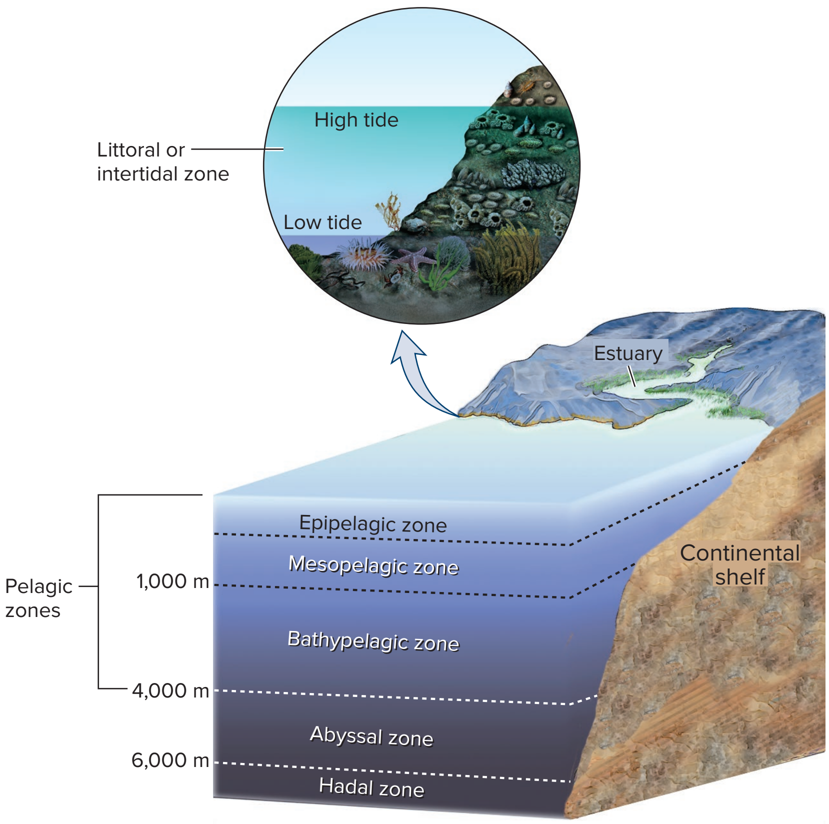

FIGURE 6.16 Light penetrates only the top 10–20 m of the ocean. Below this level, temperatures drop and pressure increases. Nearshore environments include the intertidal zone and estuaries.

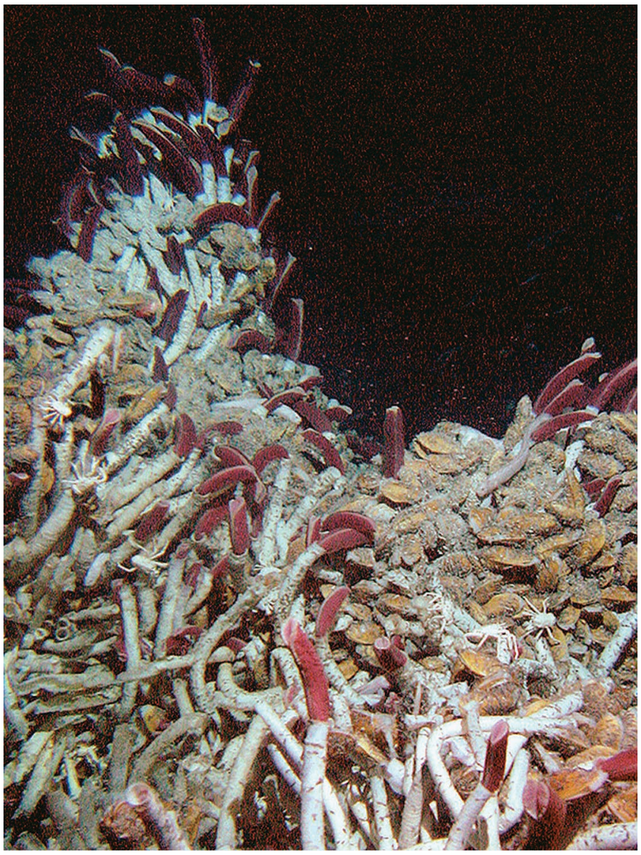

FIGURE 6.17 Deep-ocean thermal vent communities have great diversity and are unusual because they rely on chemosynthesis, not photosynthesis, for energy. Source: National Oceanic and Atmospheric Administration (NOAA)

Deep-sea thermal vent communities are another remarkable type of marine system that was completely unknown until 1977, when the deep-sea submarine Alvin descended to the deep-ocean floor. These communities are based on microbes that capture chemical energy, mainly from sulfur compounds released from thermal vents—jets of hot water and minerals on the ocean floor (fig. 6.17). Magma below the ocean crust heats these vents. Tube worms, mussels, and microbes on the vents are adapted to survive both extreme temperatures, often above 350°C (700°F), and intense water pressure at depths of 7,000 m (20,000 ft) or more. Oceanographers have discovered thousands of different types of organisms, most of them microscopic, in these communities. Some estimate that the total mass of microbes on the seafloor represents one-third of all biomass on the planet.

Tidal shores support rich, diverse communities

As in the open ocean, shoreline communities vary with depth, light, and temperature. Some shoreline communities, such as estuaries, have high biological productivity and diversity because they are enriched by nutrients washing from the land. Others, such as coral reefs, occur where there is little runoff from shore but where shallow, clear, warm water supports photosynthesis.

Coral reefs are among the best-known marine systems, because of their extraordinary biological productivity and their diverse and beautiful organisms (fig. 6.18a). Reefs are colonies of minute, colonial animals ("coral polyps") that live symbiotically with photosynthetic algae. Calcium-rich coral skeletons shelter the algae, and algae nourish the coral animals. The complex structure of a reef also shelters countless species of fish, worms, crustaceans, and other life-forms. Reefs occur where the water is shallow and clear enough for sunlight to reach the photosynthetic algae. They cannot tolerate abundant nutrients in the water, as nutrients support plankton (tiny floating plants and animals), which block sunlight.

Reefs are among the most endangered biological communities. Sediment from coastal development, farming, sewage, or other pollution can reduce water clarity and smother coral. Destructive fishing practices, including dynamite and cyanide poison, have destroyed many Asian reefs. Reefs can also be damaged or killed by changes in temperature, by invasive fish, and by diseases. **Coral bleaching**, the

(a) Coral reefs and islands

(b) Mangroves

(c) Estuary and salt marsh

(d) Tide pool

FIGURE 6.18 Coastal environments support incredible diversity and help stabilize shorelines. Coral reefs (a), mangroves (b), and estuaries (c) also provide critical nurseries for marine ecosystems. Tide pools (d) shelter highly specialized organisms.

whitening of reefs due to stress, often followed by coral death, is a growing and spreading problem that worries marine biologists.

Sea-grass beds, occupy shallow, warm, sandy coastlines. Like reefs, these support rich communities of grazers, from snails to turtles to Florida's manatees. Also, like coral reefs, sea-grass systems are very vulnerable to ocean warming.

Mangroves are a diverse group of salt-tolerant trees that grow along warm, calm marine coasts around the world (fig. 6.18b). Growing in shallow, tidal mudflats, mangroves help stabilize shorelines, blunt the force of storms, and build land by trapping sediment and organic material. After the devastating Indonesian tsunami in 2004, studies showed that mangroves, where they still stood, helped reduce the speed, height, and turbulence of the tsunami waves. Detritus, including fallen leaves, collects below mangroves and provides nutrients for a diverse community of animals and plants. Both marine species (such as crabs and fish) and terrestrial species (such as birds and bats) rely on mangroves for shelter and food.

Like coral reefs and sea-grass beds, mangrove forests provide sheltered nurseries for juvenile fish, crabs, shrimp, and other marine species on which human economies depend. However, like reefs and sea-grass beds, mangroves have been devastated by human activities. More than half of the world's mangroves that stood a century ago, perhaps 22 million ha, have been destroyed or degraded. The leading cause of mangrove destruction has been clearing for coastal shrimp or fish farms. Timber production, urban development, municipal sewage, and industrial waste also destroy mangroves. Parts of Southeast Asia and South America have lost 90 percent of their mangrove forests.

Estuaries are bays where rivers empty into the sea, mixing fresh water with salt water. **Salt marshes**, shallow wetlands flooded regularly or occasionally with seawater, occur on shallow coastlines, including estuaries (fig. 6.18c). Usually calm, warm, and nutrient-rich, estuaries and salt marshes are biologically diverse and productive. Rivers provide nutrients and sediments, and a muddy bottom supports emergent plants (whose leaves emerge above the water surface), as well as the young forms of crustaceans, such as crabs and shrimp, and mollusks, such as clams and oysters. Nearly two-thirds of all marine fish and shellfish rely on estuaries and saline wetlands for spawning and juvenile development.

Estuaries near major American cities once supported an enormous wealth of seafood. Oyster beds and clam banks in the waters adjacent to New York, Boston, and Baltimore provided free and easy food to early residents. Sewage and other contaminants long ago eliminated most of these resources, however. Recently, major efforts have been made to revive Chesapeake Bay, America's largest and most productive estuary. These efforts have shown some success, but many challenges remain.

Get it?

Choose two of the marine environments discussed and explain how each supports a diversity of marine life.

In contrast to the shallow, calm conditions of estuaries, coral reefs, and mangroves, there are violent, wave-blasted shorelines that support fascinating life-forms in **tide pools**. Tide pools are depressions in a rocky shoreline that are flooded at high tide but retain some water at low tide. These areas remain rocky where wave action prevents most plant growth or sediment (mud) accumulation. Extreme conditions, with frigid flooding at high tide and hot, desiccating sunshine at low tide, make life impossible for most species. But the specialized animals and plants that do occur in this rocky intertidal zone are astonishingly diverse and beautiful (fig. 6.18d).

Section Review

- Nutrients and living organisms are sparse in open oceans.
- Shallow, near-shore communities can have very high productivity and biodiversity.
- Near-shore communities are vulnerable to human disturbances.

1. Why are living organisms sparce in the open ocean?

2. Compare and contrast mangroves, estuaries, and salt marshes.

3. What makes shore communities more vulnerable to human disturbances?

6.3 FRESHWATER ECOSYSTEMS

Guiding Questions

What factors contribute to the high diversity found in freshwater ecosystems?

Use the Practices

Developing and Using Models: Compare and contrast the vertical zones of the open ocean with the layers of a deep lake by drawing a diagram. Include the ecological conditions of each zone and common organisms found there.

Freshwater environments are far less extensive than marine environments, but they are centers of biodiversity. Most terrestrial communities rely, to some extent, on freshwater environments. Isolated pools, streams, and even underground water systems support astonishing biodiversity in deserts, as well as provide water to land animals. In Arizona, for example, many birds are found in trees and bushes surrounding the few available rivers and streams.

Lakes have extensive open water

Freshwater lakes, like marine environments, have distinct vertical zones (fig. 6.19). Near the surface a subcommunity of plankton, mainly microscopic plants, animals, and protists (single-celled organisms, such as amoebae), floats freely in the water column. Insects such as water striders and mosquitoes also live at the air-water interface. Fish move through the water column, sometimes near the surface and sometimes at depth.

Finally, the bottom, or benthos, is occupied by a variety of snails, burrowing worms, fish, and other organisms. These make up the benthic community. Oxygen levels are lowest in the benthic environment, mainly because there is little mixing to introduce oxygen to this zone. Anaerobic (not using oxygen) bacteria may live in low-oxygen sediments. In the littoral zone, emergent plants, such as cattails and rushes, grow in the bottom sediment. These plants create important functional links between layers of an aquatic ecosystem, and they may provide the greatest primary productivity to the system.

Lakes, unless they are shallow, have a warmer upper layer that is mixed by wind and warmed by the sun. This layer is the epilimnion. Below the epilimnion is the

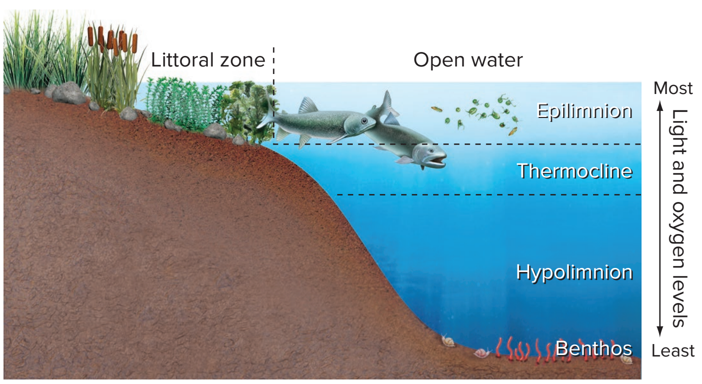

FIGURE 6.19 The layers of a deep lake are determined mainly by gradients of light, oxygen, and temperature. The epilimnion is affected by surface mixing from wind and thermal convections, while mixing between the hypolimnion and epilimnion is inhibited by a sharp temperature and density difference at the thermocline.

hypolimnion (hypo = below), a colder, deeper layer that is not mixed. If you have gone swimming in a moderately deep lake, you may have discovered the sharp temperature boundary, known as the **thermocline**, between these layers. Below this boundary, the water is much colder. This boundary is also called the mesolimnion.

Local conditions that affect the characteristics of an aquatic community include (1) nutrient availability (or excess), such as nitrates and phosphates; (2) suspended matter, such as silt, that affects light penetration; (3) depth; (4) temperature; (5) currents; (6) bottom characteristics, such as muddy, sandy, or rocky floor; (7) internal currents; and (8) connections to, or isolation from, other aquatic and terrestrial systems.

Wetlands are shallow and productive

Wetlands are shallow ecosystems in which the land surface is saturated or submerged at least part of the year. Wetlands have vegetation that is adapted to grow under saturated conditions. These legal definitions are important because, although wetlands make up only a small part of most countries, they are disproportionately important in conservation debates and are the focus of continual legal disputes in North America and elsewhere around the world. Beyond these basic descriptions, defining wetlands is a matter of hot debate. How often must a wetland be saturated, and for how long? How large must it be to deserve legal protection? Answers can vary, depending on political as well as ecological concerns.

These relatively small systems support rich biodiversity, and they are essential for both breeding and migrating birds. Although wetlands occupy less than 5 percent of the land in the United States, the Fish and Wildlife Service estimates that one-third of all endangered species spend at least part of their lives in wetlands. Wetlands retain storm water and reduce flooding by slowing the rate at which rainfall reaches river systems. Floodwater storage is worth $3 billion to $4 billion per year in the United States. As water stands in wetlands, it also seeps into the ground, replenishing groundwater supplies. Wetlands filter and even purify, urban and farm runoff, as bacteria and plants take up nutrients and contaminants in water. They are also in great demand for filling and development. They are often near cities or farms, where land is valuable, and, once drained, wetlands are easily converted to more lucrative uses. At least half of all the wetlands that existed in the United States when Europeans first arrived have been drained, filled, or degraded. In some major farming states, losses have been even greater. Iowa, for example, has lost 99 percent of its original wetlands.

Wetlands are described by their vegetation (fig. 6.20). **Swamps**, also called wooded wetlands, are wetlands with trees. **Marshes** are wetlands without trees. **Bogs** are areas of water—saturated ground, and usually the ground is composed of deep layers of accumulated, undecayed vegetation known as peat. **Fens** are similar to bogs except that they are mainly fed by groundwater, so that they have mineral-rich water and specially adapted plant species. Many bogs are fed mainly by precipitation. Swamps and marshes have high biological productivity. Bogs and fens, which are often nutrient-poor, have low biological productivity. They may have unusual and interesting species, though, such as sundews and pitcher plants, which are adapted to capture nutrients from insects rather than from soil.

The water in marshes and swamps usually is shallow enough to allow full penetration of sunlight and seasonal warming. These mild conditions favor great

(a) Swamp, or wooded wetland

(b) Marsh

(c) Bog

FIGURE 6.20 Wetlands provide irreplaceable ecological services, including water filtration, water storage and flood reduction, and habitat. Forested wetlands (a) are often called swamps; marshes (b) have no trees; bogs (c) are acidic and accumulate peat.

photosynthetic activity, resulting in high productivity at all trophic levels. In short, life is abundant and varied. Wetlands are major breeding, nesting, and migration staging areas for waterfowl and shorebirds.

Streams and rivers are open systems

Streams form wherever precipitation exceeds evaporation and surplus water drains from the land. Within small streams, ecologists distinguish areas of riffles, where water runs rapidly over a rocky substrate, and pools, which are deeper stretches of slowly moving current. Water tends to be well mixed and oxygenated in riffles; pools tend to collect silt and organic matter. If deep enough, pools can have vertical zones similar to those of lakes. As streams collect water and merge, they form rivers, although there isn't a universal definition of when one turns into the other. Ecologists consider a river system to be a continuum of constantly changing environmental conditions and community inhabitants, from the headwaters to the mouth of a drainage or watershed. The biggest distinction between stream and lake ecosystems is that, in a stream, materials, including plants, animals, and water, are continually moved downstream by flowing currents. This downstream drift is offset by active movement of animals upstream, productivity in the stream itself, and input of materials from adjacent wetlands or uplands.

Get it?

What types of freshwater conditions could affect the characteristics of aquatic communities?

Section Review

- Freshwater systems vary in depth, nutrients, and circulation.
- Wetlands are disproportionately important for biodiversity.

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1. Compare and contrast bogs, fens, marshes, and swamps.
2. Why are wetlands important for biodiversity?
3. Why are wetlands important and valuable to humans?

6.4 BIODIVERSITY

Guiding Questions

What do we mean by biodiversity? List several regions of high biodiversity.

Use the Practices

Analyzing and Interpreting Data: Explain why flowering plants have the greatest number of endangered species but not the highest percentage of endangered species. Explain why gymnosperms have such a high percentage of endangered species.

The biomes you've just learned about shelter an astounding variety of living organisms. From the driest desert to the dripping rainforests, from the highest mountain peaks to the deepest ocean trenches, life occurs in a marvelous spectrum of sizes, colors, shapes, life cycles, and interrelationships. The varieties of organisms and complex ecological relationships give the biosphere its unique, productive characteristics. **Biodiversity**, the variety of living things, also makes the world a more beautiful and exciting place to live. Three kinds of biodiversity are essential to preserve ecological systems and functions: (1) Genetic diversity is a measure of the variety of versions of the same genes within individual species; (2) species diversity describes the number of different kinds of organisms within individual communities or ecosystems; and (3) ecological diversity specifies the number of niches, trophic levels, and ecological processes that capture energy, sustain food webs, and recycle materials within this system. Redundancy in each of these categories enhances resiliency in a biome.

Get it?

What are the three main types of biodiversity and which one describes the number of different kinds of organisms in a community or ecosystem?

Diversity can have many benefits. It may help biological communities withstand environmental stress and recover from disturbances, such as fire, drought, storms, or pest invasions. In a diverse community some species are likely to survive disturbance, so that ecological functions persist, even if some resident species disappear.

It is estimated that 95 percent of the potential pests and disease-carrying organisms in the world are controlled by natural predators and competitors. Maintaining biodiversity can be essential for pest control and other ecological functions.

Biodiversity also has cultural and aesthetic value. The U.S. Fish and Wildlife Service estimates that Americans spend $104 billion every year on wildlife-related recreation. This is 25 percent more than the $81 billion spent each year on new automobiles. Often recreation is worth far more than the resources that can be extracted from an area. Fishing, hunting, camping, hiking, and other nature-based activities also have cultural value. These activities provide exercise and contact with nature can be emotionally restorative. Often the idea of biodiversity is important: Even if you will never see a tiger or a blue whale, it may be important or gratifying to know these animals exist. This idea is termed existence value. In many cultures, nature carries spiritual connotations, and observing and protecting nature have religious or moral significance.

Increasingly we identify species by genetic similarity

The concept of a species is fundamental in understanding biodiversity, but what is a species? In general, species are distinct organisms that persist because they can produce fertile offspring. But many organisms reproduce asexually; others don't reproduce in nature just because they don't normally encounter one another. Because of such ambiguities, evolutionary biologists favor the **phylogenetic species concept**, which identifies genetic similarity. Alternatively, the **evolutionary species concept** defines species according to evolutionary history and common ancestors. Both of these approaches rely on DNA analysis to define similarity among organisms.

How many species are there? Biologists have identified about 1.7 million species, but these probably represent only a small fraction of the actual number (table 6.2).

Estimated Number of Species

Group	Known	Endangered	Percentage Endangered
Mammals	5,560	1,194	22
Birds	11,121	1,460	13
Reptiles	10,450	1,090	10
Amphibians	7,635	2,067	27
Fish	33,500	2,359	7
Insects	100,000	1,298	0.1
Mollusks	85,000	1,984	2
Crustaceans	47,000	732	1.6
Other animals	173,250	539	0.003
Mosses	16,236	76	0.5
Ferns and Allies	12,000	217	2
Gymnosperms	1,052	400	38
Flowering plants	268,000	10,972	4
Fungi, Lichens, protists	65,464	43	0.001

TABLE 6.2 Estimated Number of Species. Source: Data from IUCN RedList, 2017.

FIGURE 6.21 Insects and other invertebrates make up more than half of all known species. Many, like this blue morpho butterfly, are beautiful as well as ecologically important.

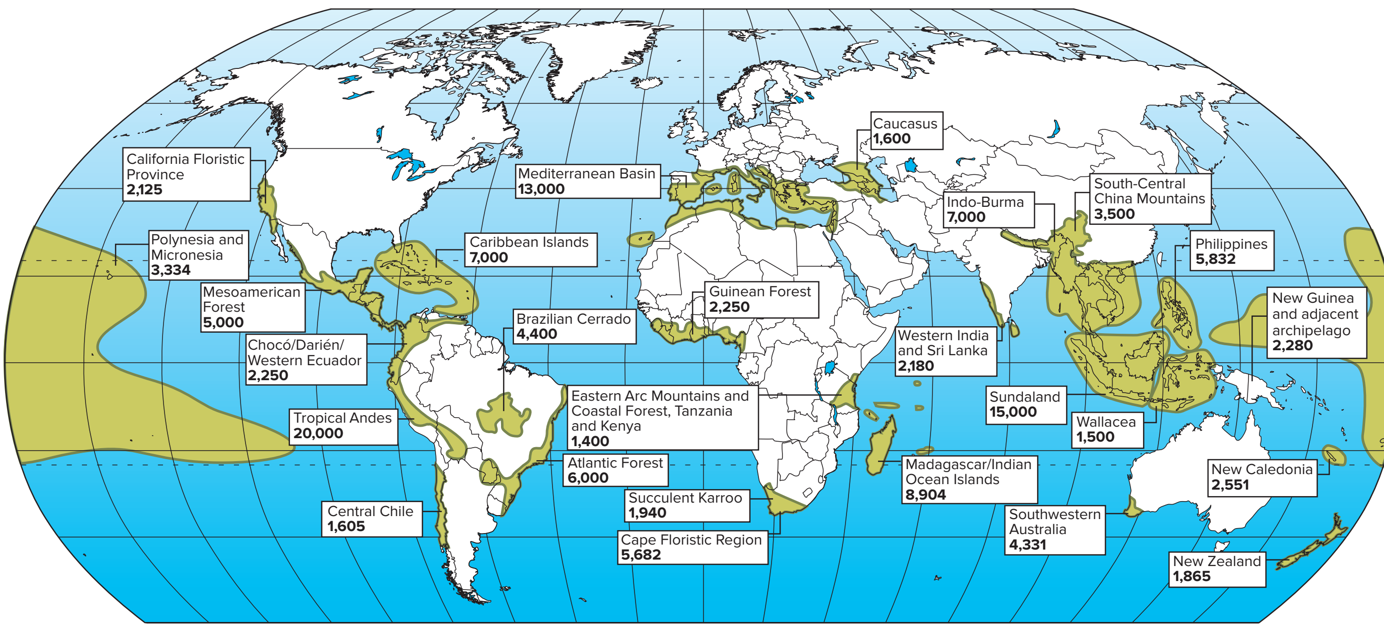
Based on the rate of new discoveries by research expeditions—especially in the tropics—taxonomists estimate that between 3 million and 50 million different species may be alive today. About 70 percent of all known species are invertebrates (animals without backbones, such as insects, sponges, clams, and worms) (fig. 6.21). This group probably makes up the vast majority of organisms yet to be discovered and may constitute 90 percent of all species.

Biodiversity hot spots are rich and threatened

Most of the world's biodiversity concentrations are near the equator, especially tropical rainforests and coral reefs (fig. 6.22). Of all the world's species, only 10 to 15 percent live in North America and Europe. Many of the organisms in megadiversity countries have never been studied by scientists. The Malaysian Peninsula, for instance, has at least 8,000 species of flowering plants, while Britain, with an area twice as large, has only 1,400 species. There may be more botanists in Britain than there are species of higher plants. South America, on the other hand, has fewer than 100 botanists to study perhaps 200,000 species of plants.

Areas isolated by water, deserts, or mountains can also have high concentrations of unique species and biodiversity. Madagascar, New Zealand, South Africa, and California are all midlatitude areas isolated by barriers that prevent mixing with biological communities from other regions and produce rich, unusual collections of species.

FIGURE 6.22 Biodiversity "hot spots" identified by Conservation International tend to be in tropical or Mediterranean climates and on islands, coastlines, or mountains where many habitats exist and physical barriers encourage speciation. Numbers represent estimated endemic (locally unique) species in each area. Source: Data from Conservation International.



Biodiversity provides food and medicines

Wild plant species make important contributions to human food supplies. Genetic material from wild plants has been used to improve domestic crops. Noted tropical ecologist Norman Myers estimates that as many as 80,000 edible wild plant species could be utilized by humans. Villagers in Indonesia, for instance, are thought to use some 4,000 native plant and animal species for food, medicine, and other products. Few of these species have been explored for possible domestication or more widespread cultivation. Wild bees, moths, bats, and other organisms provide pollination for most of the world's crops. Without these we would have little agriculture in much of the world.

FIGURE 6.23 The rosy periwinkle (*Catharanthus roseus*) from Madagascar provides anticancer drugs that now make childhood leukemias and Hodgkin's disease highly remissible.

Pharmaceutical products derived from developing world plants, animals, and microbes have a value of more than $30 billion per year, according to the United Nations Development Programme (Key Concepts, p. 214). Consider the success story of vinblastine and vincristine. These anticancer alkaloids are derived from the Madagascar periwinkle (Catharanthus roseus, fig. 6.23). They inhibit the growth of cancer cells and are very effective in treating certain kinds of cancer. Twenty years ago, before these drugs were introduced, childhood leukemias were invariably fatal. Now the remission rate for some childhood leukemias is 99 percent. Hodgkin's disease was 98 percent fatal a few years ago but is now only 40 percent fatal, thanks to these compounds. The total value of the periwinkle crop is roughly $17 million per year, although Madagascar gets little of those profits.

Get it?

Where is most of the world's biodiversity found?

Section Review

- Genetic, species, and ecological diversity influence ecosystem function.
- Amphibians and gymnosperms are widely threatened, and many groups are poorly known.
- Biodiversity is important for ecosystem stability and for resources we use.

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1. Define *biodiversity* and name three types essential in preserving ecological systems and functions.
2. What is a biodiversity hot spot? List three examples (see fig. 6.22).
3. How do humans benefit from biodiversity?

6.5 WHAT THREATENS BIODIVERSITY?

Guiding Questions

What are the major human-caused threats to biodiversity?

What are the major benefits of biodiversity?

Use the Practices

Engaging in Argument: Pick a threat to biodiversity and construct an argument as to why you think it is the greatest threat. Discuss your arguments as a group to hear other points of view.

Extinction, the elimination of a species, is a normal process of the natural world. Species die out and are replaced by others, often their own descendants, as part of evolutionary change. In undisturbed ecosystems the rate of extinction appears to be about one species lost every decade. Over the past century, however, human impacts on populations and ecosystems have accelerated that rate, possibly causing untold thousands of species, subspecies, and varieties to become extinct every year. Many of these are probably invertebrates, fungi, and microbes, which are unstudied but may perform critical functions for ecosystems. The very high proportion of higher plants and animals listed as endangered in table 6.2 probably reveals more about what we like to study than about what species are really most endangered. Large or charismatic species frequently receive more attention and research funding.

In geologic history, extinctions are common. Studies of the fossil record suggest that more than 99 percent of all species that ever existed are now extinct. Most of those species were gone long before humans came on the scene. Periodically, mass extinctions have wiped out vast numbers of species and even whole families (fig. 6.24). The best-studied of these events occurred at the end of the Cretaceous period, when dinosaurs disappeared, along with at least 50 percent of

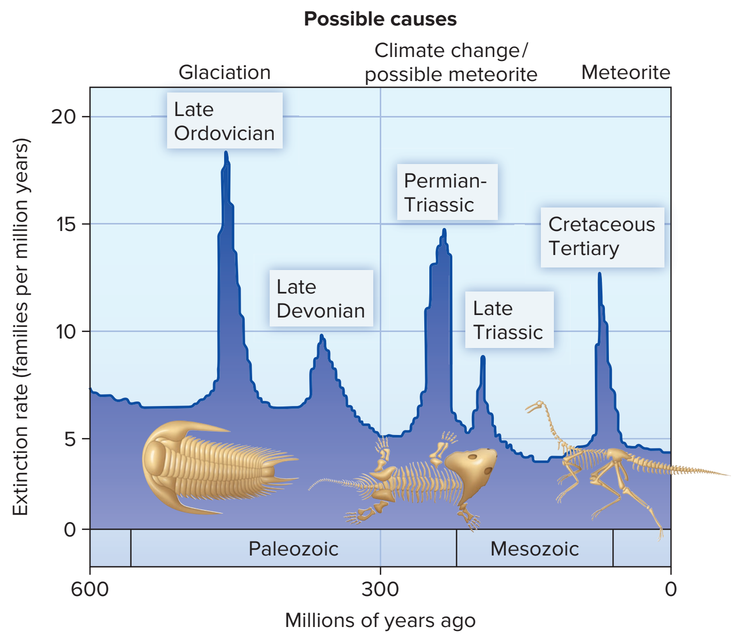


FIGURE 6.24 Major mass extinctions through history. We may be in a sixth mass extinction now, caused by human activities.

existing species. An even greater disaster occurred at the end of the Permian period, about 250 million years ago, when 95 percent of species and perhaps half of all families died out over a period of about 10,000 years—a mere moment in geologic time. Current theories suggest that these catastrophes were caused by climate changes, perhaps triggered by volcanic eruptions or large asteroids striking the earth. Many ecologists worry that global climate change caused by our release of greenhouse gases into the atmosphere could have similarly catastrophic effects (see chapter 7). Notice that we name these geologic ages (and the extinctions that occurred in them) after their dominant life-forms. Many scientists believe that the present age should be named the Anthropocene and that the current extinction crisis ranks with those of the past.

HIPPO summarizes human impacts

The rate at which species are disappearing has increased dramatically over the past 150 years. Between a.d. 1600 and 1850, human activities appear to have eliminated two or three species per decade, about double the natural extinction rate. In the past 150 years the extinction rate has increased to thousands per decade. Conservation biologists call this the sixth mass extinction but note that this time it's not asteroids or volcanoes but human impacts that are responsible. E. O. Wilson summarizes human threats to biodiversity with the acronym **HIPPO**, which stands for **H**abitat destruction, **I**nvasive species, **P**ollution, **P**opulation of humans, and **O**verharvesting. Let's look in more detail at each of these issues.

Habitat destruction is usually the main threat

The most important extinction threat for most species—especially terrestrial ones—is habitat loss. Perhaps the most obvious example of habitat destruction is conversion of forests and grasslands to farmland (fig. 6.25). Over the past 10,000 years,

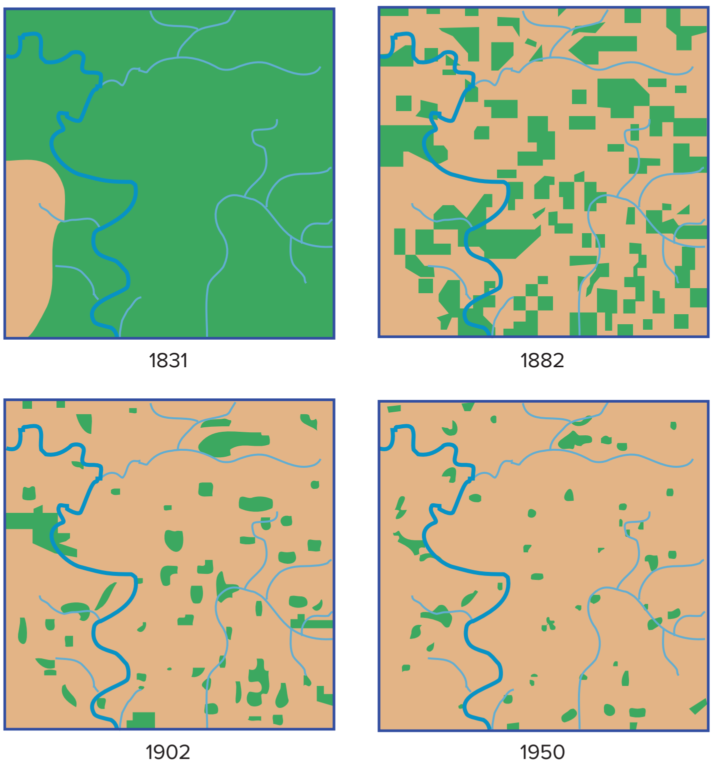


FIGURE 6.25 Decrease in wooded area of Cadiz Township in southern Wisconsin during European settlement. Green areas represent the amount of land in forest each year. Republished with permission of the University of Chicago Press, from Curtis, J. in William L. Thomas (ed.), *Man's Role in Changing the Face of the Earth*, 1956; permission conveyed through Copyright Clearance Center, Inc.

Key Concepts

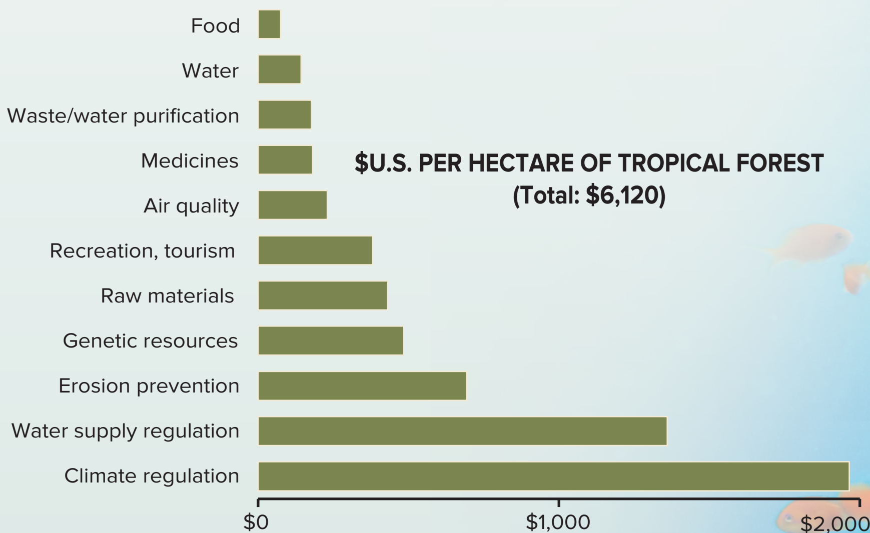
What is biodiversity worth?

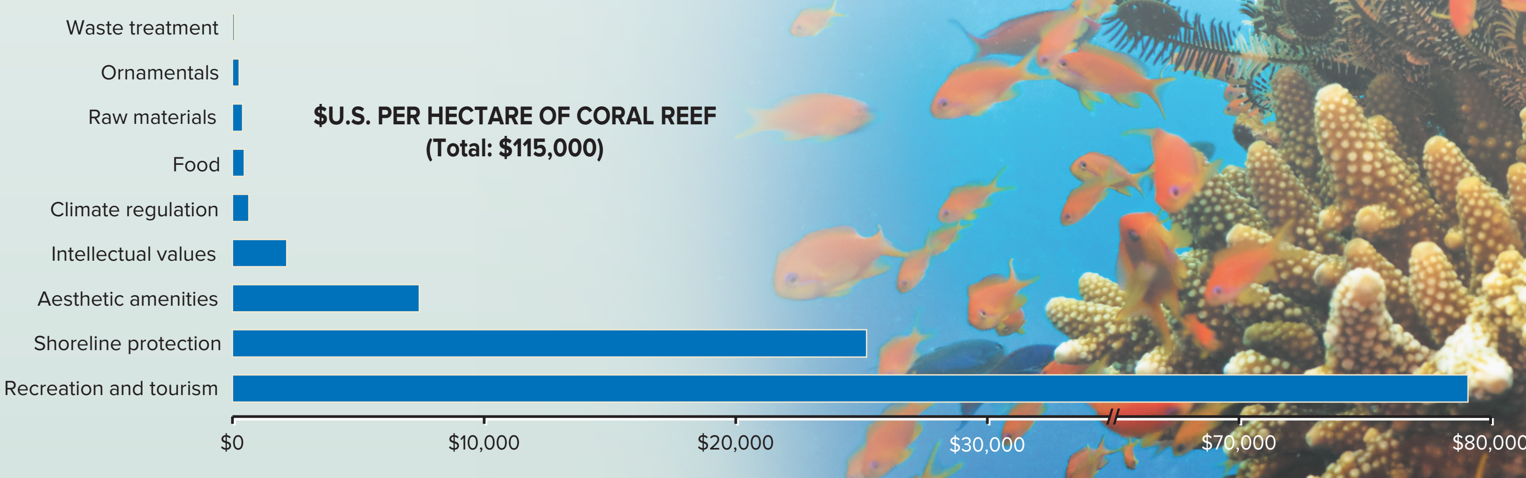
Often we consider biodiversity conservation a luxury: It's nice if you can afford it, but most of us need to make a living. We find ourselves weighing the pragmatic economic value of resources against the ethical or aesthetic value of ecosystems. **Is conservation necessarily contradictory to good economic sense?** This question can only be answered if we can calculate the value of ecosystems and biodiversity. For example, how does the value of a standing forest compare to the value of logs taken from the forest? Assigning value to ecosystems has always been hard. We take countless ecosystem services for granted: water purification, prevention of flooding and erosion, soil formation, waste disposal, nutrient cycling, climate regulation, crop pollination, food production, and more. We depend on these services, but because nobody sells them directly, it's harder to name a price for these services than for a truckload of timber.

In 2009–2010, a series of studies called The Economics of Ecosystems and Biodiversity (TEEB) compiled available research findings on valuing ecosystem services. TEEB reports found that **the value of ecological services is more than double the total world GNP,** or at least $33 trillion per year.

The graphs below show values for two sample ecosystems: tropical forests and coral reefs. These graphs show average values among studies, because values vary widely by region.

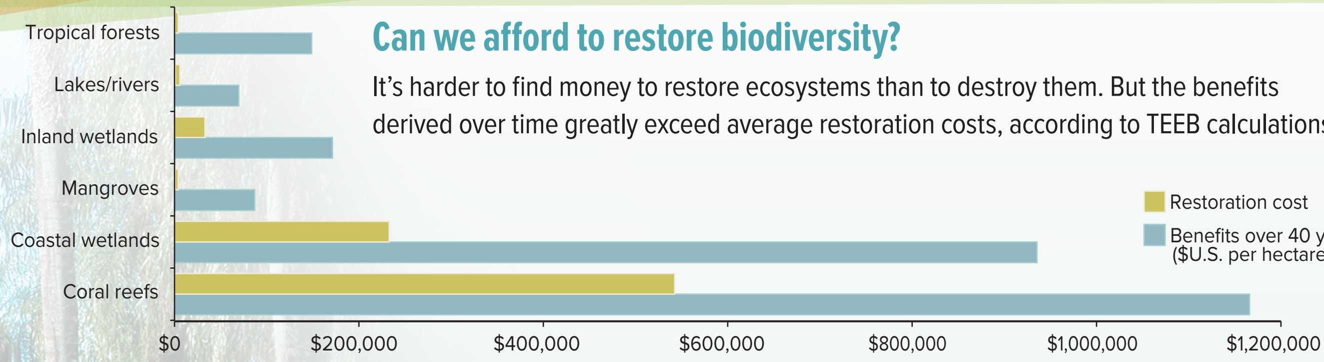
Note that these graphs have different scales.





Can we afford to restore biodiversity?

It's harder to find money to restore ecosystems than to destroy them. But the benefits derived over time greatly exceed average restoration costs, according to TEEB calculations.



Climate and water supplies These may be the most valuable aspects of forests. Effects of these services impact areas far beyond forests themselves.

Foods and wood products These are easy to imagine but much lower in value than erosion prevention, climate controls, and water supplies provided by forested ecosystems. Still, we depend on biodiversity for foods. By one estimate, Indonesia produces 250 different edible fruits. All but 43, including this mangosteen, are little known outside the region.

Pollination Most of the world is completely dependent on wild insects to pollinate crops. Natural ecosystems support populations year-round, so they are available when we need them.

Fish nurseries As discussed in chapter 1, the biodiversity of reefs and mangroves is necessary for reproduction of the fisheries on which hundreds of millions of people depend. Marine fisheries, including most farmed fish, depend entirely on wild food sources. These fish are worth a great deal as food, but they are worth far more for their recreation and tourism value.

Some natural medicine products

Product	Source	Use
Penicillin	Fungus	Antibiotic
Bacitracin	Bacterium	Antibiotic
Tetracycline	Bacterium	Antibiotic
Erythromycin	Bacterium	Antibiotic
Digitalis	Foxglove	Heart stimulant
Quinine	Chincona bank	Malaria treatment
Diosgenin	Mexican yam	Birth control drug
Cortisone	Mexican yam	Anti-inflammation treatment
Cytarabine	Sponge	Leukemia cure
Vinblastine, vincristine	Periwinkle plant	Anticancer drugs
Reserpine	Rauwolfia	Hypertension drugs
Bee venom	Bee	Arthritis relief
Allantoin	Blowfly larva	Wound healer
Morphine	Poppy	Analgesic

Medicines More than half of all prescriptions contain some natural products. The United Nations Development Programme estimates the value of pharmaceutical products derived from developing world plants, animals, and microbes to be more than $30 billion per year.

Can You Explain?

1. Do the relative costs and benefits justify restoring a coral reef? a tropical forest?
2. Identify the primary economic benefits of tropical forest and reef systems. Can you explain how each works?

humans have transformed billions of hectares of former forests and grasslands to croplands, cities, roads, and other uses. These human-dominated spaces aren't devoid of wild organisms, but they generally favor weedy species adapted to coexist with us.

Today forests cover less than half the area they once did, and only around one-fifth of the original forest retains its old-growth characteristics. Species that depend on the varied structure and resources of old-growth forest, such as the northern spotted owl (Strix occidentalis caurina), vanish as their habitat disappears. Grasslands currently occupy about 4 billion ha (roughly equal to the area of closed-canopy forests). Much of the most highly productive and species-rich grasslands—for example, the tallgrass prairie that once covered the U.S. Corn Belt—has been converted to cropland. Much more may need to be used as farmland or pasture if human populations continue to expand.

Sometimes we destroy habitat as a side effect of resource extraction, such as mining, dam-building, and indiscriminate fishing methods. Surface mining, for example, strips off the land covering along with everything growing on it. Waste from mining operations can bury valleys and poison streams with toxic material. Dam-building floods vital stream habitat under deep reservoirs and eliminates food sources and breeding habitat for some aquatic species. Our current fishing methods are highly unsustainable. One of the most destructive fishing techniques is bottom trawling, in which heavy nets are dragged across the ocean floor, scooping up every living thing and crushing the bottom structure to lifeless rubble. Marine biologist Jan Lubechenco says that trawling is "like collecting forest mushrooms with a bulldozer."

Get it?

Provide two reasons why habitat destruction is considered a major threat to biodiversity.

Fragmentation reduces habitat to small, isolated areas

In addition to the loss of total habitat area, the loss of large, contiguous areas is a serious problem. A general term for this is habitat **fragmentation**—the reduction of habitat into small, isolated patches. Breaking up habitat reduces biodiversity because many species, such as bears and large cats, require large territories to subsist. Other species, such as forest interior birds, reproduce successfully only in deep forest far from edges and human settlement. Predators and invasive species often spread quickly into new regions following fragment edges.

Fragmentation also divides populations into isolated groups, making them much more vulnerable to catastrophic events, such as storms or diseases. A very small population may not have enough breeding adults to be viable even under normal circumstances. An important question in conservation biology is, what is the **minimum viable population** size for a species, and when have dwindling populations grown too small to survive?

Much of our understanding of fragmentation was outlined in the theory of **island biogeography**, developed by R. H. MacArthur and E. O. Wilson in the 1960s. Noticing that small islands far from a mainland have fewer terrestrial species than larger islands, or those nearer a continent, MacArthur and Wilson proposed that species diversity is a balance between colonization and extinction rates.

A remote island is hard for terrestrial organisms to reach, so new species rarely arrive and establish new populations. An island near other land may have new arrivals frequently. At the same time, the population of any single species on a small island is likely to be small and therefore vulnerable to extinction. By contrast, a large island can support more individuals of a given species and is, therefore, less vulnerable to natural disasters or genetic problems.

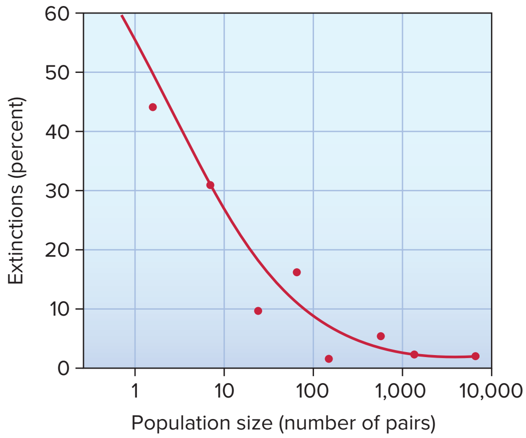


FIGURE 6.26 Extinction rates of bird species on the California Channel Islands as a function of population size over 80 years. Source: Data from Jones, H. L., and Diamond, J., "Short-term-base Studies of Turnover in Breeding Bird Populations on the California Coast Island," in *Condor*, vol. 78, 1976, 526–549.

Large islands also tend to have more variation in habitat types than small islands do, and this contributes to higher species counts in large islands.

The effect of island size has been observed in many places. Cuba, for instance, is 100 times as large and has about 10 times as many amphibian species as its Caribbean neighbor Montserrat. Similarly, in a study of bird species on the California Channel Islands, Jared Diamond observed that on islands with fewer than 10 breeding pairs, 39 percent of the populations went extinct over an 80-year period, whereas only 10 percent of populations with 10 to 100 pairs went extinct in the same time (fig. 6.26). Only one species numbering between 100 and 1,000 pairs went extinct, and no species with over 1,000 pairs disappeared over this time.

The island idea has informed our understanding of parks and wildlife refuges, which are effectively islands of habitat surrounded by oceans of inhospitable territory. Like small, remote islands, they may be too isolated to be reached by new migrants, and they can't support large enough populations to survive catastrophic events or genetic problems. Often they are also too small for species that require large territories. Tigers and wolves, for example, need large expanses of contiguous range relatively free of human incursion to survive. Glacier National Park in Montana, for example, is excellent habitat for grizzly bears. It can support only about 100 bears, however, and if there isn't migration at least occasionally from other areas, this probably isn't a large enough population to survive in the long run.

Invasive species are a growing threat

A major threat to native biodiversity in many places is from accidentally or deliberately introduced species. Called a variety of names—alien, exotic, non-native, nonindigenous, pests—**invasive species** are organisms that thrive in new territory where they are free of predators, diseases, or resource limitations that may have controlled their population in their native habitat. Note that not all exotic species expand after introduction: For example, peacocks have been introduced to many city zoos, but they tend not to escape and survive in the wild in most places. At the same time, not all invasive species are foreign. But most of the uncontrollable invasive species are introduced from elsewhere.

Humans have always transported organisms into new habitats, but the rate of movement has risen sharply in recent years with the huge increase in speed and

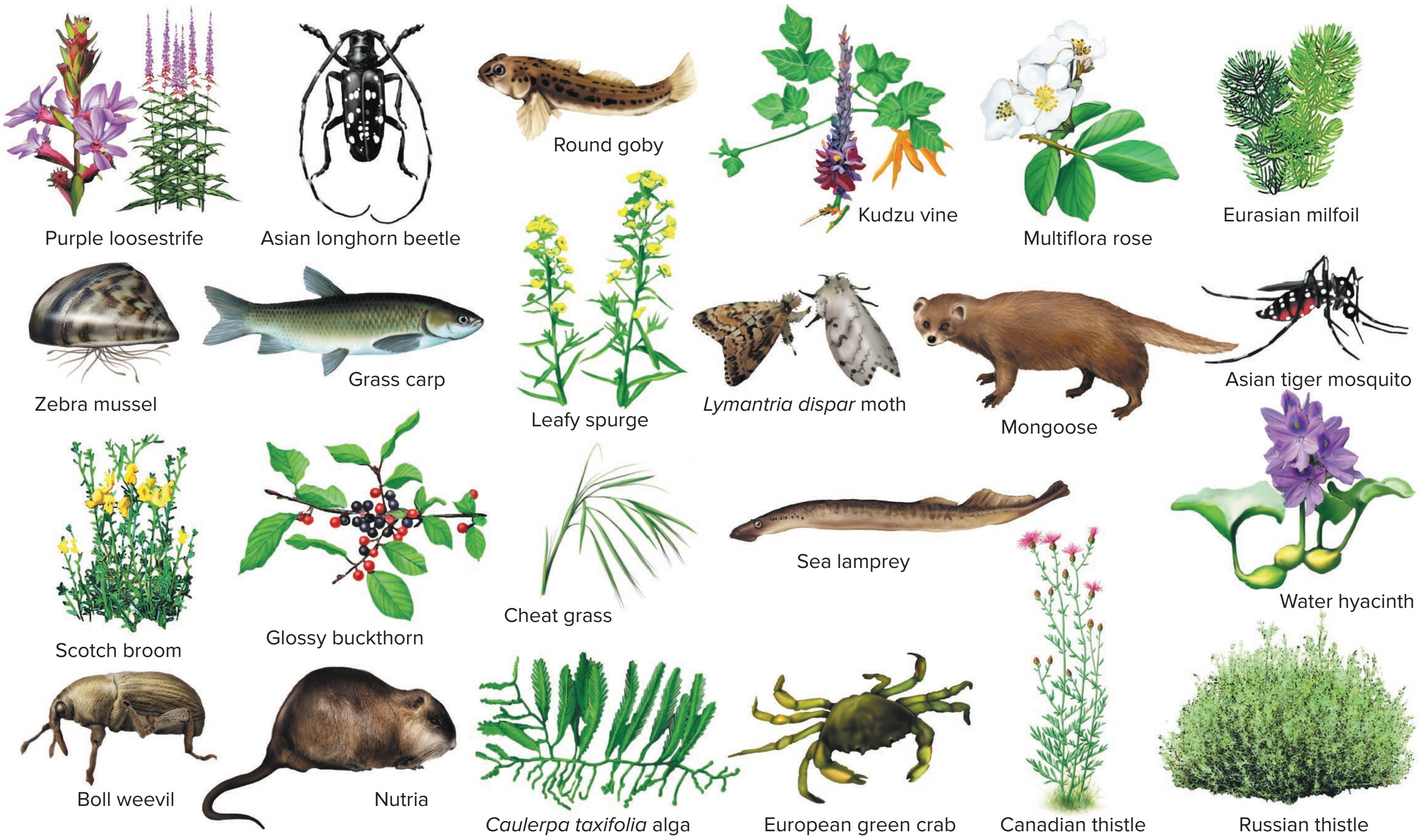


FIGURE 6.27 A few of the approximately 50,000 invasive species in North America. Do you recognize any that occur where you live? What others can you think of?

volume of travel by air, water, and land. Some species are deliberately released because people believe they will be aesthetically pleasing or economically beneficial. Some of the worst are pets released to the wild when owners tire of them. Many hitch a ride in ship ballast water, in the wood of packing crates, inside suitcases or shipping containers, or in the soil of potted plants (fig. 6.27). Sometimes we introduce invasive species into new habitats thinking that we're being kind and compassionate without being aware of the ecological consequences.

Over the past 300 years, approximately 50,000 non-native species have become established in the United States. Many of these introductions, such as corn, wheat, rice, soybeans, cattle, poultry, and honeybees, were intentional and mostly beneficial. At least 4,500 of these species have established wild populations, of which 15 percent cause environmental or economic damage (fig. 6.28). Invasive species are estimated to cost the United States $138 billion annually and are forever changing a variety of ecosystems (What Can You Do?, p. 222).

A few important examples of invasive species include the following:

- Eurasian milfoil (*Myriophyllum spicatum* L.) is an exotic aquatic plant native to Europe, Asia, and Africa. Scientists believe that milfoil arrived in North America during the late nineteenth century in shipping ballast. It grows rapidly and tends to form a dense canopy on the water surface, which displaces native vegetation, inhibits water flow, and obstructs boating, swimming, and fishing. Humans spread the plant between water body systems from boats and boat trailers carrying the plant fragments. Herbicides and mechanical harvesting are

FIGURE 6.28 Invasive leafy spurge (*Euphorbia esula*) blankets a formerly diverse pasture. Introduced accidentally, and inedible for most herbivores, this plant costs hundreds of millions of dollars each year in lost grazing value and in weed control.

effective in milfoil control but can be expensive (up to $5,000 per hectare per year). There is also concern that the methods may harm nontarget organisms. A native milfoil weevil, *Euhrychiopsis lecontei*, is being studied as an agent for milfoil biocontrol.

- Water hyacinth (*Eichhornia crassipes*) is a free-floating aquatic plant that has thick, waxy, dark green leaves with bulbous, spongy stalks. It grows a tall spike of lovely blue or purple flowers. This South American native was introduced into the United States in the 1880s. Its growth rate is among the highest of any plant known: Hyacinth populations can double in as little as 12 days. Many lakes and ponds are covered from shore to shore with up to 500 tons of hyacinths per hectare. Besides blocking boat traffic and preventing swimming and fishing, water hyacinth infestations also prevent sunlight and oxygen from getting into the water. Thus, water hyacinth infestations reduce fisheries, shade-out submersed plants, crowd-out immersed plants, and diminish biological diversity. Water hyacinth is controlled with herbicides, machines, and biocontrol insects.
- The emerald ash borer (*Agrilus planipennis*) is an invasive wood-boring beetle from Siberia and northern China. It was first identified in North America in the summer of 2002 in southeast Michigan and in Windsor, Ontario. It's believed to have been introduced into North America in shipping pallets and wooden containers from Asia. In just 8 years the beetle spread into 13 states from West Virginia to Minnesota. Adult emerald ash borers have golden or reddish-green bodies with dark metallic emerald green wing covers. More than 40 million ash trees have died or are dying from emerald ash borer attack in the United States, and more than 7.5 billion trees are at risk.
- In the 1970s several carp species, including bighead carp (*Hypophthalmichthys nobilis*), grass carp (*Ctenopharyngo donidella*), and silver carp *Hypophthalmichthys molitrix*), were imported from China to control algae in aquaculture ponds. Unfortunately, they escaped from captivity and

have become established—often in very dense populations—throughout the Mississippi River Basin. Silver carp can grow to 100 pounds (45 kg). They are notorious for being easily frightened by boats and personal watercraft, which causes them to leap as much as 8–10 feet (2.5–3 m) into the air. Getting hit in the face by a large carp when you're traveling at high speed in a boat can be life threatening. Large amounts of money have been spent trying to prevent Asian carp from spreading into the Great Lakes, but carp DNA has already been detected in every Great Lake except Lake Superior.

- Zebra mussels (Dreissena polymorpha) probably made their way from their home in the Caspian Sea to the Great Lakes in ballast water of transatlantic cargo ships, arriving sometime around 1985. Attaching themselves to any solid surface, zebra mussels reach enormous densities—up to 70,000 animals per square meter—covering fish spawning beds, smothering native mollusks, and clogging utility intake pipes. Found in all the Great Lakes, zebra mussels have moved into the Mississippi River and its tributaries. Public and private costs for zebra mussel removal now amount to some $400 million per year. On the good side, mussels have improved water clarity in Lake Erie at least fourfold by filtering out algae and particulates.

Disease organisms, or pathogens, may also be considered predators. When a disease is introduced into a new environment, an epidemic may sweep through the area.

The American chestnut (Castanea dentata) was once the heart of many eastern hardwood forests. In the Appalachian Mountains, at least one of every four trees was a chestnut. Often over 45 m (150 ft) tall, 3 m (10 ft) in diameter, fast growing, and able to sprout quickly from a cut stump, it was a forester's dream. Its nutritious nuts were important for birds (such as the passenger pigeon), forest mammals, and humans. The wood was straight-grained, light, and rot-resistant, and it was used for everything from fence posts to fine furniture. In 1904 a shipment of nursery trees from China brought a fungal blight to the United States, and within 40 years the American chestnut had all but disappeared from its native range. Efforts are now under way to transfer blight-resistant genes into the few remaining American chestnuts that weren't reached by the fungus or to find biological controls for the fungus that causes the disease.

The flow of organisms happens everywhere. The Leidy's comb jelly (Mnemiopsis leidyi), native to North American coastal areas, has devastated the Black Sea, where it now makes up more than 90 percent of all biomass at certain times of the year. Similarly, the bristle worm from North America has invaded the coast of Poland and now is almost the only thing living on the bottom of some of Poland's bays and lagoons. A tropical seaweed named Caulerpa taxifolia, originally grown for the aquarium trade, has escaped into the northern Mediterranean, where it covers the shallow seafloor with a dense, meter-deep shag carpet from Spain to Croatia. Producing more than 5,000 leafy fronds per square meter, this aggressive weed crowds out everything in its path. This type of algae grows low and sparse in its native habitat, but aquarium growers transformed it into a robust competitor that has transformed much of the Mediterranean.

Pollution poses many types of risk

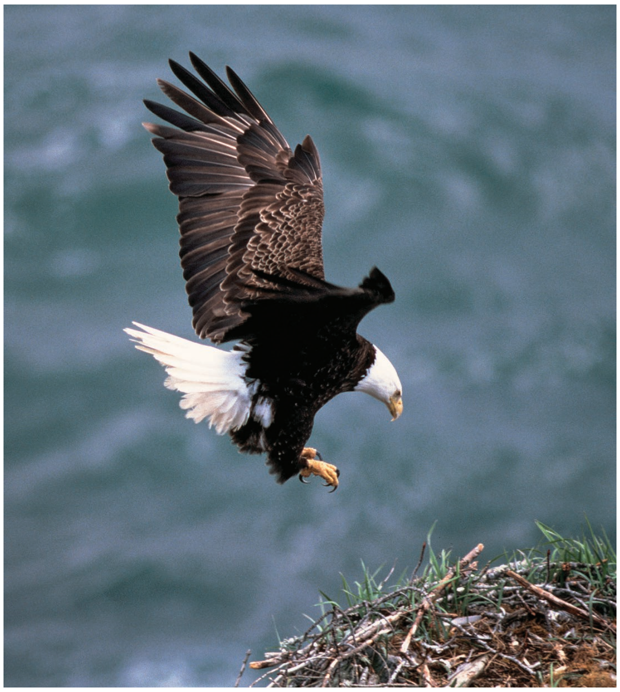


FIGURE 6.29 Bald eagles, and other bird species at the top of the food chain, were decimated by DDT in the 1960s. Many such species have recovered since DDT was banned in the United States and because of protection under the Endangered Species Act. Source: Dave Menke/U.S. Fish and Wildlife Service

We have long known that toxic pollutants can have disastrous effects on local populations of organisms. The links between pesticides and the declines of fish-eating birds were well documented in the 1970s (fig. 6.29). Population declines are especially likely in species high in the food chain, such as marine mammals, alligators, fish, and fish-eating birds. Mysterious, widespread deaths of thousands of Arctic seals are thought to be linked to an accumulation of persistent chlorinated hydrocarbons, such as DDT, PCBs, and dioxins, in the food chain. These chemicals accumulate in fat and cause weakened immune systems. Mortality of Pacific sea lions, beluga whales in the St. Lawrence estuary, and striped dolphins in the Mediterranean is similarly thought to be caused by accumulation of toxic pollutants.

Get it?

Explain why an invasive species can easily survive and have major effects on their new environment.

Lead poisoning is another major cause of mortality for many species of wildlife. Bottom-feeding waterfowl, such as ducks, swans, and cranes, ingest spent shotgun pellets that fall into lakes and marshes. They store the pellets, instead of stones, in their gizzards and the lead slowly accumulates in their blood and other tissues. The U.S. Fish and Wildlife Service (USFWS) estimates that 3,000 metric tons of lead shot are deposited annually in wetlands and that between 2 and 3 million waterfowl die each year from lead poisoning (fig. 6.30). Copper bullets and shot cost about the same, have just as good ballistics, and fragment much less than lead.

FIGURE 6.30 Lead shot shown in the stomach of a bald eagle, consumed along with its prey. Fishing weights and shot remain a major cause of lead poisoning in aquatic and fish-eating birds. Source: Dave Menke/U.S. Fish and Wildlife Service

What Can YOU DO?

You Can Help Preserve Biodiversity

Our individual actions are some of the most important obstacles—and most important opportunities—in conserving biodiversity.

- Don't buy rare or exotic houseplants. Rare orchids, cacti, and other plants are often collected and sold illegally and unsustainably.

Pets and Plants

- Help control invasive species. Never release fish or vegetation from fish tanks into waterways or sewers. Pet birds, cats, dogs, snakes, lizards, and other animals, released by well-meaning owners, are widespread invasive predators.
- Keep your cat indoors. House cats are major predators of woodland birds and other animals.
- Plant native species in your garden. Exotic nursery plants often spread from gardens, compete with native species, and introduce parasites, insects, or diseases that threaten ecosystems. Local-origin species are an excellent, and educational, alternative.
- Don't buy exotic birds, fish, turtles, reptiles, or other pets. These animals are often captured, unsustainably, in the wild. The exotic pet trade harms ecosystems and animals.

Food and Products

- When buying seafood, inquire about the source. Try to buy species from stable populations. Farm-raised catfish, tilapia, trout, Pacific pollack, Pacific salmon, mahimahi, squid, crabs, and crayfish are some of the stable or managed species that are good to buy. Avoid slow-growing top predators, such as swordfish, marlin, bluefin tuna, and albacore tuna.
- Buy shade-grown coffee and chocolate. These are also organic and often "fair trade" varieties that support workers' families as well as biodiversity in growing regions.
- Buy sustainably harvested wood products. Your local stores will start carrying sustainable wood products if you and your friends ask for them. Persistent consumers are amazingly effective forces of change!

Population growth consumes space, resources

Even if per-capita consumption patterns remain constant, more people will require more timber harvesting, fishing, farmland, and extraction of fossil fuels and minerals. In the past 40 years, the global population has doubled from about 3.5 billion to about 7 billion. In that time, according to calculations of the Worldwide Fund for Nature (WWF), our consumption of global resources has grown from 60 percent of what the earth can support over the long term to 150 percent. At the same time, global wildlife populations have declined by more than a third because of expanding agriculture, urbanization, and other human activities.

The human population growth curve is leveling off (see chapter 5), but it remains unclear whether we can reduce poverty and provide a tolerable life for all humans while preserving healthy natural ecosystems and a high level of biodiversity.

Overharvesting depletes or eliminates species

Overharvesting involves taking more individuals than reproduction can replace. A classic example is the extermination of the American passenger pigeon

(Ectopistes migratorius). Even though it inhabited only eastern North America, 200 years ago this was the world's most abundant bird, with a population of 3 to 5 billion animals (fig. 6.31). It once accounted for about one-quarter of all birds in North America. In 1830 John James Audubon saw a single flock of birds estimated to be 10 miles wide and hundreds of miles long and thought to contain perhaps a billion birds. In spite of this vast abundance, market hunting and habitat destruction caused the entire population to crash in only about 20 years between 1870 and 1890. The last known wild bird was shot in 1900 and the last existing passenger pigeon, a female named Martha, died in 1914 in the Cincinnati Zoo.

FIGURE 6.31 A pair of stuffed passenger pigeons (*Ectopistes migratorius*). The last member of this species died in the Cincinnati Zoo in 1914.

At about the same time that passenger pigeons were being extirpated, the American bison, or buffalo (Bison bison), was being hunted to near extinction on the Great Plains. In 1850 some 60 million bison roamed the western plains. Many were killed only for their hides or tongues, leaving millions of carcasses to rot. Much of the bison's destruction was carried out by the U.S. Army to eliminate them as a source of food, clothing, and shelter for Indians, thereby forcing Indians onto reservations. After 40 years, there were only about 150 wild bison left and another 250 in captivity. Today the herd has regrown to about half a million animals, but many are crossbreeds with domestic cattle.

Fish stocks have been seriously depleted by overharvesting in many parts of the world. A huge increase in fishing fleet size and efficiency in recent years has led to a crash of many oceanic populations. Worldwide, 13 of 17 principal fishing zones are now reported to be commercially exhausted or in steep decline. At least three-quarters of all commercial oceanic species are overharvested. Canadian fisheries biologists estimate that only 10 percent of the top predators, such as swordfish, marlin, tuna, and shark, remain in the Atlantic Ocean. Groundfish, such as cod, flounder, halibut, and hake, also are severely depleted. You can avoid adding to this overharvest by eating only abundant, sustainably harvested varieties.

Perhaps the most destructive example of harvesting terrestrial wild animal species today is the African bushmeat trade. Wildlife biologists estimate that 1 million tons of bushmeat, including antelope, elephants, primates, and other animals, are sold in African markets every year. Thousands of tons more are probably sold illegally in New York, Paris, and other global cities each year. For many poor Africans, this is the only source of animal protein in their diet. If we hope to protect the animals targeted by bushmeat hunters, we will need to help them find alternative livelihoods and replacement sources of high-quality protein. Bushmeat can endanger those who eat it, too. Outbreaks of Ebola and other diseases are thought to result from capturing and eating wild monkeys and other primates. The emergence of the respiratory disease known as SARS in 2003 (see chapter 14) resulted from the wild food trade in China and Southeast Asia, where millions of civets, monkeys, snakes, turtles, and other animals are consumed each year as luxury foods.

Collectors Serve Medicinal and Pet Trades In addition to harvesting wild species for food, we also obtain a variety of valuable commercial products from nature. Much of this represents sustainable harvest, but some forms of commercial exploitation are highly destructive and a serious threat to certain rare species (fig. 6.32). Despite international bans on trade in products from endangered species, smuggling of furs, hides, horns, live specimens, and folk medicines amounts to millions of dollars each year.

Developing countries in Asia, Africa, and Latin America with the richest biodiversity in the world are the main sources of wild animals and animal products, while Europe, North America, and some of the wealthy Asian countries are the principal importers. Japan and China (including Taiwan and Hong Kong) buy three-quarters of all cat and snake skins, for instance, while European countries buy most live wild birds, such as South American parrots. The United States imports 99 percent of all live cacti and 75 percent of all orchids sold each year.

The profits to be made in wildlife smuggling are enormous. Tiger or leopard fur coats can bring $700,000 in China. The population of African black rhinos dropped from approximately 100,000 in the 1960s to about 5,000 today because of a demand for their horns. In Asia, where it is prized for its supposed medicinal properties, powdered rhino horn fetches as much as $100,000 per kilogram. The entire species is classified as critically endangered, and the western population is officially extinct.

Plants also are threatened by overharvesting. Wild ginseng has been nearly eliminated in many areas because of the Asian demand for the roots, which are used as an aphrodisiac and folk medicine. Cactus “rustlers” steal cacti by the ton

FIGURE 6.32 Parts from rare and endangered species for sale on the street in China. Use of animal products in traditional medicine and prestige diets is a major threat to many species.

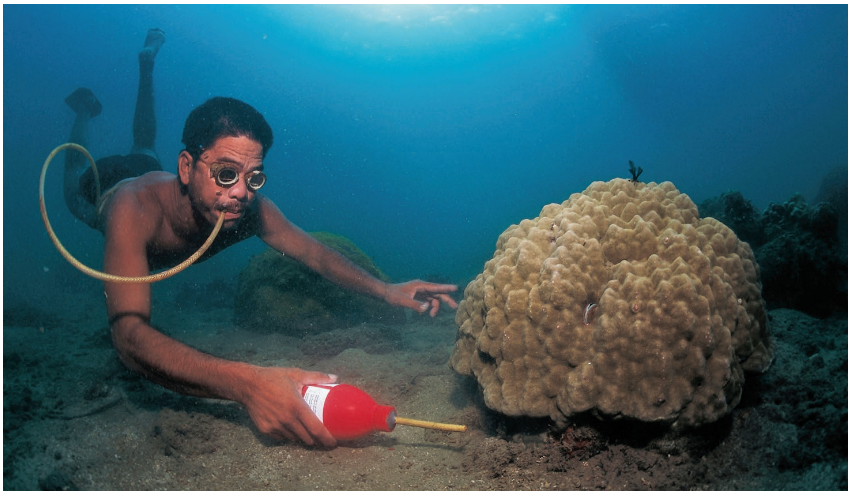


FIGURE 6.33 A diver uses cyanide to stun tropical fish being caught for the aquarium trade. Many fish are killed by the method itself, while others die later during shipment. Even worse is the fact that cyanide kills the coral reef itself.

from the American Southwest and Mexico. With prices as high as $1,000 for rare specimens, it's not surprising that many are now endangered.

The trade in wild species for pets is a vast global business. Worldwide, some 5 million live birds are sold each year for pets, mostly in Europe and North America. Pet traders import (often illegally) into the United States some 2 million reptiles, 1 million amphibians and mammals, 500,000 birds, and 128 million tropical fish each year. About 75 percent of all saltwater tropical aquarium fish sold come from coral reefs of the Philippines and Indonesia. Some of these wild animal harvests are sustainable; many are not.

Many of these fish are caught by divers using plastic squeeze bottles of cyanide to stun their prey (fig. 6.33). Far more fish die with this technique than are caught. Worst of all, it kills the coral animals that create the reef. A single diver can destroy all of the life on 200 m^2 of reef in a day. Altogether, thousands of divers destroy about 50 km^2 of reefs each year. Net fishing would prevent this destruction, and it could be enforced if pet owners would insist on net-caught fish. More than half the world's coral reefs are potentially threatened by human activities, with up to 80 percent at risk in the most populated areas. But efforts are currently under way to breed corals in captivity and to restore reefs (Exploring Science, p. 226).

Predator and Pest Control Is Expensive but Widely Practiced Some animal populations have been greatly reduced, or even deliberately exterminated, because they are regarded as dangerous to humans or livestock or because they compete with our use of resources. Every year U.S. government animal-control agents trap, poison, or shoot thousands of coyotes, bobcats, prairie dogs, and other species considered threats to people, domestic livestock, or crops.

This animal-control effort costs about $20 million in federal and state funds each year and kills some 700,000 birds and mammals, about 100,000 of which are coyotes. Defenders of wildlife regard this program as cruel, callous, and mostly ineffective in reducing livestock losses. Protecting flocks and herds with guard dogs or herders or keeping livestock out of areas that are the home range of wild species would be a better solution, they believe. Ranchers, on the other hand, argue that without predator control western livestock ranching would be impossible.

Exploring Science

Restoring Coral Reefs

Coral reefs are among the richest and most endangered biological communities on earth, the marine equivalent of tropical rainforests in diversity, productivity, and complexity. One-quarter of all marine species are thought to spend some or all of their life cycle in the shelter of coral reefs. Globally, at least 17 percent of the protein we eat depends on coral reef systems. In some coastal areas that number is 70 percent. Reefs protect shorelines from storms, and they support tourism economies worldwide.

But reefs are in serious trouble. We've already lost about 30 percent of coral worldwide to pollution, destructive fishing methods, and especially climate warming and ocean acidification. We are likely to lose another 60 percent in coming decades. Some researchers warn that if current trends continue there won't be any viable coral reefs anywhere in the world by the end of this century.

Can knowledge of corals' reproduction and genetic diversity help us find ways to regrow corals, or even help them adapt to warming seas? Some branched corals, such as staghorn and elkhorn, which are among the most threatened of all species, can grow and reproduce through fragmentation. If a branch breaks off and conditions are favorable, it can reattach to the rock substrate and begin to grow a new colony. Taking advantage of this trait, conservationists are harvesting coral fragments and growing them in underwater nurseries until they're large enough to be relocated to suitable areas (fig. 1). Dozens of these nurseries now operate worldwide, and tens of thousands of small corals have been transplanted to damaged or depleted reefs.

Focusing on genetic variants might increase the success of restoration efforts. In a lagoon in American Samoa, corals have been found that can survive much warmer water than most corals can tolerate. Natural selection has produced this unusual population, as heat-tolerant individuals survived but intolerant ones did not. Might other coral populations also contain tolerant traits? Similarly, in the Miami ship channel, a colony of corals was discovered growing in highly contaminated, turbid water. Here again, natural selection produced a population capable of withstanding badly polluted conditions. If geneticists can pinpoint the traits that make these specimens so tough, that knowledge might help improve other colonies.

Some biologists aren't waiting for nature to produce resistant coral strains. Labs in Australia and Hawaii are working on "assisted evolution." By growing corals in warm and acidic water, conditions similar to those we expect to see in the future, they are attempting to select for advantageous genes. These breeding experiments are assisted by using species that reproduce continuously rather than only once a year, as most corals do. Transplanting new, improved varieties could help restore or re-create these critically important systems.

Saving coral reefs, if it is possible at all, will involve insights from a variety of sciences, from evolution and genetics to ecology and conservation biology. Applying this knowledge just might make it possible to save these wonderful, endangered communities.

FIGURE 1 Fragments of staghorn and elkhorn coral can be cultivated in nurseries and used to replenish damaged reef systems.

Section Review

- Extinction rates are far higher now than in the past.
- Habitat loss, climate change, invasive species, pollution, and overharvesting, all enhanced by population growth, are the main threats to biodiversity.
- Invasive species seriously threaten islands and specialized habitats.

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1. How do extinction rates now compare to other times in history and pre-history?
2. What are the main threats to biodiversity?
3. Why are exotic or invasive species a threat to biodiversity? Give several examples of exotic invasive species (see fig. 6.27).

6.6 BIODIVERSITY PROTECTION

Guiding Questions

How can we reduce threats to biodiversity?

Use the Practices

Planning and Carrying Out Investigations: What are the top 5 protected species in your area? Investigate which factors caused those species to be protected. Do you agree with their protection status?

We have gradually become aware of our damage to biological resources and of reasons for conserving them. Slowly, we are adopting national legislation and international treaties to protect these irreplaceable assets. Parks, wildlife refuges, nature preserves, zoos, and restoration programs have been established to protect nature and rebuild depleted populations. There has been encouraging progress in this area, but much remains to be done.

In this section we examine legal protections for species in the United States, but keep in mind that this is only a small part of species protection measures worldwide. Most countries now have laws protecting endangered species (though many laws remain unenforced), and dozens of international treaties aim to reduce the decline of biodiversity worldwide.

Hunting and fishing laws protect useful species

In 1874 a bill was introduced in the U.S. Congress to protect the American bison, whose numbers were falling dramatically. This initiative failed, partly because most legislators could not imagine that wildlife that was so abundant and prolific could ever be depleted by human activity. By the end of the nineteenth century, bison numbers had plunged from some 60 million to only a few hundred animals.

By the 1890s, though, most states had enacted some hunting and fishing restrictions. The general idea behind these laws was to conserve the resource for future human use rather than to preserve wildlife for its own sake. The wildlife regulations and refuges established since that time have been remarkably successful for many species. A hundred years ago, there were an estimated half a million white-tailed deer in the United States; now there are some 14 million—more in some places than the environment can support. Wild turkeys and wood ducks were nearly gone 50 years ago. By restoring habitat, planting food crops, transplanting breeding stock, building shelters or houses, protecting these birds during breeding season, and using other conservation measures, we have restored populations of these beautiful and iconic birds to several million each. Snowy egrets, which were almost wiped out by plume hunters 80 years ago, are now common again.

The Endangered Species Act protects habitat and species

The Endangered Species Act (ESA) is one of our most powerful tools for protecting biodiversity and environmental quality. It not only defends rare and endangered organisms but also helps protect habitat that benefits a whole biological community and safeguards valuable ecological services.

What does the ESA do? It provides (1) criteria for identifying species at risk, (2) directions for planning for their recovery, (3) assistance to landowners to help them find ways to meet both economic needs and the needs of a rare species, and (4) enforcement of measures for protecting species and their habitat.

The act identifies three degrees of risk: **Endangered species** are those considered in imminent danger of extinction; **threatened species** are likely to become endangered, at least locally, within the foreseeable future. **Vulnerable species** are naturally rare or have been locally depleted by human activities to a level that puts them at risk. Vulnerable species are often candidates for future listing as endangered species. For vertebrates, a protected subspecies or a local race or ecotype can be listed, as well as an entire species.

Currently, the United States has 1,372 species on the endangered and threatened species lists and about 386 candidate species waiting to be considered. The number of listed species in different taxonomic groups reflects much more about the kinds of organisms that humans consider interesting and desirable than the actual number in each group. In the United States, invertebrates make up about three-quarters of all known species but only 9 percent of those considered worthy of protection.

Worldwide, the International Union for Conservation of Nature and Natural Resources (IUCN) lists 24,431 endangered and threatened species, including nearly one-fifth of mammals; nearly one-third of amphibians, reptiles, and fish; and most of the few mosses and flowering plants that have been evaluated (see table 6.2). IUCN has no direct jurisdiction for slowing the loss of those species. Within the United States, the ESA provides mechanisms for reducing species losses.

Recovery plans aim to rebuild populations

Once a species is listed, the Fish and Wildlife Service (FWS) is given the task of preparing a recovery plan. This plan details how populations will be stabilized or rebuilt to sustainable levels. A recovery plan could include many different kinds of strategies, such as buying habitat areas, restoring habitat, reintroducing a species to its historic ranges (as with Yellowstone's gray wolves), instituting captive breeding programs, and negotiating the needs of a species and the people who live in an area.

The FWS can then help landowners prepare habitat conservation plans. These plans are specific management approaches that identify steps to conserve particular pieces of critical habitat. For example, the red-cockaded woodpecker is an endangered species that preys on insects in damaged pine forests from North Carolina to Texas. Few suitable forests remain on public lands, so much of the remaining population occurs on privately owned lands that are actively managed for timber production.

International Paper and other corporations have collaborated with the FWS to devise management strategies that conserve specified amounts of damaged tree stands while harvesting other areas. These plans restrict cutting of some trees, but they also ensure that the FWS will not interfere further with management of the timber, as long as the provisions of the plan continue to protect the woodpecker. This approach has helped to stabilize populations of the red-cockaded woodpecker, and timber companies have gained goodwill and sustainable forestry certification for their products. Habitat conservation plans are not always perfect, but often they can produce mutually satisfactory solutions.

Get it?

What are the three degrees of risk for species and describe one way to reduce those risks?

Restoration can be slow and expensive, because it tries to undo decades or centuries of damage to species and ecosystems. About half of all funding is spent on a dozen charismatic species, such as the California condor, the Florida panther, and the grizzly bear, which receive around $13 million per year. By contrast, the 137 endangered invertebrates and 532 endangered plants get less than $5 million per year altogether. This disproportionate funding results from political and emotional preferences for large, charismatic species (fig. 6.34). There are also scientifically established designations that make some species merit special attention:

- Keystone species are those with major effects on ecological functions and whose elimination would affect many other members of the biological community; examples are prairie dogs (Cynomys ludovicianus) and bison (Bison bison).
- Indicator species are those tied to specific biotic communities or successional stages or environmental conditions. They can be reliably found under certain conditions but not others; an example is brook trout (Salvelinus fontinalis).

FIGURE 6.34 The Endangered Species Act seeks to restore populations of species, such as the bighorn sheep, which has been listed as endangered in much of its range. Charismatic species are easier to get listed than obscure ones.

- Umbrella species require large blocks of relatively undisturbed habitat to maintain viable populations. Saving this habitat also benefits other species. Examples of umbrella species are the northern spotted owl (Strix occidentalis caurina), tiger (Panthera tigris), and gray wolf (Canis lupus).
- Flagship species are especially interesting or attractive organisms to which people react emotionally. These species can motivate the public to preserve biodiversity and contribute to conservation; an example is the giant panda (Ailuropoda melanoleuca).

Landowner collaboration is key

Two-thirds of listed species occur on privately owned lands, so cooperation between federal, state, and local agencies and private and tribal landowners is critical for progress. Often the ESA is controversial because protecting a species is legally enforceable, and that protection can require that landowners change their plans for their property. On the other hand, many landowners and communities appreciate the value of biodiversity on their land and like the idea of preserving species for their grandchildren to see. Others, like International Paper, have decided they can afford to allow some dying trees for woodpeckers, and they benefit from goodwill generated by preserving biodiversity.

A number of provisions protect landowners, and these serve as incentives for them to participate in developing habitat conservation plans. For example, permits can be issued to protect landowners from liability if a listed species is accidentally harmed during normal land use activities. In a Candidate Conservation Agreement, the FWS helps landowners reduce threats to a species in an effort to avoid listing it at all. A Safe Harbor Agreement is a promise that, if landowners voluntarily implement conservation measures, the FWS will not require additional actions that could limit future management options. For example, suppose a landowner's efforts to improve red-cockaded woodpecker habitat lead to population increases. A Safe Harbor Agreement ensures that the landowners would not be required to do further management for additional woodpeckers attracted to the improved habitat.

The U.S. Fish and Wildlife Service is currently using innovative agreements with private landholders to create “pop-up wildlife refuges.” In California’s Central Valley, for example, extensive wetlands used to provide food and resting areas for vast flocks of migratory birds. However, much of those wetlands have been drained for agriculture, and there isn’t money to buy land for permanent refuges. But for relatively modest payments, many farmers are willing to flood rice fields in the spring and fall to provide temporary habitat. Millions of birds benefit, along with other wildlife and the people who like to watch them.

The ESA has seen successes and controversies

The ESA has held off the extinction of hundreds of species. Some have recovered and been delisted, including the brown pelican, the peregrine falcon, and the bald eagle, which was delisted in 2007. In 1967, before the ESA was passed, only about 800 bald eagles remained in the contiguous United States. DDT poisoning, which prevented the hatching of young eagles, was the main cause. By 1994, after the banning of DDT, the population had rebounded to 8,000 birds; there are now an estimated 70,000 bald eagles in the United States and Canada. The habitat appears to be fully occupied in most places. Similarly, peregrine falcons, which had been down to 39 breeding pairs in the 1970s, had rebounded to 1,650 pairs by 1999 and were taken off the list. The American alligator was listed as endangered in 1967 because hunting and habitat destruction had reduced populations to precarious levels. Protection has been so effective that the species is now plentiful throughout its entire southern range. Florida alone may have a population of 1 million or more.

Many people are dissatisfied with the slow pace of listing new species, however. Hundreds of species are classified as “warranted but precluded,” or deserving of protection but lacking funding or local support. At least 18 species have gone extinct since being nominated for protection.

Part of the reason listing is slow is that political and legal debates can drag on for years. Political opposition is especially fierce when large profits are at stake. An important test of the ESA occurred in 1978 in Tennessee, when construction of the Tellico Dam threatened a tiny fish called the snail darter. The powerful Tennessee Valley Authority, which was building the dam, argued to the Supreme Court that the dam was more important than the fish. After this case a new federal committee was given power to override the ESA for economic reasons. (This committee subsequently became known as the God Squad because of its power over the life and death of a species.)

Another important debate over the economics of endangered species protection has been that of the northern spotted owl (see chapter 10). Preserving this owl requires the conservation of expansive, undisturbed areas of old-growth temperate rainforest in the Pacific Northwest, where old-growth timber is extremely valuable and increasingly scarce (fig. 6.35). Timber industry economists calculated the cost of conserving a population of 1,600 to 2,400 owls at $33 billion. Ecologists countered that this number was highly inflated; moreover, forest

FIGURE 6.35 Endangered species often serve as a barometer for the health of an entire ecosystem and as surrogate protector for a myriad of less well-known creatures. "DAMN SPOTTED OWL" A 1990 Herblock Cartoon, copyright by The Herb Block Foundation.

conservation would preserve countless other species and ecosystem services, whose values are almost impossible to calculate.

Sometimes the value of conserving a species is easier to calculate. Salmon and steelhead in the Columbia River are endangered by hydropower dams and water storage reservoirs that block their migration to the sea. Opening the floodgates could allow young fish to run downriver and adults to return to spawning grounds, but at high costs to electricity consumers, barge traffic, and farmers who depend on cheap water and electricity. On the other hand, commercial and sport fishing for salmon is worth over $1 billion per year and employs about 60,000 people directly or indirectly.

Many countries have species protection laws

In the past 25 years or so, many countries have recognized the importance of legal protection for endangered species. Rules for listing and protecting endangered species are established by Canada's Committee on the Status of Endangered Wildlife in Canada (COSEWIC) of 1977, the European Union's Birds Directive (1979) and Habitat Directive (1991), and Australia's Endangered Species Protection Act (1992). International agreements have also been developed, including the Convention on Biological Diversity (1992).

The Convention on International Trade in Endangered Species (CITES) of 1975 provides a critical conservation strategy by blocking the international sale of wildlife and their parts. The Convention makes it illegal to export or import elephant ivory, rhino horns, tiger skins, or live endangered birds, lizards, fish, and orchids. CITES enforcement has been far from perfect: Smugglers hide live animals in their clothing and luggage; the volume of international shipping makes it impossible to inspect transport containers and ships; documents may be falsified. The high price of these products in North America and Europe, and increasingly in wealthy cities of China, makes the risk of smuggling worthwhile: A single rare parrot can be worth tens of thousands of dollars, even though its sale is illegal. Even so, CITES provides a legal structure for restricting this trade, and it raises public awareness of the real costs of the trade in endangered species.

A striking example of success in endangered species under CITES is the recovery of the southern white rhino in Africa. A century ago these huge herbivores were near extinction, but now there are at least 17,500 white rhinos in parks and game preserves.

Habitat protection may be better than individual species protection

Growing numbers of scientists, land managers, policymakers, and developers are arguing that we need a rational, continent-wide preservation of ecosystems that supports maximum biological diversity. They argue that this would be more effective than species-by-species battles for desperate cases. By concentrating on individual species, we spend millions of dollars to breed plants or animals in captivity that have no natural habitat where they can be released. While flagship species, such as mountain gorillas and Indian tigers, are reproducing well in zoos and wild animal parks, the ecosystems they formerly inhabited have largely disappeared.

A leader of this new form of conservation has been J. Michael Scott, who was project leader of the California condor recovery program in the mid-1980s

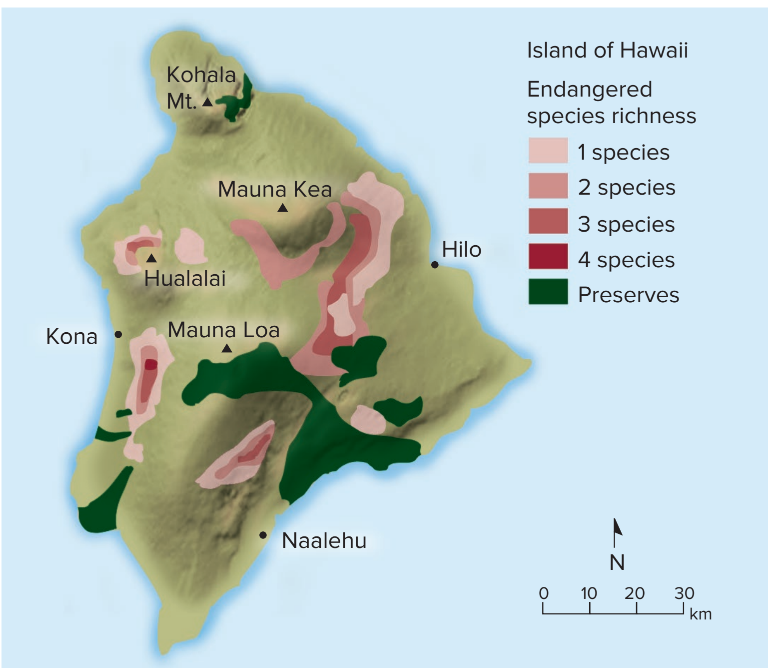

FIGURE 6.36 Protected lands (green) are often different from biologically diverse areas (red shades), as shown here on the island of Hawaii.

and had previously spent 10 years working on endangered species in Hawaii. In making maps of endangered species, Scott discovered that even Hawaii, where more than 50 percent of the land is federally owned, has many vegetation types completely outside of natural preserves (fig. 6.36). The gaps between protected areas may contain more endangered species than are preserved within them.

This observation has led to an approach called **gap analysis**, in which conservationists and wildlife managers look for unprotected landscapes, or gaps in the network of protected lands, that are rich in species. Gap analysis involves mapping protected conservation areas and high-biodiversity areas. Overlaying the two makes it easy to identify priority spots for conservation efforts. Maps also help biologists and land use planners communicate about threats to biodiversity. This broad-scale, holistic approach seems likely to save more species than a piecemeal approach.

Conservation biologist R.-E. Grumbine suggests four remanagement principles for protecting biodiversity in a large-scale, long-range approach:

1. Protect enough habitat for viable populations of all native species in a given region.
2. Manage at regional scales large enough to accommodate natural disturbances (fire, wind, climate change, etc.).
3. Plan over a period of centuries, so that species and ecosystems can continue to evolve.
4. Allow for human use and occupancy at levels that do not result in significant ecological degradation.

Section Review

- The Endangered Species Act is one of our most important environmental laws.
- Protecting a keystone or flagship species protects its ecosystem.
- Species protection can be controversial.

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1. What does the Endangered Species Act do?
2. Why are flagship, keystone, indicator, and umbrella species important to conservation?
3. Why is species conservation and protection often controversial?

Chapter Review

6.1 Terrestrial Biomes

Guiding Questions

What are nine major terrestrial biomes, and what environmental conditions control their distribution?

Vocabulary

biome
biodiversity
vertical zonation
cloud forests
tropical rainforests
tropical seasonal forests
grasslands
savannas
deserts
deciduous
coniferous
temperate rainforests
boreal forest
taiga
tundra

6.2 Marine Environments

Guiding Questions

How does vertical stratification differentiate life zones in oceans?

Vocabulary

phytoplankton
benthic
pelagic
coral reefs
coral bleaching
sea-grass beds
mangroves
estuaries
salt marshes
tide pools

6.3 Freshwater Ecosystems

Guiding Questions

What factors contribute to the high diversity found in freshwater ecosystems?

Vocabulary

thermocline
wetlands
swamps
marshes
bogs
fens

6.4 Biodiversity

Guiding Questions

What do we mean by biodiversity? List several regions of high biodiversity.

Vocabulary

biodiversity
phylogenetic species concept
evolutionary species concept

6.5 What Threatens Biodiversity?

Guiding Questions

What are the major human-caused threats to biodiversity?

What are the major benefits of biodiversity?

Vocabulary

extinction
HIPPO
fragmentation
minimum viable population
island biogeography
invasive species
overharvesting

6.6 Biodiversity Protection

Guiding Questions

How can we reduce these threats to biodiversity?

Vocabulary

endangered species
threatened species
vulnerable species
gap analysis

Chapter Review Continued

CER Revisit the Case Study

Ecosystems in Transition

Recall the Case Study at the beginning of this chapter (p. 185). You read about how forests transition after a fire. Throughout the chapter, you read about how biomes transition over time and distance. Now, it is time to revisit your claim, summarize your evidence, and analyze what you have learned.

Claim, Evidence, Reasoning

Revisit Your Claim: Review your CER chart where you recorded your claim about how forests transition after a fire.

Summarize Your Evidence: Summarize the evidence you gathered from your investigations and research and finalize your Summary Table.

Explain Your Reasoning: Does your evidence support your claim? Explain why your evidence supports your claim. If it does not, revise your claim

Review Questions

1. Using the Climate Graphs in Figure 6.6, which major city presented has exceptionally dry periods throughout the months of May to October?
   a. San Diego
   b. Philadelphia
   c. Belém
   d. All of them do
2. Identify which biome has an average annual precipitation of 250 cm that comes with distinct wet and dry periods and a temperature range between 20°C–30°C?
   a. tropical rainforest
   b. tropical seasonal forest
   c. temperate rainforest
   d. boreal forest
3. Which of the following is not part of the Endangered Species Act?
   a. directions for planning for at risk species' recovery
   b. assistance to landowners to help meet economic needs and protect rare species
   c. criteria for identifying species at risk
   d. protection for every species that inhabits an area where deforestation occurs
4. Which type of species merits special attention due to the ties it has to specific biotic communities, successional stages, or environmental conditions?
   a. keystone species
   b. indicator species
   c. umbrella species
   d. flagship species
5. How can the tundra biome be negatively impacted by humans since there is little human activities or interference in the environment?
   a. pollution from runoff of nearby agricultural farms
   b. increased occurrences of forest fires from campers
   c. air pollution blown in from distant cities
   d. an increased amount of tourist destinations
6. What is the main threat to biodiversity caused by humans?
   a. invasive species
   b. pollution
   c. habitat destruction
   d. overharvesting
7. When a new species is introduced, what is one of the signs that the species may become invasive to the environment?
   a. They are free of predators.
   b. They are aesthetically pleasing.
   c. The species is not carrying a genetic disease.
   d. The species does not migrate.

Critical Thinking

1. How do elevation (on mountains) and depth (in water) affect environmental conditions?
2. Throughout the central portion of North America is the temperate grasslands and savannas. Describe how physical conditions and other factors have changed this biome.
3. Explain how an estuary forms and the important characteristics needed for organisms to survive.
4. Describe what it means if a region is rich in biodiversity and the three essential ways to preserve biodiversity.
5. Explain why many scientists, land managers, policymakers, and developers are arguing that a continent-wide preservation of ecosystems would be more effective than a species-by species preservation.

Go Further: Data Analysis Lab

Climatologists, geographers, biologists, and others often want to explain differences in biodiversity, or in water resources, for example. To describe and compare regional climate conditions, they use climographs, graphs that plot precipitation and temperature variation over a year. If you take a few minutes to make sure you understand these graphs, they will be useful in helping you remember and explain differences in the biomes discussed in this chapter.

Data and Observations: Each climograph shows long-term averages for each month. Plotting 12 months gives a picture of the year. Temperature (°C) is plotted on the left axis. Precipitation (mm of rain or snow) uses the right axis. Yellow areas indicate how much of the year evaporation exceeds precipitation—that is, when conditions are dry. Dry conditions could occur because it's hot and evaporation is rapid or simply because there's little precipitation. In yellow months, little moisture is available for plant growth. Blue areas show when precipitation exceeds evaporation, leaving moisture available for plants to thrive. Examine these graphs to answer these questions.

Analyze and Interpret Data

1. What are the maximum and minimum temperatures in each location?
2. Which area has the wettest climate? Which is driest?
3. How do the maximum and minimum monthly rainfalls in San Diego and Belém compare? Note that the axis scale changes for Belém, because there's no room to plot such high numbers.
4. What would a climate graph look like where you live? Sketching one out, then compare it to a graph for a biome similar to yours in this chapter.

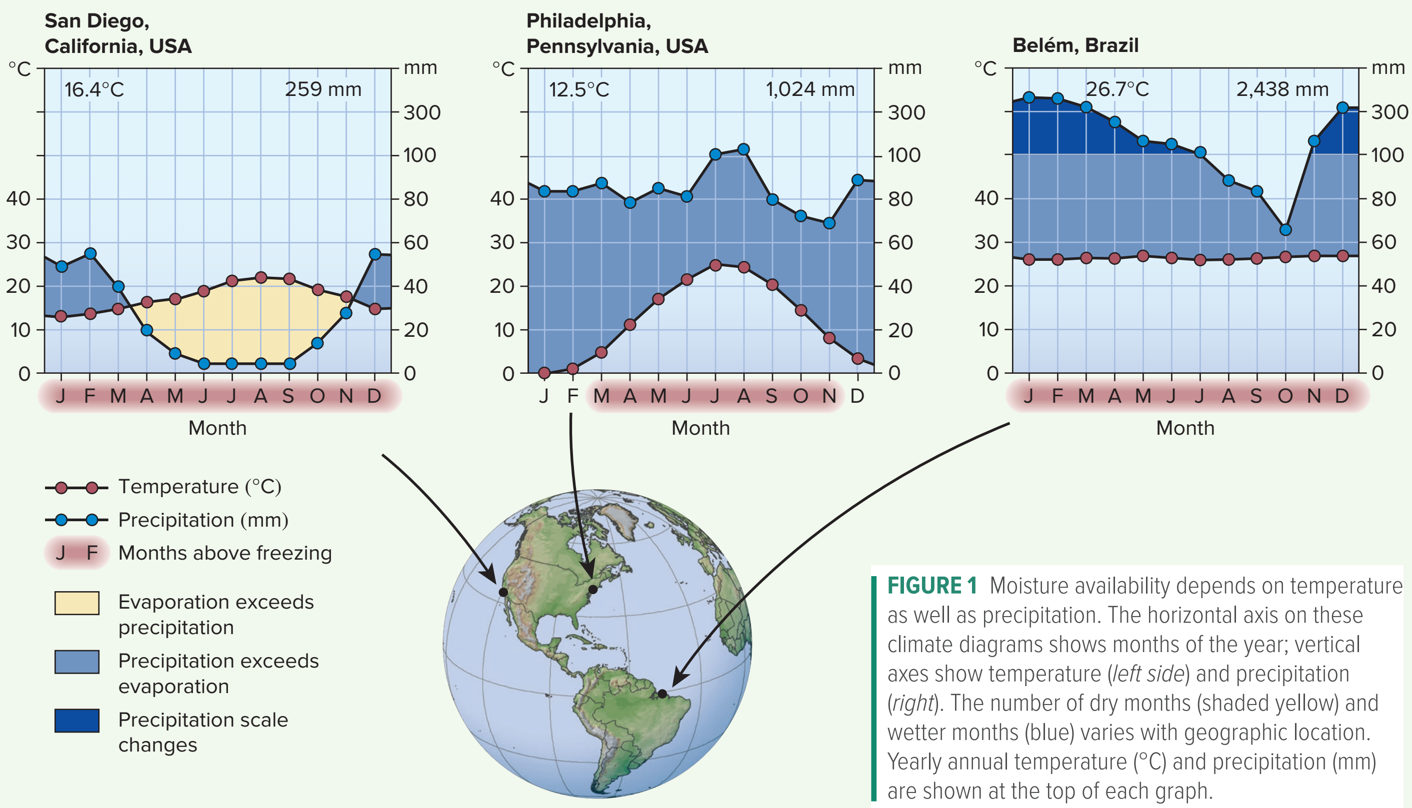

FIGURE 1 Moisture availability depends on temperature as well as precipitation. The horizontal axis on these climate diagrams shows months of the year; vertical axes show temperature (*left side*) and precipitation (*right*). The number of dry months (shaded yellow) and wetter months (blue) varies with geographic location. Yearly annual temperature (°C) and precipitation (mm) are shown at the top of each graph.