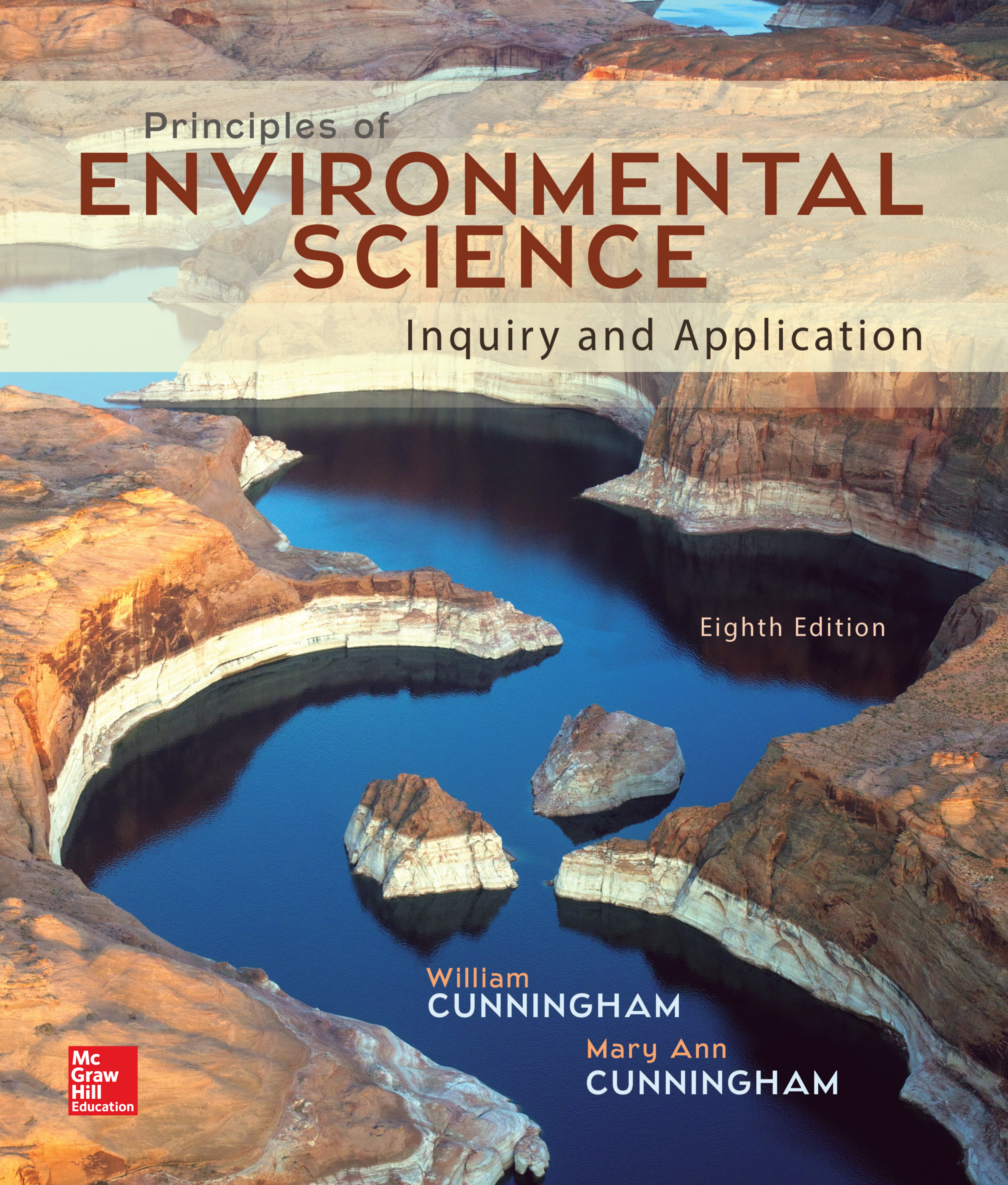

Principles of

ENVIRONMENTAL SCIENCE

Inquiry and Application

Eighth Edition

William
CUNNINGHAM

Mary Ann
CUNNINGHAM

Mc
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Hill
Education

PRINCIPLES OF

Environmental Science

Inquiry & Application

Eighth Edition

William P. Cunningham
University of Minnesota

Mary Ann Cunningham
Vassar College

Mc Graw Hill Education

PRINCIPLES OF ENVIRONMENTAL SCIENCE: INQUIRY & APPLICATIONS, EIGHTH EDITION

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About the Authors

WILLIAM P. CUNNINGHAM

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

Mary Ann Cunningham is an associate 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 has been co-author of this book since its first edition. She is also co-author of *Environmental Science: A Global Concern*, now in its thirteenth 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.

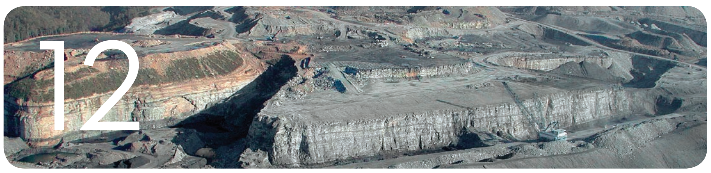
Research and teaching activities have included work in the Great Plains, the Adirondack Mountains, and northern Europe, as well as in New York's Hudson Valley, where she lives and teaches. In her spare time she loves to travel, hike, and watch birds. She holds a bachelor's degree from Carleton College,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

Brief Contents

Contents


8


9
STOP



12

13


14
Skånetrafiken


15


16
350

List of Case Studies

Over 200 additional Case Studies can be found online on the instructor's resource page at www.mcgrawhillconnect.com.

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, healthcare, information, even political participation and human rights. Birthrates 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

Climate change is a central theme in this book and in environmental science generally. As in other topics, we face dire risks but also surprising new developments and new paths toward sustainability. China, the world's largest emitter of carbon dioxide, expects to begin reducing its emissions within in a decade, much sooner than predicted. Many countries are starting to show declining emissions, and there is clear evidence that economic growth no longer depends on carbon fossil fuels. Greenhouse gas emissions continue to rise, but nations are showing unexpected willingness to cooperate in striving to reduce emissions. Much of this cooperation is driven by growing acknowledgment of the widespread economic and humanitarian costs of climate change. Additional driving forces, though, are the growing list of alternatives that make carbon reductions far easier to envision, or even to achieve, than a few years ago.

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.

Students are Providing Leadership

Students are leading the way in reimagining our possible futures. Student movements have led innovation in technology and science, in sustainability planning (chapter 1), in environmental governance (chapter 9), and in environmental justice around the world. The organization 350.org (chapter 16) was started by a small group of students seeking to address climate change. That movement has energized local communities to join the public debate on how to seek a sustainable future. Students have the vision and the motivation to create better paths toward sustainability and social justice, at home and globally.

You may be like many students who find environmental science an empowering field. It provides the knowledge needed to use your efforts more effectively. Environmental science applies to our everyday lives and the places where we live, and we can apply ideas learned in this discipline to any place or occupation in which we find ourselves. And environmental science can connect to any set of interests or skills you might bring to it: Progress in the field involves biology, chemistry, geography, and geology. Communicating and translating ideas to the public, who are impacted by changes in environmental quality, requires writing, arts, media, and other communication skills. Devising policies to protect resources and enhance cooperation involves policy, anthropology, culture, and history. What this means is that while there is much to learn, this field can also connect with whatever passions you bring to the course.

WHAT SETS THIS BOOK APART?

Solid science and an emphasis on sustainability: This book reflects the authors' decades of experience in the field and in the classroom, which make it up-to-date in approach, in data, and in applications of critical thinking. The authors have been deeply involved in sustainability, environmental science, and conservation programs at the University of Minnesota and at Vassar College. Their experience and courses on these topics have strongly influenced the way ideas in this book are presented and explained.

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.

Critical thinking: We provide a focus on critical thinking, one of the most essential skills for citizens, as well as for students. Starting with a focused discussion of critical thinking in chapter 1, we offer abundant opportunities for students to weigh contrasting evidence and evaluate assumptions and arguments, including *What Do You Think*? readings.

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—*Active Learning 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.

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.

A global perspective: Environmental science is a globally interconnected discipline. Case studies, data, and examples from around the world give opportunities to examine international questions. Half of the 16 case studies examine international issues of global importance, such as forest conservation in Indonesia, soy production in Brazil, and car-free cities in Germany. Half of all boxed readings and Key Concepts are also global in focus. In addition, Google Earth place marks take students virtually to locations where they can see and learn the context of the issues they read.

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 on 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 (chapter 1) to public activism (chapter 13) to global environmental organizing (chapter 16) 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.

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 ConnectPlus (www.mcgrawhillconnect.com) is a web-based assignment and assessment platform that gives students the means to better connect with their coursework, with their instructors, and with the important concepts that they will need to know for success now and in the future. Valuable assets such as LearnSmart (an adaptive learning system), an interactive ebook, *Data Analysis* exercises, the extensive case study library, and Google Earth exercises are all available in Connect.

WHAT'S NEW IN THIS EDITION?

This edition has an enhanced focus on two major themes, climate and sustainability. These themes have always been central to this book, but the current edition gives additional explanation and examples that help students consider these dominant ideas of our time. The climate chapter (chapter 9) provides up-to-date data from the Intergovernmental Panel on Climate Change (IPCCC) as well as expanded explanations of climate dynamics, including positive feedbacks and why greenhouse gases capture energy. Overall, one-third of chapter-opening case studies are new, and data and figures have been updated throughout the book. Specific chapter changes include the following:

Chapter 1: New opening case study focuses on campus sustainability and how students can contribute. There is a revised discussion of methods in science and of major themes in the course, to give students a sense of direction through the book and the course. The *Exploring Science* boxed reading is updated to focus on statistics for the Human Development Index.

Chapter 2: This chapter emphasizes connections between general ideas in environmental chemistry and environmental systems, and why they matter for understanding topics in an environmental science class: For example why should you know about isotopes, and how does pH or radioactivity matter in water pollution?

Chapter 3: Expanded attention to the importance of symbiotic and coevolutionary relationships among species. Included in this is a new boxed reading on the microbiome of organisms that live in and on our bodies and aid our survival (p. 63). We have retained the focus on Darwin, evolution, and principles of speciation that are central to this chapter.

Chapter 4: Updated figures on global population growth, fertility rates, resource consumption, and hunger. Updated data regarding mortality, disease risk, life expectancy, and other demographic factors. Estimates of global population trends by 2050 are updated.

Chapter 6: New opening case study on declining forest habitat for orangutans, associated with forest clearance for palm oil production and other purposes. This phenomenon is spreading throughout the tropics and represents one of the greatest recent threats to forest conservation. The case study links to a new boxed reading on Norwegian REDD investments in Indonesian forest conservation in the interest of slowing climate change. Updated figures on global forest extent and changes, including evident declines in deforestation rates in Brazil.

Chapter 7: Updated figures on food production and access, also updated data on hunger, obesity, and food insecurity, including the role of conflict in famines. Expanded discussion of pesticides, including a new graph and map of glyphosate applications (fig. 7.22).

Chapter 8: New section on emergent diseases, including those associated with bushmeat in developing areas and updated map of major emergent disease incidents (fig. 8.5). There is a new discussion of antibiotic resistant bacterial infections and their link to confined livestock production, as well as to misuse of antibiotics in healthcare.

Chapter 9: New opening case study on sea level change and its impacts on coastal areas, such as Florida, as well as 11 new or revised figures, including figures from recent IPCC reports. A new *Active Learning* section (p. 213) asks students to explain key evidence for climate change; a new section on positive feedbacks explains the role of sea ice in global climate regulation (fig. 9. 18). The chapter closes with an updated discussion of policy responses to climate change.

Chapter 10: Updated discussion of EPA regulation of carbon as a pollutant, and of controlling halogen emissions. New discussion of persistent air pollution challenges in India, China, and other parts of the industrializing world.

Chapter 11: New opening case study on water resources in California and the impacts of drought on agriculture and cities. Because the previous case study on Lake Mead and the Colorado River remains newsworthy, the topic has been revised and updated as a *What do you think?* boxed reading. Largely revised section on clean water protections, and clean water in developing areas.

Chapter 12: Updated notes on fossil fuel extraction and its effects in the continental United States, including earthquakes. The Kathmandu earthquake of spring 2015 is noted, with reasons for its extreme destructiveness.

Chapter 13: The energy chapter is largely revised to reflect recent changes in both conventional energy and sustainable energy resources. Updates include expanded attention to the emerging importance of alternative energy resources, as well as developments in the conventional energy resources that still dominate supplies. A new opening case study highlights the importance of energy policy for climate change. The chapter has 11 new figures, including updated maps of gas, wind, and solar energy resources.

Chapter 14: Figures on waste production and management are updated.

Chapter 16: Recasts policy to more explicitly integrate environmental science with the policy options that apply environmental data to decision making (section 16.1). The discussion of judicial impacts on policy includes updated notes on Supreme Court's rulings requiring that the EPA regulate carbon dioxide, as well as the Court's impacts on campaign finance debates. The section on individual actions is revised, as is the *What can you do*? box and a discussion of the successes of the Millennium Development Goals and the challenge of the UN's emerging Sustainable Development Goals.

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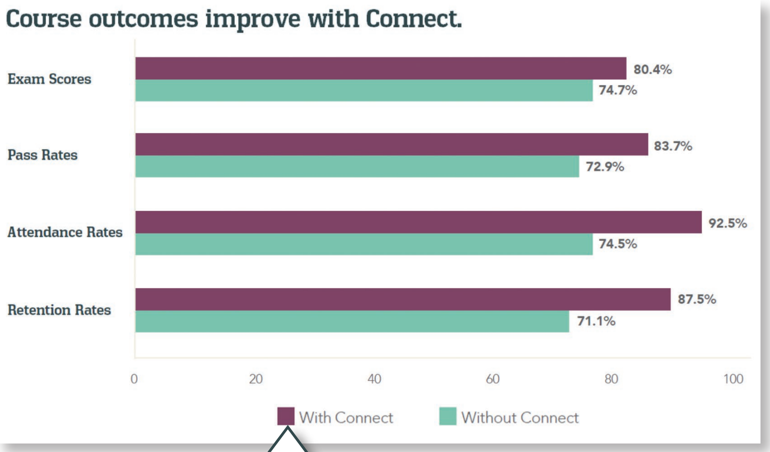

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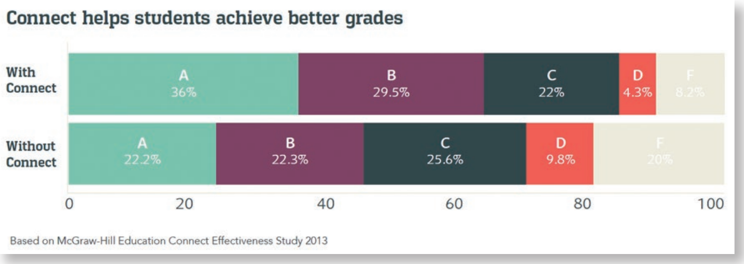

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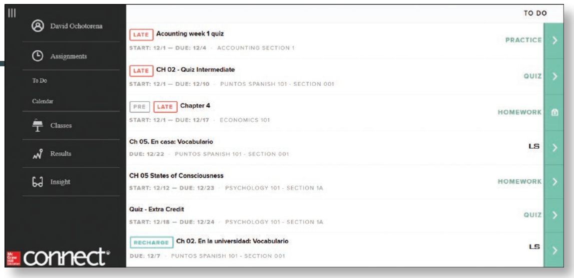

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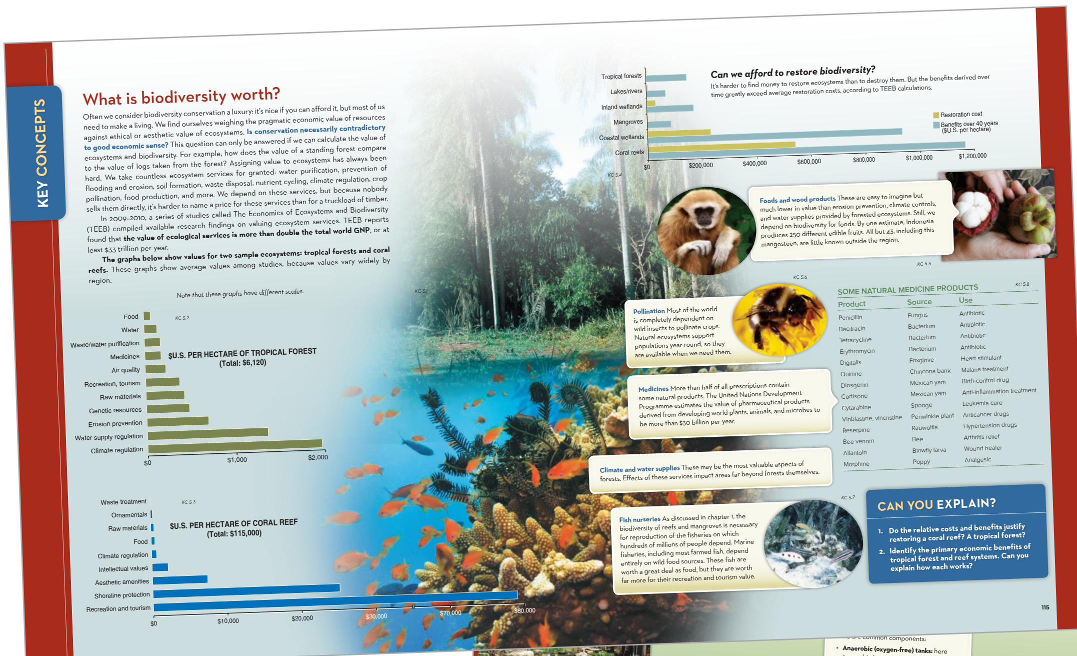
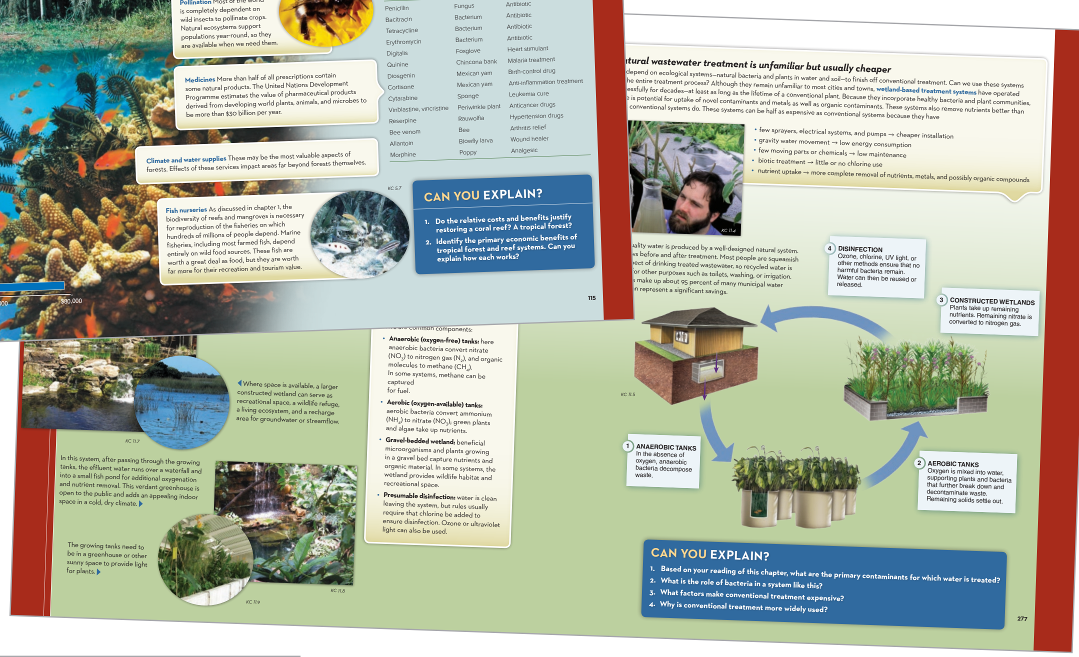


Key Concepts

Key concepts from each chapter are presented in a beautifully arranged layout to guide the student through the often complex network issues.



Case Studies

All chapters open with a real-world case study to help students appreciate and understand how environmental science impacts lives and how scientists study complex issues.

CASE STUDY

Palm Oil and Endangered Species

Are your donuts, toothpaste, or shampoo killing critically endangered orangutans and tigers in Sumatra and Borneo? How could that be possible, you may wonder. The link is in rapidly expanding Indonesian palm plantations, which are destroying the habitat of rare species, such as orangutans, tigers, rhinos, and elephants. What were once some of the most highly productive and biologically diverse lowland rainforests in the world are rapidly being converted into palm monocultures that have no room for endangered species.

In Indonesian *Orang* means person or people, and *utan* means of the forest. Orangutans are among the closest and most charismatic of our primate relatives, sharing at least 97 percent of our genes. They're also among the most critically endangered of all the great apes. It's estimated that between 1,000 and 5,000 of these shy forest giants are killed every year by loggers or poachers. Today only about 6,000 orangutans are left in Sumatra and about 50,000 in Borneo. The United Nations warns that unless current practices change, there may be no wild orang-

▲ **FIGURE 6.1** Over the past 15 years, palm plantation area in Indonesia has more than quadrupled to 11 million ha (27 million acres) and now produces about 60 percent of the world supply of this valuable oil. This rapid growth has destroyed habitat and displaced many critically endangered species.

of any country and the world's third highest greenhouse gas emissions. And expansion of palm oil is a driving force in both forest destruction and climate-changing gas releases. The process usually starts with logging to harvest the valuable hardwoods. Habitat destruction drives out wildlife, while a network of logging roads makes it possible for poachers to enter inaccessible areas. Logging slash is burned to clear the land for planting (and in many cases, fires cover up illegal logging), and finally, vast areas are planted in sterile monotony.

Oil palms are highly profitable. A single hectare (2.47 acres) of palms can yield 30 metric tons of oil per year, or as much as ten times as much as other oilseed crops (Fig. 6.1). Palm oil is now Indonesia's third largest import, bringing in $18 billion annually. One of the worst kinds of forest destruction for plantations is on deep peatlands, where waterlogged soils prevent biomass decomposition. Peat can contain more than 28 times as much carbon as mineral soil, and draining and burning of a hectare of peatland can release 15,000 tons of

Google Earth™ interactive satellite imagery gives students a geographic context for global places and topics discussed in the text. Google Earth™ icons indicate a corresponding exercise in Connect. In these exercises students will find links to locations mentioned in the text, and corresponding assessments that will help them understand environmental topics.

Active Learning

Students will be encouraged to practice critical thinking skills and apply their understanding of newly learned concepts and to propose possible solutions.

Active LEARNING

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. 5.6). 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?

ANSWERS: San Diego is about 13°C colder in January, about 6°C colder in July; San Diego has the greater range of temperature; there is about 250 mm difference in precipitation in December–February.

What Can YOU DO?

Working Locally for Ecological Diversity

You might think that 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

What Can You Do?

Students can employ these practical ideas to make a positive difference in our environment.

EXPLORING *Science* — *Remote Sensing, Photosynthesis, and Material Cycles*

Measuring primary productivity is important for understanding individual plants and local environments. Understanding the rates of primary productivity is also key to understanding global processes, such as material cycling, and biological activity:

- In global carbon cycles, how much carbon is stored by plants, how quickly is it stored, and how does carbon storage compare in contrasting environments, such as the Arctic and the tropics?
- How does this carbon storage affect global climates (see chapter 9)?
- In global nutrient cycles, how much nitrogen and phosphorus wash offshore, and where?

How can environmental scientists measure primary production (photosynthesis) at a global scale? In a small, relatively closed ecosystem, such as a pond, ecologists can collect and analyze samples of all trophic levels. But that method is impossible for large ecosystems, especially for oceans, which cover 70 percent of the earth's surface. One of the newest methods of quantifying biological productivity involves remote sensing, or using data collected from satellite sensors that observe the energy reflected from the earth's surface.

As you have read in this chapter, chlorophyll in green plants *absorbs* red and blue

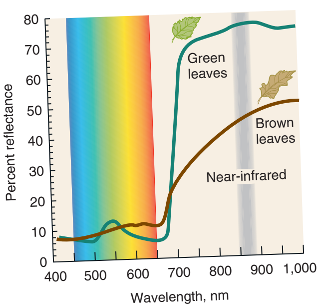


FIGURE 1 Energy wavelengths reflected by green and brown leaves.

Exploring Science

Current environmental issues exemplify the principles of scientific observation and data-gathering techniques to promote scientific literacy.

What Do YOU THINK?

Shade-Grown Coffee and Cocoa

Do your purchases of coffee and chocolate help to protect or destroy tropical forests? Coffee and cocoa are two of the many products grown exclusively in developing countries but consumed almost entirely in the wealthier, developed nations. Coffee grows in cool, mountain areas of the tropics, while cocoa is native to the warm, moist lowlands. What sets these two apart is that both come from small trees adapted to grow in low light, in the shady understory of a mature forest. **Shade-grown** coffee and cocoa (grown beneath an understory of taller trees) allow farmers to produce a crop at the same time as forest habitat remains for birds, butterflies, and other wild species.

Until a few decades ago, most of the world's coffee and cocoa were shade-grown. But new varieties of both crops have been developed that can be grown in full sun. Growing in full sun, trees can be crowded together more closely. With more sunshine, photosynthesis and yields increase.

Cocoa pods grow directly on the trunk and large branches of cocoa trees.

ha of coffee and cocoa plantations in these areas are converted to monocultures, an incalculable number of species will be lost.

The Brazilian state of Bahia demonstrates both the ecological importance of these crops and how they might help preserve forest species. At one time, Brazil produced much of the world's cocoa, but in the early 1900s, the crop was introduced into West Africa. Now Côte d'Ivoire alone grows more than 40 percent of the world total. Rapid increases in global supplies have made prices plummet, and the value of Brazil's harvest has dropped by 90 percent. Côte d'Ivoire is aided in this competition by a labor system that reportedly includes widespread child slavery. Even adult workers in Côte d'Ivoire get only about $165 (U.S.) per year (if they get paid at all), compared with a mini-

What Do You Think?

Students are presented with challenging environmental studies that offer an opportunity to consider contradictory data, special interest topics, and conflicting interpretations within a real scenario.

Pedagogical Features Facilitate Student Understanding of Environmental Science

CHAPTER 6

Environmental Conservation: Forests, Grasslands, Parks, and Nature Preserves

Orangutans are among the most critically endangered of all the great apes. Over the past 20 years, about 90 percent of their rainforest habitat in Borneo and Sumatra has been destroyed by logging and conversion to palm oil plantations.

LEARNING OUTCOMES

After studying this chapter, you should be able to answer the following questions:

- What portion of the world's original forests remains?
- What activities threaten global forests? What steps can be taken to preserve them?
- Why is road construction a challenge to forest conservation?
- Where are the world's most extensive grasslands?
- How are the world's grasslands distributed, and what activities degrade grasslands?
- What are the original purposes of parks and nature preserves in North America?
- What are some steps to help restore natural areas?

Learning Outcomes

Questions at the beginning of each chapter challenge students to find their own answers.

Practice Quiz

Short-answer questions allow students to check their knowledge of chapter concepts.

PRACTICE QUIZ

1. What are the two most important nutrients causing eutrophication in the Chesapeake Bay?
2. What are systems and how do feedback loops regulate them?
3. Your body contains vast numbers of carbon atoms. How is it possible that some of these carbons may have been part of the body of a prehistoric creature?
4. List six unique properties of water. Describe, briefly, how each of these properties makes water essential to life as we know it.
5. What is DNA, and why is it important?
6. The oceans store a vast amount of heat, but this huge reservoir of energy is of little use to humans. Explain the difference between high-quality and low-quality energy.
7. In the biosphere, matter follows circular pathways, while energy flows in a linear fashion. Explain
8. Which wavelengths do our eyes respond to, and why? (Refer to fig. 2.13.) About how long are short ultraviolet wavelengths compared to microwave lengths?
9. Where do extremophiles live? How do they get the energy they need for survival?
10. Ecosystems require energy to function. From where does most of this energy come? Where does it go?
11. How do green plants capture energy, and what do they do with it?
12. Define the terms *species*, *population*, and *biological community*.
13. Why are big, fierce animals rare?
14. Most ecosystems can be visualized as a pyramid with many organisms in the lowest trophic levels and only a few individuals at the top. Give an example of an inverted numbers pyramid

CRITICAL THINKING AND DISCUSSION

Apply the principles you have learned in this chapter to discuss these questions with other students.

1. Ecosystems are often defined as a matter of convenience because we can't study everything at once. How would you describe the characteristics and boundaries of the ecosystem in which you live? In what respects is your ecosystem an open one?
2. Think of some practical examples of increasing entropy in everyday life. Is a messy room really evidence of thermodynamics at work, or merely personal preference?
3. Some chemical bonds are weak and have a very short half-life (fractions of a second, in some cases); others are strong and stable, lasting for years or even centuries. What would our world be like if all chemical bonds were either very weak or extremely strong?
4. If you had to design a research project to evaluate the relative biomass of producers and consumers in an ecosystem, what would you measure? (*Note:* This could be a natural system or a human-made one.)
5. Understanding storage compartments is essential to understanding material cycles, such as the carbon cycle. If you look around your backyard, how many carbon storage compartments are there? Which ones are the biggest? Which ones are the longest lasting?

Critical Thinking and Discussion Questions

Brief scenarios of everyday occurrences or ideas challenge students to apply what they have learned to their lives.

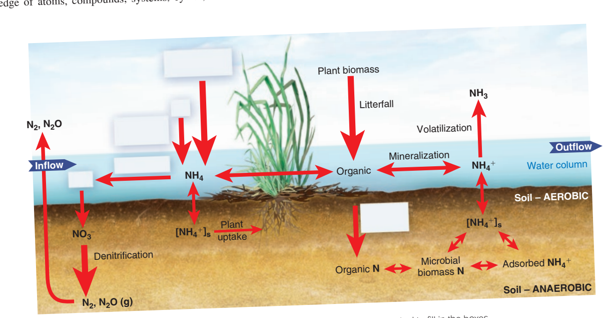
Data Analysis

At the end of each chapter, these exercises give students further opportunities to apply critical thinking skills and analyze data. These are assigned through Connect in an interactive online environment. Students are asked to analyze data in the form of documents, videos, and animations.

DATA ANALYSIS Examining Nutrients in a Wetland System

As you have read, movements of nitrogen and phosphorus are among the most important considerations in many wetland systems, because high levels of these nutrients can cause excessive algae and bacteria growth. This is a topic of great interest, and many studies have examined how nutrients move in a wetland, as well as in other ecosystems. Taking a little time to examine these nutrient cycles in detail will draw on your knowledge of atoms, compounds, systems, cycles, and other ideas in this chapter. Understanding nutrient cycling will also help you in later chapters of this book.

One excellent overview was produced by the Environmental Protection Agency. Go to Connect to find a description of the figure shown here, and to further explore the movement of our dominant nutrient, nitrogen, through environmental systems.

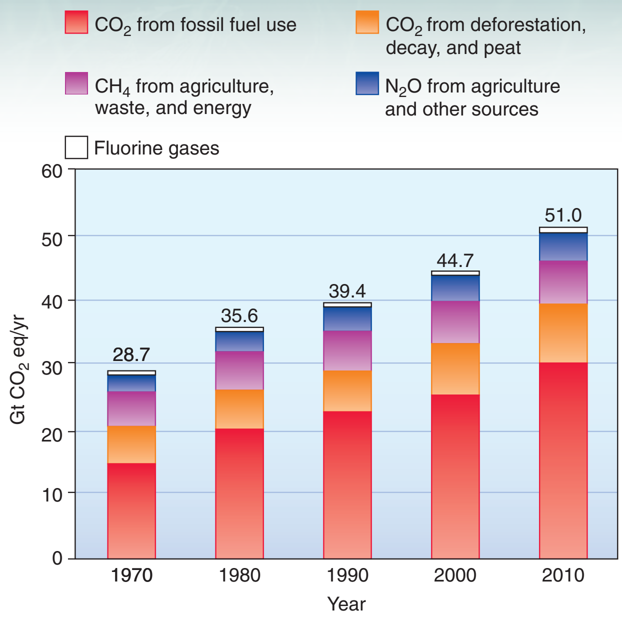


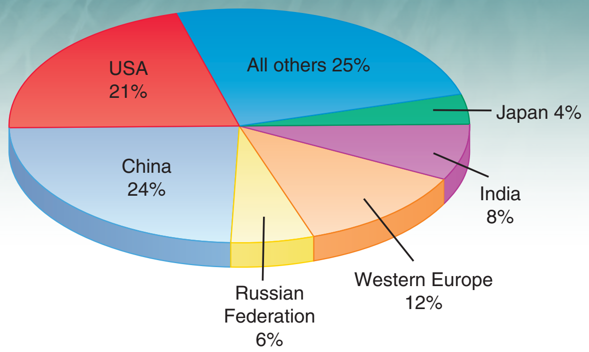
▲ FIGURE 1 A detailed schematic diagram of the nitrogen cycle in a wetland. Study the online original to fill in the boxes.
SOURCE: EPA Nutrient Criteria Technical Guidance Manual, www.epa.gov/waterscience/criteria/nutrient/guidance/.

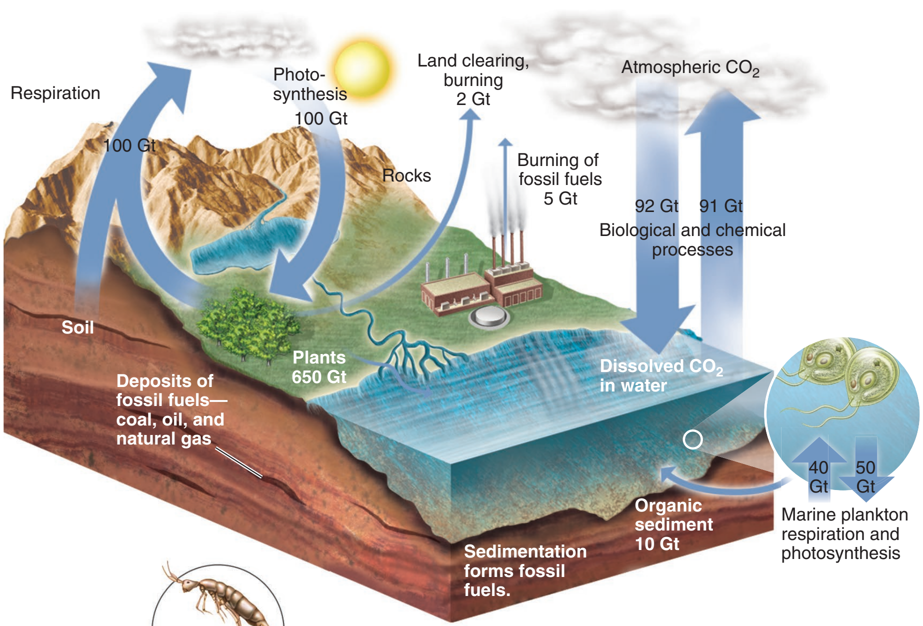
TO ACCESS ADDITIONAL RESOURCES FOR THIS CHAPTER, PLEASE VISIT CONNECT AT www.connect.mheducation.com

You will find Smartbook, an interactive and adaptive reading experience, Google Earth™ Exercises, additional Case Studies, and Data Analysis exercises.

Topical Photos and Instructional Art Support Learning







Numerous high-quality photos and realistic illustrations display detailed diagrams, graphs, and real-life situations.


REJECT
THE KXL
PIPELINE

CHAPTER

1 Understanding Our Environment

Students work on landscape plantings at Furman University's Shi Center for Sustainability cottage. Students here contribute energy and ideas while they learn about sustainability.

LEARNING OUTCOMES

After studying this chapter, you should be able to answer the following questions:

- Describe several important environmental problems facing the world.
- List several examples of progress in environmental quality.
- Explain the idea of sustainability and some of its aims.
- Why are scientists cautious about claiming absolute proof of particular theories?
- What is critical thinking, and why is it important in environmental science?
- Why do we use graphs and data to answer questions in science?
- Identify several people who helped shape our ideas of resource conservation and preservation—why did they promote these ideas when they did?

CASE STUDY

Assessing Sustainability

If you're taking a course in environmental science, chances are you are interested in understanding environmental resources and our impacts on them. You might be interested in water resources, biodiversity, environmental health, climate change, chemistry, population change, ecology, or other aspects of our environment. You might also be interested in how you can apply your knowledge for ensuring the longevity, or sustainability, of environmental resources over time.

One of the ways you can apply your knowledge at your own college or university is by helping with sustainability assessment and reporting. Sustainability assessments ask a range of questions: Does an institution actively conserve water or energy? Does it work to promote biodiversity or reduce pollution? Does it cooperate with the local community to improve living conditions around it?

Furman University, in Greenville, SC, is one of about 240 schools that have been using the Sustainability Tracking, Assessment and Rating System (STARS) to track their progress. STARS is one of several reporting systems that help colleges and universities understand, compare, and ideally improve environmental performance in relation to peer institutions. The rating system is run by the Association for the Advancement of Sustainability in Higher Education (AASHE), an organization of institutions that also provides a network for sharing ideas and gives a platform for schools to show off their successes.

In 2015, Furman's assistant sustainability coordinator Yancey Fouché turned in the university's third report, raising the school's rating from Silver to Gold. This improvement reflects the work of students, faculty, administrators, staff, and alums who want to see their university do well *and* do good. The report also reflects the contributions of students who assisted with data collection and analysis, a valuable contribution to their educational experience. Furman is one of only about 80 colleges and universities to get a Gold rating in the recent round of submissions.

How did Furman achieve its high score? By performing well across a wide range of criteria. STARS gives points for evidence of sustainability in the curriculum, in research activities by students and faculty, and for campus engagement and community service. There are points for operations: greenhouse gas emissions, building management, use of renewable energy, purchasing of environmentally safe cleaning products, and other practices. Grounds management that preserves biodiversity, conserves water resources, reduces storm water runoff, and cuts pesticide use also gets points. Policies on transportation and waste management (especially recycling and composting rates) matter. Governance—the ways administrators and committees support these practices—also contributes points. STARS also gives credits for measures of health and well-being: are there wellness programs in place, health and safety, and comfortable work spaces? Points are also available for sustainable investment practices with an institution's endowment. Some of these points are easier to achieve than others. New sustainability courses can be instituted relatively rapidly. Building efficiency and energy systems, "operations," are expensive and difficult to change (fig. 1.1).

Furman did especially well in curriculum, research, and campus engagement, getting 50 of 52 possible points in these categories. Like other schools, it didn't do as well on building operations—Furman earned only 15 of 36 points in these categories—or on waste minimization and transportation (8 of 17 points). The fact that Furman is better than average shows that most institutions have considerable room for improvement.

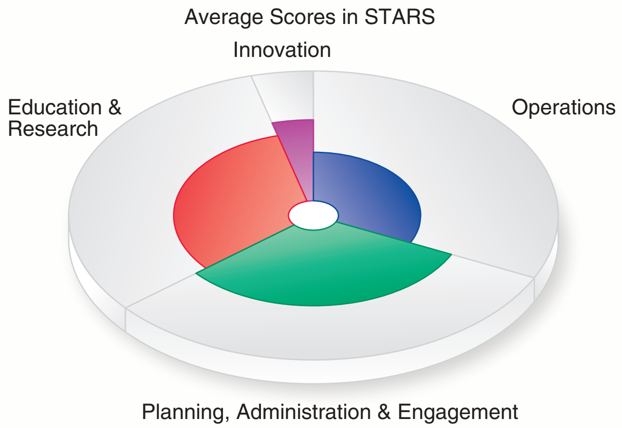
Even though it's hard to change an institution's energy use and transportation practices, having benchmarks to aim for, and peer institutions for comparison, is essential. These measures motivate improvements when opportunities arise, and provide a common framework for campus conversations. Renovations and new buildings, like Furman's showcase Shi Center for Sustainability Cottage (opening photo), are always an opportunity to invest in new systems that save both energy and money over the long term.

Most of us won't submit a STARS report ourselves—it requires a lot of specialized data collection—but just about anybody can do something that helps improve a STARS rating, and with it the campus environment. Student environmental activities add points. Participation in student governance, environmental coursework, work with the local community, and many other activities contribute. And student groups are essential in pushing administrations to support energy conservation, waste reduction, local foods, community empowerment, and other priorities.

All this has a great deal to do with the environmental science you're about to study. Almost every resource and environmental question in a STARS report is related to a topic you'll explore here. Biodiversity, water conservation, energy use and alternative energy resources, waste management, sustainable food resources, environmental health, and environmental policy are all concerns of a STARS report, and you will learn about them in an environmental science course.

Environmental science also emphasizes the value of quantifying answers. If you can measure something, from pollution levels to STARS index values, you have the opportunity to see if progress is happening over time.

The chapters that follow are intended to give you grounding in the knowledge you need to make these contributions. They also aim to help you understand the basics of scientific approaches to understanding our environment. ■



▲ **FIGURE 1.1** This pie chart shows the proportion of a STARS score contributed by different categories (slice width) and overall average score (length of slice) for all reporting institutions. Operations tend to score low, while innovation and engagement tend to score higher, on average.
DATA SOURCE: Association for the Advancement of Sustainability in Higher Education.

> *Today we are faced with a challenge that calls for a shift in our thinking, so that humanity stops threatening its life-support system.*
>
> —WANGARI MAATHAI,
> WINNER OF 2004 NOBEL PEACE PRIZE

1.1 WHAT IS ENVIRONMENTAL SCIENCE?

Environmental science is the use of scientific approaches to understand the complex systems in which we live. It is the systematic study of our environment and our place in it. Much, though not all, of environmental science involves applying basic knowledge to real-world problems: an environmental scientist might study patterns of biodiversity or river system dynamics for their own sake. An environmental scientist might also study these systems with the larger aim of saving species or cleaning up a river. Environmental scientists often get involved in sustainability efforts, such as the issues in a STARS report, in their home universities, colleges, or communities.

In this chapter we will examine some main ideas and approaches used in environmental science. You will explore these themes in greater depth in later chapters. We will examine the scientific method, critical thinking, and other approaches to evaluating evidence. Finally we will examine some key ideas that have influenced our understanding of environmental science.

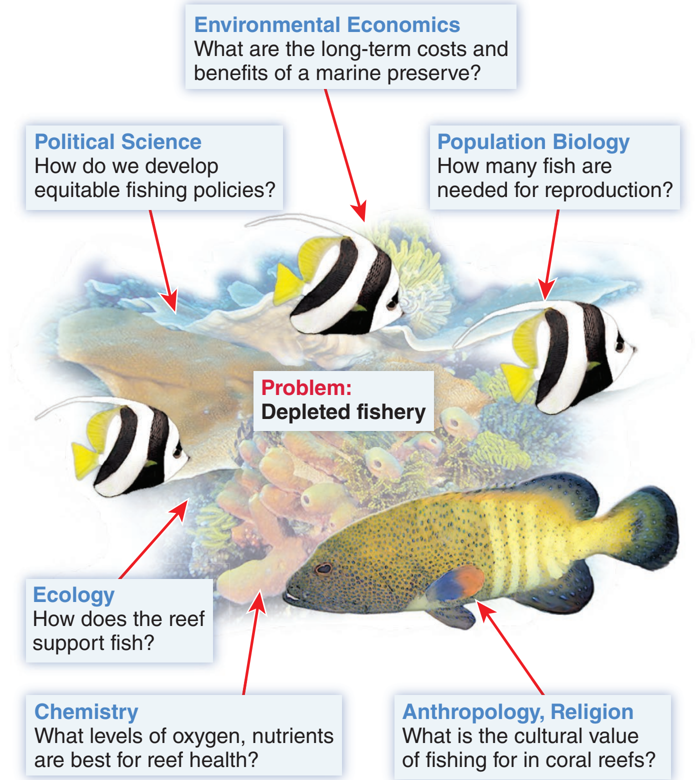


FIGURE 1.2 Many types of knowledge are needed in environmental science. A few examples are shown here.

Environmental science is integrative

We inhabit both a natural world of biological diversity and physical processes and a human environment of ideas and practices. Environmental science involves both these natural and human worlds. Because environmental systems are complex and interconnected, the field also draws on a wide range of disciplines and skills, and multiple ways of knowing are often helpful for finding answers (fig. 1.2). Biology, chemistry, earth science, and geography contribute ideas and evidence of basic science. Political science, economics, communications, and arts help us understand how people share resources, compete for them, and evaluate their impacts on society. One of your tasks in this course may be to understand where your own knowledge and interests contribute (Active Learning, p. 4). Identifying your particular interest will help you do better in this class, because you'll have more reason to explore the ideas you encounter.

Environmental science is not the same as environmental advocacy. Environmental science itself requires no positions regarding environmental policy. However, environmental science is an analytical approach that is needed to make us confident that policy positions we do take are reasonable and are based on observable evidence, not just assumption or hearsay.

Environmental science is global

You are already aware of our global dependence on resources and people in faraway places, from computers built in China to oil extracted in Iraq or Venezuela. These interdependencies become clearer as we learn more about global and regional environmental systems. Often the best way to learn environmental science is to see how principles play out in real places. Familiarity with the world around us will help you understand the problems and their context. Throughout this book we've provided links to places you can see in Google Earth, a free online mapping program that you can download from googleearth.com. When you see a blue globe in the margin of this text, like the one at left, you can go to Connect and find placemarks that let you virtually visit places discussed. In Google Earth you can also save your own placemarks and share them with your class.

Environmental science helps us understand our remarkable planet

Imagine that you are an astronaut returning to the earth after a trip to the moon or Mars. What a relief it would be, after the silent void of outer space, to return to this beautiful, bountiful planet (fig. 1.3). We live in an incredibly prolific and colorful world that is, as far as we know, unique in the universe. Compared with other planets in our solar system, temperatures on the earth are mild and relatively constant. Plentiful supplies of clean air, fresh water, and fertile soil are regenerated endlessly and spontaneously by biogeochemical cycles and biological communities (discussed in chapters 2 and 3). The value of these ecological services is almost incalculable, although economists estimate that they account for a substantial proportion of global economic activity (see chapter 15).

Active LEARNING

Finding Your Strengths in This Class

A key strategy for doing well in this class is to figure out where your strengths and interests intersect with the subjects you will be reading about. As you have read, environmental science draws on many kinds of knowledge (fig. 1.2). Nobody is good at all of these, but everyone is good at some of them. Form a small group of students; then select one of the questions in section 1.2. Explain how each of the following might contribute to understanding or solving that problem:

artist, writer, politician, negotiator, chemist, mathematician, hunter, angler, truck driver, cook, parent, builder, planner, economist, speaker of multiple languages, musician, business person

ANSWERS: All of these provide multiple insights; answers will vary.

▲ **FIGURE 1.4** Perhaps the most amazing feature of our planet is its rich diversity of life.

Perhaps the most amazing feature of our planet is its rich diversity of life. Millions of beautiful and intriguing species populate the earth and help sustain a habitable environment (fig. 1.4). This vast multitude of life creates complex, interrelated communities where towering trees and huge animals live together with, and depend upon, such tiny life-forms as viruses, bacteria, and fungi. Together, all these organisms make up delightfully diverse, self-sustaining ecosystems, including dense, moist forests; vast, sunny savannas; and richly colorful coral reefs.

From time to time we should pause to remember that, in spite of the challenges of life on earth, we are incredibly lucky to be here. Because environmental scientists observe this beauty around us, we often ask what we can do, and what we *ought* to do, to ensure that future generations have the same opportunities to enjoy this bounty.

Methods in environmental science

Keep an eye open for the ideas that follow as you read this book. These are a few of the methods that you will find in science generally. They reflect the fact that environmental science is based on careful, considered observation of the world around us.

Observation: A first step in understanding our environment is careful, detailed observation and evaluation of factors involved in pollution, environmental health, conservation, population, resources, and other issues. Knowing about the world we inhabit helps us understand where our resources originate, and why.

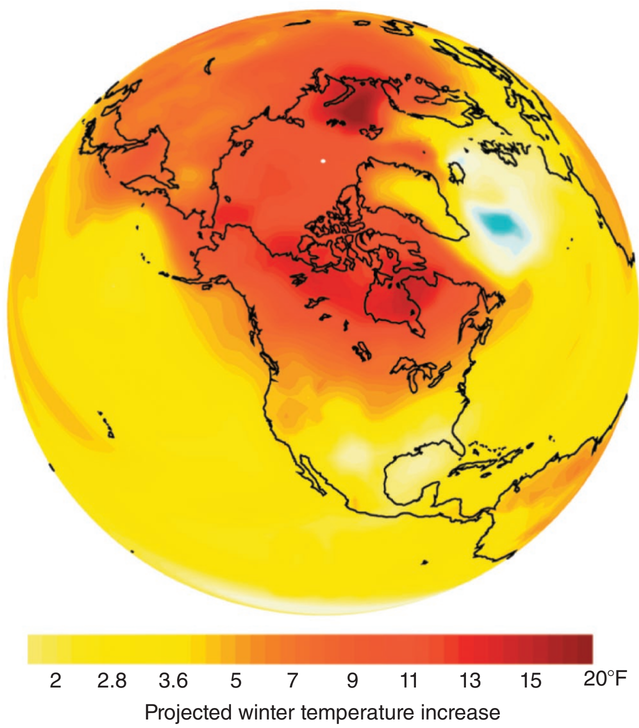
The scientific method: Discussed later in this chapter, the scientific method is an orderly approach to asking questions, collecting observations, and interpreting those observations to find an answer to a question. In daily life, many of us have prior expectations when we start an investigation, and it takes discipline to avoid selecting evidence that conveniently supports our prior assumptions. In contrast, the scientific method aims to be rigorous, using statistics, blind tests, and careful replication to avoid simply confirming the investigator's biases and expectations.

Quantitative reasoning: This means understanding how to compare numbers and interpret graphs, to perceive what they show about problems that matter. Often this means interpreting changes in values, such as population size over time.

Uncertainty: A repeating theme in this book is that uncertainty is an essential part of science. Science is based on observation and testable hypotheses, but we know that we cannot make all observations in the universe, and we have not asked all possible questions. We know there are limits to our knowledge. Understanding how much we *don't* know, ironically, can improve our confidence in what we *do* know.

Critical and analytical thinking: The practice of stepping back to examine what you think and why you think it, or why someone says or believes a particular idea, is known generally as critical thinking. Acknowledging uncertainty is one part of critical thinking. This is a skill you can practice in all your academic pursuits, as you make sense of the complexity of the world we inhabit.

▶ **FIGURE 1.3** The life-sustaining ecosystems on which we all depend are unique in the universe, as far as we know.



▲ **FIGURE 1.5** Climate change is projected to raise temperatures, especially in northern winter months. DATA SOURCE: NOAA, 2010.

1.2 MAJOR THEMES IN ENVIRONMENTAL SCIENCE

In this section we review some of the main themes in this book. All of these are serious problems, but they are also subjects of dramatic innovation. Often solutions lie in policy and economics, but environmental scientists provide the evidence on which policy decisions can be made.

We often say that crisis and opportunity go hand in hand. Serious problems can drive us to seek better solutions. As you read, ask yourself what factors influence these conditions, and what steps might be taken to resolve them.

Environmental quality

Climate Change The atmosphere retains heat near the earth's surface, which is why it is warmer here than in space. But burning fossil fuels, clearing forests and farmlands, raising billions of methane-producing cattle, and other activities have greatly increased concentrations of carbon dioxide and other "greenhouse gases." In the past 200 years, concentrations of CO_2 in the atmosphere have increased nearly 50 percent. Climate models indicate that by 2100, if current trends continue, global mean temperatures will probably increase by 2° to 6°C compared to 1990 temperatures (3.6° to 12.8°F; fig. 1.5), far warmer than the earth has been since the beginning of human civilization. For comparison, the last ice age was about 4°C cooler than now. Increasingly severe droughts and heat waves are expected in many areas. Greater storm intensity and flooding are expected in many regions. Disappearing glaciers and snowfields threaten the water supplies on which cities such as Los Angeles and Delhi depend.

Military experts argue that climate change is a greater global threat than terrorism. Climate change could force hundreds of millions of people from their homes, trigger economic and social catastrophe, and instigate wars over water and arable land. Many people have argued that recent insurgencies and terrorism result from the dislocation and desperation of climate refugees in regions now too dry and hot for reliable farming.

On the other hand, efforts to find solutions to climate change may force new kinds of international cooperation. New strategies for energy production could reduce conflicts over oil and promote economic progress for the world's poorest populations.

Clean Water Water may be the most critical resource in the twenty-first century. At least 1.1 billion people lack access to safe drinking water, and twice that many don't have adequate sanitation. Polluted water contributes to the death of more than 15 million people every year, most of them children under age 5. About 40 percent of the world population lives in countries where water demands now exceed supplies, and the United Nations projects that by 2025 as many as three-fourths of us could live under similar conditions. Despite ongoing challenges, more than 800 million people have gained access to improved water supplies and modern sanitation since 1990.

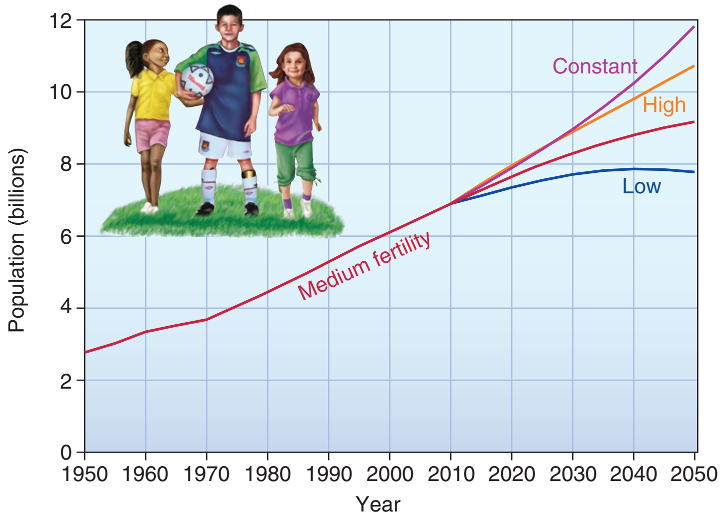
Air Quality Air quality has worsened dramatically in newly industrializing areas, especially in much of China and India. In Beijing and Delhi, wealthy residents keep their children indoors on bad days and install air filters in their apartments. Poor residents become ill, and cancer rates are rising in many areas. Millions of early deaths and many more illnesses are triggered by air pollution each year. Worldwide, the United Nations estimates, more than 2 billion metric tons of air pollutants (not including carbon dioxide or windblown soil) are released each year. These air pollutants travel easily around the globe. On some days 75 percent of the smog and airborne particulates in California originate in Asia; mercury, polychlorinated biphenyls (PCBs), and other industrial pollutants accumulate in arctic ecosystems and in the tissues of native peoples in the far north.

The good news is that environmental scientists in China, India, and other countries suffering from poor air quality are fully aware that Europe and the United States faced deadly air pollution decades ago. They know that enforceable policies on pollution controls, together with newer, safer, and more efficient technology will correct the problem, if they can just get needed policies in place.

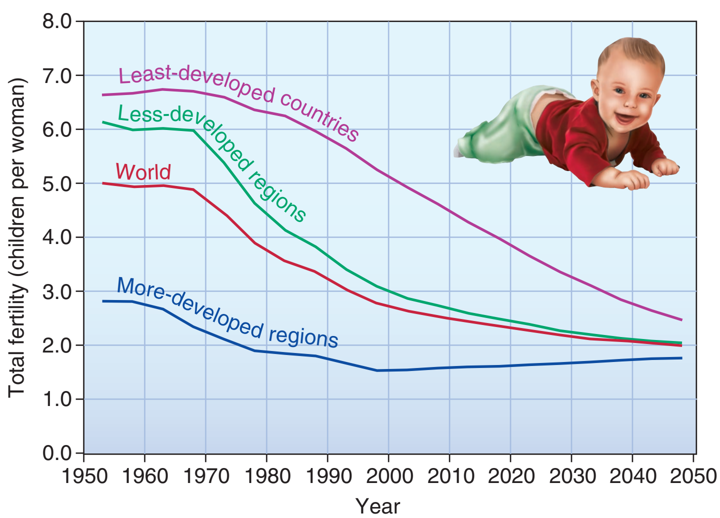
Human population and well-being

Population growth There are well over 7 billion people on earth, about twice as many as there were 40 years ago. We are adding about 80 million more each year. Demographers report a transition to slower growth rates in most countries: improved education for girls and better health care are chiefly responsible. But present trends project a population between 8 and 10 billion by 2050 (fig. 1.6a). The impact of that many people on our natural resources and ecological systems strongly influences many of the other problems we face.

The slowing growth rate is encouraging, however. In much of the world, better health care and a cleaner environment have improved longevity and reduced infant mortality. Social stability has allowed families to have fewer, healthier children. Population has stabilized in most industrialized countries and even in some very



(a) Possible population trends



(b) Fertility rates

▲ **FIGURE 1.6** Bad news and good news: globally, populations continue to rise (a), but our rate of growth has plummeted (b). Some countries are below the replacement rate of about two children per woman. SOURCE: United Nations Population Program, 2011.

poor countries where social security, education, and democracy have been established. Since 1960 the average number of children born per woman worldwide has decreased from 5 to 2.45 (fig. 1.6b). By 2050 the UN Population Division predicts, most countries will have fertility rates below the replacement rate of 2.1 children per woman. If this happens, the world population will stabilize at about 8.9 billion rather than the 9.3 billion previously expected.

Infant mortality in particular has declined in most countries, as vaccines and safe water supplies have become more widely available. Smallpox has been completely eradicated, and polio has been vanquished except in a few countries, where violent conflict has contributed to a resurgence of the disease. Life expectancies have nearly doubled, on average (fig. 1.7a).

Hunger and food Over the past century, global food production has increased faster than human population growth. We now produce about half again as much food as we need to survive, and consumption of protein has increased worldwide. In most countries weight-related diseases are far more prevalent than hunger-related illnesses. In spite of population growth that added nearly a billion people to the world during the 1990s, the number of people facing food insecurity and chronic hunger during this period actually declined by about 40 million.

Despite this abundance, hunger remains a chronic problem worldwide because food resources are unevenly distributed. At the same time, soil scientists report that about two-thirds of all agricultural lands show signs of degradation. The biotechnology and intensive farming techniques responsible for much of our recent production gains are too expensive for many poor farmers. Can we find ways to produce the food we need without further environmental degradation? And can we distribute food more equitably? In a world of food surpluses, currently more than 850 million people are chronically undernourished, and at least 60 million people face acute food shortages due to weather, politics, or war (fig. 1.7b).

Information and Education Because so many environmental issues can be fixed by new ideas, technologies, and strategies, expanding access to knowledge is essential to progress. The increased speed at which information now moves around the world offers unprecedented opportunities for sharing ideas. At the same time, literacy and access to education are expanding in most regions of the world (fig. 1.7c). Rapid exchange of information on the Internet also makes it easier to quickly raise global awareness of environmental problems, such as deforestation or pollution, that historically would have proceeded unobserved and unhindered. Improved access to education is helping to release many of the world's population from cycles of poverty and vulnerability. Expanding education for girls is a primary driver for declining birth rates worldwide.

Natural Resources

Biodiversity Loss Biologists report that habitat destruction, overexploitation, pollution, and the introduction of exotic organisms are eliminating species as quickly as the great extinction that marked the end of the age of dinosaurs. The United Nations Environment Programme reports that over the past century more than 800 species have disappeared and at least 10,000 species are now considered threatened. This includes about half of all primates and freshwater fish, together with around 10 percent of all plant species. Top predators, including nearly all the big cats in the world, are particularly rare and endangered. A nationwide survey of the United Kingdom in 2004 found that most bird and butterfly populations had declined by 50 to 75 percent over the previous 20 years. At least half of the forests existing before the introduction of agriculture have been cleared, and many of the ancient forests, which harbor some of the greatest biodiversity, are rapidly being cut for timber, for oil extraction, or for agricultural production of globally traded commodities such as palm oil or soybeans.

Conservation of Forests and Nature Preserves While exploitation continues, the rate of deforestation has slowed in many regions. Brazil, which led global deforestation rates for decades, has dramatically reduced deforestation rates. Nature preserves and protected areas have increased sharply over the past few decades.

Ecoregion and habitat protection remains uneven, and some areas are protected only on paper. Still, this is dramatic progress in biodiversity protection.

Marine Resources The ocean provides irreplaceable and imperiled food resources. More than a billion people in developing countries depend on seafood for their main source of animal protein, but most commercial fisheries around the world are in steep decline. According to the World Resources Institute, more than three-quarters of the 441 fish stocks for which information is available are severely depleted or in urgent need of better management. Some marine biologists estimate that 90 percent of all the large predators, including bluefin tuna, marlin, swordfish, sharks, cod, and halibut, have been removed from the ocean.

Despite this ongoing overexploitation, many countries are beginning to acknowledge the problem and find solutions. Marine protected areas and improved monitoring of fisheries provide opportunities for sustainable management (fig. 1.7d). The strategy of protecting fish nurseries is an altogether new approach to sustaining ocean systems and the people who depend on them. Marine reserves have been established in California, Hawaii, New Zealand, Great Britain, and many other areas.

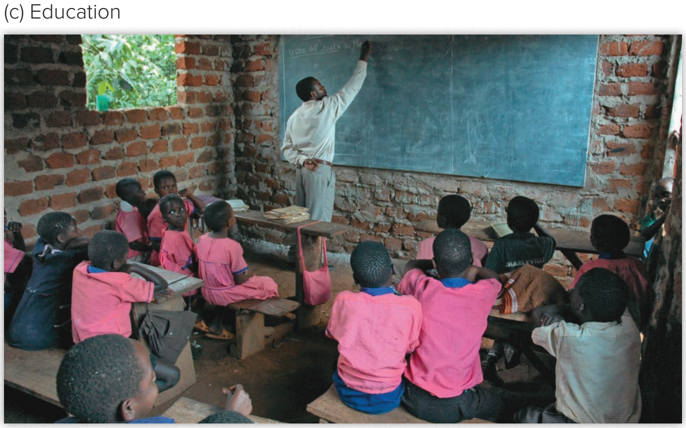
Energy Resources How we obtain and use energy will greatly affect our environmental future. Fossil fuels (oil, coal, and natural gas) presently provide around 80 percent of the energy used in industrialized countries. The costs of extracting and burning these fuels are among our most serious environmental challenges. Costs include air and water pollution, mining damage, and violent conflicts, in addition to climate change.

At the same time, improving alternatives and greater efficiency are beginning to reduce reliance on fossil fuels. The cost

(a) Health care

(b) Hunger

(c) Education



(d) Sustainable resource use

▲ **FIGURE 1.7** Human welfare is improving in some ways and stubbornly difficult in others. Health care is improving in many areas (a). Some 800 million people lack adequate nutrition. Hunger persists, especially in areas of violent conflict (b). Access to education is improving, including for girls (c), and local control of fishery resources is improving food security in some places (d).

of solar power has plummeted, and in many areas solar costs the same as conventional electricity over time. Solar and wind power are now far cheaper, easier, and faster to install than nuclear power or new coal plants.

1.3 HUMAN DIMENSIONS OF ENVIRONMENTAL SCIENCE

Aldo Leopold, one of the greatest thinkers on conservation, observed that the great challenges in conservation have less to do with managing resources than with managing people and our demands on resources. Foresters have learned much about how to grow trees, but still we struggle to establish conditions under which villagers in developing countries can manage plantations for themselves. Engineers know how to control pollution but not how to persuade factories to install the necessary equipment. City planners know how to design urban areas, but not how to make them affordable for everyone. In this section we'll review some key ideas that guide our understanding of human dimensions of environmental science and resource use. These ideas will be useful throughout the rest of this book.

How do we describe resource use and conservation?

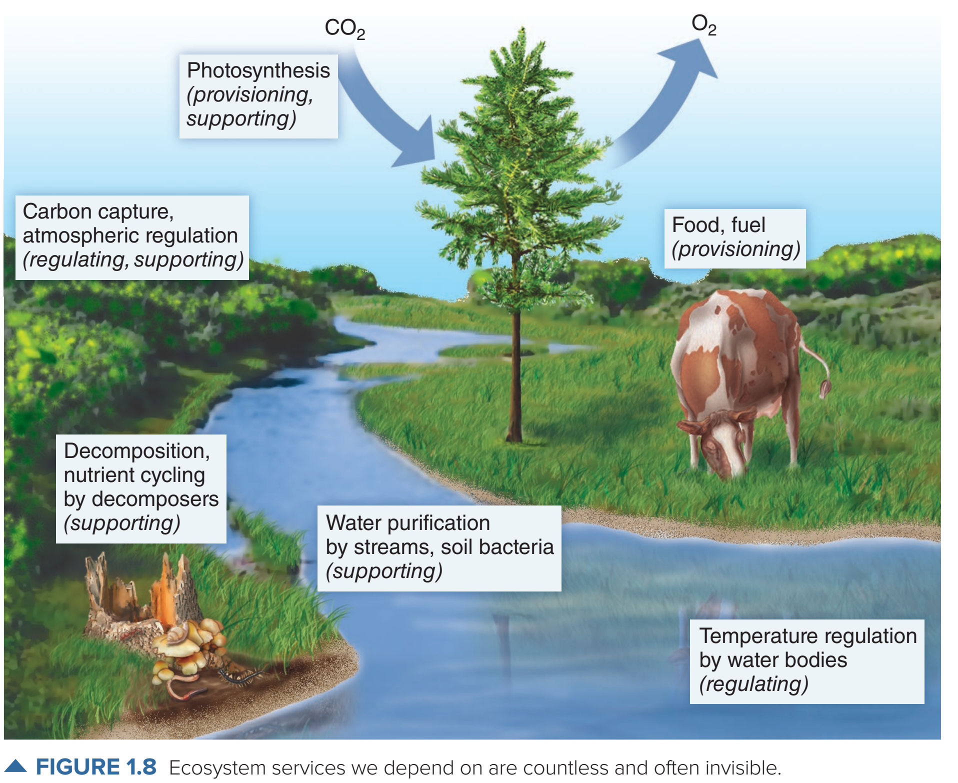
The natural world supplies the water, food, metals, energy, and other resources we use. Some of these resources are finite; some are constantly renewed (see chapter 14). Often, renewable resources can be destroyed by excessive exploitation, as in the case of fisheries or forest resources (see section 1.2). When we consider resource consumption, an important idea is **throughput**, the amount of resources we use and dispose of. A household that consumes abundant consumer goods, foods, and energy brings in a great deal of natural resource–based materials; that household also disposes of a great deal of materials. Conversely a household that consumes very little also produces little waste (see chapter 2).

Ecosystem services, another key idea, refers to services or resources provided by environmental systems (fig. 1.8). *Provisioning* of resources, such as the fuels we burn, may be the most obvious service we require. *Supporting* services are less obvious until you start listing them: these include water purification, production of food and atmospheric oxygen by plants, and decomposition of waste by fungi and bacteria. *Regulating* services include maintenance of temperatures suitable for life by the earth's atmosphere and carbon capture by green plants, which maintains a stable atmospheric composition. Cultural services include a diverse range of recreation, aesthetic, and other nonmaterial benefits. Usually we rely on these resources without thinking about them. They support all our economic activities in some way, but we don't put a price on them because nature doesn't force us to pay for them.

Are there enough resources for all of us? One of the answers to this basic question was given in an essay entitled "**Tragedy of the Commons**," published in 1968 in the journal *Science* by ecologist Garret Hardin. In this classic framing of the problem, Hardin argues that population growth leads inevitably to overuse and then destruction of common resources—such as shared pastures, unregulated fisheries, fresh water, land, and clean air. This classic essay has challenged many to explore alternative ideas about resource management. In many cases, agreed-upon rules for regulating and monitoring a resource ensure that it is preserved. Another strategy is to assign prices to ecological services, to force businesses and economies to account for damages to life-supporting systems. This approach is discussed in chapter 15. The idea of sustainable development is yet another answer.

Sustainability means environmental and social progress

Sustainability is a search for ecological stability and human progress that can last over the long term. Of course, neither ecological systems nor human institutions can continue forever. We can work, however, to protect the best aspects of both realms and to encourage resiliency and adaptability in both of them. World Health Organization director Gro Harlem Brundtland has defined **sustainable development** as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." In these terms, development means bettering people's lives. Sustainable development, then, means



▲ **FIGURE 1.8** Ecosystem services we depend on are countless and often invisible.

▲ **FIGURE 1.9** In impoverished areas, survival can mean degrading resources that are already overstressed. Helping the poorest populations is not only humane, it is essential for protecting our shared environment.

progress in human well-being that we can extend or prolong over many generations, rather than just a few years.

This idea became widely publicized after the 1992 Earth Summit, a United Nations meeting held in Rio de Janeiro, Brazil. The Rio meeting was a pivotal event. It brought together many diverse groups—environmentalists and politicians from wealthy countries, indigenous people and workers struggling for rights and land, and government representatives from developing countries. The meeting helped these better understand their common needs, and it forced wealthy nations to admit that poorer populations also had a right to a healthy and comfortable life.

Addressing uneven distribution of resources is one of the first tasks of sustainable development. While a few of us live in increasing luxury, the poorest populations suffer from inadequate diet, housing, basic sanitation, clean water, education, and medical care, while the wealthiest consume far more resources than we can readily understand. Policymakers now recognize that eliminating poverty and protecting our common environment are inextricably interlinked. The world's poorest people are both the victims and the agents of environmental degradation (fig. 1.9). Desperate for croplands to feed themselves and their families, many move into virgin forests or cultivate steep, erosion-prone hillsides, where soils are depleted after only a few years. Others migrate to the crowded slums and ramshackle shantytowns that now surround most major cities in the developing world. With no way to dispose of wastes, the residents have no choice but to foul their environment further and contaminate the air they breathe and the water they use for washing and drinking. Children raised in poverty and illness, with few economic opportunities, often are condemned to perpetuate a cycle of poverty.

Affluence is a goal and a liability

Economic growth offers a better life, more conveniences, and more material goods to the billions of people currently living in dire poverty. But social scientists have frequently pointed out that a major reason for both poverty and environmental degradation is that the wealthy consume a disproportionate share of food, water, energy, and other resources, and we produce a majority of the world's waste and pollutants. The United States, for instance, with less than 5 percent of the world's total population, consumes about one-quarter of most commercially traded commodities, such as oil, and produces a quarter to half of most industrial wastes, such as greenhouse gases, pesticides, and other persistent pollutants.

To get an average American through the day takes about 450 kg (nearly 1,000 lb) of raw materials, including 18 kg (40 lb) of fossil fuels, 13 kg (29 lb) of other minerals, 12 kg (26 lb) of farm products, 10 kg (22 lb) of wood and paper, and 450 liters (119 gal) of water. Every year Americans throw away some 160 million tons of garbage, including 50 million tons of paper, 67 billion cans and bottles, 25 billion styrofoam cups, 18 billion disposable diapers, and 2 billion disposable razors (fig. 1.10).

As the rest of the world seeks to achieve a similar standard of living, with higher consumption of conveniences and consumer goods, what will the effects be on the planet? What should we do about this? Can we reduce our consumption rates? Can we find alternative methods to maintain conveniences and a consumption-based economy with lower environmental costs? These are critical questions as we seek to ensure a reasonable future for our grandchildren.

What is the state of poverty and wealth today?

In 2011 the student-led Occupy Wall Street movement used the statistic "99 percent" to draw attention to growing economic disparities in the United States. While many Americans are jobless or homeless, the wealthiest 1 percent control over 35 percent of the nation's wealth. This imbalance has not been seen since the years leading up to the Great Depression. Students leading the Occupy movement argued that such imbalance destabilizes both

▲ **FIGURE 1.10** "And may we continue to be worthy of consuming a disproportionate share of this planet's resources."
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