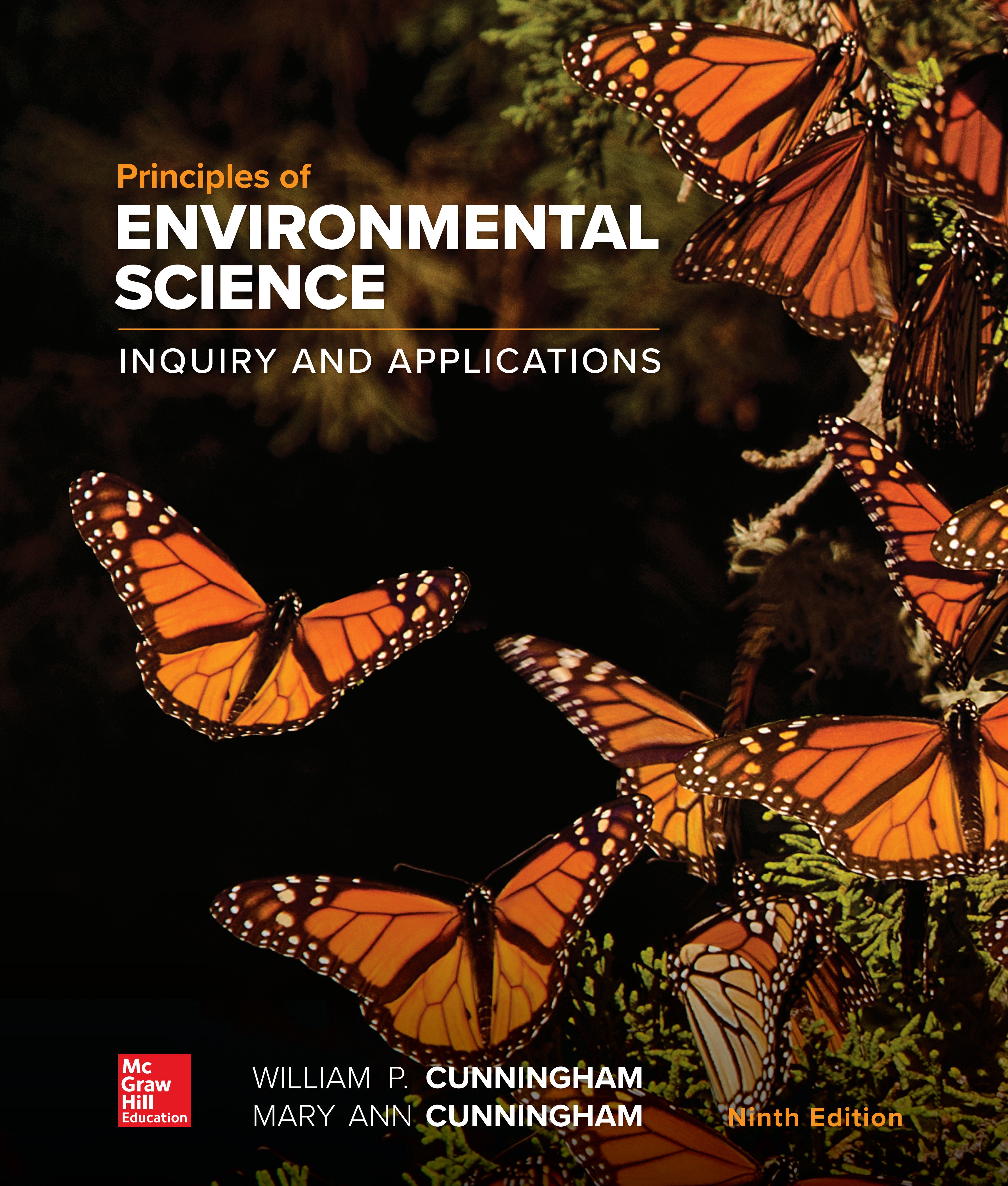

Principles of
ENVIRONMENTAL SCIENCE
INQUIRY AND APPLICATIONS

WILLIAM P. CUNNINGHAM
MARY ANN CUNNINGHAM

Ninth Edition

Mc Graw Hill Education

PRINCIPLES OF

Environmental Science

Inquiry & Applications

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University of Minnesota

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McGraw Hill Education

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About the Authors

WILLIAM P. CUNNINGHAM

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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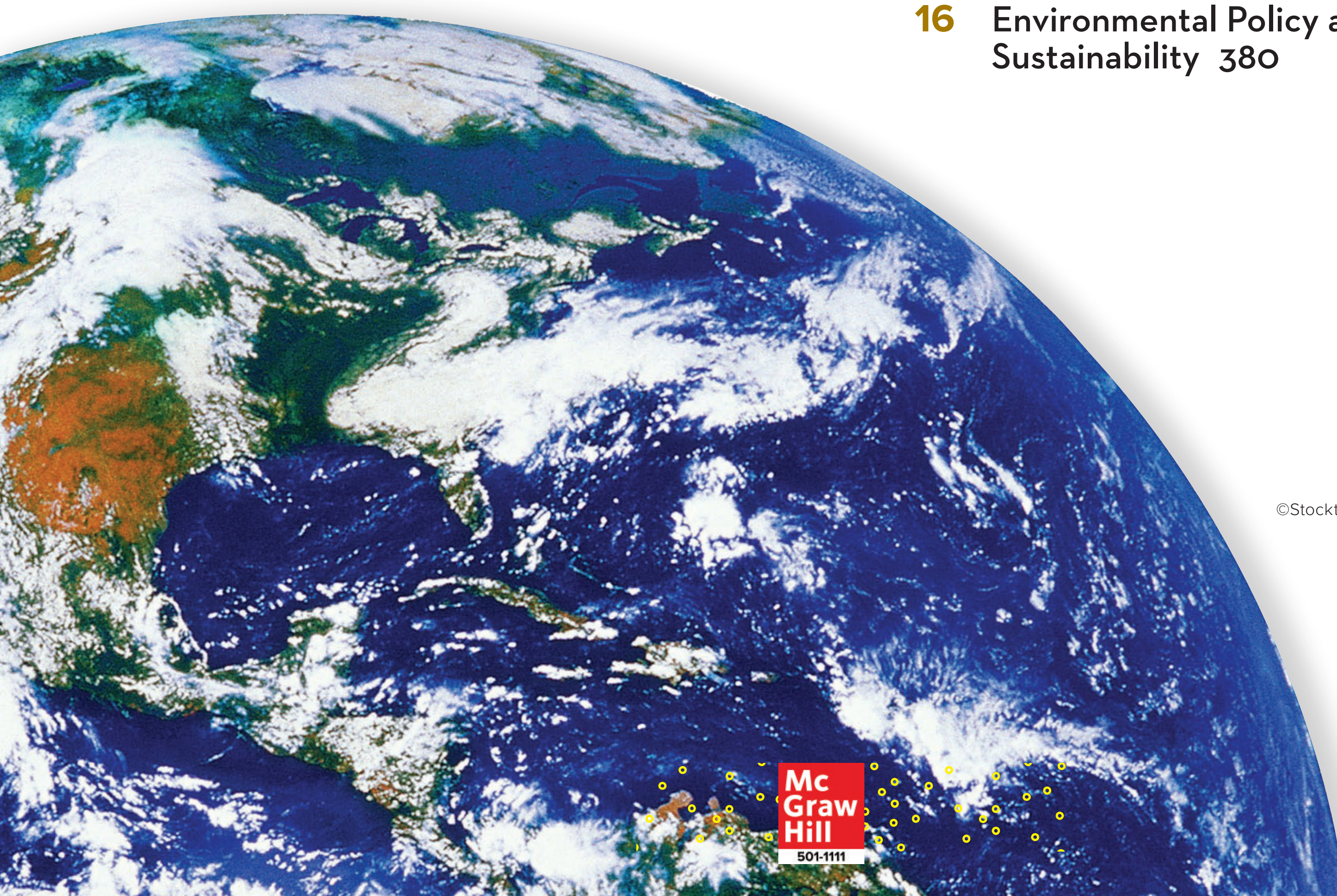

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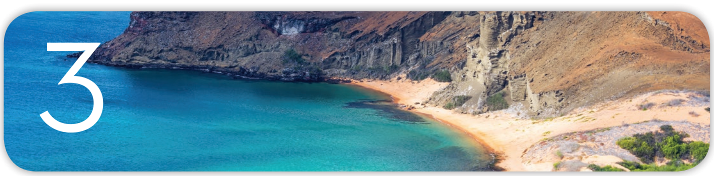

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List of Case Studies

Over 200 additional Case Studies can be found online on the instructor's resource page at www.mcgrawhill-connect.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, 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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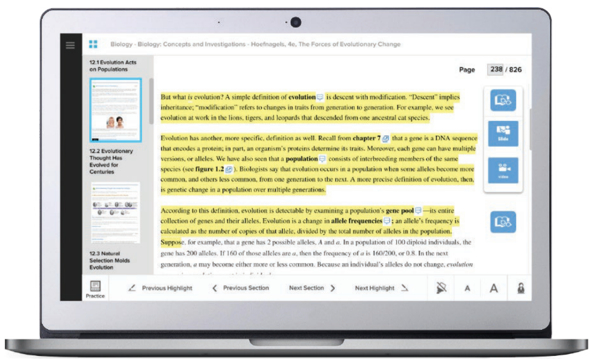

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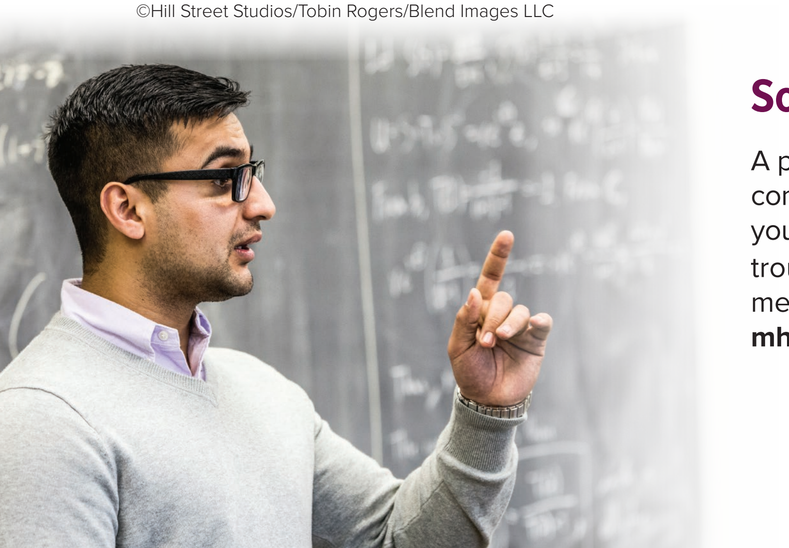

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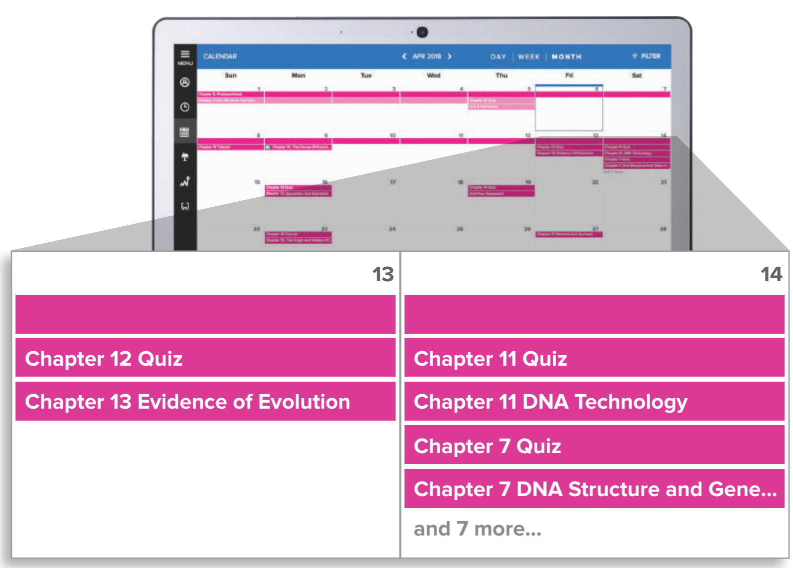

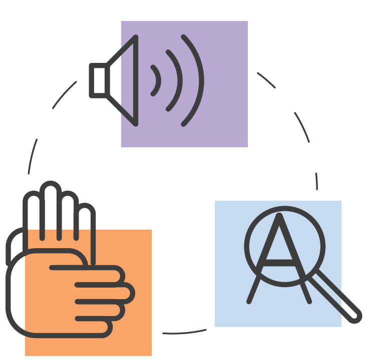

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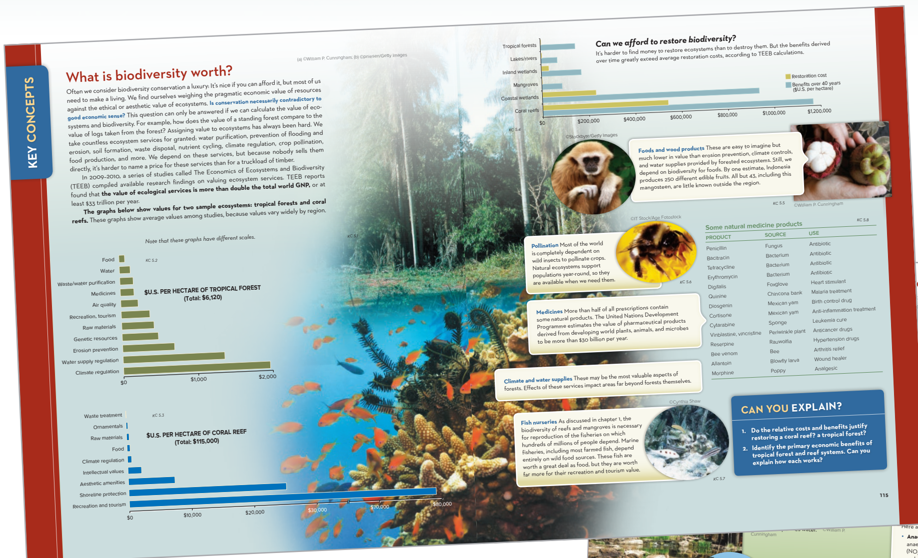
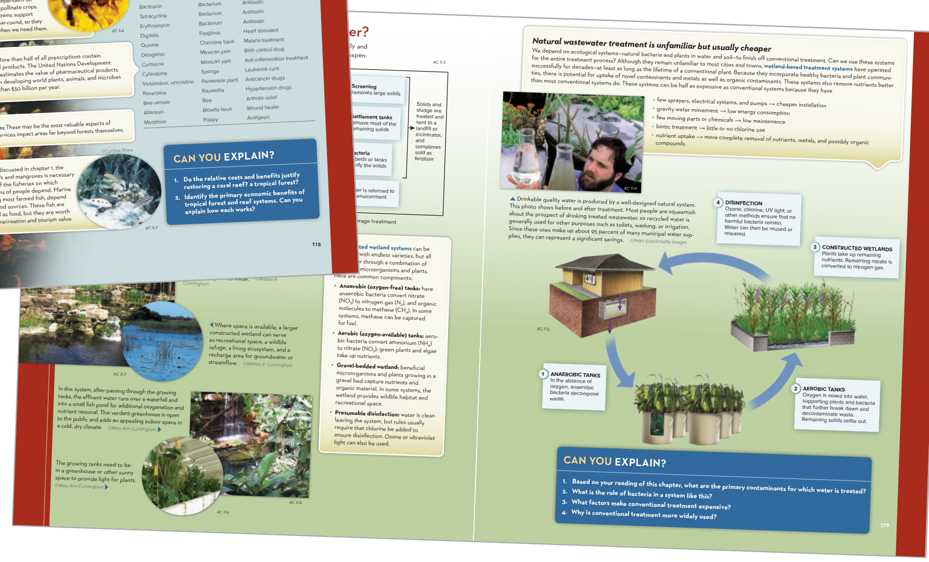
Guided Tour

Application-based learning contributes to engaged scientific investigation.



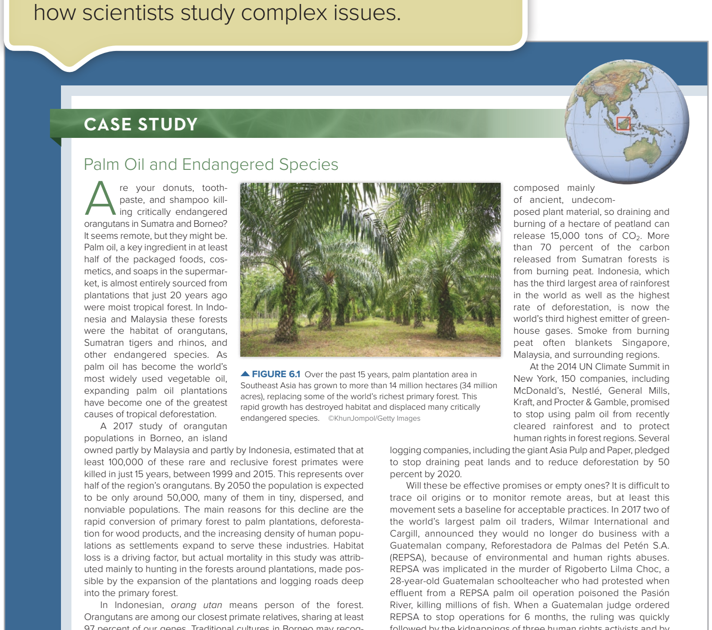
Key Concepts

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.

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

▲ **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

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[…]aintain 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?

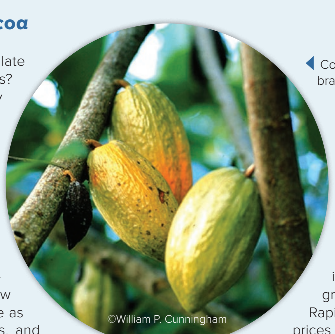
Students are presented with challenging environmental studies that offer an opportunity to consider contradictory data, special interest topics, and conflicting interpretations within a real scenario.

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-



Cocoa pods grow directly on the trunk and large branches of cocoa trees. ©William P. Cunningham

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

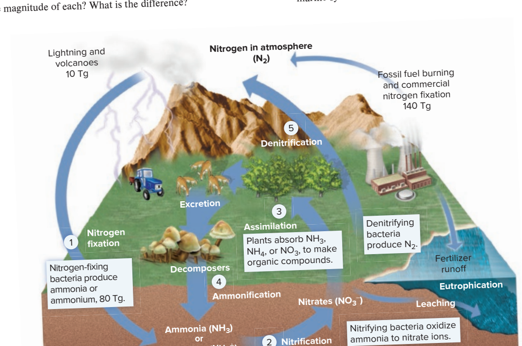
Brief scenarios of everyday occurrences or ideas challenge students to apply what they have learned to their lives.

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

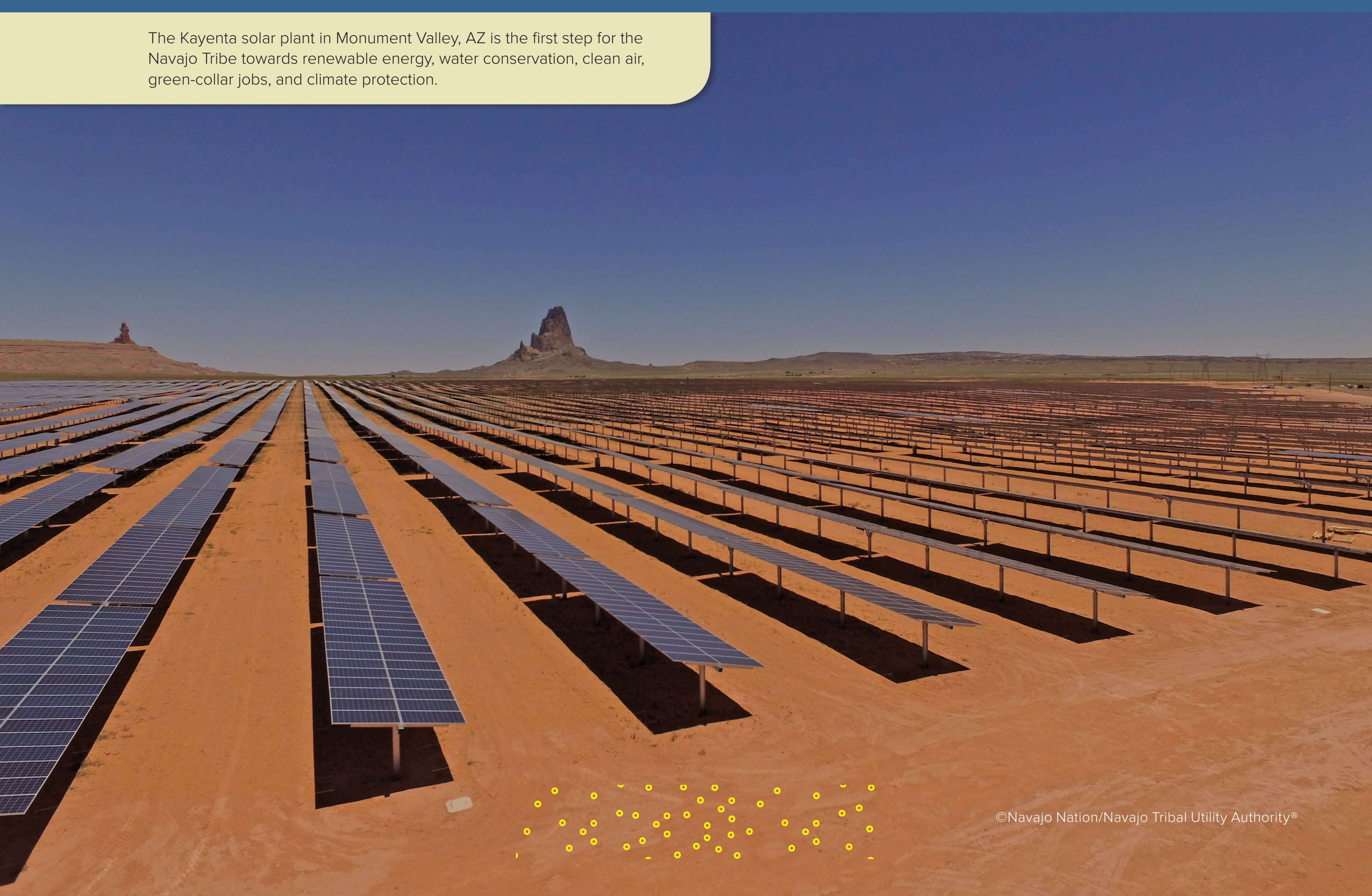
1 Understanding Our Environment

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.



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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.

> *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.*

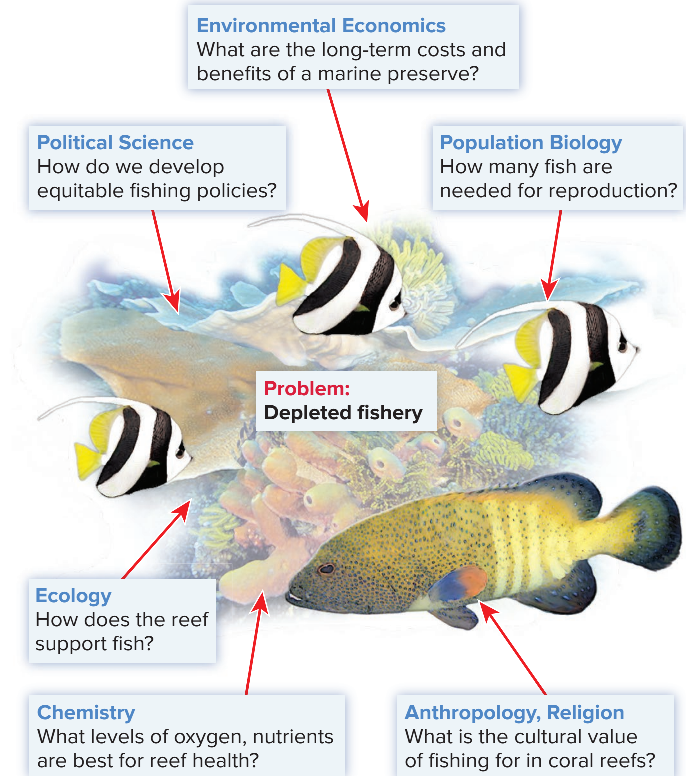
Environmental science uses scientific approaches to understand the complex systems in which we live. Often environmental science focuses on finding basic explanations for how systems function: How does biodiversity affect the ways an ecosystem functions, or how does land use affect a river system? But 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

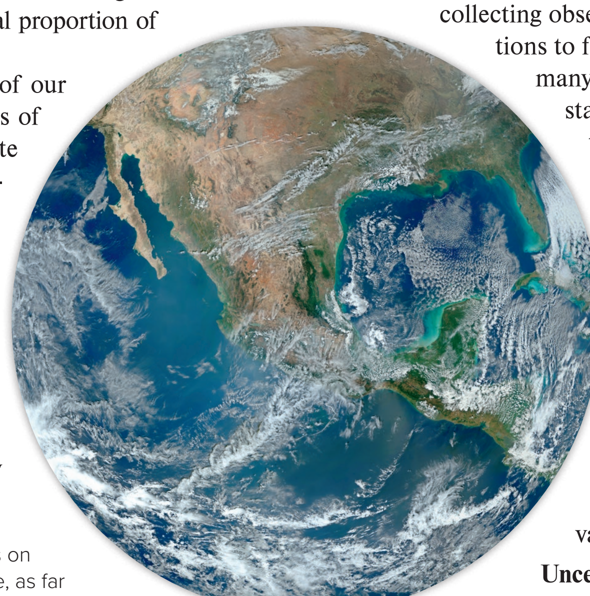
ANSWERS: All of these provide multiple insights; answers will vary.

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.*

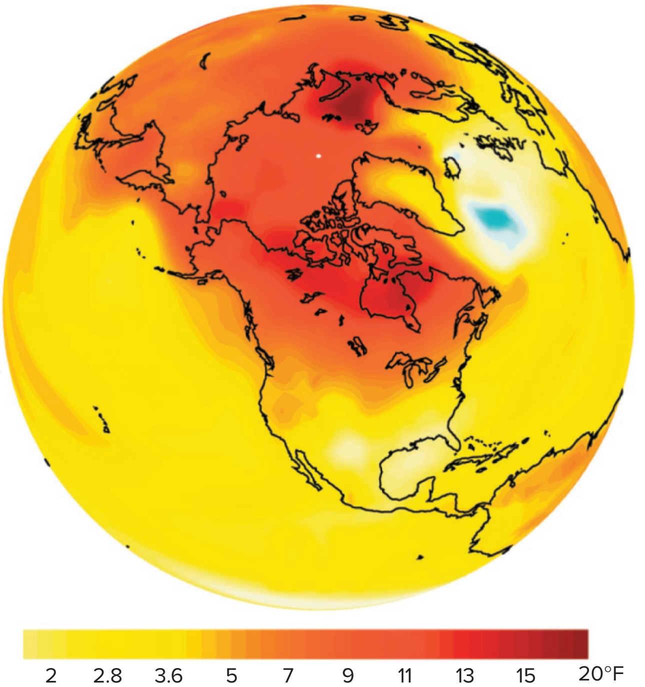
In this section we review some of the main themes in this book. All of these are serious problems, but they are also subjects of dramatic innovation. Often solutions lie in policy and economics, but environmental scientists provide the evidence on which policy decisions can be made.

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



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

other regions are vulnerable to terrorist activity and sometimes carry it abroad.

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

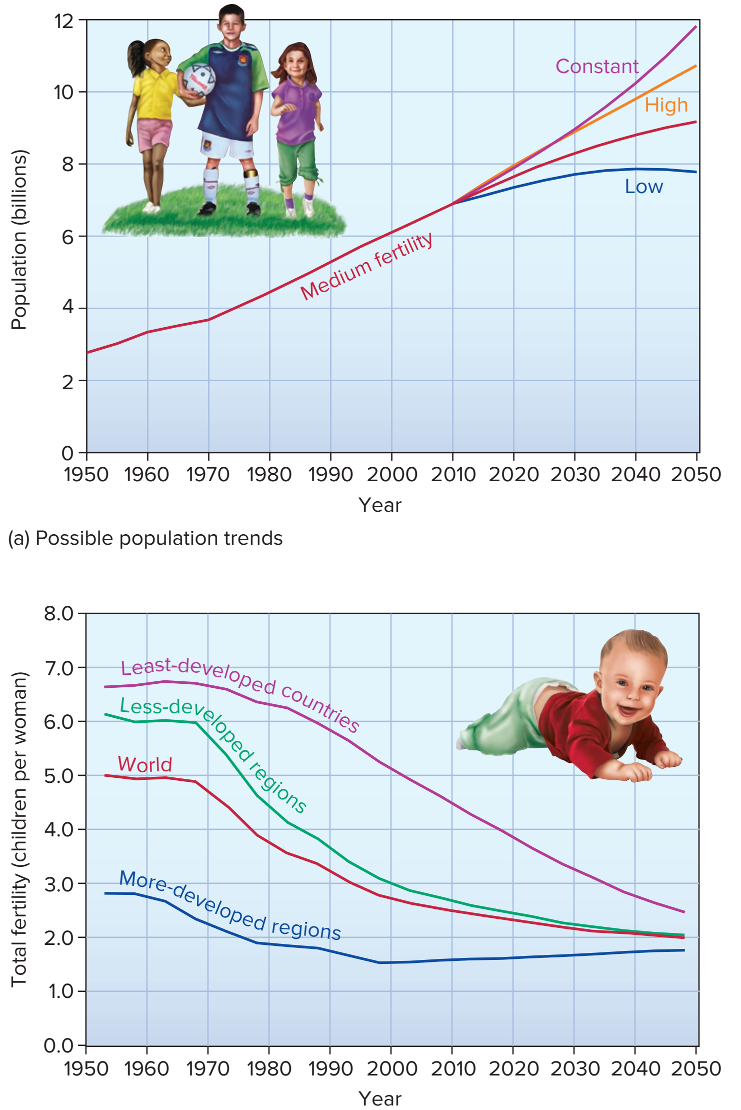
Population Growth There are now over 7.7 billion people on earth, about twice as many as there were 40 years ago. We are adding about 80 million more each year. Demographers report a transition to slower growth rates in most countries: Improved education for girls and better health care are chiefly responsible.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

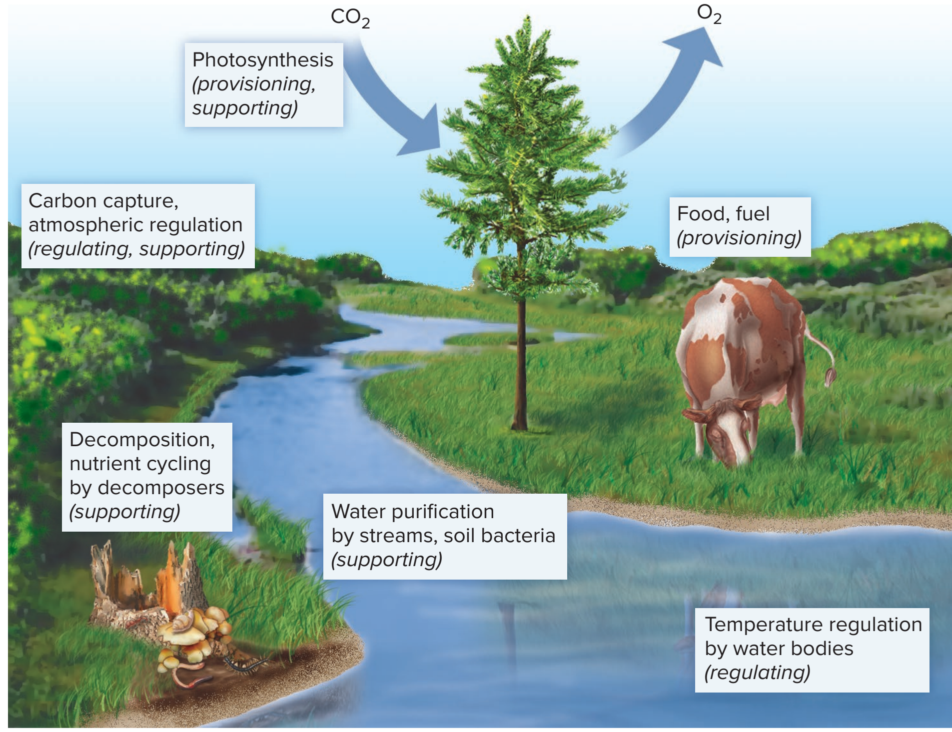
(c) Education

(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).

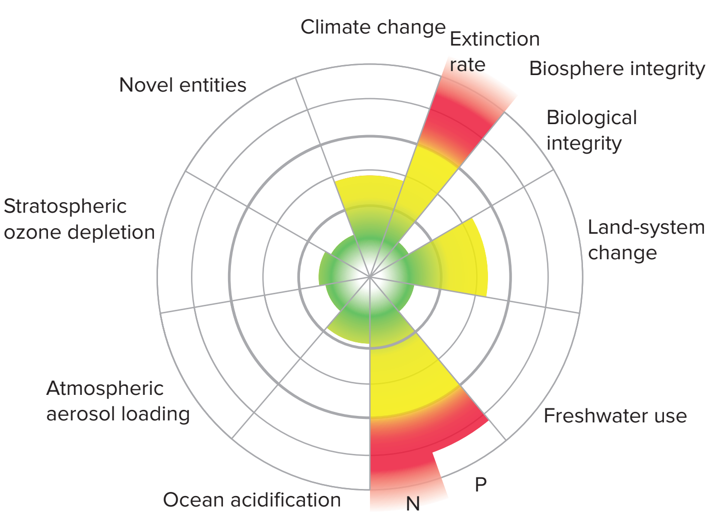
Ecosystem services, another key idea, refers to services or resources provided by environmental systems (fig. 1.8). *Provisioning* of resources, such as the fuels we burn, may be the most obvious service we require. *Supporting* services are less obvious until you start listing them: These include water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

Sustainable development

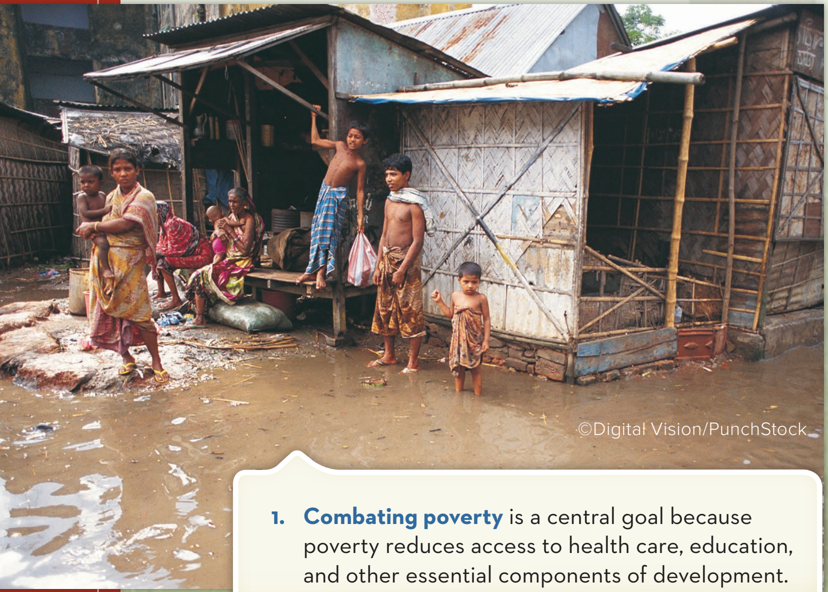
What does it mean? What does it have to do with environmental science?

Sustainable development is a goal. The aim is to meet the needs of people today without compromising resources and environmental systems for future generations. In this context, the term *development* refers to improving access to health care, education, and other conditions necessary for a healthy and productive life, especially in regions of extreme poverty. Meeting the needs of people now, while also guarding those resources for their great-great grandchildren, is both a steep challenge and a good idea.

What parts of it are achievable, and how? In general, development means equitable economic growth, which supports better education, housing, and health care. Often development involves accelerated extraction of natural resources, such as more mining, forestry, or conversion of forests and wetlands to farmlands. Sometimes development involves more efficient use of resources or growth in parts of the economy that don't depend on resource extraction, such as education, health care, or knowledge-based economic activities.

Some resources can be enhanced, for example, through reforestation, maintaining fish nurseries, or careful management of soil resources, to use them without depletion for future generations.

Here are ten key factors necessary for sustainable development, according to the United Nations agreement on development, Agenda 21.



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1. **Combating poverty** is a central goal because poverty reduces access to health care, education, and other essential components of development.

KC 1.1

2. **Reducing resource consumption** is a global consideration, but wealthy regions are responsible for most of the world's consumption. For example, the United States and Europe have less than 15 percent of the world's population, but these regions consume about half of the world's metals, food, energy, and other resources.
3. **Population growth** leads to ever-greater resource demands, because all people need some resources. Better family planning, ensuring that all children are wanted, is a matter of justice, resource supply, and economic and social stability for states as well as for families.

KC 1.2 ©Cynthia Shaw

KC 1.3 ©Dimas Ardian/Getty Images

4. **Health care,** especially for children and mothers, is essential for a productive life. Underdeveloped areas such as that shown above can lead to disease, accidents, respiratory and digestive impairments, and other conditions. Without health, economic security is at risk, and poverty can persist through generations.

5. **Sustainable cities** are key because over half of humanity now lives in cities. Sustainable development involves ensuring that cities are healthy places to live and that they cause minimal environmental impact.

KC 1.4

©William P. Cunningham

Environmental science is essential to sustainable development because it helps us understand how environmental systems work, how they are degraded, and what factors can help restore them. Studying environmental science can prepare you to aid human development and environmental quality, both at home and abroad, through better policies, resource protection, and planning.

6. **Environmental policy** needs to guide decision making in local and national governments, to ensure that environmental quality is protected before it gets damaged and to set agreed-upon rules for resource use.
7. **Protection of the atmosphere** is essential for minimizing the rate of climate change and for reducing impacts of air pollution on people, plants, and infrastructure.

©Design Pics/Getty Images *KC 1.8*

KC 1.7

©William P. Cunningham

8. **Combating deforestation and protecting biodiversity** go together because much of the world's biodiversity is in forests. We also depend on forests for water resources, climate regulation, and resources including food, wood, medicines, and building materials. Other key zones of biodiversity include coral reefs, wetlands, and coastal areas.

9. **Combating desertification and drought** through better management of water resources can save farms, ecosystems, and lives. Often removal of vegetation and soil loss make drought worse, and a few bad rainfall years can convert a landscape to desertlike conditions.

©Eye Ubiquitous/Sudan/Kordofan Province/Farming/Newscom

KC 1.6

10. **Agriculture and rural development** affect the lives of the nearly half of humanity who don't live in cities. Improving conditions for billions of rural people, including more sustainable farming systems, soil stewardship to help stabilize yields, and access to land, can help reduce populations in urban slums.

KC 1.5

©Santokh Kochar/Photodisc/Getty Images

These ten ideas and others were described in Agenda 21 of the United Nations Conference on Environment and Development (the "Earth Summit") in Rio de Janeiro, Brazil, in 1992. Laying out priorities for stewardship of resources and equity in development, the document known as Agenda 21 was a statement of principles for guiding development policies. This document has no legal power, but it does represent an agreement in principle by the more than 200 countries participating in that 1992 conference.

CAN YOU EXPLAIN?

1. **What is the relationship between environmental quality and health?**
2. **Why is sustainable development an issue for people in wealthy countries to consider?**
3. **Examine the top left photo carefully. What health risks might affect the people you see? What do you suppose the rate of material consumption is here, compared to your neighborhood? Why?**

©William P. Cunningham

▲ **FIGURE 1.10** The very poor often are forced to live in degraded or unproductive areas, where they have little access to sufficient clean water, diet, medical care, and other essentials for a humane existence. Courtesy Tom Finkle

14 percent in only 15 years. The proportion of undernourished people dropped by almost half, from 23 percent to 13 percent. Primary school enrollment rates climbed from 83 percent to 91 percent in developing countries. Girls gained access to education, employment, and political representation in national parliaments.

The value of having clearly stated goals, especially with quantifiable targets, is that they help people agree on what to work for. With so many simultaneous problems in developing areas, it can be hard for leaders to know where to focus first. Agreed-upon targets, especially when they are shared and monitored by many countries, can strongly motivate action. International agreement on goals can also help motivate financial and planning assistance, both often badly needed in developing areas.

What is the state of poverty and wealth today?

Policymakers are becoming aware that eliminating poverty and protecting our common environment are inextricably interlinked. The poorest people are often forced to meet short-term survival needs at the cost of long-term sustainability. The good news is that between 1990 and 2015 more than 1 billion people moved out of extreme poverty, mostly in China and India. But the World Bank estimates that at least 760 million people (10 percent of the world population) live below an international poverty line of (U.S.) $1.90 per day. Seventy percent of those poorest people are women and children.

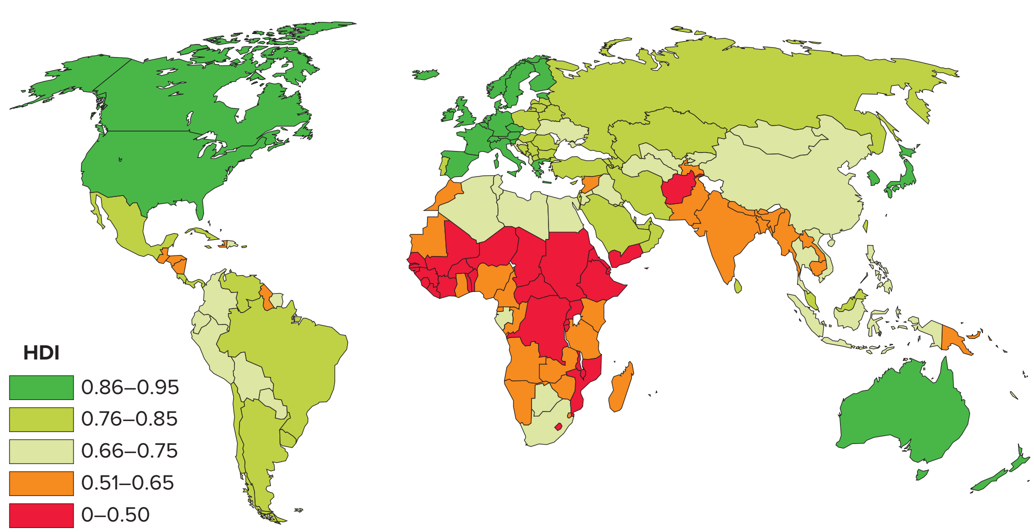
The human suffering engendered by poverty is tragic. The very poor often lack access to an adequate diet, decent housing, basic sanitation, clean water, education, medical care, and other essentials for a humane existence (fig. 1.10). Poverty is both a cause and a consequence of poor health. Every year tens of millions of poor people die from malnutrition, infectious diseases, accidents, and developmental defects that could be avoided fairly easily. People too ill to work become trapped in a cycle of poverty.

The status of well-being in different countries is reflected in **quality-of-life indicators** monitored by the United Nations (table 1.1). More than 1 billion people have insufficient access to clean water, and 2.6 billion lack basic sanitation. These measures are summarized in the Human Development Index (HDI), calculated each year by the United Nations Development Fund (fig. 1.11). The HDI represents a wide variety of factors, such as life expectancy, years of school, gross national income, and income equity. The bottom 20 HDI rankings are generally in Sub-Saharan Africa, former colonies

TABLE 1.1 Quality-of-Life Indicators

	LEAST-DEVELOPED COUNTRIES	MOST-DEVELOPED COUNTRIES
GDP/person[1]	$615	$40,677
Poverty index[2]	71.8%	0
Life expectancy	59.2 years	82.8 years
Adult literacy	34.8%	99%
Female primary education	10%	95%
Total fertility[3]	6.3	1.3
Infant mortality[4]	74.7	4.3
Improved sanitation	19.8%	100%
Improved water	50.8%	100%
CO_2/capita[5]	0.3 tons	11 tons

[1]ANNUAL gross domestic product (U.S. $).
[2]PERCENT living on less than (U.S.)$2/day.
[3]AVERAGE births/woman.
[4]PER 1,000 live births.
[5]METRIC tons/yr/person.
Source: UNDP Human Development Index, 2017.



▲ **FIGURE 1.11** Human Development Index. Values near 1 represent strong health, education, and quality of life indicators. Data Source: UNEP 2016.

of European powers. The highest HDI scores aren't usually in the richest countries—these often have repressive monarchies, a few very wealthy citizens, and large populations with few rights. The happiest and healthiest countries have high levels of economic equality, education, and human rights.

Inequality is increasingly recognized as a key concern in economic development. We used to think of the world as divided between a few rich nations, the "First World," and the vast majority of desperately poor countries, the "Third World." (The "Second World" was a group of socialist countries.) Globalization and the Internet have dramatically changed that view. Incomes have risen, but so have wealth disparities. China, for example, has more billionaires and a larger middle class than any other country, but it also has millions of extremely impoverished people. On a global scale, inequality is even more extreme: The most affluent 1 percent of the world now owns more wealth than the other 99 percent. Even more startling, the richest 62 individuals in the world own more wealth than the poorest half (3.8 billion) of the world's population.

Indigenous peoples safeguard biodiversity

In both rich and poor countries, native, or **indigenous, peoples** are generally the least powerful, most neglected groups. Typically descendants of the original inhabitants of an area taken over by more powerful outsiders, native people often are distinct from their country's dominant language, culture, religion, and racial communities. Of the world's nearly 6,000 recognized cultures, 5,000 are indigenous, and these account for only about 10 percent of the total world population. In many countries, traditional caste systems, discriminatory laws, economics, and prejudice repress indigenous people. At least half of the world's 6,000 distinct languages are dying because they are no longer taught to children. When the last elders who still speak the language die, so will much of the culture that was its origin. Lost with those cultures will be a rich repertoire of knowledge about nature and a keen understanding of a particular environment and way of life.

Nonetheless, the 500 million indigenous people who remain in traditional homelands still possess valuable ecological wisdom and remain the guardians of little-disturbed habitats that are refuges for rare and endangered species and undamaged ecosystems. The eminent ecologist E. O. Wilson argues that the cheapest and most effective way to preserve species is to protect the natural ecosystems in which they now live. As the Kuna Indians of Panama say, "Where there are forests, there are native people, and where there are native people, there are forests."

Native people also are playing a valuable role in protecting their homelands. From the Amazon jungles, where members of the Suri tribe are using smartphones and computers to track information about illegal logging, to far-northern Alaska, where the Gwich'in tribe is resisting oil drilling in the Arctic National Wildlife Refuge, indigenous people have been effective in environmental protection.

Canada's Idle No More movement, one of the largest of these, has mobilized thousands of First Nations, Métis, and Inuit people across the country to protest environmentally destructive projects and land use issues. A particular focus has been the water pollution and destruction of boreal forest and wetlands caused by tar sands mining in Alberta, as well as the dangers of pipeline spills in transporting this dirty fuel to markets (fig. 1.12).

▲ **FIGURE 1.12** Native American tribes and representatives from Canada's Idle No More movement march to protest tar sands pipelines.
©William P. Cunningham

Canada's First Nations have linked with native groups in the United States who share their concerns about the dangers of oil pipelines crossing their territories and threatening natural resources. In 2016, construction of the Dakota Access Pipeline in North Dakota prompted thousands of people representing hundreds of native tribes to gather where the pipeline route crossed treaty lands and beneath the Missouri River just upstream from the Standing Rock Reservation. The stand-off lasted for months and attracted the attention of millions of people on social media.

And as the opening case study for this chapter shows, native people are taking important steps to fight global climate change and unemployment by developing clean energy resources. Often they lead the way and help the rest of us envision alternatives to business as usual.

1.4 SCIENCE HELPS US UNDERSTAND OUR WORLD

- *The scientific method is an orderly way to ask questions.*
- *Understanding probability reduces uncertainty.*
- *Science is a cumulative process.*

Because environmental questions are complex, we need orderly methods of examining and understanding them. Environmental science provides such an approach. In this section we'll investigate what science is, what the scientific method is, and why that method is important.

What is science? **Science** (from *scire,* Latin, to know) is a process for producing knowledge based on observations (fig. 1.13). We develop or test theories (proposed explanations of how a process

▲ **FIGURE 1.13** Scientific studies rely on repeated, careful observations to establish confidence in their findings. Source: Dave Partee/Alaska Sea Grant/NOAA

works) using these observations. *Science* also refers to the cumulative body of knowledge produced by many scientists. Science is valuable because it helps us understand the world and meet practical needs, such as finding new medicines, new energy sources, or new foods. In this section we'll investigate how and why science follows standard methods.

Science rests on the assumption that the world is knowable and that we can learn about it by careful observation and logical reasoning (table 1.2). For early philosophers of science, this assumption was a radical departure from religious and philosophical approaches. In the Middle Ages the ultimate sources of knowledge about matters such as how crops grow, how diseases spread, or how the stars move were religious authorities or cultural traditions. Although these sources provided many useful insights, there was no way to test their explanations independently and objectively. The benefit of scientific thinking is that it searches for testable evidence. As evidence improves, we can seek better answers to important questions.

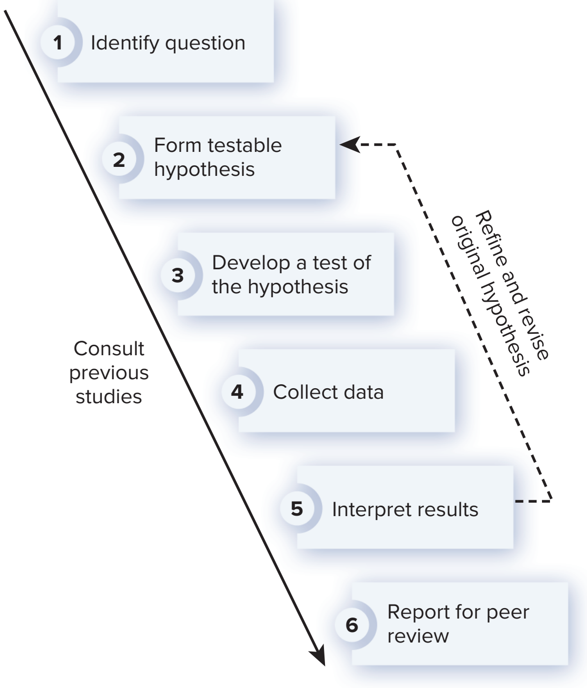
TABLE 1.2 | Basic Principles of Science

1. *Empiricism:* We can learn about the world by careful observation of empirical (real, observable) phenomena; we can expect to understand fundamental processes and natural laws by observation.
2. *Uniformitarianism:* Basic patterns and processes are uniform across time and space; the forces at work today are the same as those that shaped the world in the past, and they will continue to do so in the future.
3. *Parsimony:* When two plausible explanations are reasonable, the simpler (more parsimonious) one is preferable. This rule is also known as Ockham's razor, after the English philosopher who proposed it.
4. *Uncertainty:* Knowledge changes as new evidence appears, and explanations (theories) change with new evidence. Theories based on current evidence should be tested on additional evidence, with the understanding that new data may disprove the best theories.
5. *Repeatability:* Tests and experiments should be repeatable; if the same results cannot be reproduced, then the conclusions are probably incorrect.
6. *Proof is elusive:* We rarely expect science to provide absolute proof that a theory is correct, because new evidence may always improve on our current explanations. Even evolution, the cornerstone of modern biology, ecology, and other sciences, is referred to as a "theory" because of this principle.
7. *Testable questions:* To find out whether a theory is correct, it must be tested; we formulate testable statements (hypotheses) to test theories.

Science depends on skepticism and reproducibility

Ideally scientists are skeptical. They are cautious about accepting a proposed explanation until there is substantial evidence to support it. Even then, every explanation is considered only provisionally true, because there is always a possibility that some additional evidence will appear to disprove it. Scientists also aim to be methodical and unbiased. Because bias and methodical errors are hard to avoid, scientific tests are subject to review by informed peers, who can evaluate results and conclusions (fig. 1.14). The peer review process is an essential part of ensuring that scientists maintain good standards in study design, data collection, and interpretation of results.

Scientists demand **reproducibility** because they are cautious about accepting conclusions. Making an observation or obtaining a result just once doesn't count for much. You have to produce the same result consistently to be sure that your first outcome wasn't a fluke. Even more important, you must be able to describe the conditions of your study, so that someone else can reproduce your findings. Repeating studies or tests is known as **replication.**



▲ **FIGURE 1.14** Ideally, scientific investigation follows a series of logical, orderly steps to formulate and test hypotheses.

We use both deductive and inductive reasoning

Ideally, scientists deduce conclusions from general laws that they know to be true. For example, if we know that massive objects attract each other (because of gravity), then it follows that an apple will fall to the ground when it releases from the tree. This logical reasoning from general to specific is known as **deductive reasoning.** Often, however, we do not know general laws that guide natural systems. Then we must rely on observations to find general rules. We observe, for example, that birds appear and disappear as a year goes by. Through many repeated observations in different places, we can infer that the birds move from place to place in the spring and fall. We can develop a general rule that birds migrate seasonally. Reasoning from many observations to produce a general rule is **inductive reasoning.** Although deductive reasoning is more logically sound than inductive reasoning, it only works when our general laws are correct. We often rely on inductive reasoning to understand the world because we have few absolute laws.

Insight, creativity, and experience can also be essential in science. Often discoveries are made by investigators who are passionately interested in their subjects and who pursue hunches that appear unreasonable to other scientists. For example, some of our most basic understanding of plant genetics comes from the intuitive guesses of Barbara McClintock, a geneticist who discovered that genes in corn can move and recombine spontaneously. Where other corn geneticists saw random patterns of color and kernel size, McClintock's years of experience in corn breeding and her uncanny ability to recognize patterns led her to guess that genes can recombine in ways that no one had previously imagined. This intuition helped to transform our understanding of genetics.

The scientific method is an orderly way to examine problems

You may use the scientific method even if you don't think about it. Suppose you have a flashlight that doesn't work. The flashlight has several components (switch, bulb, batteries) that could be faulty. If you change all the components at once, your flashlight might work, but a more methodical series of tests will tell you more about what was wrong with the system—knowledge that may be useful next time you have a faulty flashlight. So you decide to follow the standard scientific steps:

1. *Observe* that your flashlight doesn't light and that there are three main components of the lighting system (batteries, bulb, and switch).
2. Propose a **hypothesis,** a testable explanation: "The flashlight doesn't work because the batteries are dead."
3. Develop a *test* of the hypothesis and *predict* the result that would indicate your hypothesis was correct: "I will replace the batteries; the light should then turn on."
4. Gather *data* from your test: After you replaced the batteries, did the light turn on?
5. *Interpret* your results: If the light works now, then your hypothesis was right; if not, then you should formulate a new hypothesis—perhaps that the bulb is faulty—and develop a new test for that hypothesis.

In systems more complex than a flashlight, it is almost always easier to prove a hypothesis wrong than to prove it unquestionably true. This is because we usually test our hypotheses with observations but there is no way to make every possible observation. The philosopher Ludwig Wittgenstein illustrated this problem as follows: Suppose you saw hundreds of swans, and all were white. These observations might lead you to hypothesize that all swans were white. You could test your hypothesis by viewing thousands of swans, and each observation might support your hypothesis, but you could never be entirely sure that it was correct. On the other hand, if you saw just one black swan, you would know with certainty that your hypothesis was wrong.

As you'll read in later chapters, the elusiveness of absolute proof is a persistent problem in environmental policy and law. Rarely can you absolutely prove that the toxic waste dump up the street is making you sick. You could collect evidence to show that it is very probable that the waste has made you and your neighbors sick (fig. 1.15). But scientific uncertainty is often used as an excuse to avoid environmental protection.

When an explanation has been supported by a large number of tests, and when a majority of experts have reached a general consensus that it is a reliable description or explanation, we call it a **scientific theory.** Note that scientists' use of this term is very different from the way the public uses it. To many people, a theory is speculative and unsupported by facts. To a scientist, it means just the opposite: While all explanations are tentative and open to revision and correction, an explanation that counts as a scientific theory is supported by an overwhelming body of data and experience, and it is generally accepted by the scientific community, at least for the present.

Understanding probability reduces uncertainty

One strategy to improve confidence in the face of uncertainty is to focus on probability. **Probability** is a measure of how likely something is to occur. Usually probability estimates are based on a set of previous observations or on standard statistical measures. Probability

▲ **FIGURE 1.15** Careful, repeated measurements, and well-formed hypotheses are essential for good science. ©Chris Sattlberger/Getty Images does not tell you what *will* happen, but it tells you what *is likely* to happen. If you hear on the news that you have a 20 percent chance of catching a cold this winter, that means that 20 of every 100 people are likely to catch a cold. This doesn't mean that *you* will catch one. In fact, it's more likely, an 80 percent chance, that you *won't* catch a cold. If you hear that 80 out of every 100 people will catch a cold, you still don't know whether you'll get sick, but there's a much higher chance that you will.

Science often involves probability, so it is important to be familiar with the idea. Sometimes probability has to do with random chance: If you flip a coin, you have a random chance of getting heads or tails. Every time you flip, you have the same 50 percent probability of getting heads. The chance of getting ten heads in a row is small (in fact, the chance is 1 in 2^{10}, or 1 in 1,024), but on any individual flip, you have exactly the same 50 percent chance, since this is a random test. Sometimes probability is weighted by circumstances: Suppose that about 10 percent of the students in your class earn an A each semester. Your likelihood of being in that 10 percent depends a great deal on how much time you spend studying, how many questions you ask in class, and other factors. Sometimes there is a combination of chance and circumstances: The probability that you will catch a cold this winter depends partly on whether you encounter someone who is sick (largely random chance) and on whether you take steps to stay healthy (get enough rest, wash your hands frequently, eat a healthy diet, and so on).

Probability is often a more useful idea than proof. This is because absolute proof is hard to achieve, but we can frequently demonstrate a strong trend or relationship, one that is unlikely to be achieved by chance. For example, suppose you flipped a coin and got heads 20 times in a row. That could happen by chance, but it would be pretty unlikely. You might consider it very likely that there was a causal explanation, such as that the coin was weighted toward heads. Often we consider a causal explanation reliable (or "significant") if there is less than 5 percent probability that it happened by random chance.

Experimental design can reduce bias

Many research problems in environmental science involve observational experiments, in which you observe natural events and interpret a causal relationship between the variables. This kind of study is also called a **natural experiment,** one that involves observation of events that have already happened. Many scientists depend on natural experiments: A geologist, for instance, might want to study mountain building, or an ecologist might want to learn about how species evolve, but neither scientist can spend millions of years watching the process happen. Similarly, a toxicologist cannot give people a disease just to see how lethal it is.

Other scientists can use **manipulative experiments,** in which conditions are deliberately altered and all other variables are held constant. Most manipulative experiments are done in the laboratory, where conditions can be carefully controlled. Suppose you are interested in studying whether lawn chemicals contribute to deformities in tadpoles. You might keep two groups of tadpoles in fish tanks and expose one to chemicals. In the lab you can ensure that both tanks have identical temperatures, light, food, and oxygen. By comparing a treatment (exposed) group and a control (unexposed) group, you also make this a **controlled study.**

Often there is a risk of experimenter bias. Suppose the researcher sees a tadpole with a small nub that looks like it might become an extra leg. Whether she calls this nub a deformity might depend on whether she knows that the tadpole is in the treatment group or the control group. To avoid this bias, **blind experiments** are often used, in which the researcher doesn't know which group is treated until after the data have been analyzed. In health studies, such as tests of new drugs, **double-blind experiments** are used, in which neither the subject (who receives a drug or a placebo) nor the researcher knows who is in the treatment group and who is in the control group.

In each of these studies there is one **dependent variable** and one, or perhaps more, **independent variables.** The dependent variable, also known as a response variable, is affected by the independent variables. In a graph, the dependent variable is on the vertical (Y) axis, by convention. Independent variables are rarely really independent (they may be affected by the same environmental conditions as the dependent variable, for example). Often we call them **explanatory variables** because we hope they will explain differences in a dependent variable (Exploring Science, p. 17).

Science is a cumulative process

The scientific method outlined in figure 1.14 is the process used to carry out individual studies. Larger-scale accumulation of scientific knowledge involves cooperation and contributions from countless people. Good science is rarely carried out by a single individual working in isolation. Instead, a community of scientists collaborates in a cumulative, self-correcting process. You often hear about big breakthroughs and dramatic discoveries that change our understanding

Active LEARNING

Calculating Probability

An understanding of probability (the likelihood of an event) is fundamental in most areas of modern science. Working with these concepts is critical to your ability to comprehend scientific information.

Every time you flip a coin, the chance that heads will end up on top is 1 in 2 (50 percent, assuming you have a normal coin). The odds of getting heads two times in a row is 1/2 × 1/2, or 1/4.

1. What are the odds of getting heads five times in a row?
2. As you start the fifth flip, what are the odds of getting heads?
3. If there are 100 students in your class and everybody flips a coin five times, how many people are likely to get five heads in a row?

ANSWERS: 1. 1/2 × 1/2 × 1/2 × 1/2 × 1/2 = 1/32; 2. 1 in 2; 3. 100 students × 1/32 = about 3.

EXPLORING Science

Understanding sustainable development with statistics

In environmental science, we know sustainable development is important, but how do we evaluate it? Mainly with statistics. Distilling complex problems to a few numbers can allow you to see the state of a group, compare groups, and see change over time. One key statistic for understanding poverty is the Human Development Index (HDI), a measure that combines national scores for income, education, health care, and other measures (Key Concepts, p. 10).

Suppose you want to know how India is doing on human development and environmental conditions. You might recall that India has a growing population—soon to be the world's largest—and that poverty remains a persistent problem there. If you look up India's HDI score on the website of the United Nations Development Programme (UNDP), you can find that India's HDI is 0.59, on a scale from 0 to 1.0. Does this mean India is doing well? Or not?

Finding the center and distribution of a data set Many statistics mean little without context. To understand an HDI of 0.59, you can compare it to those of other countries. To start, you can compare India's HDI to the mid-point of the group. One common measure of the mid-point is the mean (or average): Add up all the HDI values for the 182 countries with reported scores; then divide the sum by the number of countries (182). It turns out that the mean HDI among these countries is 0.69. Evidently India is slightly below average in development.

Many of us understand visual patterns more readily than numbers. A **histogram,** for example, is a graph that shows the distribution of a data set at a glance. To make a histogram, we first specify ranges of HDI values—say, 0.3 to 0.4, 0.4 to 0.5, and so on. Then we count up the number of countries that fall in each value range. The resulting distribution appears in figure 1.

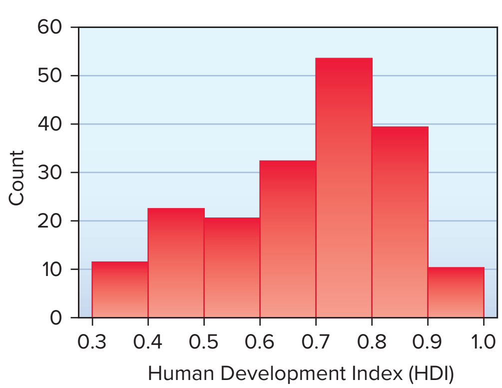


FIGURE 1 A histogram shows a distribution.

Plotting relationships among variables You may recall from earlier in this chapter that many developing areas lack access to safe drinking water and that young children, especially, are vulnerable to waterborne illness. How strong is the relationship between pollution-related deaths and HDI? The UNDP keeps data on estimated numbers of children under 5 years old who die each year from unsafe water. You can use a scatterplot to show the relationship between this variable and HDI (fig. 2). Each point represents a country.

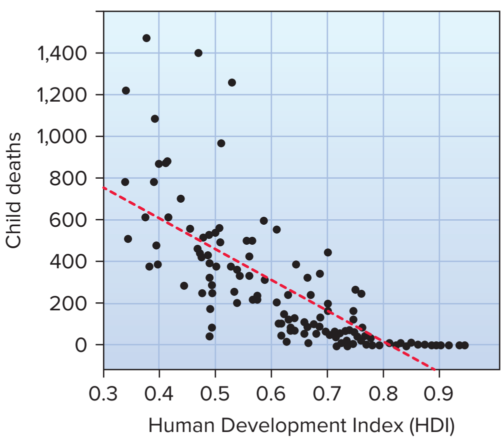


FIGURE 2 A scatter plot shows the relationship.

The scatterplot shows a pattern that generally declines from left to right. Look carefully at the axis labels: Number of deaths generally *decreases* (vertical axis) as HDI *increases* (horizontal axis). This is a **negative relationship.** A straight line shows the approximate trend in the data.

The points don't fit the straight line very tightly, though. Countries with low HDI, around 0.3 to 0.5, have a very wide range of infant deaths, from about 400 to 1,400. Some countries clearly have better success than others in controlling this risk factor. Almost every country with an HDI above about 0.75 has near zero infant deaths from unsafe water. It appears that while there is a negative relationship, countries don't need perfect HDI scores to see much improved infant health.

Error bars improve confidence When you calculate a mean of a *sample* (a portion of all possible observations), your calculated mean is properly considered an approximation of the universal *population* mean. In our case, we have HDI numbers for most countries but not all, and the data set excludes dozens of regions that were once independent states. So we basically have a sample of a larger population. To be confident that we have a reasonable approximation of the population mean from our sample, it is best to estimate the range of *likely* values for the actual (universal) population mean. One approach is *standard error bars*, which use sample size (were there many observations or few?) and variation in the data (all similar? widely different?) to calculate the likely range of the population mean.

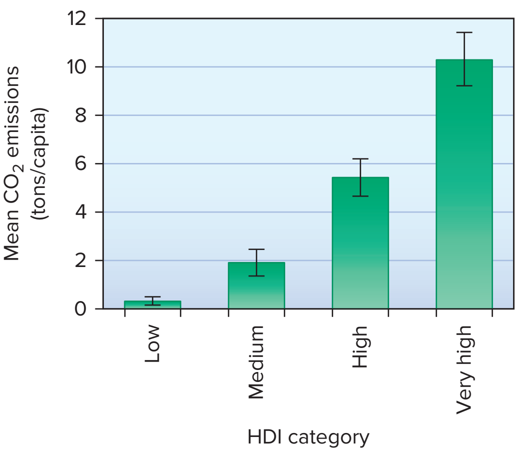
This becomes important if you are comparing groups. Suppose you are concerned that affluence is associated with environmental harm, such as climate-changing greenhouse gas emissions. You could compare the average emissions and see if the high-HDI countries also tend to have high CO_2 emissions.

Continued ▶

◀ *Continued*

Figure 3 shows that your hunch was correct. Not only is the mean higher for high-HDI countries, the standard error bars (the likely range of means) don't overlap. You can say with confidence that these groups are really different in their climate impacts.

Statistics give useful insights into problems we care about. Like any source of knowledge, they are often just part of the story, but they can provide good confidence about what we know, and what we don't know, about an issue.



◀ **FIGURE 3** Standard error bars show whether groups differ meaningfully.

overnight, but in reality these changes are usually the culmination of the labor of many people, each working on different aspects of a common problem, each adding small insights to solve a problem. Ideas and information are exchanged, debated, tested, and retested to arrive at **scientific consensus,** or general agreement among informed scholars.

The idea of consensus is important. For those not deeply involved in a subject, the multitude of contradictory results can be bewildering: Are coral reefs declining, and does it matter? Is climate changing, and how much? Among those who have done many studies and read many reports, there tends to emerge a general agreement about the state of a problem. Scientific consensus now holds that many coral reefs are in danger, as a result of pollution, physical damage, and warming seas. Consensus is that global climate conditions are changing, though models differ somewhat on how rapidly they will change in different regions.

Sometimes new ideas emerge that cause major shifts in scientific consensus. These great changes in explanatory frameworks were termed **paradigm shifts** by Thomas Kuhn (1967), who studied revolutions in scientific thought. According to Kuhn, paradigm shifts occur when a majority of scientists accept that the old explanation no longer describes new observations very well. For example, two centuries ago geologists explained many of the earth's features in terms of Noah's flood. The best scientists held that the flood created beaches well above modern sea level, scattered boulders erratically across the landscape, and gouged enormous valleys where there is no water now (fig. 1.16). Then the Swiss glaciologist Louis Agassiz and others suggested that the earth had once been much colder and that glaciers had covered large areas. Periodic ice ages proved to be a more durable explanation for geologic features than did a flood, and this new idea completely altered the way geologists explained their subject. Similarly, the idea of tectonic plate movement, in which continents shift slowly around the earth's surface (see chapter 11), revolutionized the ways geologists, biogeographers, ecologists, and others explained the development of the earth and its life-forms.

▲ **FIGURE 1.16** Paradigm shifts change the ways we explain our world. Geologists now attribute Yosemite's valleys to glaciers, where once they believed catastrophes like Noah's flood were responsible for geological features like these. ©John A. Karachewski

What is sound science?

Environmental science often deals with questions that are emotionally or politically charged. Scientific studies of climate change may be threatening to companies that sell coal and oil; studies of the health costs of pesticides worry companies that use or sell these chemicals. When controversy surrounds science, claims about **sound science** and accusations of "junk science" often arise. What do these terms mean, and how can you evaluate who is right?

When you hear arguments about whose science is valid, you need to remember the basic principles of science: Are the disputed studies reproducible? Are conclusions drawn with caution and skepticism? Are samples large and random? Are conclusions supported by a majority of scholars who have studied the problem? Do any of the experts have an economic interest in the outcome?

What Do YOU THINK?

Science and Citizenship: Evidence-Based Policy vs. Policy-Based Evidence?

> [This] was not evidence-based policymaking—this was policy-based evidence-making.
>
> —Michael Greenstone, University of Chicago economist, describing Energy Secretary Scott Pruitt's effort to recalculate the cost of carbon emissions

Suppose you observe that your local lake has become brown and smelly, and kids swimming in it are starting to get sick. You want to find out why and what to do about it. Of course, you want the best available information and a reliable solution to the problem. Who wouldn't want to use the best available evidence to keep people safe?

It turns out that it is surprisingly common for people to ignore evidence in decision making. Sometimes it's easier to pretend the lake is still clean enough. Sometimes we assume there is no alternative, and we just put up with getting sick. Sometimes we like the person responsible for polluting the lake, so we don't want to complain. Sometimes the polluter is skilled in suppressing information. He or she might even present creative "alternative facts" to explain or distract from the problem.

What to do? As an educated member of the community, you know to look for reliable, impartial information about water contaminants and to evaluate that information in the context of other studies. This is what much of environmental science is about. It uses the methods of science (orderly collection and analysis of evidence) to understand how environmental systems function, to evaluate environmental conditions, and to address issues of environmental quality.

We collect and evaluate information in decision making all the time. You might evaluate weather data every day, as you decide how to dress or if it's likely to rain. You might closely evaluate your budget when deciding if you should get a new cell phone or a new car. If you don't evaluate the evidence in your budget, there might be painful consequences.

Of course, it's easy to disregard consequences if they only affect someone else, especially someone far away or in the future. If your neighbor is polluting the lake and *you* suffer, should he really care? Why? If the pollution has a delayed effect—say, a pesticide that gradually degrades the lake ecosystem—but the damage doesn't become evident for years, whose problem is that (fig. 1)?

In a larger society, if we want to minimize conflict, then we try to ensure that one group doesn't systematically harm another group. So policymakers, who influence policies about water quality, health, or environmental releases of pesticides, need the best possible information (that is, data) and analysis for decision making. We set up agencies to collect, store, and analyze information. The Environmental Protection Agency has responsibility for monitoring pollution in order to protect public health. The Centers for Disease Control and Prevention monitors illnesses and environmental health, to catch and control the spread of diseases. Dozens of agencies collect data, and they share it with the public because data are so critical to public health and well-being.

Science and citizenship often go hand in hand. A functioning society depends on informed, thoughtful members who look out for the community's interests. Being educated in environmental science helps you develop a number of useful analytical skills, such as these:

▲ **FIGURE 1** Should pollutants be regulated? How? These and other policy questions involve your knowledge of science and of civil society.
©Leks_Laputin/Getty Images

- Critically analyzing data, ideas, and arguments
- Evaluating complex systems—understanding that interconnections are complex and diverse and indirect consequences can be important
- Knowing how to gather and weigh evidence, including data visualization (graphs and maps)
- Understanding the environmental context of policies or events
- Understanding the logic and scientific evidence invoked in policymaking

Being aware of complex relationships and systems helps you understand your interrelationships with your community. Part of citizenship, of course, is to consider consequences beyond ourselves and to minimize harm to others in the community. As a well-informed citizen, you can decide whether or not you want to vote for a candidate who has promised to dismantle water monitoring systems or air quality protections, or whether you should support a policymaker who has eliminated funding for chemical safety.

Most of us are interested in staying healthy and living in a healthy environment. Whether we act or vote accordingly depends on whether we are thinking about evidence when decision time comes around, or how near and personal the consequences of our decisions might be.

Many policymakers today criticize science, scientific agencies like the EPA, and even the colleges and universities that educate the next generation of scientists and citizens. As you listen to them, consider why. Are data standing in the way of their intentions? Does evidence contradict their statements? Are "alternative facts" more convenient than impartial and reproducible ones? Are they practicing "policy-based evidence-making"? As you read this book and as you listen to the news, these are good questions to keep in mind.

TABLE 1.3 Questions for Baloney Detection

1. How reliable are the sources of this claim? Is there reason to believe that they might have an agenda to pursue in this case?
2. Have the claims been verified by other sources? What data are presented in support of this opinion?
3. What position does the majority of the scientific community hold in this issue?
4. How does this claim fit with what we know about how the world works? Is this a reasonable assertion, or does it contradict established theories?
5. Are the arguments balanced and logical? Have proponents of a particular position considered alternate points of view or only selected supportive evidence for their particular beliefs?
6. What do you know about the sources of funding for a particular position? Are studies financed by groups with partisan goals?
7. Where was evidence for competing theories published? Has it undergone impartial peer review, or is it only in proprietary publication?

Source: Carl Sagan, *The Demon Haunted World: Science as a Candle in the Dark*, 1997.

Often media figures on television or radio will take a position contrary to the scientific majority. A contrarian position gains them publicity and political allies (and sometimes money). This strategy has been especially popular around large issues such as climate change. For decades now, almost all climate scientists have agreed that human activities, such as fossil fuel burning and land clearing, are causing climate change. But it is always possible to find a contrarian scientist who is happy to contradict the majority of evidence. Especially when political favors, publicity, or money is involved, there are always "expert" witnesses who will testify on opposite sides of any case.

If you see claims of fake news and junk science, how can you evaluate them? How can you identify bogus analysis that is dressed up in quasi-scientific jargon but that has no objectivity? This is such an important question that astronomer Carl Sagan proposed a "Baloney Detection Kit" (table 1.3) to help you out.

Uncertainty, proof, and group identity

Scientific uncertainty is frequently invoked as a reason to postpone actions that a vast majority of informed scientists consider to be prudent. In questions of chemical safety, energy conservation, climate change, or air pollution control, opponents of change may charge that the evidence doesn't constitute absolute proof, so that no action needs to be taken. You will see examples of this in later chapters on environmental health, climate, air and water pollution, and other topics.

Similarly, disputes over evolution often hinge on the concept of uncertainty and proof in science. Opponents of teaching evolution in public schools often charge that because scientists call evolution a "theory," evolution is just a matter of conjecture. This is a confused use of terminology. The theory of evolution is supported by overwhelming evidence, but we still call it a theory because scientists prefer to be precise about the idea of proof.

In recent years sociologists have pointed out that our decisions to accept or dispute scientific evidence often depend on group identity. We like to associate with like-minded people, so we tend to adhere to a group viewpoint. Subconsciously we may ask, "Does the community I belong to agree with evolution? Does it accept the evidence for climate change?" Our urge to be agreeable to our group can be surprisingly strong, compared to our interest in critically analyzing evidence. Expectations of group behavior can shift over time, though. In decades past, you might have asked, "Am I the kind of person who recycles?" Today recycling is normal for most people, and few people probably decline to recycle just because their friends don't. Resolving differences on environmental policy sometimes requires recognition of group identity in our attitudes toward science, as well as our attitudes toward policies and issues beyond science. In these ways, you are often integrating your education in environmental science with your actions as a member of society (What Do You Think?, p. 19).

1.5 CRITICAL THINKING

- *Critical thinking helps us analyze information.*
- *There are many aspects of critical thinking.*

In science we frequently ask, "How do I know that what you just said is true?" Part of the way we evaluate arguments in science has to do with observable evidence, or data. Logical reasoning from evidence is also essential. And part of the answer lies in critical evaluation of evidence.

An ability to think critically, clearly, and analytically about a problem may be the most valuable skill you can learn in any of your classes. As you know by now, many issues in environmental science are hotly disputed, with firm opinions and plenty of evidence on both sides. How do you evaluate contradictory evidence and viewpoints? **Critical thinking** is a term we use to describe logical, orderly, analytical assessment of ideas, evidence, and arguments. Developing this skill is essential for the course you are taking now. Critical thinking is also an extremely important skill for your life in general. You can use it when you evaluate the claims of a car salesman, a credit card offer, or the campaign rhetoric of a political candidate.

Critical thinking helps us understand why prominent authorities can vehemently disagree about a topic. Disagreements may be based on contradictory data, on different interpretations of the same data, or on different priorities. One expert might consider economic health the overriding priority; another might prioritize environmental quality. A third might worry only about company stock prices, which might depend on the outcome of an environmental policy debate. You can examine the validity of contradictory claims by practicing critical thinking.

Critical thinking is part of science and of citizenship

We evaluate many claims every day, in class, in TV advertising, in understanding public affairs and polices, in reading or watching the news. It is worth pausing to think about what critical thinking means. In general, it means examining sources and considering

TABLE 1.4 Steps in Critical Thinking

1.	What is the purpose of my thinking?
2.	What precise question am I trying to answer?
3.	Within what point of view am I thinking?
4.	What information am I using?
5.	How am I interpreting that information?
6.	What concepts or ideas are central to my thinking?
7.	What conclusions am I aiming toward?
8.	What am I taking for granted; what assumptions am I making?
9.	If I accept the conclusions, what are the implications?
10.	What would the consequences be if I put my thoughts into action?

Source: Paul, R. (1993). Critical Thinking. Foundation for Critical Thinking.

how a source influences statements or ideas. But you can also distinguish among different kinds of critical thinking: **Analytical thinking** involves breaking down a problem into its constituent parts. **Creative thinking** means envisioning new, different approaches to a problem. **Logical thinking** examines the structure of an argument, from premises to conclusions. **Reflective thinking** means asking, "What does it all mean?"

These processes are often self-reflective and self-correcting. They encourage you to ask, "How do I know that what I just said is true?" Developing habits of critical thinking can help you identify unspoken assumptions, biases, beliefs, priorities, or motives (table 1.4 and fig. 1.17). These habits will also help you do well in class, and they can help you be an informed, thoughtful reader of the world around you.

▲ **FIGURE 1.17** Critical thinking evaluates premises, contradictions, and assumptions. Is this sign, in the middle of a popular beach near Chicago, the only way to reduce human exposure to bacteria? What other strategies might there be? Why was this one chosen? Who might be affected?
©Mary Ann Cunningham

Here are some steps to practice in critical thinking:

1. *Identify and evaluate premises and conclusions in an argument.* What is the basis for the claims made? What evidence is presented to support these claims, and what conclusions are drawn from this evidence? If premises and evidence are reasonable, do the conclusions truly follow from them?
2. *Acknowledge and clarify uncertainties, vagueness, equivocation, and contradictions.* Are terms used in vague or ambiguous ways? Are all participants in an argument using the same meanings? Is ambiguity or equivocation deliberate?
3. *Distinguish between facts and values.* Can claims be tested, or are statements based on untestable assumptions and beliefs? Are claims made about the worth or lack of worth of something? (If so, these are value statements or opinions and probably cannot be verified objectively.)
4. *Recognize and assess assumptions.* Consider the backgrounds and views behind an argument: What underlying reasons might there be for the premises, evidence, or conclusions presented? Does anyone have a personal agenda in this issue? What does he or she think you know, need, want, or believe? Do hidden biases based on race, gender, ethnicity, economics, or belief systems distort arguments?
5. *Distinguish source reliability from unreliability.* What qualifies the experts on this issue? Is that qualification sufficient for you to believe them? Why or why not?
6. *Recognize and understand conceptual frameworks.* What basic beliefs, attitudes, and values underlie an argument or action? How do these beliefs and values affect the way people view themselves and the world around them?

In this book you will have many opportunities to practice critical thinking skills. Every chapter includes facts, figures, opinions, and theories. Are all of them true? Probably not. They were the best information available when this text was written, but new evidence is always emerging. Data change constantly, as does our interpretation of data.

You'll find more on critical thinking, as well as some useful tips on how to study effectively, on our website at www.connect.mheducation.com.

1.6 WHERE DO OUR IDEAS ABOUT THE ENVIRONMENT COME FROM?

- *Utilitarian conservation focuses on usable resources.*
- *Preservation of nature recognizes the rights of other species.*
- *Modern environmentalism focuses on health and social justice.*

Historically, many societies have degraded the resources on which they depended, while others have lived in relative harmony with their surroundings. Today our burgeoning population and our technologies that accelerate resource exploitation have given the problems of environmental degradation increased urgency.

Many of our current responses to these changes are rooted in the writings of relatively recent environmental thinkers. For simplicity, their work can be grouped into four distinct stages: (1) resource conservation for optimal use, (2) nature preservation for moral and aesthetic reasons, (3) concern over health and ecological consequences of pollution, and (4) global environmental citizenship. These stages are not mutually exclusive. You might embrace them all simultaneously. As you read this section, consider why you agree with those you find most appealing.

Environmental protection has historic roots

Recognizing human misuse of nature is not unique to modern times. Plato complained in the fourth century B.C. that Greece once was blessed with fertile soil and clothed with abundant forests of fine trees. After the trees were cut to build houses and ships, however, heavy rains washed the soil into the sea, leaving only a rocky "skeleton of a body wasted by disease." Springs and rivers dried up, and farming became all but impossible. Despite these early observations, most modern environmental ideas developed in response to resource depletion associated with more recent agricultural and industrial revolutions.

Some of the earliest recorded scientific studies of environmental damage were carried out in the eighteenth century by French or British colonial administrators, many of whom were trained scientists and who observed rapid soil loss and drying wells that resulted from intensive colonial production of sugar and other commodities. Some of these colonial administrators considered responsible environmental stewardship as an aesthetic and moral priority, as well as an economic necessity. These early conservationists observed and understood the connections among deforestation, soil erosion, and local climate change. The pioneering British plant physiologist Stephen Hales, for instance, suggested that conserving green plants preserves rainfall. His ideas were put into practice in 1764 on the Caribbean island of Tobago, where about 20 percent of the land was marked as "reserved in wood for rains."

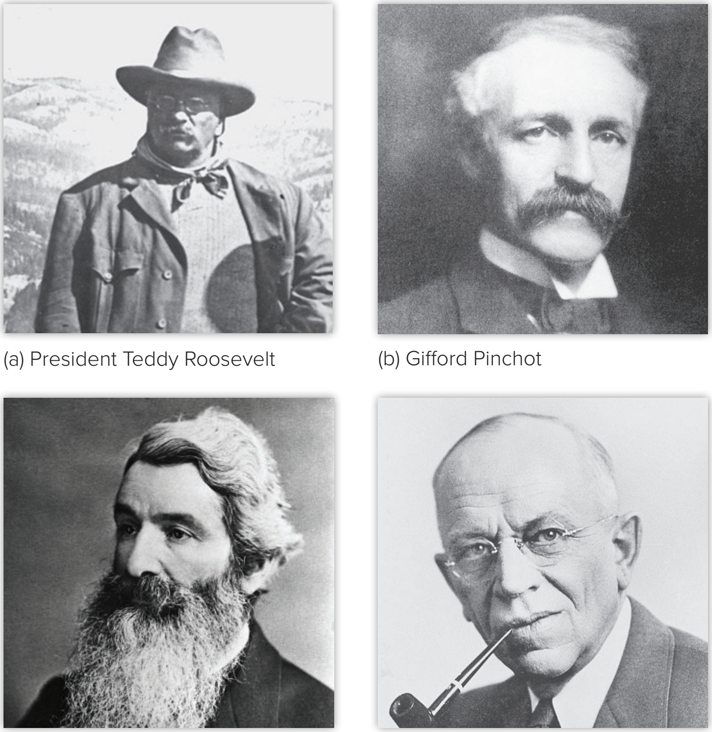
Pierre Poivre, an early French governor of Mauritius, an island in the Indian Ocean, was appalled at the environmental and social devastation caused by the destruction of wildlife (such as the flightless dodo) and the felling of ebony forests on the island by early European settlers. In 1769 Poivre ordered that one-quarter of the island be preserved in forests, particularly on steep mountain slopes and along waterways. Mauritius remains a model for balancing nature and human needs. Its forest reserves shelter more original species than are found on most other populated islands.

Resource waste triggered pragmatic resource conservation (stage 1)

Many historians consider the publication of *Man and Nature* in 1864 by geographer George Perkins Marsh as the wellspring of environmental protection in North America. Marsh, who also was a lawyer, politician, and diplomat, traveled widely around the Mediterranean as part of his diplomatic duties in Turkey and Italy. He read widely in the classics (including Plato) and personally observed the damage caused by excessive grazing by goats and sheep and by the deforestation of steep hillsides. Alarmed by the wanton destruction and profligate waste of resources still occurring on the American frontier in his lifetime, he warned of its ecological consequences. Largely because of his book, national forest reserves were established in the United States in 1873 to protect dwindling timber supplies and endangered watersheds.

Among those influenced by Marsh's warnings were U.S. President Theodore Roosevelt and his chief conservation adviser, Gifford Pinchot (fig. 1.18a,b). In 1905 Roosevelt, who was the leader of the populist Progressive movement, moved forest management out of the corruption-filled Interior Department into the Department of Agriculture. Pinchot, who was the first American-born professional forester, became the first chief of the new Forest Service. He put resource management on an honest, rational, and scientific basis for the first time in American history. Together with naturalists and activists such as John Muir, Roosevelt and Pinchot established the framework of the national forest, park, and wildlife refuge system. They passed game protection laws and tried to stop some of the most flagrant abuses of the public domain. In 1908 Pinchot organized and chaired the White House Conference on Natural Resources, perhaps the most prestigious and influential environmental meeting ever held in the United States. Pinchot also was governor of Pennsylvania and founding head of the Tennessee Valley Authority, which provided inexpensive power to the southeastern United States.

The basis of Roosevelt's and Pinchot's policies was pragmatic **utilitarian conservation.** They argued that the forests should be



(a) President Teddy Roosevelt (b) Gifford Pinchot (c) John Muir (d) Aldo Leopold

▲ **FIGURE 1.18** Some early pioneers of the American conservation movement. (a) President Teddy Roosevelt and his main adviser, (b) Gifford Pinchot, emphasized pragmatic resource conservation, whereas (c) John Muir and (d) Aldo Leopold focused on ethical and aesthetic relationships.
(a): Source: Underwood & Underwood, Library of Congress, LC-USZC4-4698; (b): ©Grey Towers National Historic Landmark; (c): ©Bettmann/Getty Images; (d): ©AP Images

saved "not because they are beautiful or because they shelter wild creatures of the wilderness, but only to provide homes and jobs for people." Resources should be used "for the greatest good, for the greatest number, for the longest time." "There has been a fundamental misconception," Pinchot wrote, "that conservation means nothing but husbanding of resources for future generations. Nothing could be further from the truth. The first principle of conservation is development and use of the natural resources now existing on this continent for the benefit of the people who live here now. There may be just as much waste in neglecting the development and use of certain natural resources as there is in their destruction." This pragmatic approach still can be seen in the multiple-use policies of the U.S. Forest Service.

Ethical and aesthetic concerns inspired the preservation movement (stage 2)

John Muir (fig. 1.18c), amateur geologist, popular author, and first president of the Sierra Club, strenuously opposed Pinchot's utilitarian policies. Muir argued that nature deserves to exist for its own sake, regardless of its usefulness to us. Aesthetic and spiritual values formed the core of his philosophy of nature protection. This outlook prioritizes **preservation** because it emphasizes the fundamental right of other organisms—and nature as a whole—to exist and to pursue their own interests (fig. 1.19). Muir wrote, "The world, we are told, was made for man. A presumption that is totally unsupported by the facts. . . . Nature's object in making animals and plants might possibly be first of all the happiness of each one of them. . . . Why ought man to value himself as more than an infinitely small unit of the one great unit of creation?"

Muir, who was an early explorer and interpreter of California's Sierra Nevada range, fought long and hard for establishment of Yosemite and Kings Canyon national parks. The National Park Service, established in 1916, was first headed by Muir's disciple, Stephen Mather, and has always been oriented toward preservation of nature rather than consumptive uses. Muir's preservationist ideas have often been at odds with Pinchot's utilitarian approach. One of Muir and Pinchot's biggest battles was over the damming of Hetch Hetchy Valley in Yosemite. Muir regarded flooding the valley a sacrilege against nature. Pinchot, who championed publicly owned utilities, viewed the dam as a way to free San Francisco residents from the clutches of greedy water and power monopolies.

In 1935, pioneering wildlife ecologist Aldo Leopold (fig. 1.18d) bought a small, worn-out farm in central Wisconsin. A dilapidated chicken shack, the only remaining building, was remodeled into a rustic cabin. Working together with his children, Leopold planted thousands of trees in a practical experiment in restoring the health and beauty of the land. "Conservation," he wrote, "is the positive exercise of skill and insight, not merely a negative exercise of abstinence or caution." The shack became a writing refuge and the main focus of *A Sand County Almanac,* a much beloved collection of essays about our relation with nature. In it, Leopold wrote, "We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect." Together with Bob Marshall and two others, Leopold was a founder of the Wilderness Society.

▲ **FIGURE 1.19** A conservationist might say this forest is valuable as a supplier of useful resources, including timber and fresh water. A preservationist might argue that this ecosystem is important for its own sake. Many people are sympathetic with both outlooks. ©Altrendo nature/Getty Images

Rising pollution levels led to the modern environmental movement (stage 3)

The undesirable effects of pollution probably have been recognized as long as people have been building smoky fires. In 1723 the acrid coal smoke in London was so severe that King Edward I threatened to hang anyone who burned coal in the city. In 1661 the English diarist John Evelyn complained about the noxious air pollution caused by coal fires and factories and suggested that sweet-smelling trees be planted to purify city air. Increasingly dangerous smog attacks in Britain led, in 1880, to formation of a national Fog and Smoke Committee to combat this problem. But nearly a century later, London's air (like that of many cities) was still bad. In 1952 an especially bad episode turned midday skies dark and may have caused 12,000 deaths (see chapter 10). This event was extreme, but noxious air was common in many large cities.

The tremendous expansion of chemical industries during and after World War II added a new set of concerns to the environmental agenda. *Silent Spring,* written by Rachel Carson (fig. 1.20a) and published in 1962, awakened the public to the threats of pollution and toxic chemicals to humans as well as other species. The movement she engendered might be called **modern environmentalism** because its concerns extended to include both natural resources and environmental pollution.

Under the leadership of a number of other brilliant and dedicated activists and scientists, the environmental agenda was expanded in the 1970s to most of the issues addressed in this textbook, such as human population growth, atomic weapons testing and atomic power, fossil fuel extraction and use, recycling, air and water pollution, and wilderness protection. Environmentalism has become well established in the public agenda since the first national Earth Day in 1970.

As environmental concerns have expanded to climate action, one of the new leaders has been Bill McKibben (fig. 1.20b), an author, educator, and environmentalist who has written extensively

(a) Rachel Carson

(b) Bill McKibben

(c) Van Jones

(d) Wangari Maathai

▲ FIGURE 1.20 Among many distinguished environmental leaders in modern times, (a) Rachel Carson, (b) Bill McKibben, (c) Van Jones, and (d) Wangari Maathai stand out for their dedication, innovation, and bravery. (a): ©RHS/AP Images; (b): ©Cindy Ord/Getty Images; (c): ©Ryan Rodrick Beiler/Shutterstock; (d): ©s_bukley/Shutterstock

about climate change and has led campaigns to demand political action on this existential threat. As scholar in residence at Middlebury College, he worked with a group of undergraduate students to create 350.org, an organization that has sponsored thousands of demonstrations in 181 countries to raise public awareness about climate change and has sparked actions for fossil fuel divestment on many campuses. The group has been widely praised for its creative use of social media and public organization. McKibben and 350.org led the opposition to the Keystone XL pipeline project, which was designed to transport crude oil from Alberta's tar sands to export terminals in Texas.

Environmental quality is tied to social progress (stage 4)

In recent years some people have argued that the roots of the environmental movement are elitist—promoting the interests of a wealthy minority who can afford to vacation in wilderness. In fact, most environmental leaders have seen social justice and environmental equity as closely intertwined. Gifford Pinchot, Teddy Roosevelt, and John Muir all strove to keep nature accessible to everyone, at a time when public lands, forests, and waterways were increasingly controlled by a few wealthy individuals and private corporations. The idea of national parks, one of our principal strategies for nature conservation, is to provide public access to natural beauty and outdoor recreation. Aldo Leopold, a founder of the Wilderness Society, promoted ideas of land stewardship among farmers, fishers, and hunters. Robert Marshall, also a founder of the Wilderness Society, campaigned all his life for social and economic justice for low-income groups.

Increasingly, environmental activists are making explicit the links between environmental quality and social progress on a global scale (fig. 1.21). But issues of sustainable development are also being recognized across economic divides in wealthy countries. Anthony Kapel "Van" Jones (fig. 1.20c) is one of those who has been a powerful voice for social and environmental progress, and he has helped bring visibility to the role of people of color in environmental action. As both a social justice and environmental activist, Jones has fought poverty and racial injustice by creating hundreds of thousands of "green-collar" jobs installing solar systems and upgrading the energy efficiency of millions of American homes. He served as President Barack Obama's Special Advisor for Green Jobs and has worked to build a "green economy for everyone." He has also brought artists, athletes, and local leaders into national dialogues and engagement around social and environmental issues.

Some of today's leading environmental thinkers come from developing nations, where poverty and environmental degradation together plague hundreds of millions of people. Dr. Wangari Maathai of Kenya (1940–2011) was a notable example. In 1977 Dr. Maathai (see fig. 1.20d) founded the Green Belt Movement in her native Kenya as a way to both organize poor rural women and restore their environment. Beginning at a small, local scale, this organization has grown to more than 600 grassroots networks across Kenya. They have planted more than 30 million trees while mobilizing communities for self-determination, justice, equity, poverty reduction, and environmental conservation. Dr. Maathai was elected to the Kenyan Parliament and served as Assistant Minister for Environment and Natural Resources. Her leadership helped bring

▲ FIGURE 1.21 Environmental scientists increasingly try to address both public health and environmental quality. The poorest populations often suffer most from environmental degradation. ©Kaetana/Shutterstock democracy and good government to her country. In 2004 she received the Nobel Peace Prize for her work, the first time a Nobel has been awarded for environmental action. In her acceptance speech she said, "Working together, we have proven that sustainable development is possible; that reforestation of degraded land is possible; and that exemplary governance is possible when ordinary citizens are informed, sensitized, mobilized and involved in direct action for their environment."

Photographs of the earth from space (see fig. 1.3) provide powerful icons for the fourth wave of ecological concern, which might be called **global environmentalism.** Such photos remind us how small, fragile, beautiful, and rare our home planet is. We all share an environment at this global scale. As Ambassador Adlai Stevenson noted in his 1965 farewell address to the United Nations, we now need to worry about the life-support systems of the planet as a whole: "We cannot maintain it half fortunate, half miserable, half confident, half despairing, half slave to the ancient enemies of mankind and half free in a liberation of resources undreamed of until this day. No craft, no crew, can travel with such vast contradictions. On their resolution depends the security of us all."

CONCLUSION

Environmental science gives us useful tools and ideas for understanding environmental problems and for finding new solutions to those problems. Environmental science draws on many disciplines, and on people with diverse interests, to understand the persistent problems we face, including human population growth, contaminated water and air, climate change, and biodiversity losses. There are also encouraging examples of progress. Population growth has slowed, the extent of habitat preserves has expanded greatly in recent years, we have promising new energy options, and in many regions we have made improvements in air and water quality.

The scientific method provides an orderly way to examine these issues. Ideally, scientists are skeptical about evidence and cautious about conclusions. These practices are much like critical thinking, which is also emphasized in environmental science.

Environmental science also is concerned with sustainable development because both poverty and affluence contribute to environmental degradation. Impoverished populations often overexploit land and water supplies, while wealthy populations consume or degrade extraordinary amounts of energy, water, forest products, food, and other resources. Differences in wealth lead to contrasts in life expectancy, infant mortality, and other measures of well-being. Resolving these multiple problems together is the challenge for sustainability.

Our ideas about conservation and environment have evolved in response to environmental conditions, from a focus on conservation of usable resources to preservation of nature for its own sake. Throughout these ideas has been a concern for social equity, for the rights of low-income people to have access to resources and to a healthy environment. In recent years these twin concerns have expanded to recognize the possibilities of change in developing countries and the global interconnections of environmental and social concerns.

PRACTICE QUIZ

1. Describe how global fertility rates and populations are changing (see fig. 1.6).
2. What is the idea of "ecological services"? Give an example.
3. Distinguish between a hypothesis and a theory.
4. Describe the steps in the scientific method.
5. What is probability? Give an example.
6. Why are scientists generally skeptical? Why do tests require replication?
7. What is the first step in critical thinking, according to table 1.4?
8. Distinguish between utilitarian conservation and preservation. Name two environmental leaders associated with each of these philosophies.
9. Why do some experts regard water as the most critical natural resource for the twenty-first century?
10. Where in figure 1.5 does the most dramatic warming occur?
11. What are the HDI ranges for the United States, India, and China (see fig. 1.11)?
12. What is the link between poverty and environmental quality?
13. Define *sustainability* and *sustainable development*.

CRITICAL THINKING AND DISCUSSION

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

1. Changing fertility rates are often explained in terms of better education for girls and women. What might be some reasons for this association?
2. The analytical approaches of science are suitable for answering many questions. Are there some questions that science cannot answer? Why or why not?
3. Often opinions diverge sharply in controversial topics, such as the allowable size of fish catches or the balance of environmental and economic priorities in land management. Think of a controversial topic with which you are familiar. What steps can you take to maintain objectivity and impartiality in evaluating the issue?
4. Environmental activists often focus on questions of social justice and environmental justice. Consider an issue such as air or water quality. Why does it affect different groups unequally?
5. Suppose you wanted to study the environmental impacts of a rich versus a poor country. What factors would you examine, and how would you compare them?

DATA ANALYSIS Working with Graphs

To understand trends and compare values in environmental science, we need to examine a great many numbers. Most people find it hard to quickly assess large amounts of data in a table. Graphing a set of data makes it easier to see patterns, trends, and relationships. For example, scatter plots show relationships between two variables, while bar graphs show the range of values in a set (figs. 1 and 2). Reading graphs takes practice, but it is an essential skill that will serve you well in this course and others.

You will encounter several common types of graphs in this book. Go to the Data Analysis exercise on Connect to practice these skills and demonstrate your knowledge of how to read and use graphs.

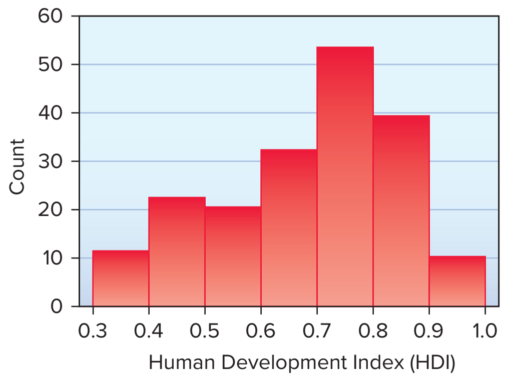


FIGURE 1 A histogram shows a distribution.

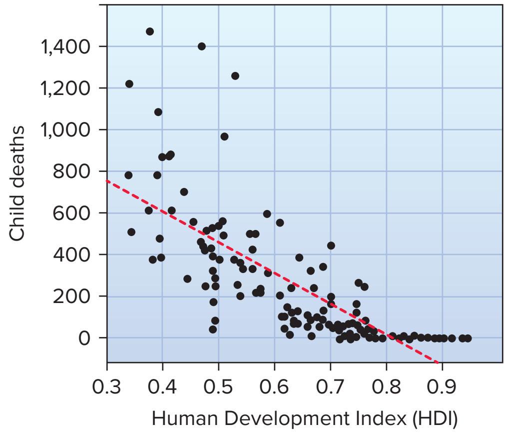


FIGURE 2 A scatter plot shows the relationship.

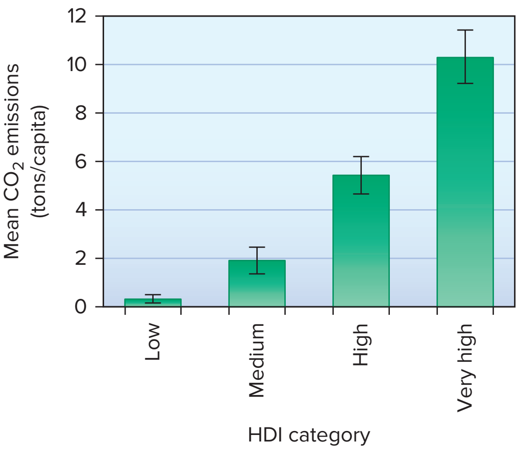


FIGURE 3 Standard error bars show whether groups differ meaningfully.