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Principles of

ENVIRONMENTAL SCIENCE

INQUIRY AND APPLICATIONS

WILLIAM P. CUNNINGHAM

MARY ANN CUNNINGHAM

Ninth Edition

Mc Graw Hill Education

PRINCIPLES OF

Environmental Science

Inquiry & Applications

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About the Authors

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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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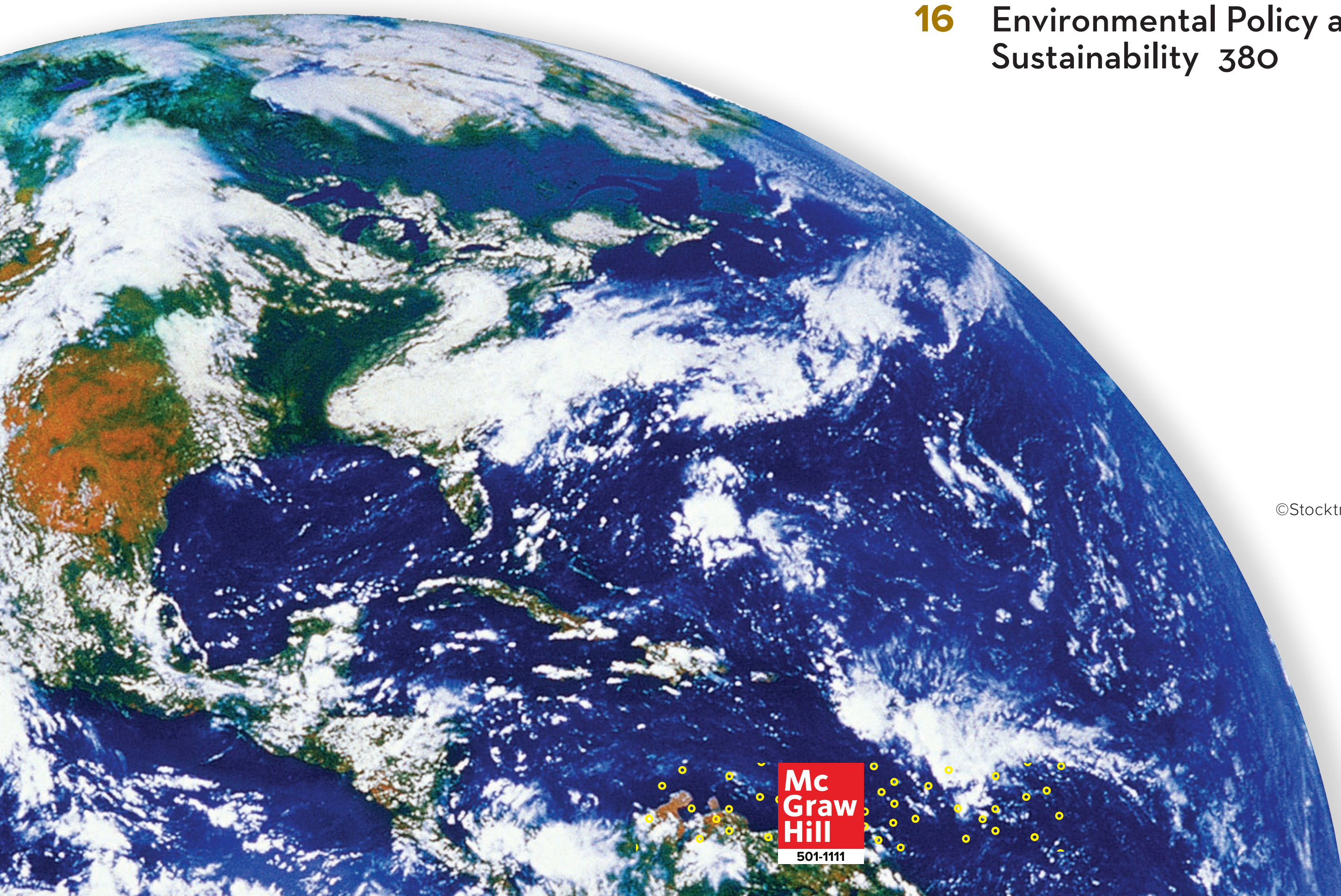

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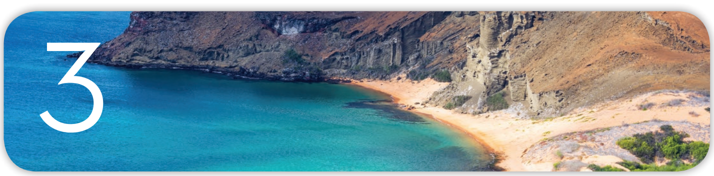

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List of Case Studies

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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

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 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, in environmental governance, and in environmental justice around the world. They have 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. Nearly half of the opening case studies, and many of the boxed readings, examine international issues of global importance, such as forest conservation in Indonesia, air quality in India, or family planning in Thailand. 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 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 16) to public activism (chapter 13) 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 continues our focus on two major themes, **climate protection and sustainability.** These topics are evolving rapidly, often with student leadership, and they greatly impact the future and the career paths of students. We explore **emerging ideas and examples** to help students consider these dominant issues of our time. The climate chapter (chapter 9), for example, provides up-to-date data from the Paris Accord to the latest Intergovernmental Panel on

Climate Change (IPCC) as well as in-depth explanations of climate dynamics, including positive feedbacks and how greenhouse gases capture energy. The energy chapter (chapter 13) explores the rapidly changing landscape of energy production, in which fossil fuels still dominate, but explosive growth of renewables in China, India, and Europe have altered what we think is possible for renewable energy systems.

We also provide a new emphasis on **science and citizenship.** In a world overflowing with conflicting views and arguments, students today need to understand the importance of being able to evaluate evidence, to think about data, to understand environmental systems, and to see linkages among systems we exploit and depend on. And they need to understand their responsibility, as voters and members of civil society, to apply these abilities to decision making and participation in their communities.

Many topics in environmental science are shifting rapidly, and so much of the material in this edition is updated. Nearly two-thirds of the chapters have new opening case studies, and data and figures have been updated throughout the book. Brief **learning objectives** have been added to every A head to help students focus on the most important topics in each major section.

We also recognize that students have a lot to remember from each chapter. As teachers, we have found it is helpful to provide a few key reference ideas, which students can focus on and even compare to other data they encounter. So in this edition, we have provided short lists of **benchmark data,** selected to help students anchor key ideas and to understand the big picture. Specific chapter changes include the following.

In **Chapter 1,** a new opening case study describes an important development in renewable energy on the Navajo Reservation in Arizona. In a dramatic shift, the tribe has decided to move away from a reliance on dirty fossil fuels and to turn instead to clean, renewable solar energy. This shift will protect precious water resources, improve air quality for the whole region, reduce health risks from mining and burning coal, and help fight climate change for all of us. The chapter also has a new *Exploring Science* box on recent United Nations Sustainable Development Goals and the most current Human Development Index. We also have added text and a figure explaining planetary boundaries for critical resources and ecosystem services as well as how we may transgress crucial systems on which we all depend. We introduce a new feature in this chapter on science and citizenship with a focus on evidence and critical thinking.

Chapter 2 opens with a case study on the Gulf of Mexico's "dead zone," which continues to grow in size despite the good intentions of many stake-holders. This example shows the importance of understanding principles of chemistry and biogeochemical cycles in ecology. We expand on the discussion of trophic levels in biological communities with an essay on how overexploitation of Antarctic krill is disrupting the entire Antarctic Ocean food chain.

Chapter 3 provides new insights into the importance of the microbiome in chronic diseases and the possible effects of chronic exposure to antimicrobial compounds on our microbiological symbionts.

Chapter 4 features a new opening case study on the success of family planning in Thailand, where total fertility rates have fallen from 7 children per woman on average in 1974 to 1.5 in 2017. This dramatic change is linked to a new section later in the chapter describing how about half the world's countries are now at or below the replacement rate. The *What Do You Think?* essay on China's one-child policy has been updated to reflect emerging worries about a birth dearth in China. Population data have been updated throughout the chapter, reflecting ongoing demographic changes in many regions of the world.

Chapter 5 has a new opening case study on the growing threat of bark beetles in forest destruction and the frequency and cost of wild fires. This is a major case of ecosystem disturbance, state shift, and resource management policy, as well as a dramatic illustration of how climate shapes biomes. The *Exploring Science* essay in this chapter describes efforts to restore coral reefs, including breeding experiments that seek to create coral strains that can grow in warmer, more acidic sea water. Successful recovery of protected species under the Endangered Species Act is highlighted, along with the benefits of habitat protection.

Chapter 6 provides new data on the effects of palm oil plantations on biodiversity, including endangered orangutans, in the opening case study. Although many major food companies and oil traders have pledged to stop using or selling oil from recently deforested areas, compliance is difficult to monitor. In the meantime, orangs and people who try to protect them continue to be killed. Adding to this discussion, we have added a new *Exploring Science* essay on how we can use remote sensing to assess forest loss. We also have an updated *What Can You Do?* box with suggestions for individual actions to reduce forest impacts. Habitat loss isn't just a problem in other countries; the U.S. also has continued threats to natural areas. We address threats to the Alaska National Wildlife Refuge and to recently created national monuments in two new boxes for this edition.

Chapter 7 opens with a new case study about introduction of crop varieties engineered to tolerate multiple herbicides, and herbicide "cocktails" containing mixtures of different herbicides. This innovation is meant to combat pesticide resistance, but will it simply accelerate evolution of super weeds? And what are the potential human health effects and the ecological consequences of ever greater exposure to these compounds? Fuel consumption in crop production is addressed in light of concern about global climate change, along with questions about how we'll feed a growing human population in a changing world. Low-input, sustainable farming is discussed as an alternative to modern industrial-scale farming methods.

Chapter 8 introduces environmental health with a new case study about the toxic floods that inundated Houston after Hurricane Harvey in 2017. The long-term effects of flooding thousands of chemical plants and Superfund sites remain to be seen, but this is an excellent example of a growing threat from pollutants and synthetic chemicals, especially in vulnerable coastal cities. Our discussion of global health burdens is updated to reflect the threats of chronic conditions. Many new outbreaks of emergent diseases are noted. And we provide a new profile of important persistent organic pollutants (POPs).

Chapter 9's focus on the causes and consequences of climate change remains among the most important topics in the book. An extensive new section on the potential effects of a 2-degree average global temperature updates this discussion. Because no one can take action without hope, we emphasize the many, readily available strategies we can take to avoid these changes. A thorough examination of possible solutions, including goals and accomplishments of the Paris Accord, shows the many options that we have right now to solve our climate challenges. This chapter also contains updated discussions of basic climate processes and feedbacks.

Chapter 10 begins with a new case study about air quality in Delhi, India, which is now worse than that in Beijing, China. We amplify this case study with a new discussion in the text about health effects of air pollution, using Asia as an example. We also note that more than half of the 3 billion air pollution–related deaths worldwide are thought to be caused by indoor air. This is elaborated on in a new *Exploring Science* box about black carbon from combustion and its effects on health and climate.

Chapter 11 is a rare example in which the opening case study hasn't changed because water emergencies in California remain a critical long-term problem. Other topics, such as inexpensive water purification techniques and water recycling, also remain relevant and current.

Chapter 12 introduces a new case study on the Pebble mine, a proposed giant strip mine at the headwaters of rivers flowing into Bristol Bay, Alaska. This mine, which had been blocked during the Obama administration, is now in play again with a new regime in Washington. It threatens the largest remaining sockeye salmon fishery on the planet along with thousands of fish-related jobs and traditional native ways of life. It's an example of the many controversies about mining and mineral production. We update the discussion of induced seismicity with a new *Exploring Science* box about saltwater injection wells associated with oil and gas production in Oklahoma. Surface mining and coal sludge storage remain a serious problem in many places, so we've incorporated a new section into the text about these topics. And discussion of 2017 floods in South Asia, which displaced more than 40 million people and killed at least 1,200, illustrates the dangers of global climate change for geological hazards.

Chapter 13, which focuses on energy, is a focal chapter for climate solutions and sustainability. The opening case study on New York City's commitment to 80 percent reduction of greenhouse gas reductions becomes even more important with the 2017 announcement that both the city and state of New York would divest $5 billion in fossil fuel investments from their retirement funds (discussed in chapter 16). The chapter also reviews dramatic shifts in the price and efficiency of solar and wind power, which have made renewable energy cheaper than fossil fuels or nuclear even for existing facilities. An extensive new section on an energy transition explores future options for generating, storing, and transmitting energy. Drawing on the work of Jacobson and Delucchi, and Pawl Hawken's recent *Drawdown* study, we show how sustainable energy could supply all our power needs.

Chapter 14 starts with a new opening case study about the huge problem of plastic trash accumulating in the oceans. In particular, the estimated 100 million tons of plastic circulating in a massive gyre the size of California just northwest of Hawaii is a threat both to fish and to oceanic birds. A new *What Do You Think?* essay examines new Chinese policies that outlaw shipment of two dozen kinds of low-quality or dangerous solid waste and threaten to upend waste disposal practices throughout the world.

Chapter 15 opens with an important new case study on British Columbia's groundbreaking carbon tax. This revenue-neutral use tax has been a tremendous environmental and economic success and has provided millions to decrease corporate and personal taxes as well as to accomplish broader social goals while fostering an economic boom. This is an excellent and positive application of environmental economics. The section on cities and city planning in this chapter builds on the discussion in chapter 10 on New Delhi air pollution. We also return to the Human Development Index and the problems of massive urban agglomerations in developing countries, some of which, like Lagos, Nigeria, could reach 100 million inhabitants by the end of this century. Valuation of nature is discussed in a new *Exploring Science* essay, which examines a new estimate that raises the value of all global ecological services from $33 trillion to as much as $173 trillion, or more than twice the current global GDP.

Chapter 16 commences with a new case study on fossil fuel divestment pledges by New York City and New York State. Decarbonization of these huge economies is inspired by the damage done by Hurricane Sandy, which resulted in more than $70 billion in damages. Even more notable than its divestment pledge, New York City is suing the world's five largest publicly traded oil companies for their role in climate change. The divestment movement in colleges, universities, and other entities represents more than $6 trillion in assets. We support this discussion with a new section on policy making at both the individual and collective levels. We discuss the creation and implementation of some of our most important environmental laws, but we also examine how those rules and laws are now under attack by the current administration. We also have added an extensive new section on how colleges and universities can be powerful catalysts for change. Finally, we end with a review of the 2016 UN Sustainable Development Goals.

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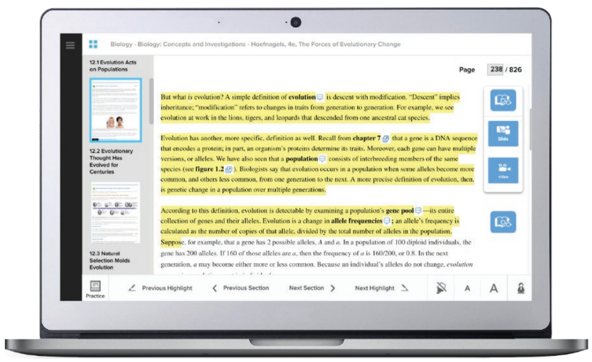

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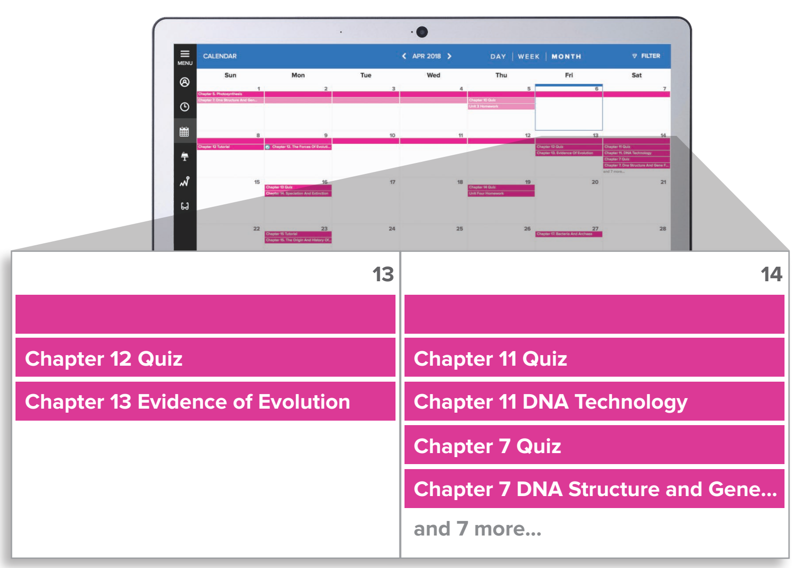

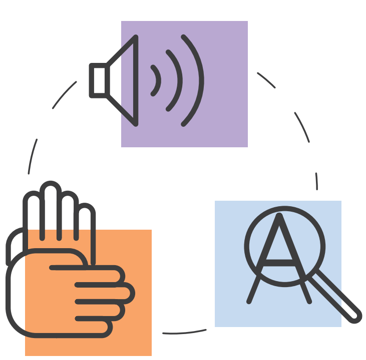

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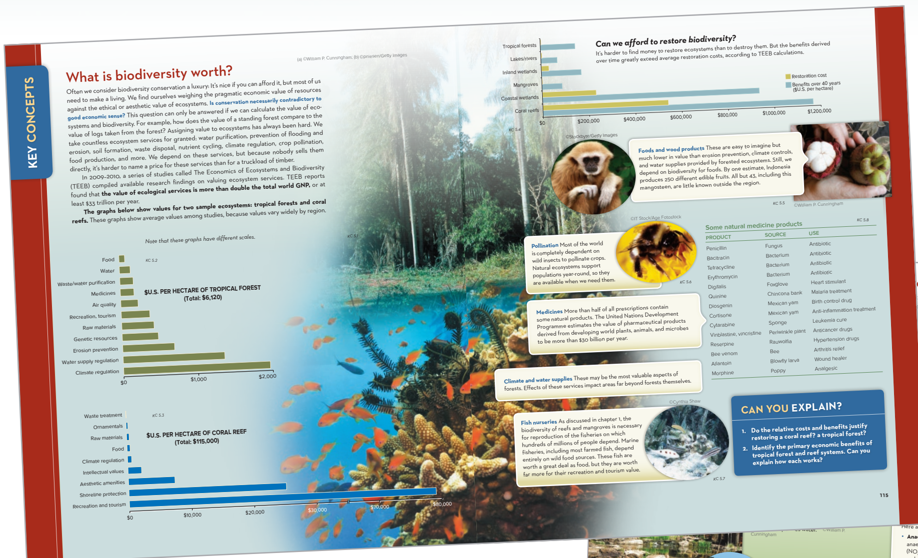
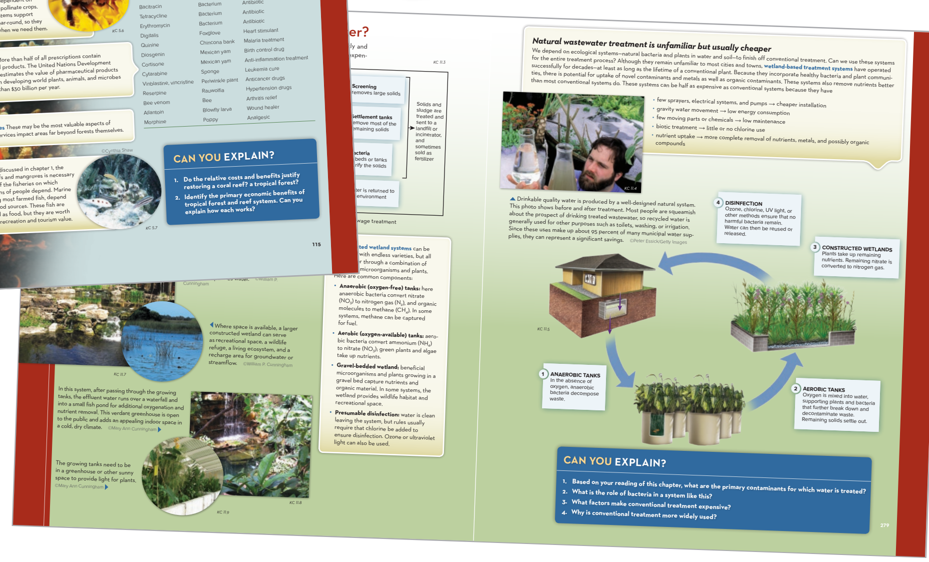
Guided Tour

Application-based learning contributes to engaged scientific investigation.



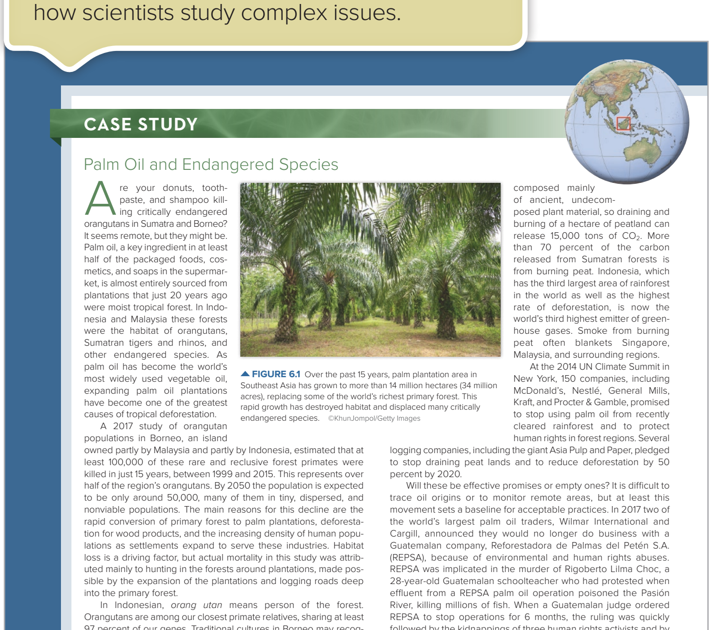


Key Concepts

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, and shampoo killing critically endangered orangutans in Sumatra and Borneo? It seems remote, but they might be. Palm oil, a key ingredient in at least half of the packaged foods, cosmetics, and soaps in the supermarket, is almost entirely sourced from plantations that just 20 years ago were moist tropical forest. In Indonesia and Malaysia these forests were the habitat of orangutans, Sumatran tigers and rhinos, and other endangered species. As palm oil has become the world's most widely used vegetable oil, expanding palm oil plantations have become one of the greatest causes of tropical deforestation.

▲ FIGURE 6.1 Over the past 15 years, palm plantation area in Southeast Asia has grown to more than 14 million hectares (34 million acres), replacing some of the world's richest primary forest. This rapid growth has destroyed habitat and displaced many critically endangered species. ©KhunJompol/Getty Images

A 2017 study of orangutan populations in Borneo, an island owned partly by Malaysia and partly by Indonesia, estimated that at least 100,000 of these rare and reclusive forest primates were killed in just 15 years, between 1999 and 2015. This represents over half of the region's orangutans. By 2050 the population is expected to be only around 50,000, many of them in tiny, dispersed, and nonviable populations. The main reasons for this decline are the rapid conversion of primary forest to palm plantations, deforestation for wood products, and the increasing density of human populations as settlements expand to serve these industries. Habitat loss is a driving factor, but actual mortality in this study was attributed mainly to hunting in the forests around plantations, made possible by the expansion of the plantations and logging roads deep into the primary forest.

In Indonesian, *orang utan* means person of the forest. Orangutans are among our closest primate relatives, sharing at least 97 percent of our genes. Traditional cultures in Borneo may recognize this relationship, because taboos have discouraged hunting

composed mainly of ancient, undecomposed plant material, so draining and burning of a hectare of peatland can release 15,000 tons of CO_2. More than 70 percent of the carbon released from Sumatran forests is from burning peat. Indonesia, which has the third largest area of rainforest in the world as well as the highest rate of deforestation, is now the world's third highest emitter of greenhouse gases. Smoke from burning peat often blankets Singapore, Malaysia, and surrounding regions.

At the 2014 UN Climate Summit in New York, 150 companies, including McDonald's, Nestlé, General Mills, Kraft, and Procter & Gamble, promised to stop using palm oil from recently cleared rainforest and to protect human rights in forest regions. Several logging companies, including the giant Asia Pulp and Paper, pledged to stop draining peat lands and to reduce deforestation by 50 percent by 2020.

Will these be effective promises or empty ones? It is difficult to trace oil origins or to monitor remote areas, but at least this movement sets a baseline for acceptable practices. In 2017 two of the world's largest palm oil traders, Wilmar International and Cargill, announced they would no longer do business with a Guatemalan company, Reforestadora de Palmas del Petén S.A. (REPSA), because of environmental and human rights abuses. REPSA was implicated in the murder of Rigoberto Lima Choc, a 28-year-old Guatemalan schoolteacher who had protested when effluent from a REPSA palm oil operation poisoned the Pasión River, killing millions of fish. When a Guatemalan judge ordered REPSA to stop operations for 6 months, the ruling was quickly followed by the kidnappings of three human rights activists and by Choc's murder. Cargill then cut ties with REPSA, citing its failure to

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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 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 work... 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* — *Inexpensive Water Purification*

When Ashok Gadgil was a child in Bombay, India, five of his cousins died in infancy from diarrhea spread by contaminated water. Although he didn't understand the implications of those deaths at the time, as an adult he realized how heartbreaking and preventable those deaths were. After earning a degree in physics from the University of Bombay, Gadgil moved to the University of California at Berkeley, where he was awarded a PhD in 1979. He's now senior staff scientist in the Environmental Energy Technology Division, where he works on solar energy and

▲ A woman fills her jug with clean water from the village WaterHealth kiosk. More than 6 million people's lives have been improved by this innovative system of water purification. ©Waterhealth International

mount the UV source above the water where it couldn't develop mineral deposits. He designed a system in which water flows through a shallow, stainless steel trough. The apparatus can be gravity fed and requires only a car battery as an energy source.

The system can disinfect 15 liters (4 gallons) of water per minute, killing more than 99.9 percent of all bacteria and viruses. This produces enough clean water for a village of 1,000 people. This simple system costs only about 5 cents per ton (950 liter). Of course, removing pathogens doesn't do anything about minerals, such as arsenic,

Exploring Science

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

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.

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, photosyn-

©William P. Cunningham

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

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 minimum wage of $850 (U.S.) per year in Brazil. As African cocoa

Pedagogical Features Facilitate Student Understanding of Environmental Science

Learning Outcomes

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

CHAPTER

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

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?

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.

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 Gulf of Mexico?
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. To which wavelengths do our eyes respond, 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.
15. What is the ratio of human-caused carbon releases into the atmosphere shown in figure 2.18 compared to the amount released by terrestrial respiration?

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

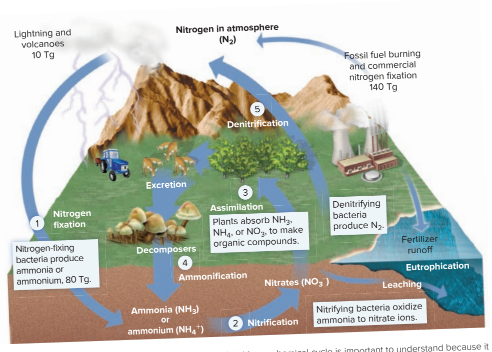
Brief scenarios of everyday occurrences or ideas challenge students to apply what they have learned to their lives.

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: A Closer Look at Nitrogen Cycling

1. Which forms of N do plants take up? Can they capture N_2 from the air?
2. Refer to section 2.5. How is N_2 captured, or fixed, from the air into the food web?
3. Most of the processes are hard to quantify, but the figure shown here 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?
4. 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.)
5. Why is N so important for living organisms?
6. 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?



▲ Nitrogen cycles through living and nonliving systems. This biogeochemical cycle is important to understand because it strongly influences how ecosystems function.

CHAPTER

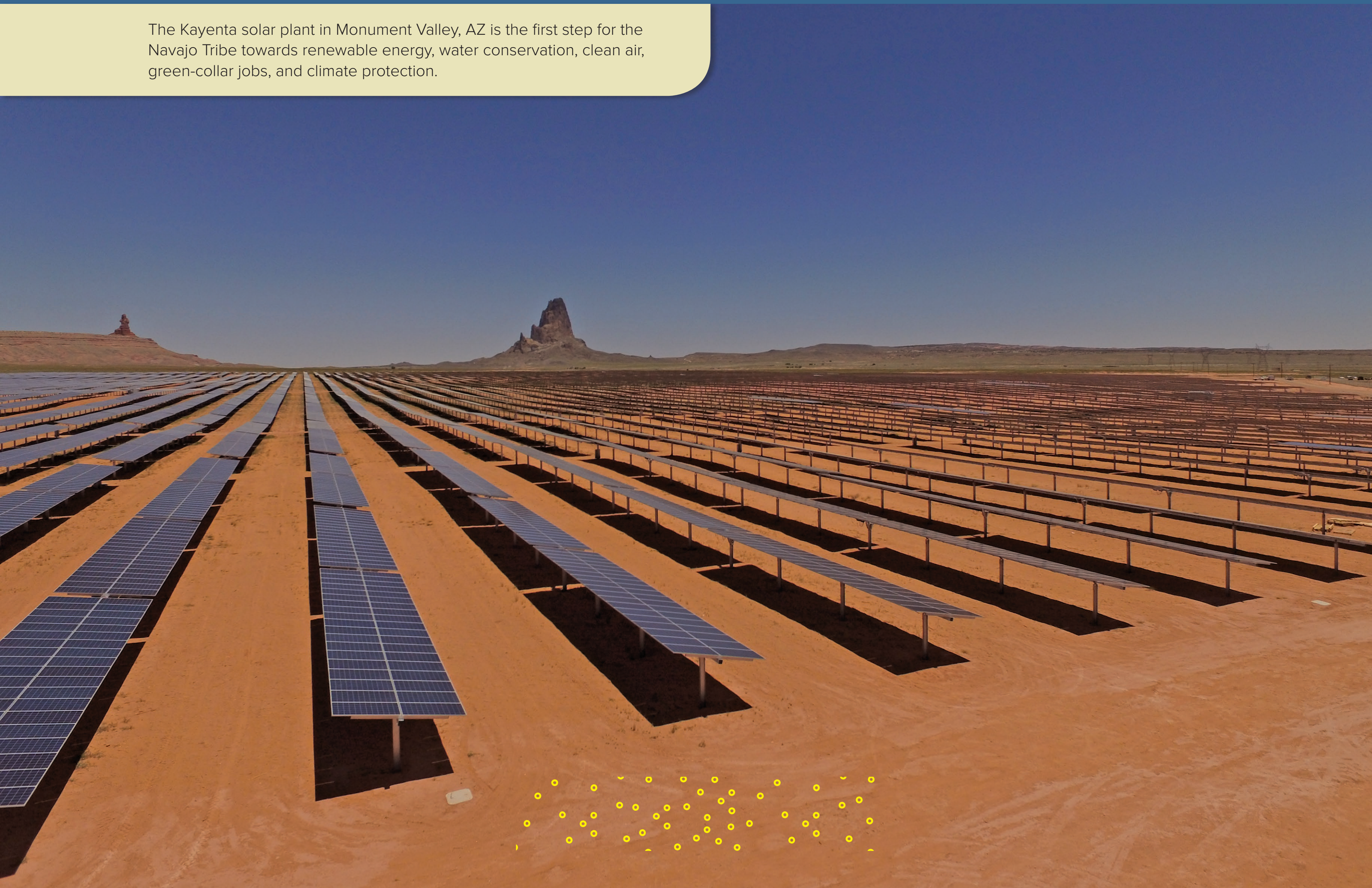
1 Understanding Our Environment

LEARNING OUTCOMES

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

- List several major environmental challenges and some ways to address them.
- 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?

The Kayenta solar plant in Monument Valley, AZ is the first step for the Navajo Tribe towards renewable energy, water conservation, clean air, green-collar jobs, and climate protection.



CASE STUDY

Sustainability and Power on the Reservation

Sustainable development is a challenge faced by all developing nations and regions. How can they ensure a healthy, safe environment and also provide jobs for young people? Can they reduce air, water, and soil pollution and simultaneously reduce poverty?

These are questions members of the Navajo, or Diné, Nation have been asking. The largest tribe in the United States, they are a nation within another nation, but they share challenges of most developing areas. They have half the per-capita income and twice the unemployment of the rest of Arizona. Rural poverty, lack of water and sanitation, and inadequate electricity connection are chronic conditions that hinder education and health care.

Also like other developing nations, the Navajo are debating their energy future. Since 1973 one of the most important employers on the reservation has been the Navajo Generating Station, a coal-powered plant that produces 16 percent of Arizona's electricity and employs about 500 people, 90 percent of them Navajo. The power plant is also an environmental liability. It produces 30 percent of Arizona's carbon dioxide and 25 percent of the state's sulfur dioxide, a source of smog and acid rain, as well as airborne mercury and cadmium. For over 45 years, the plant has been one of Arizona's worst polluters, often obscuring visibility in the nearby Grand Canyon. The Kayenta coal mine, which supplies the plant, produces dust and other airborne pollutants and threatens local waterways with acidic runoff. The multinational Peabody Energy, one of the world's largest coal companies, owns the mine. The plant and mine also consume water extravagantly: about 33 million m^3 every year for steam, cooling, and dust control, with most of it from the declining Colorado River. Filters and other equipment capture much of the pollution at the Navajo station, but ongoing upgrades and maintenance are costly. At the same time, other sources of power are becoming cheaper to produce. Despite opposition from Peabody and other interests, owners of the plant and Navajo leaders agreed that it was time to transition away from coal. They agreed to shutter the facility by 2020.

The decision has been controversial, as closing the plant eliminates hundreds of steady jobs. But many members of the Navajo Nation want independence from coal and they want to diversify energy and the economy, with more local ownership. They want to develop in green jobs that don't undermine their children's health. They are motivated to provide energy while protecting the land they live on and their scarce water resources. And they want to address climate change, to which coal is the worst single contributor. Financial cost doomed the plant, but these social and environmental costs also weighed heavily in the decision.

An important step in the energy transition was the Kayenta photovoltaic solar plant, owned by the Navajo Tribal Utility Authority and the first utility-scale solar power plant on the reservation. Kayenta began delivering clean electricity in June 2017. Rated for 27.5 megawatts (MW) of electricity, the solar plant produces far less than the 1,700 MW delivered by the Navajo Generating Station. (A megawatt is a million watts, enough to power 100,000 10-watt lightbulbs simultaneously or about 500 U.S. households.) But it was just the beginning. Six months after Kayenta opened, tribal authorities signed an agreement to build Kayenta II, doubling production to over 50 MW. Tribal officials have planned another 500 MW of solar in the next few years.

Constructing the Kayenta site took only about 6 months, which is good for energy production but employed its 275 workers for only a short time. As installations scale up, however, employment is expected to increase and stabilize. Increasing investment in solar could also aid remote rural access to electricity. Hooking up a household on the reservation to the electric grid can cost $50,000, far more than solar panels and battery storage.

A solar plant is cleaner than coal, but what about space and financial costs? These are similar: The 120-hectare (300-acre) Kayenta plant uses about 4.5 hectares/MW (11 acres/MW), while the Navajo Generating Station, including its active coal mines (but excluding closed, spent mining areas), comes to about 4–5 hectares/MW (10–12 acres/MW). The $64 million cost of the Kayenta plant's first phase amounted to about $2.3 million/MW. Adjusted for inflation, the coal plant cost about $2.5 million/MW, plus the cost of continuously supplying coal, at a rate of 240 100-ton train car loads every day.

Access to clean energy is often central to sustainable development. Electric lights help you study and learn. Water pumps can improve sanitation. "Green-collar" jobs can transform lives and livelihoods. These aspects of sustainable development are goals for communities around the world. In this chapter we explore some of the ways environmental science contributes to understanding and addressing the widespread need for more equitable economies, societies, and environmental quality. ■

▲ **FIGURE 1.1** The Navajo Generating Station has been a major source of revenue and of pollution for almost 50 years.
©Mr. James Kelley/Shutterstock

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 draws on diverse disciplines, skills, and interests.*
- *A global perspective helps us understand environmental systems.*
- *The scientific method makes inquiry orderly.*

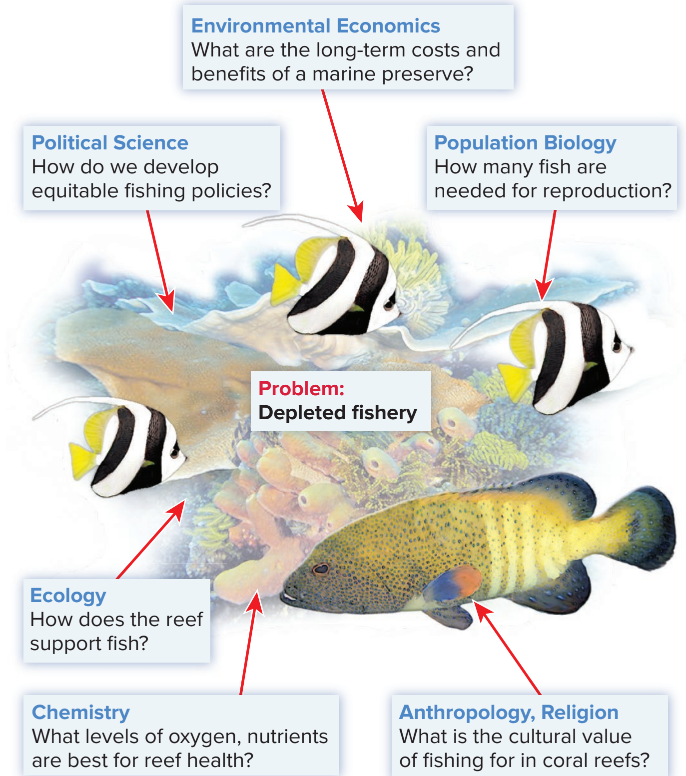
Environmental science uses scientific approaches to understand the complex systems in which we live. Often environmental science focuses on finding basic explanations for how systems function: How does biodiversity affect the ways an ecosystem functions, or how does land use affect a river system? But because human decisions about resources, land use, or waste management affect environmental systems, decisions and policies about resources are also a part of environmental science.

In this chapter we examine some central ideas and approaches in environmental science. You will explore these themes in greater depth in later chapters. We focus on issues of sustainability, environmental justice, and the scientific method that underlies our understanding of these ideas. We also examine some key ideas that have influenced our understanding of environmental science.

Environmental science integrates many fields

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 often informs policy, because it provides information for decision making about resources and the living systems we occupy. This doesn't imply particular policy positions, but it does provide an analytical approach to using observable evidence, rather than assumptions or hearsay, in making decisions.



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

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

Benchmark Data

Among the ideas and values in this chapter, these are a few worth remembering.

280 ppm	Pre-industrial concentration of CO_2 in the atmosphere, in parts per million
410 ppm	Approximate concentration of CO_2 now
6 billion	Global population 2000
9 billion	Global population in 2050 (projected)
5	Average number of children per woman in 1950
2	Average number by 2050 (projected)

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, businessperson

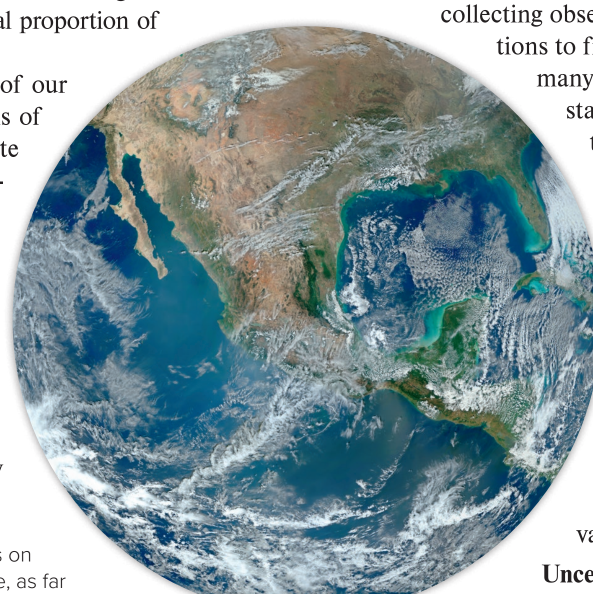
ANSWERS: All of these provide multiple insights; answers will vary.

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 were an astronaut returning home 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).

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.



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

▲ **FIGURE 1.4** Perhaps the most amazing feature of our planet is its rich diversity of life. ©Fuse/Getty Images

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.

1.2 MAJOR THEMES IN ENVIRONMENTAL SCIENCE

- *Water, air quality, and climate change are key concerns.*
- *Population growth has slowed, as food resources and education have improved.*
- *Natural resource depletion is a major concern.*

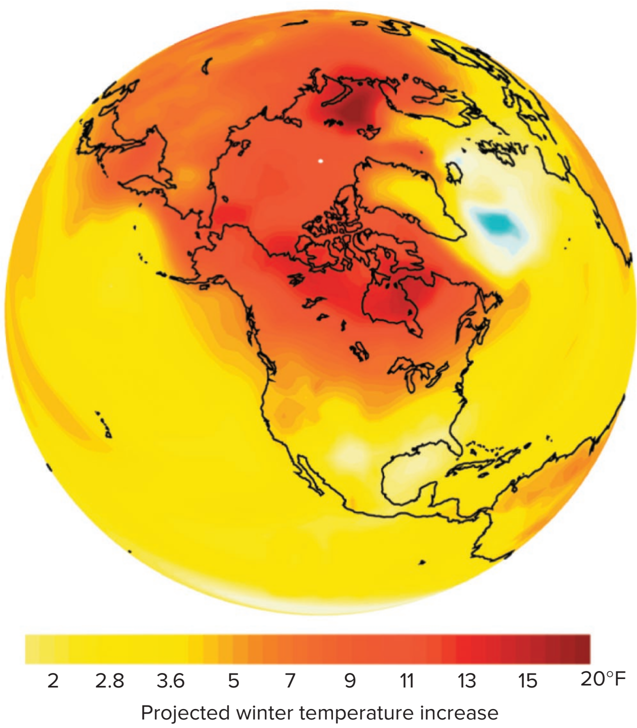
In this section we review some of the main themes in this book. All of these are serious problems, but they are also subjects of dramatic innovation. Often solutions lie in policy and economics, but environmental scientists provide the evidence on which policy decisions can be made.

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 concentrations of heat-trapping "greenhouse gases," especially CO_2, increased dramatically, from 280 parts per million (ppm) 200 years ago to about 410 ppm in 2019. Burning fossil fuels, clearing forests and farmlands, and raising billions of methane-producing cattle are some of the main causes. 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 among our greatest threats, contributing to refugee crises and terrorism. Already, climate change has forced hundreds of millions of people from farmlands that have become too dry or hot to produce crops. Storms, floods, and rising sea levels, threaten villages in many regions. Climate refugees in Syria, Nigeria, Pakistan, and other regions are vulnerable to terrorist activity and sometimes carry it abroad.



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

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 treated 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

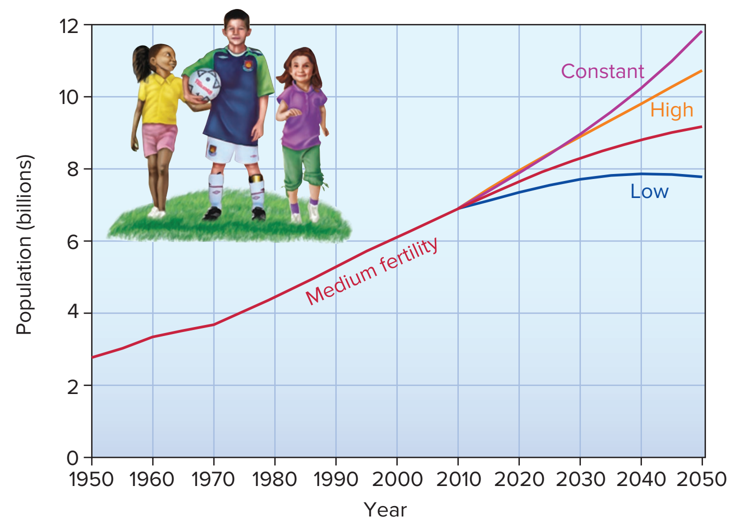
Population Growth There are now over 7.7 billion people on earth, about twice as many as there were 40 years ago. We are adding about 80 million more each year. Demographers report a transition to slower growth rates in most countries: Improved education for girls and better health care are chiefly responsible. 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 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.

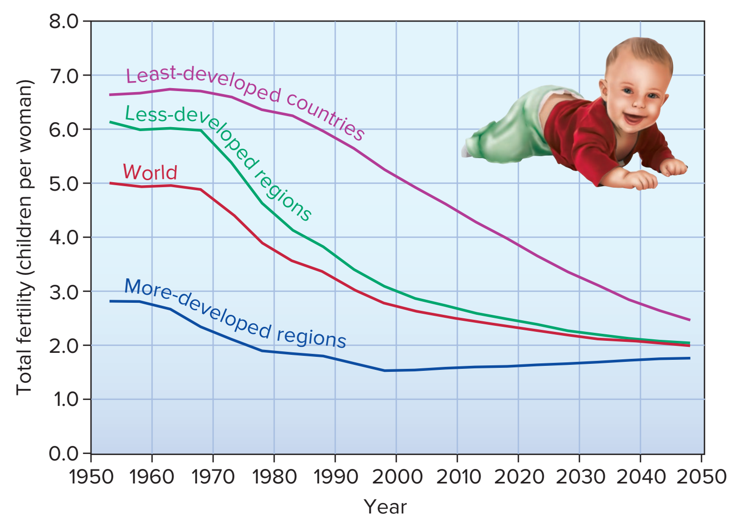
Infant mortality in particular has declined in most countries, as vaccines and safe water supplies have become more widely available. Smallpox has been completely eradicated, and polio has been vanquished except in a few countries, where violent conflict has contributed to a resurgence of the disease.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



(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.

How can we produce food sustainably and distribute it fairly? These are key questions in environmental science.

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 2017 study in Germany found that populations of insects, key pollinators and components of the food web, had declined 75 percent since 1990, and bird populations were 15 percent lower. 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 Although exploitation continues, the rate of deforestation has slowed in many regions. Brazil, which led global deforestation rates for decades, has

(a) Health care

(b) Hunger

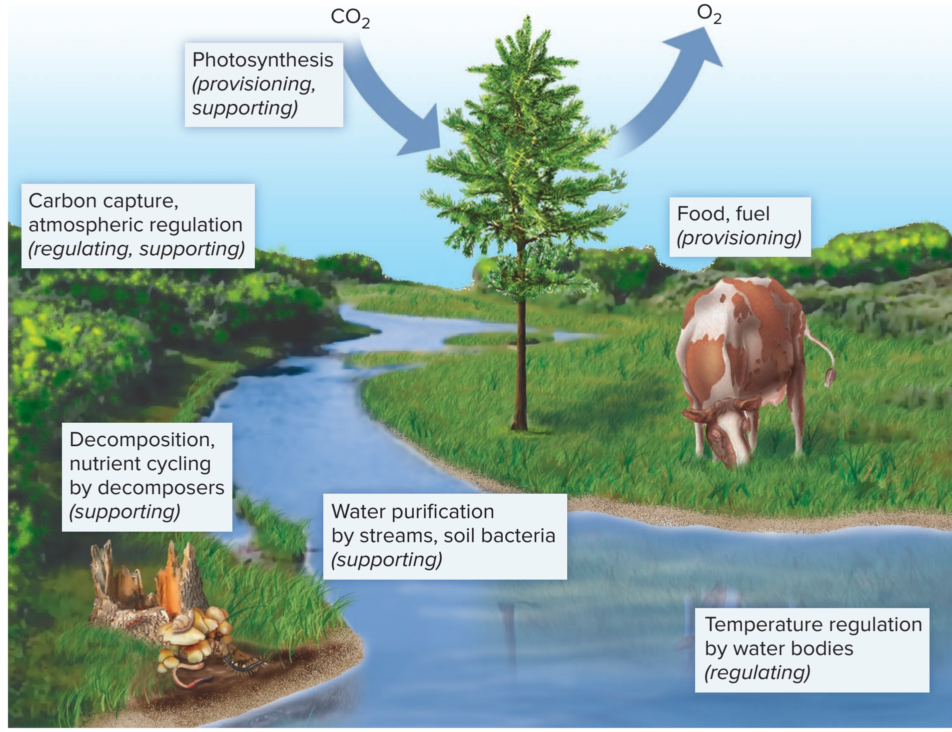
(c) Education

(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). (a): ©Dimas Ardian/Getty Images; (b): ©Jonas Gratzer/Getty Images; (C): ©Anjo Kan/Shutterstock; (d): ©William P. Cunningham 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.



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

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. As noted in the opening case study, renewable energy is an increasingly available and attractive option. The cost 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

- *Ecosystem services are important in evaluating system values.*
- *Sustainable development goals identify key needs.*
- *Both poverty and wealth produce environmental challenges.*

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).

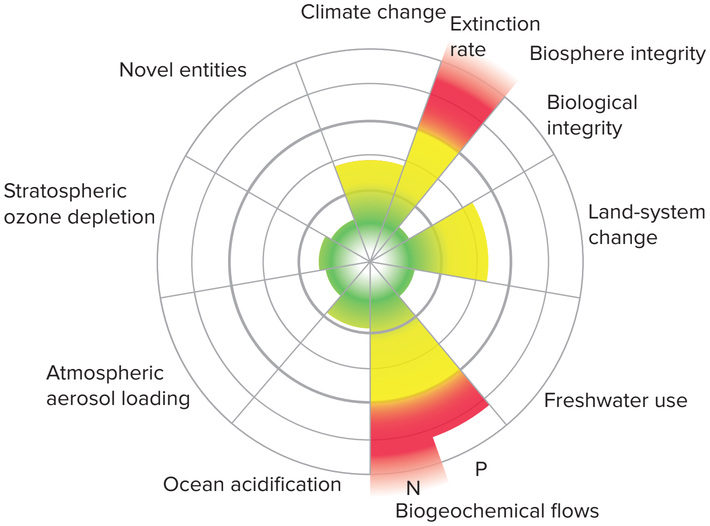
Ecosystem services, another key idea, refers to services or resources provided by environmental systems (fig. 1.8). *Provisioning* of resources, such as the fuels we burn, may be the most obvious service we require. *Supporting* services are less obvious until you start listing them: These include water 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.

Global ecosystem services amounted to a value of about $124 trillion to $145 trillion per year in 2011, according to ecological economist Robert Costanza, far more than the $65 trillion global economy in that year. These services support most other economic activity, but we tend to forget our reliance on them, and conventional economics has little ability to value them.

Planetary boundaries

Another way to think about environmental services is planetary boundaries, or thresholds of abrupt or irreversible environmental change. Studies by Johan Rockström and colleagues at the Stockholm Resilience Centre have identified nine major systems with these critical thresholds: climate change, biodiversity, land system change, freshwater use, biogeochemical flows (nitrogen and phosphorus), ocean acidification, atmospheric aerosols, stratospheric ozone loss, and "novel entities," including chemical pollution and other factors (fig. 1.9). Calculations are that we have already passed the planetary boundaries for three of these—climate change, biodiversity loss, and nitrogen cycling. We are approaching the limits for freshwater supplies, land use, ocean acidification, and phosphorus loading.

These ecosystem services are tightly coupled. Destruction of tropical forests in Southeast Asia, for example, can influence heat and drought in North America. Drought and fires in North America enhance climate warming and sea ice loss in the Arctic. A planetary perspective helps us see interconnections in global systems and their effects on human well-being. What it means to pass these boundaries remains uncertain.



▲ **FIGURE 1.9** Calculated planetary boundaries, or thresholds beyond which irreversible change is likely. Green shading represents safe ranges; yellow represents a zone of increasing risk; red wedges represent factors exceeding boundaries. Source: Will Steffen, Katherine Richardson, Johan Rockström, et al. 2015. Planetary boundaries: Guiding human development on a changing planet. *Science* 15 Jan 2015: 1259855 DOI: 10.1126/science.1259855.

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

In 2016 the United Nations initiated a 15-year program to promote 17 **Sustainable Development Goals** (SDGs). Ambitious and global, the goals include eliminating the most severe poverty and hunger; promoting health, education, and gender equality; providing safe water and clean energy; and preserving biodiversity. This global effort seeks to coordinate data gathering and reporting, so that countries can monitor their progress, and to promote sustainable investment in developing areas.

For each of the 17 goals, organizers identified targets: some quantifiable, some more general. For example, Goal 1, "End poverty," includes targets to eradicate extreme poverty, defined as less than $1.90 per day, and to ensure that all people have rights to basic services, ownership and inheritance of property, and other necessities for economic stability. Goal 7, "Ensure access to affordable, sustainable energy," includes targets of doubling energy efficiency and enhancing international investment in clean energy. Goal 12, "Ensure sustainable consumption and production," calls for cutting food waste in half and phasing out fossil fuel subsidies that encourage wasteful consumption. These goals may not be accomplished by 2030, but having a target to aim for improves the odds of success. And targets allow us to measure how far we have fallen short.

The SDGs also include targets for economic and social equity and for better governance. To most economists and policymakers it seems clear that economic growth is the only way to improve the lot of all people: As former U.S. president John F. Kennedy put it, "a rising tide lifts all boats." But history shows that equity is also essential. Extreme inequality undermines democracy, opportunity, and political stability. Economic and social equality, on the other hand, can promote economic growth by ensuring that extreme poverty and political unrest don't impede progress.

These ambitious goals might appear unrealistic, but they build on the remarkable (though not complete) successes of the **Millennium Development Goals** program, from 2000 to 2015. Targets included an end to poverty and hunger, universal education, gender equity, child health, maternal health, combating of HIV/AIDS, environmental sustainability, and global cooperation in development efforts. While only modest progress was achieved on some goals, UN Secretary General Ban Ki-Moon called that effort "the most successful anti-poverty movement in history." Extreme poverty dropped from nearly half the population of developing countries to just