Richard T. Wright | Dorothy F. Boorse

ENVIRONMENTAL Science

TOWARD A SUSTAINABLE FUTURE 13E

Brief Contents

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Gordon College

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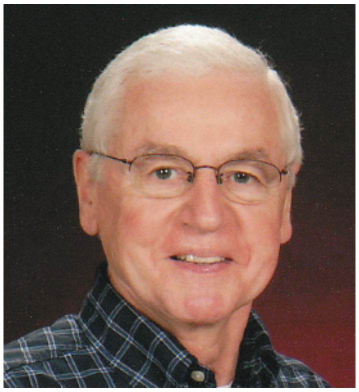

Richard T. Wright is Professor Emeritus of Biology at Gordon College in Massachusetts, where he taught environmental science for 28 years. He earned a B.A. from Rutgers University and an M.A. and a Ph.D. in biology from Harvard University. For many years, Wright received grant support from the National Science Foundation for his work in marine microbiology, and in 1981, he was a founding faculty member of Au Sable Institute of Environmental Studies in Michigan, where he also served as Academic Chairman for 11 years. He is a Fellow of the American Association for the Advancement of Science, Au Sable Institute, and the American Scientific Affiliation. In 1996, Wright was appointed a Fulbright Scholar to Daystar University in Kenya, where he taught for two months. He is a member of many environmental organizations, including the Nature Conservancy, Habitat for Humanity, the Union of Concerned Scientists, and the Audubon Society, and is a supporting member of the Trustees of Reservations. He volunteers his services at the Parker River National Wildlife Refuge in Newbury, Massachusetts, and is an elder in First Presbyterian Church of the North Shore. Wright and his wife, Ann, live in Byfield, Massachusetts, and they drive a Toyota Camry hybrid vehicle as a means of reducing their environmental impact. Wright spends his spare time birding, fishing, hiking, and enjoying his three children and seven grandchildren.

Dorothy F. Boorse is a professor of biology at Gordon College in Wenham, Massachusetts. Her research interest is in drying wetlands, such as vernal pools and prairie potholes, and in salt marshes. Her research with undergraduates has included wetland and invasive species projects. She earned a B.S. in biology from Gordon College, an M.S. in entomology from Cornell University, and a Ph.D. in oceanography and limnology from the University of Wisconsin–Madison. Boorse teaches, writes, and speaks about biology, the environment, ecological justice, and care of creation. She was recently an author on a report on poverty and climate change. In 2005, Boorse provided expert testimony on wildlife corridors and environmental ethics for a Congressional House subcommittee hearing. Boorse is a member of a number of ecological and environmental societies, including the Ecological Society of America, the Society of Wetland Scientists, the Nature Conservancy, the Audubon Society, the New England Wildflower Society, and the Trustees of Reservations (the oldest land conservancy group in the United States). She and her family live in Beverly, Massachusetts. They belong to Appleton Farms, a CSA (community-supported agriculture) farm. At home, Boorse has a native plant garden and has planted two disease-resistant elm trees.

Dedication

This edition is dedicated to Sylvia Earle (1935–), marine scientist and tireless advocate for the environment. An oceanographer, explorer, author, company founder, and lecturer, Earle has lived out a fantastic dream to study the oceans, and fearlessly pursued that goal when opportunities for women were limited. After receiving her Ph.D. in 1966, Earle was a research fellow at Harvard and then moved to Florida, where she took underwater research dives, setting records for women's depth diving, and leading an all-female team of aquanauts in an underwater research project. While she has many other accomplishments as well, Earle is particularly noted for being Chief Scientist at the National Oceanic and Atmospheric Administration from 1990 to 1992, and a National Geographic Explorer-in-Residence since 1998. Earle has founded three companies, which produce robotics and other ocean exploration equipment.

In 1998, Earle was named the first "Hero for the Planet" by *Time* magazine. In 2009, she won a TED prize, which come with money to carry out a vision for global change. She used that opportunity to launch a nonprofit, Mission Blue, which aims to establish what Earle calls "hope spots," or marine protected areas around the globe. It is an honor to dedicate this book to someone who is such a good scientist and has done so much to help the environment. Earle represents the themes of sound science, stewardship, and sustainability in a way few people do. She is a real hero for our time. In her own words, she calls upon us to act to protect the ocean:

> *"People ask: Why should I care about the ocean? Because the ocean is the cornerstone of Earth's life support system, it shapes climate and weather. It holds most of life on Earth. Ninety-seven percent of Earth's water is there. It's the blue heart of the planet—we should take care of our heart. It's what makes life possible for us. We still have a really good chance to make things better than they are. They won't get better unless we take the action and inspire others to do the same thing. No one is without power. Everybody has the capacity to do something."*
>
> – Sylvia Earle in the film *Bag It: Is Your Life Too Plastic?* *(Paramount Classics 2010)*

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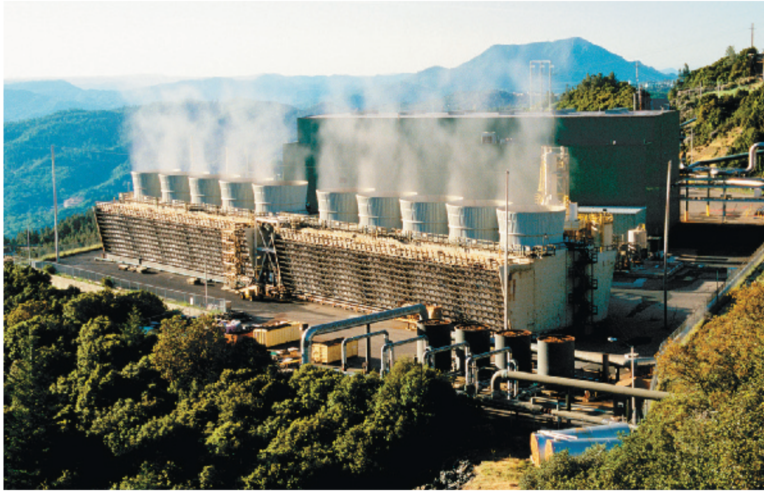

Essay List

SOUND SCIENCE

SUSTAINABILITY

STEWARDSHIP

Preface

We are now well into the 21st century and are at critical junctures in the relationship between humans and the rest of the environment. Globally, major changes are taking place in the atmosphere and climate, the human population and its well-being, and the Earth's natural resources. We are still recovering from a major global economic recession, the scientific evidence for climate change continues to accumulate, terrorism and conflict continue to grip the Middle East, and an extended drought in the western half of the United States and elsewhere is affecting food production and water availability.

In contrast to these trends, there are some changes that point to a brighter future. Renewable energy is ramping up swiftly in its share of the world's energy portfolio; many of the UN Millennium Development Goals (MDGs) were achieved by their target date of 2015; the Sustainable Development Goals that follow them have been crafted and are close to launching.

Even though international accord on climate change is slow in coming, many countries are achieving major reductions in greenhouse gas emissions; death by tobacco use is being addressed in a global campaign; AIDS, tuberculosis, and malaria are on the defensive as public-health agencies expand treatment options and research; and population growth rates in many regions are continuing to decline.

The most profound change that must happen, and soon, is the transition to a sustainable civilization—one in which a stable human population recognizes the finite limits of Earth's systems to produce resources and absorb wastes, and acts accordingly. This is hard to picture at present, but it is the only future that makes any sense. If we fail to achieve it by our deliberate actions, the natural world will impose it on us in highly undesirable ways.

Core Values

Environmental science stands at the interface between humans and Earth and explores the interactions and relations between them. This relationship will need to be considered in virtually all future decision making. This text considers a full spectrum of views and information in an effort to establish a solid base of understanding and a sustainable formula for the future. What you have in your hands is a readable guide and up-to-date source of information that will help you to explore the issues in more depth. It will also help you to connect them to a framework of ideas and values that will equip you to become part of the solution to many of the environmental problems confronting us.

In this new edition, we hope to continue to reflect accurately the field of environmental science; in so doing, we have constantly attempted to accomplish each of the following objectives:

- To write in a style that makes learning about environmental science both interesting to read and easy to understand, without overwhelming students with details;
- To present well-established scientific principles and concepts that form the knowledge base for an understanding of our interactions with the natural environment;
- To organize the text in a way that promotes sequential learning yet allows individual chapters to stand on their own;
- To address all of the major environmental issues that confront our society and help to define the subject matter of environmental science;
- To present the latest information available by making full use of resources such as the Internet, books, and journals, every possible statistic has been brought up to date;
- To assess options or progress made in solving environmental problems; and
- To support the text with excellent supplements for teachers and students that strongly enhance the teaching and learning processes.

Because we believe that learning how to live in the environment is one of the most important subjects in every student's educational experience, we have made every effort to put in their hands a book that will help the study of environmental science come alive.

New to This Edition

Building on its core values, *Environmental Science* has several new features that help make the content more approachable to students.

- **Concept Check** questions appear at the end of sections to help students check their understanding. Each concept check aligns with the learning objectives at the start of the chapter.
- **Understanding the Data** questions appear alongside figures, such as graphs or maps, to help students further engage with the data and build data analysis skills.
- Content has been thoroughly updated throughout; environmental science and the related issues are complex and constantly evolving. The thirteenth edition features the most current research presented in a balanced manner.

- Transitioning beyond the Millennium Development Goals of 2000–2015, discussions of environmental issues and solutions have been reframed to reflect the new Sustainable Development Goals.
- New Everyday Environmental Science videos and coaching activities in MasteringEnvironmentalScience accompany the thirteenth edition and will help students to see the application of the key concepts presented throughout the text to the real world.

Content Updates to the Thirteenth Edition of Environmental Science

Part One—Framework for a Sustainable Future

- The Part One opener focuses on the vision of sustainability and the challenges facing us that are inconsistent with that vision.
- Chapter 1 (Science and the Environment) The chapter has been restructured so that each of our three unifying themes (sustainability, sound science, and stewardship) now has its own major section. A new essay (Stewardship: "Protecting Forests") introduces the concept of stewardship. Hypothesis formation is illustrated with a revised essay, "Oysters Sound the Alarm," while a new graphic better explains the scientific method, which now includes more emphasis on the community of science. A new table (1–2) lists previous and ongoing ecosystem and biodiversity assessments.
- Chapter 2 (Economics, Politics, and Public Policy) A new chapter opener shows the impact of China's rapid economic growth on air pollution there. The chapter was reorganized into six sections rather than five. A figure illustrating the global environmental footprint and human development index shows the narrowing safe space for humanity. The chapter's end was significantly rewritten. It includes new information on international politics that informs discussion on global issues in later chapters. It also has a stronger tie between ethics and indigenous rights.

Part Two—Ecology: The Science of Organisms and Their Environment

- Part two begins with a part opener about the importance of science in understanding the ecosystems around us. Chapters 3–5 include topics that flow from basic to more complex, small to large, and species to ecosystems and humans.
- Chapter 3 (Basic Needs of Living Things) has a new chapter opener on the ecology of the Emperor penguin, which is followed as an illustration throughout the chapter. The chapter covers the science of ecology, needs of organisms, matter and energy, respiration and photosynthesis, and four material cycles. The carbon cycle has been updated to include the impact of volcanoes.
- Chapter 4 (Populations and Communities) opens with a new chapter opener (savanna elephants controlling a non-native plant by their herbivory). The examples of population growth have been simplified somewhat. While mathematical equations are not included, descriptions of the meanings of those equations are. A new Sustainability box ("Elephants in Kruger National Park: How Many Is Too Many?") illustrates concepts covered in sections on growth and limits of populations.
- Chapter 5 (Ecosystems: Energy, Patterns, and Disturbance) includes a new Sound Science essay ("What Are the Effects of Reintroducing a Predator?") and a new Stewardship essay ("Local Control Helps Restore Woodlands"). There is more information on the oceans, including the importance of picophytoplankton. New biomes or ecosystems (chaparral, tropical dry forest, coral reefs, and deep sea vents) are described and a new biome map is included. A new figure depicts ecosystem services. The concept of Human Appropriation of Net Primary Production (HANPP) has been added in the discussion of human effects on ecosystems.
- Chapter 6 (Wild Species and Biodiversity) features expanded discussion on the Aichi Biodiversity Targets. The section on the Endangered Species Act has been rewritten and a new table (6–4, Important U.S. Federal and International Conservation Regulations) streamlines discussion on regulation. The newest *Global Biodiversity Outlook 4* report is also included.
- Chapter 7 (The Value, Use, and Restoration of Ecosystems) has been reorganized. A central section on ecosystems under pressure has been divided into two sections—one on forests and grasslands and another on oceans—with restoration and conservation moved to the end of the chapter. A section on maximum sustainable yield is explained more thoroughly. Land protection has been expanded to include international protection as well. The chapter has an even greater focus on ecosystem goods and services and a completely rewritten final section on restoration, with examples of restoration from a number of biomes.

Part Three—The Human Population and Essential Resources

- Part 3 begins with a new part opener about community-supported agriculture and the resources we need to support 7.2 billion people.
- Chapter 8 (The Human Population) still covers population growth, the various revolutions that have increased

growth, and concepts such as the IPAT and ImPACT equations and the Gini index of inequality. Sections 8.1 and 8.3 have been streamlined substantially to place more emphasis on humans as populations.

- Chapter 9 (Population and Development) has a new Sustainability box ("Dealing with Graying Populations"), which covers the needs of increasingly elderly populations, using Japan as an example. The examples of China and India have been made into case studies of population growth. Later in the chapter, the Millennium Development Goals are discussed with a new table (9–2) that describes their levels of success. The new Sustainable Development Goals are rolled out in a new table (9–3).
- Chapter 10 (Water: Hydrologic Cycle and Human Use) has a new chapter opener on drought in California. More has been added on climate change and the concept of peak water. The section on dams has been made clearer and shortened. There is an added figure on the over-pumping of ground water. Additional information on water loss from aging infrastructure, water in agriculture and fracking, and on the UN's efforts to promote water planning is included.
- Chapter 11 (Soil: Foundation for Land Ecosystems) begins with a new picture of a dust storm in Arizona and a story about the Dust Bowl. A new story of land creation in China illustrates a different type of mountaintop removal. Throughout the chapter, there is more on mining, soil pollution, and reclamation. A new concept (the land-degradation neutral world) is introduced. And a new section on international efforts to protect soil is added. Soil is connected to the new Sustainable Development Goals as the chapter wraps up.
- Chapter 12 (The Production and Distribution of Food) has been altered significantly. The chapter is organized around three ideas—production, environmental sustainability, and effective distribution. The section on GMO crops has been substantially rewritten and updated. The last section, "Feeding the World as We Approach 2030–2050," has been rewritten and broken into four subsections: increasing food production, using current production more efficiently, sustainable agriculture, and policy changes. The term *food justice* is introduced and described.
- Chapter 13 (Pests and Pest Control) maintains many of the changes made in the twelfth edition, including a chapter opener on bedbugs and the updated essays. Throughout the chapter, as in all chapters, data and graphics have been updated. A new example of APHIS stopping a coconut rhinoceros beetle infestation in Hawaii is included.

Part Four—Harnessing Energy for Human Societies

- Part Four begins with an updated part opener with bad news and good news about energy.
- Chapter 14 (Energy from Fossil Fuels) includes an expanded discussion on oil sands, and the Keystone pipeline proposal is presented and illustrated. Discussions of natural gas, coal, and hydraulic fracturing (fracking) are expanded, with a new figure illustrating fracking. Policy is better described with two new tables dealing with demand-side and supply-side policy actions to lower U.S. dependence on foreign oil. More analysis of three major laws makes it clear they have both positive and negative aspects. The chapter also includes two new rules by the EPA, one about power plants and emissions and the other about coal ash.
- Chapter 15 (Nuclear Power) opens with a shortened and updated chapter opener about the earthquake and tsunami that rocked northern Japan in 2011, leading to the nuclear disaster at the Fukushima Daiichi power plant. New information is presented on the recent ecology of the area around Chernobyl, the current status of U.S. nuclear waste disposal, and on issues with extending power plant life spans.
- Chapter 16 (Renewable Energy) opens with a new opener about Germany's extraordinary effort to change its energy economy. An initial section ("Strategic Issues") examines the issues surrounding calls for great changes in renewable energy. A new figure (16-4) shows relative amounts of energy availability from different sources. The chapter has been changed to better reflect the pros and cons of each type of renewable energy and updates to their levels of use. Sections on dams and on energy laws have been shortened, as these concepts are covered in other chapters. A Sustainability box ("Transfer of Energy Technology to the Developing World") has been rewritten to reflect new dilemmas in that transfer.

Part Five—Pollution and Prevention

- Part Five begins with a part opener that describes the problems of pollution and lays out the coming chapters.
- Chapter 17 (Environmental Hazards and Human Health) opens with a new opener on Ebola covering the 2014–2015 international outbreak. The chapter has been restructured to begin with definitions of environmental health, focusing more on environmental harms and less on cultural hazards. Pollution is moved later and set in the context of other hazards. A new figure on malaria simplifies the discussion on that disease. A new Stewardship box ("A Cultural Hazard Worsens Other Risks") connects tobacco use to a range of other public health issues. New information on heavy metal, mining and industry as a pathway to risk, unintended poisonings, urban air pollution, radiation, climate change and public health, and exposure to animals as a pathway to infectious risk broadens the discussion on risks and pathways. A new Sound Science box ("Water Pollution Drives Malnutrition in India") describes cutting-edge research on the connection between water-borne disease and childhood stunting.
- Chapter 18 (Global Climate Change) is significantly revised. The chapter has been reframed around the newest (2013–2014) IPCC report (AR5) and includes information from the AAAS report *What We Know*

(2014) and *National Climate Assessment 3* (2014). The sections are reorganized so that the physical science basis of the atmosphere and how climate change occurs is in the first section, followed by evidence that climate change is occurring. The third section covers the effects of climate change, including new information on effects on glaciers. The term "risk multiplier" is introduced. Adaptation, mitigation, and geo-engineering are expanded. The major international climate conferences are rewritten and summarized in a new table. Information on talks between the United States and India, and the United States and China climate talks in 2014, is included, and the idea of "contract and converge" is added.

- Chapter 19 (Atmospheric Pollution) begins with an updated chapter opener on air pollution in Donora, Pennsylvania. The chapter now more clearly emphasizes two trends: global air quality is declining, while U.S. air quality is improving. There is a great deal more on international air pollution. A new Sound Science feature ("Complex Clouds and Co-Benefits of Solutions") explores the complexity of the environmental and health effects of atmospheric brown clouds and the positive benefits of solving multiple problems at the same time.
- Chapter 20 (Water Pollution and Its Prevention) begins with an updated chapter opener. A new Sound Science box ("Can Salt Marshes Absorb Our Nutrients?") explores new long-term research on the effects of nutrient pollution on salt marshes. International water issues are emphasized more, particularly in sections on sewage treatment and on policy. A new graphic makes the workings of composting toilets more clear. Water pollution is connected to themes from other chapters on global N and P cycles and planetary boundaries, as well as to both Millennium Development Goals and Sustainable Development Goals.
- Chapter 21 (Municipal Solid Waste: Disposal and Recovery) has a new chapter opener on positive waste management examples in both the country of Sweden and in Lagos, Nigeria. The chapter is revised to introduce waste disposal globally first, followed by waste disposal solutions in the United States such as recycling, and public policy. There is more on the ocean and new art depicting garbage gyres and the effects of trash on wildlife. More types of recycling are showcased, especially the recycling of tires, batteries, and e-waste. The chapter is more international, with more about informal recycling and reuse, people who live as waste pickers, and international regulations. There are more examples of positive change such as Big Belly Solar trash compactors, new materials replacing plastics, bag laws, and student volunteerism. New box features (Stewardship: "Citizen Power," and Sustainability: "Taking the Waste Out of Take-Out") highlight positive stories.
- Chapter 22 (Hazardous Chemicals: Pollution and Prevention) has a new opener on the contamination of water and soil from the mining of rare earth minerals in Inner Mongolia. Information on Bisphenol A, an endocrine disruptor, has been moved to a new box feature (Sound Science: "Disrupting Hormones with Pollution"). The historic protests in Warren County, North Carolina, in 1982 are used to introduce the environmental justice movement, a new topic in the final section.

Part Six—Stewardship for a Sustainable Future

- Chapter 23 (Sustainable Communities and Lifestyles) has been significantly reorganized to begin with a section on definitions and megatrends in communities (urbanization and the collapse of rural communities), followed by trends in U.S. communities. The urban heat-island effect and new art illustrating it have been added. The development of sustainable communities follows. A new box feature (Sustainability: "Curitiba, Brazil—City Planning Meets Growth") describes some of the successes and struggles of one of the most sustainable cities in Latin America. Discussions of urban homesteading, the revitalization of Detroit, city climate adaptation, smart growth (planning to avoid sprawl), smart cities (using big data), green buildings, and networks of big cities have been added. A new feature (Stewardship: "Living in Tiny Houses") highlights decisions some are making to lower their resource footprint.

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I would like to thank my husband, Gary, my biggest supporter. I am also very thankful to my mentors—particularly Richard Wright, who has known me for years and helped me inestimably—and Calvin DeWitt of the University of Wisconsin–Madison, who has been one of the foremost figures in motivating young people to care about the environment and ethics.

Finally, it is our hope that this book can inspire a new generation to work toward bringing healing to a Creation suffering from human misuse.

Dorothy F. Boorse

BE EQUIPPED TO UNDERSTAND THE ROLES OF **SCIENCE**, **SUSTAINABILITY**, AND **STEWARDSHIP**

The thirteenth edition builds on its student friendly approach with new built-in study tools, and retains its focus on science, sustainability and stewardship, equipping students with a current understanding of environmental science issues and research.

Populations and Communities

African savanna elephants (*Loxodonta africana africana*) saunter through the glaring sun of the East African savanna. Trunks swaying side to side, they seek out shrubs and grasses. Nearby, the indigenous people graze their herds of rangy cattle on the sparse, tough grasses. These pastoralists view the elephants as competitors that reduce the amount of food available to their cattle. The herders resent the elephants' use of the land, while the villagers fear that the elephants will trample their crops.

Current Threats. Like many large, slow-growing animals, these elephants are increasingly rare. Numbering from 3 to 5 million at the start of the 20th century, today there are only 450,000 to 700,000. Loss of habitat is one reason for their decline. In addition, poachers kill them for their ivory, even though the ivory trade is illegal. As climate change increases drought, elephants have to migrate farther and face more conflicts with humans than before. In 2014, a team of researchers from Elephants Without Borders began using light aircraft to document every group of elephants in the 13 sub-Saharan countries where 90% of savanna elephants live. Their initial findings documented the heavy poaching of elephants in numerous places.

While the number of elephants is declining, another native species, the aggressive Sodom apple (*Solanum campylacanthum*), is increasing. Unfortunately for the herders, this weedy shrub is toxic to grazing animals such as cattle, sheep, and zebras. In Kenya, the eradication of the noxious Sodom apple is costing the government millions.

A Win-Win Solution? In spite of the problems caused by the ongoing changes in East Africa, there is a small amount of good news. Unlike grazing animals, browsers such as elephants and impalas can eat the Sodom apple. In fact, elephants have a voracious appetite for the shrub, which may provide a

▲ African savanna elephants can eat plants that are unpalatable to sheep and cattle.

Chapter 4

Learning Objectives

4.1 Dynamics of Natural Populations: Describe three models of the way populations grow and the graph that would illustrate each.

4.2 Limits on Populations: Identify factors that limit populations, including those that increase as populations become more dense (such as predation and resource limitation) and factors that are unrelated to population density.

4.3 Community Interactions: Define the types of interactions that can occur between species in a community and the effect of those interactions on each species.

4.4 Evolution as a Force for Change: Describe the major ideas in the theory of evolution, such as inheritance and natural selection, and list examples of adaptations that allow organisms to survive. Explain how major changes in the Earth facilitate evolutionary change.

4.5 Implications for Management by Humans: Describe at least three ways in which human actions alter populations and communities.

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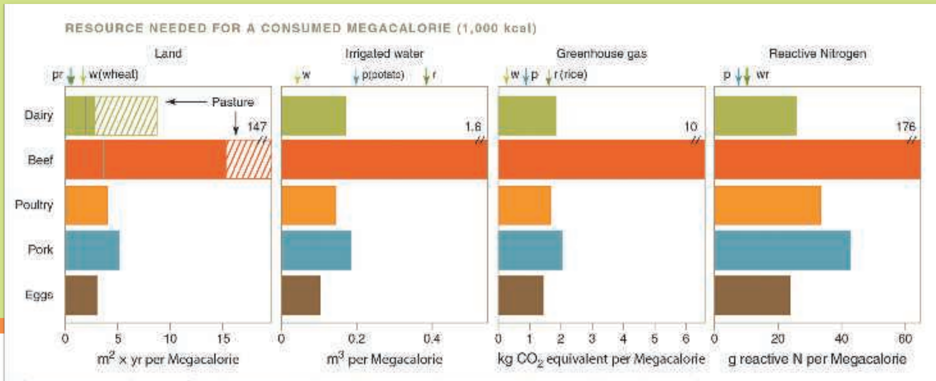
Numbered Learning Objectives open each chapter and introduce you to key concepts that you will understand at the conclusion of the chapter.

CONCEPT CHECK Which kind of population growth curve would you expect to see in a population of squirrels in a forest? Which would you expect to see in ragweed growing on a construction site? Why? ☑

CONCEPT CHECK How might the removal of a predator harm a community of a species? How might the removal of a competitor affect the community? ☑

CONCEPT CHECK Describe a human action that increases the size of a species' population and an action that decreases the size of a wild population. Give an example of each. ☑

NEW! Concept Check Questions align with each learning objective and appear at the end of each chapter section to provide you with opportunities to check and deepen understanding as you read each chapter. You can quickly check your knowledge by consulting the answer key at the back of the text.

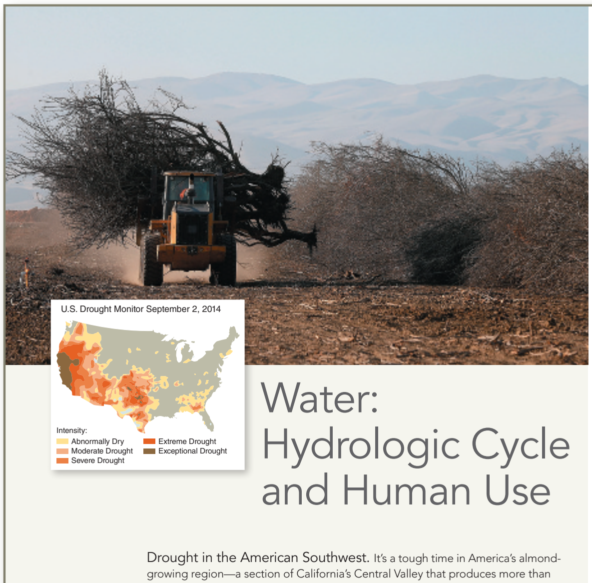


The Environmental Costs of Producing Meat. The graphs compare the environmental impact of the production of five types of animal-based foods. The resources needed to produce each food are listed per Megacalorie (1,000 kilo-calories), about half of the daily energy requirement for an adult. (The nutritional unit 1 Calorie is equal to 1 kilocalorie). Arrows at the top show the environmental costs of growing wheat, rice, and potatoes. Pastureland is marked with hatch marks. For some factors, the value for beef is off the scale and the correct number is marked at the end of the bar.

UNDERSTANDING THE DATA

1. What is the ratio between the amount of nitrogen used to grow beef and that used to produce eggs?
2. Which is greater, the pastureland or the other land used for beef production?
3. Is there a difference in the amount of irrigation water needed for poultry and pork?
4. Which emits more greenhouse gases, producing a Megacalorie (1,000 kilocalories) of rice or of eggs?

NEW! Understanding the Data ▶ questions prompt you to practice data interpretation skills and build understanding of environmental issues presented in select graphs, maps and tables in each chapter.



Chapter 10

Water: Hydrologic Cycle and Human Use

Learning Objectives

10.1 Water, a Vital Resource: Describe the unique properties that make water so vital, the differences in water availability in different societies, and conflicts over availability of clean water.

10.2 Hydrologic Cycle and Human Impacts: Explain the movement of water through the hydrologic cycle and human impacts on the cycle.

10.3 Water: Getting Enough, Controlling Excess: Describe the ways humans try to provide clean freshwater and some of their outcomes.

10.4 Water Stewardship, Economics, and Policy: Describe options for meeting rising demands for water, new innovations in water science and technology, and public policies for water in a water-scarce world.

Drought in the American Southwest. It's a tough time in America's almond-growing region—a section of California's Central Valley that produces more than 80% of the world's almonds. For several years this region has languished in deep drought, threatening the survival of the almond orchards. Almonds are a water-needy crop—it takes about 1.1 gallons of water to produce each nut. Indeed, almond trees require a great investment of water during all the years they are growing, including the first five years when they produce no nuts. The millions of gallons of water used to grow almonds cannot simply be turned off in a drought year. If farmers do not irrigate the almond trees, they will die, and the farmer will lose an investment of years.

California contains one sixth of the irrigated land in the country. Much of the water used for this irrigation has been diverted from far-away rivers. Those diversions endanger the salmon in the rivers, which require more water than is left for them. Some of the water used for irrigation is pumped from new wells that tap into ancient reserves of water that percolated underground millions of years ago. That groundwater is being withdrawn faster than any rain could replace it, depleting an underground resource owned by all.

Mega-Drought. California is not the only state in drought—the drought encompasses much of the Southwest. The drought, which has been going on since 2000, is now being called a "mega-drought." It is estimated to be the fifth most severe drought in that region since AD 1000. Stressed by the lack of water, trees in the forests are dying. The dry forests sit like tinder, waiting for a spark to set off a wildfire. The risk of wildfire is increased by the heavy load of unburned brush lying on the forest floor, the product of years of fire suppression. Large,

▲ These California almond trees are being removed because there is not enough water to irrigate them.

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▲

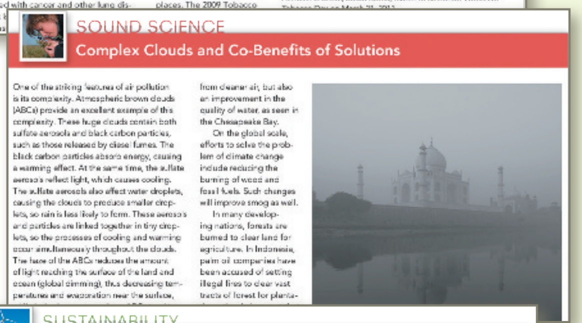
UPDATED! Engaging stories open each chapter and draw students into reading the chapter topic at hand. New topics include the drought in the western United States, the recent Ebola outbreak, and more.

Three unifying themes of science, sustainability, and stewardship help students conceptualize the task of forging a sustainable future. Essays appear at appropriate points within chapters and provide a current perspective on the topic.

▼

STEWARDSHIP

A Cultural Hazard Worsens Other Risks



SOUND SCIENCE

Complex Clouds and Co-Benefits of Solutions

SUSTAINABILITY

Taking the Waste Out of Take-Out

This filament is made of a plastic-like substance produced from the shells of shrimp and crabs.

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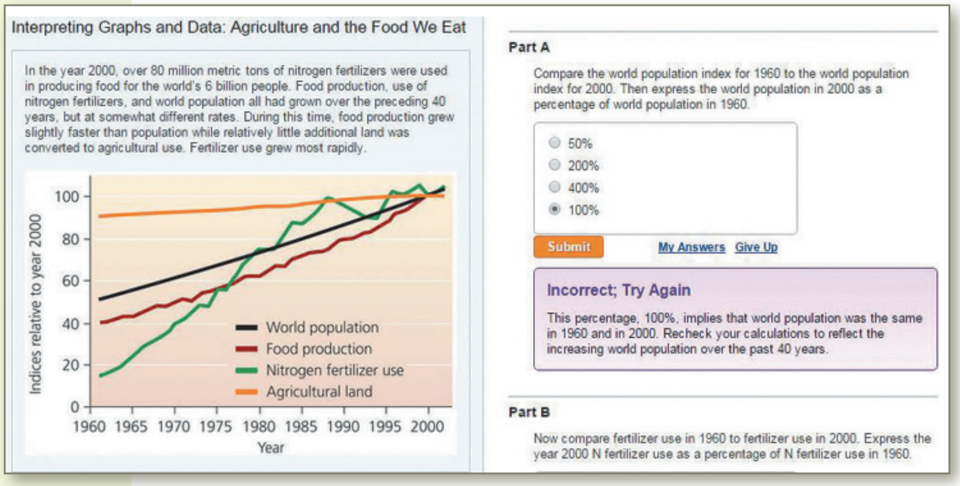

FRAMEWORK FOR A SUSTAINABLE FUTURE

PART ONE

Nights spent pouring over blueprints, days looking at budgets, time spent deciding what parts need to be purchased and who will maintain a structure after it is built: you might imagine these activities being performed by professionals building a road or school, but they aren't. This is the work of a team of dedicated engineering undergraduates from Purdue University and their advisors. They are designing a small hydropower facility in Banyang, Cameroon, which will provide water and irrigation for a village.

The project is designed to promote sustainability—the ongoing thriving of people in a context of the natural world, living in a way that doesn't use up resources, harm other creatures, or degrade our environment in the long term. Right now, there is evidence that we are not living sustainably: Our global economy relies on the use of fossil fuels and nuclear power, but continued emissions of carbon dioxide into the atmosphere and oceans are bringing major changes in the climate as Earth warms up and the oceans acidify. The human population will likely exceed 9 billion by 2050, but the populations of many wild plant and animal species are declining. For the poorest people, the availability of food, clean water, and basic health care remains low. Natural disasters such as the Japanese tsunami of 2011 can interact with the built environment to cause radiation leaks and other problems. Human activities such as coal mining can interact with the natural environment to cause events like the 2014 spill of thousands of gallons of an industrial chemical used to clean coal; when the chemical leaked into the Elk River in West Virginia, thousands were without drinkable water for weeks. We are all bound together: humanity, the other creatures, and the world around us.

We begin our framework for a sustainable future in Chapter 1, where we introduce environmental science and what it might mean for you. In Chapter 2, we look at three features of human societies that interact with science—economics, politics, and public policy—as we come to understand the environment and address the challenges we face.

Chapter 1

Learning Objectives

1.1 The State of the Planet: Explain the main reasons for concern about the health of our planet today. Describe what the environmental movement has achieved in recent years, and explain how environmental science has greatly contributed to the environmental movement.

1.2 Sustainability: Define sustainability and explain ways in which our relationship with the environment needs to be more sustainable.

1.3 Sound Science: Explain the process of science, how the scientific community tests new ideas, and contrast sound science with junk science, with examples.

1.4 Stewardship: Define the principle of stewardship and give examples.

1.5 Moving Toward a Sustainable Future: Identify trends that must be overcome in order to pursue a sustainable future and trends that promote sustainability.

Science and the Environment

"There was once a town in the heart of America where all life seemed to live in harmony with its surroundings. The town lay in the midst of a checkerboard of prosperous farms, with fields of grain and hillsides of orchards where, in spring, white clouds of blossom drifted above the green fields. . . . The countryside was, in fact, famous for the abundance and variety of its bird life, and when the flood of migrants was pouring through in spring and fall people traveled from great distances to observe them. . . . So it had been from the days many years ago when the first settlers raised their houses, sank their wells, and built their barns.[1]"

These are words from the classic *Silent Spring,* written by biologist Rachel Carson to open her first chapter, titled "A Fable for Tomorrow." After painting this idyllic picture, the chapter goes on to describe "a strange blight" that began to afflict the town and its surrounding area. Fish died in streams, farm animals sickened and died, families were plagued with illnesses and occasional deaths. The birds had disappeared, their songs no longer heard—it was a "silent spring." And on the roofs and lawns and fields remnants of a white powder could still be seen, having fallen from the skies a few weeks before.

Rachel Carson explained that no such town existed, but that all of the problems she described had already happened somewhere, and that there was the very real danger that ". . . this imagined tragedy may easily become a stark reality we all shall know."[2] She published her book in 1962, during an era when pesticides and herbicides were sprayed widely on the landscape to control pests in agricultural crops, forests, towns, and cities. In *Silent Spring,* Carson was particularly critical

[1]Rachel Carson, *Silent Spring* (Boston: Houghton Mifflin Company, 1962), 1, 2.
[2]Ibid., 3.

▲ Rachel Carson, the author of *Silent Spring*.

of the widespread spraying of DDT. This pesticide was used to control Dutch elm disease, a fungus that invades trees and eventually kills them. The fungus is spread by elm bark beetles and DDT was used to kill the beetles. In towns that employed DDT spraying, birds began dying off, until in some areas people reported their yards were empty of birds. Thousands of dead songbirds were recovered and analyzed in laboratories for DDT content; all had toxic levels in their tissues. DDT was also employed in spraying salt marshes for mosquito control, and the result was a drastic reduction in the fish-eating bald eagle and osprey.

Fallout. Rachel Carson brought two important qualities to her work: she was very careful to document every finding reported in the book, and she had a high degree of personal courage. She was sure of her scientific claims, and she was willing to take on the establishment and defend her work. In spite of the fact that her work was thoroughly documented, her book ignited a firestorm of criticism from the chemical and agricultural establishment. Even respected institutions such as the American Medical Association joined in the attack against her.

Despite this criticism, *Silent Spring* caught the public's eye, and it quickly made its way to the President's Science Advisory Committee when John F. Kennedy read a serialized version of it in the *New Yorker*. Kennedy charged the committee with studying the pesticide problem and recommending changes in public policy. In 1963, Kennedy's committee made recommendations that fully supported Carson's thesis. Congress began holding hearings, public debate followed, and Carson's voice was joined by others who called for new policies to deal not only with pesticides, but also with air and water pollution and more protection for wild areas. Finally, in 1969, Congress passed a bill known as the Environmental Policy Act, the first legislation to recognize the interconnectedness of ecological systems and human enterprises. Shortly after that, a commission appointed by President Richard Nixon to study environmental policy recommended the creation of a new agency that would be responsible for dealing with air, water, solid waste, the use of pesticides, and radiation standards. The new agency, called the Environmental Protection Agency (EPA), was given a mandate to protect the environment, on behalf of the public, against pressures from other governmental agencies and from industry. The year was 1970, the same year that 20 million Americans celebrated the first Earth Day.

In what must be seen as a triumph of Rachel Carson's work, DDT was banned in the United States and most other industrialized countries in the early 1970s. (The DDT story is more fully documented in Chapter 13.) Unfortunately, Rachel Carson did not live long after her world-shaking book was published; she died of breast cancer in 1964. Her legacy, however, is a lasting one: she is credited with initiating major reforms in pesticide policy as well as an environmental awareness that eventually led to the modern environmental movement and the creation of the EPA.

Moving On. This is a story of science and the environment, but it is more than that; it is a story of a courageous woman who changed the course of history. In this chapter, we briefly explore the current condition of our planet and then introduce three themes that provide structure to the primary goal of this text: *to promote a sustainable future.*

1.1 A Paradox: What Is the Real State of the Planet?

Paradox (n.): *A statement exhibiting contradictory or inexplicable aspects or qualities.*[3] A group of scientists from McGill University recently published a paper in which they identified a so-called **environmentalist's paradox.**[4] The paradox, they said, is this: over the past 40 years, human well-being has been steadily improving, while natural ecosystems (from which we derive many goods and services) have been declining.

To explain this paradox, the authors advanced four hypotheses:

1. The measurements of human well-being are flawed; it is actually declining.
2. Food production, a crucial ecosystem service that has been enhanced, outweighs the effects of declines in other ecosystem services.
3. Human technology, such as irrigation and synthetic fertilizers, makes us less dependent on ecosystem services.
4. There is a time lag between ecosystem decline and human well-being; the worst is yet to come.

We will take a brief look at four important global trends and keep in mind these hypotheses (the scientific method and hypotheses are explained later in the chapter) as we engage in our initial examination of the state of our planet: (1) human population and well-being, (2) the status of vital ecosystem services, (3) global climate change, and (4) the loss of biodiversity. Each of these topics is explored in greater depth in later chapters.

Population Growth and Human Well-Being

The world's human population, more than 7.3 billion in 2014, has grown by 2 billion in just the past 25 years. It is continuing to grow, at the rate of about 80 million persons per year. Even though the growth rate (now 1.1%/year) is gradually slowing, the world population in 2050 is likely to exceed 9.3 billion, according to the most recent projections from

[3] *Webster's II New College Dictionary* (Boston: Houghton Mifflin Company, 1995), s.v. "paradox."

[4] Ciara Raudsepp-Hearne et al., "Untangling the Environmentalist's Paradox: Why Is Human Well-Being Increasing as Ecosystem Services Degrade?" *Bioscience* 60 (September 2010): 576–589.

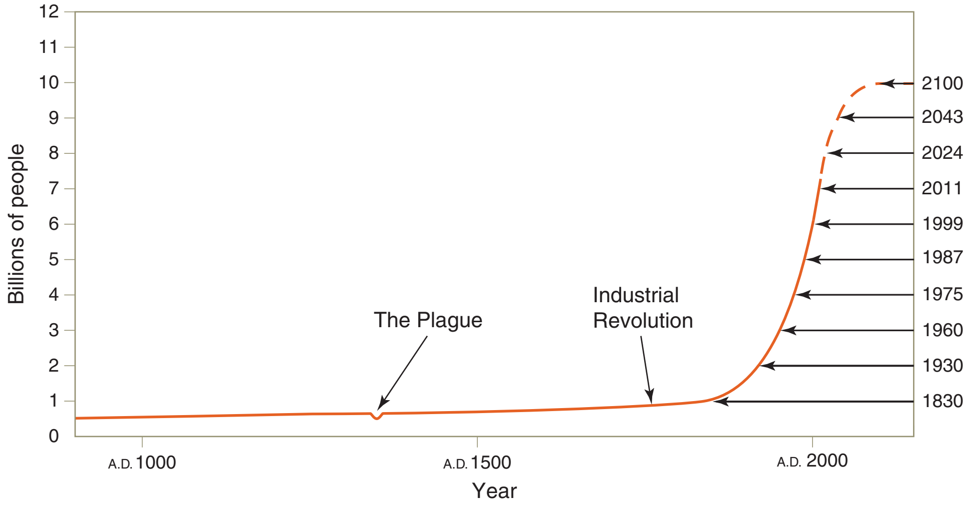

Figure 1–1 World population explosion. World population started a rapid growth phase in the early 1800s and has increased sixfold in the past 200 years. At present it is growing by 80 million people per year. Future projections are based on assumptions that birthrates will continue to decline.

(*Source:* Data from UN Population Division, 2012 revision, and from Population Reference Bureau 2014 report.)

the United Nations (UN) Population Division (Figure 1–1). The 2.2 billion persons added to the human population by 2050 will all have to be fed, clothed, housed, and, hopefully, supported by gainful employment. Virtually all of the increase will be in developing countries.

Human Development Index. Each year since 1990, the United Nations Development Program (UNDP) has published a Human Development Report.[5] A key part of the report is the *Human Development Index* (HDI), a comprehensive assessment of human well-being in most countries of the world. With this index, well-being is measured in health, education, and basic living standards. The 2014 report highlighted the importance of resiliency and the vulnerability of the poor, suggesting that poverty is not simply a function of the amount of money people have, but is also a function of factors such as literacy and stability.

The 2010 report included a unique four-decade comparison in which worldwide trends in HDI were plotted over the 40 years since 1970 (Figure 1–2). Only three of the 135 countries analyzed declined in HDI, while most of the countries showed marked improvement. During those 40 years, life expectancy rose from 59 years to 70, school enrollment climbed from 55% to 70%, and per capita gross domestic product (GDP) doubled to more than $10,000. It is this overall progress that has provided one side of the environmentalist's paradox. As a result of these facts, the McGill team concluded that its first hypothesis is not supported; there are too many indications that human well-being has indeed improved markedly.

Is It All Good? However, the overall progress can, and does, mask serious inequalities. Economic growth has been extremely unequal, both between and within countries. And there are huge gaps in human development across the world. For example, in developing countries, an estimated 1.1 billion people still experience extreme poverty, existing on an income of $1.25 a day. More than 800 million people, about 13% of the people living in developing countries, remain undernourished. Some 6.9 million children per year do not live to see their fifth birthday.

Addressing these tragic outcomes of severe poverty has been a major concern of the UNDP, and in 2000, all UN member countries adopted a set of goals—the **Millennium Development Goals (MDGs)**—to reduce extreme poverty and its effects on human well-being by 2015 (see Table 9–2 for a list of the eight goals). Several of the MDGs were met ahead of schedule, while others were not met. The world has now moved to a post-2015 development agenda, driven by a set of seventeen **Sustainable Development Goals (SDGs)** discussed at length later (Chapter 9). The SDGs are a set of goals for world development and poverty alleviation, described by the UN, for 2015–2030.

Ecosystem Goods and Services

Natural and managed ecosystems support human life and economies with a range of goods and services. As crucial as they are, there is evidence that these vital resources are not being managed well. Around the world, human societies are depleting groundwater supplies, degrading agricultural soils, overfishing the oceans, and cutting forests faster than they can regrow. The world economy depends heavily on many renewable resources, as we exploit these systems for **goods**—water, all of our food, much of our fuel, wood for lumber and paper, leather, furs, raw materials for fabrics, oils and alcohols, and much more.

These same ecosystems also provide a flow of **services** that support human life and economic well-being, such as the breakdown of waste, regulation of the climate, erosion control, pest management, and maintenance of crucial nutrient cycles. In a very real sense, these goods and services can be thought of as capital—ecosystem capital. Human well-being and economic development are absolutely dependent on the products of this capital—its income, so to speak. As a result, the stock of ecosystem capital in a nation and its income-generating capacity represent a major form of the wealth of the nation (see Chapter 2). These goods and services are provided year after year, as long as the ecosystems producing them are protected.

[5]United Nations Development Program, *Human Development Report 2014: Sustaining Human Progress: Reducing Vulnerabilities and Building Resilience.* (New York: UNDP, July 24, 2014), http://hdr.undp.org/en/2014-report.

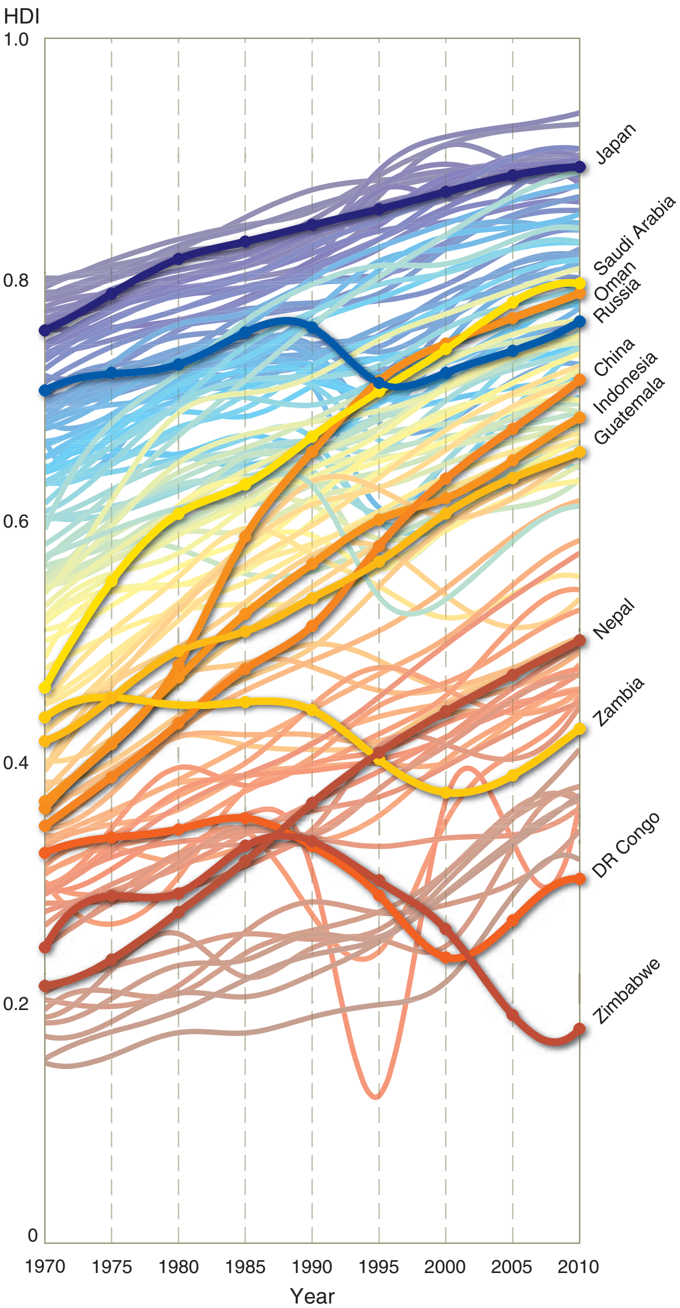

Figure 1–2 Human Development Index, 1970–2010. This complex graph shows the Human Development Index (HDI) of more than 100 countries over a period of 40 years. Countries represented by lines with similar colors began the time period with similar HDI values. Highlighted countries include top and bottom performers (in terms of increasing HDI) and selected others. (This four-decade graph accompanied a 2010 special report. Newer reports highlight these trends in other ways.)

(*Source:* United Nations Development Program, *Human Development Report 2010*. New York: UNDP, p. 27.)

UNDERSTANDING THE DATA

1. All but three of the 135 countries have a higher level of human development today than in 1970. What explains the general upward trend for most countries?
2. Which two labeled countries appear to have improved the most? Which of the labeled countries decreased?
3. What historical event might explain the pattern for the line representing Russia?

Patterns of Resource Consumption. As the human population grows, each person requires food, water, shelter, clothing, and other resources. Many of the goods and services that people need are derived from ecosystems. However, not all people use the same amount of resources. Any discussion of population growth, development, and the preservation of ecosystem services needs to include the idea that some people consume more resources than is necessary. One way to imagine individual consumption patterns is to picture what it would require to have everyone consume resources at the same level. For example, if all humans alive today replicated the resource consumption patterns of the average American, we would need more than four Earths to accommodate all of their needs. The concept of individual consumption will be covered extensively later (Chapters 2, 8, and 23).

Measuring Ecosystem Health: A Huge Undertaking. To protect ecosystem goods and services for future generations, we need to know what they are, how they are being used, and what is happening to them. To find out, scientists have carried out a number of large-scale assessments.

The most prominent, the *Millennium Ecosystem Assessment*, compiled available information on the state of ecosystems across the globe. During a period of four years, some 1,360 scientists from 95 countries gathered, analyzed, and synthesized information from published, peer-reviewed research. The project focused especially on the linkages between ecosystem services and human well-being on global, regional, and local scales. Ecosystem goods and services were grouped into *provisioning* services (goods such as food and fuel), *regulating* services (processes such as flood protection), and *cultural* services (nonmaterial benefits such as recreation) (see **Table 1–1** on the following page). *Supporting* services (not included in the table), such as primary productivity and habitat, are necessary to the other three.

In a summary report, the most prominent finding of the scientists was the widespread degradation and overexploitation of ecosystem resources. More than 60% of the classes of ecosystem goods and services assessed by the team were being degraded or used unsustainably (Table 1–1). The scientists concluded that if this trend is not reversed, the next half century could see deadly consequences for humans as the ecosystem services that sustain life are further degraded. Since the Millennium Ecosystem Assessment, a number of other assessments have been conducted; several are listed in **Table 1–2** (on the following page). Some of these assessments considered global patterns and others focused on regional ecosystems, but all found similar trends.

One set of provisioning ecosystem services has actually been enhanced over recent years: the production of crops, livestock, and aquaculture. As a result, the production of food has kept pace with population growth, improving human health and increasing life expectancy. However, many ecosystem services and resources such as groundwater, soil, wild fish, and forestry products have declined, in part because of the way we use land and other resources to provide food, shelter, and consumer goods for humans.

Paradox Resolved? The McGill team set out to explain the environmentalist's paradox—the fact that human well-being has been improving while natural ecosystems have been declining. It rejected hypothesis 1, which stated that human well-being is actually declining. The team concluded that *hypothesis 2 was confirmed*: enhanced food production outweighs the effects of declines in other ecosystem services. Two further hypotheses remain: (3) our use of technology makes us less dependent on ecosystem services, and (4) the existence of a time lag between the loss of goods and services and the impact on human well-being, with the possibility of exceeding limits and bringing on ecosystem collapse. The McGill University team concluded that these last two hypotheses help explain the environmentalist's paradox, although not as

Table 1–1 The global status of ecosystem services. Human use has degraded almost two-thirds of the identified services; 20% are mixed, meaning they are degraded in some areas and enhanced in others; and 17% have been enhanced by human use.

Ecosystem Services	Degraded	Mixed	Enhanced
Provisioning (goods obtained from ecosystems)	Capture fisheries Wild foods Wood fuel Genetic resources Biochemicals Fresh water	Timber Fiber	Crops Livestock Aquaculture
Regulating (services obtained from the regulation of ecosystem processes)	Air quality regulation Climate regulation Erosion regulation Water purification Pest regulation Pollination Natural hazard regulation	Water regulation (flood protection, aquifer recharge) Disease regulation	Carbon sequestration (trapping atmospheric carbon in trees, etc.)
Cultural (nonmaterial benefits from ecosystems)	Spiritual and religious values Aesthetic values	Recreation and ecotourism	

Source: Millennium Ecosystem Assessment, *Ecosystems and Human Well-Being: Synthesis*. Washington, DC: Island Press, 2005.

Table 1–2 Examples of previous and ongoing ecosystem and biodiversity assessments.

Title	Organization	Year(s)
Global Biodiversity Assessment	UN Environmental Programme (UNEP)	1995
Millennium Ecosystem Assessment	UNEP; World Resources Institute	2005
State of the Nation's Ecosystems	The Heinz Center	2002, 2008
National Ecosystem Assessment	United Kingdom	2011
Sustaining Environmental Capital: Protecting Society and the Economy	President's Council of Advisors on Science and Technology	2011
Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES)	UNEP	2012
Global Environmental Outlook (GEO)	UNEP	1997, 1999, 2002, 2007, 2012
IUCN Red List of Threatened Species	International Union for Conservation of Nature (IUCN)	2000, 2004, 2008, 2012
Biodiversity Ecosystems and Ecosystem Services, Technical Input	Part of National Climate Assessment	2014

Source: Adapted from Grimm, N., M. Staudinger, A. Staudt, S. Carter, F. S. Chapin III, P. Kareiva, M. Ruckelhaus, and B. Stein. "Climate-Change Impacts on Ecological Systems: Introduction to a US Assessment." *Frontiers in Ecology and the Environment* 9, no. 11 (2013): 456–464.

clearly as hypothesis 2. The team concluded that the paradox is not fully explained by any of the hypotheses, although hypothesis 1 was rejected. It also concluded that ecosystem conditions are indeed continuing to decline, with unknown and perhaps severe impacts on human well-being in the future. The most serious concern is **global climate change**, the worldwide alteration of patterns of temperature, precipitation, and the intensity of storms.

Global Climate Change

The global economy runs on fossil fuel. Every day in 2013 we burned some 91.3 million barrels of oil, 324 billion cubic feet of natural gas, and 11.6 million tons of coal. All of this combustion generates carbon dioxide (CO_2), which is released into the atmosphere at a rate of 80 million tons a day. Because of past and present burning of fossil fuels, the CO_2 content of the atmosphere increased from 280 parts per million (ppm) in 1900 to 400 ppm in 2014. For the past decade, the level of atmospheric CO_2 has increased by 2 ppm per year, and given our dependency on fossil fuels, there is no end in sight.

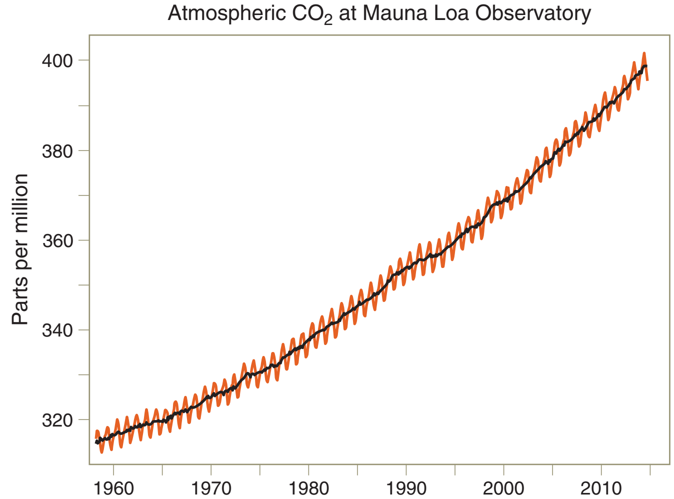

Figure 1–3 Atmospheric carbon dioxide concentrations. This record of CO_2 has been measured at the Mauna Loa Observatory since 1958. The atmospheric content of CO_2 has risen by 45% since the Industrial Revolution began around 1750.

(*Source:* Mauna Loa Observatory, Hawaii, NOAA Research Laboratory, Scripps Institution of Oceanography.)

Monitoring Carbon Dioxide and Its Effects. Carbon dioxide is a natural component of the lower atmosphere, along with nitrogen and oxygen. It is required by plants for photosynthesis and is important to the Earth-atmosphere energy system. Carbon dioxide gas absorbs infrared (heat) energy radiated from Earth's surface, thus slowing the loss of this energy to space. The absorption of infrared energy by CO_2 and other gases warms the lower atmosphere in a phenomenon known as the **greenhouse effect**. As the greenhouse gases trap heat, they keep Earth at hospitable temperatures.

Although the concentration of CO_2 is a small percentage of the atmospheric gases, increases in the volume of this gas affect temperatures. Figure 1–3 graphs changes in the concentration of CO_2 in the atmosphere from 1958 to the present. (The yearly peaks and valleys on the graph result from seasonal changes in the uptake of CO_2. In summer, plants take in more CO_2 for photosynthesis than they do in winter, causing the total concentration of CO_2 in the atmosphere to decrease. The pattern of peaks and valleys reflects the seasons of the Northern Hemisphere, where most of Earth's landmasses and plants are located.) Figure 1–4 shows changes in global temperature since 1880. Both of these parameters are increasing. This is not *proof* that increases in CO_2 caused the increase in global temperature, but the argument based on the well-known greenhouse effect is quite convincing.

The Intergovernmental Panel on Climate Change (IPCC) was established by the UN in 1988 and given the responsibility to report its assessment of climate change at five-year intervals. The latest of these assessments, the Fifth Assessment Report (AR5), was released during 2013 and 2014. The work of thousands of scientific experts, this assessment produced convincing evidence of human-induced global warming that is

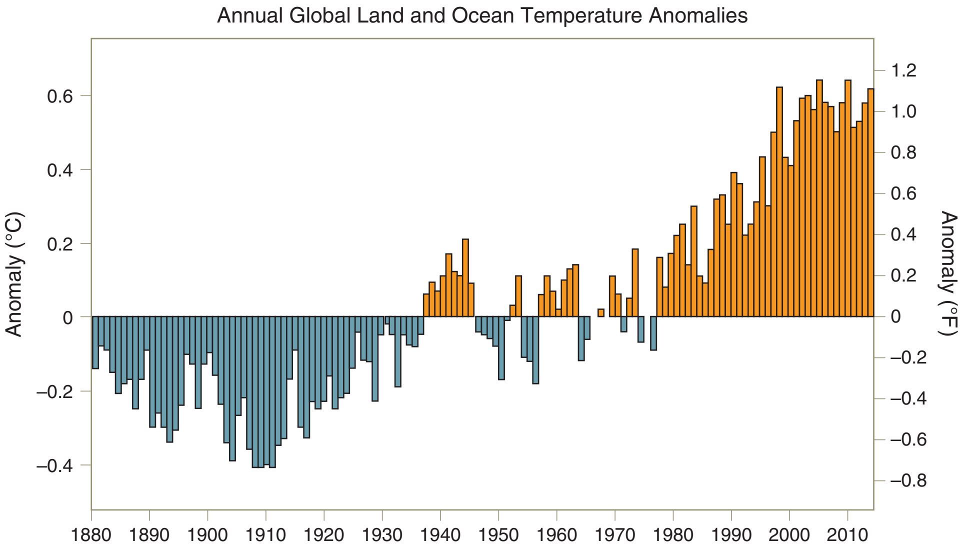

Figure 1–4 Global temperatures since 1880. This graph shows the course of global temperatures as recorded by thousands of stations around the world. The baseline, or zero point, is the 20th century average temperature. A temperature anomaly is the amount the global mean temperature for a particular year differs from that baseline.

(*Source:* National Climatic Data Center, NOAA, 2014.)

already severely affecting the global climate. Polar ice is melting at an unprecedented rate, glaciers are retreating, storms are increasing in intensity, and sea level is rising. Because the oceans are absorbing half of the CO_2 produced by burning fossil fuels and producing cement, the pH of seawater is declining, making the oceans more acidic. The Sound Science essay, *Oysters Sound the Alarm* (see p. 13) explores one consequence of ocean acidification. The IPCC concluded that future climate change could be catastrophic if something is not done to bring the rapidly rising emissions of CO_2 and other greenhouse gases under control. With few exceptions, the scientists who have studied these phenomena have reached a clear consensus: Climate change is a huge global problem, and it must be addressed on a global scale.

Responses. The solutions to this problem are not easy. The most obvious need is to reduce global CO_2 emissions; the reduction of emissions is called **mitigation**. At issue for many countries is the conflict between the short-term economic impacts of reducing the use of fossil fuels and the long-term consequences of climate change for the planet and all its inhabitants. Future climate changes are likely to disrupt the provision of ecosystem goods and services essential to human well-being, and because the extremely poor depend especially on natural ecosystems, they will suffer disproportionately. International agreements to reduce greenhouse gas emissions have been forged, and some limited mitigation has been achieved.

Most observers believe that the best course forward is to aim toward an effective, binding international treaty to reduce emissions, but for countries also to act independently on a more immediate scale. The United States is moving forward to regulate greenhouse gas emissions under existing air pollution laws and to encourage renewable energy development. Without doubt, this is one of the defining environmental issues of the 21st century. (Chapter 18 explores the many dimensions of global climate change.)

Loss of Biodiversity

Biodiversity is the variability among living organisms, both terrestrial and aquatic. It includes the variety within species, among species, and within ecosystems. The rapidly growing human population, with its increasing appetite for food, water, timber, fiber, and fuel, is accelerating the conversion of forests, grasslands, and wetlands to agriculture and urban development. The inevitable result is the loss of many of the wild plants and animals that occupy those natural habitats. Pollution also degrades habitats—particularly aquatic and marine habitats—eliminating the species they support. Further, hundreds of species of mammals, reptiles, amphibians, fish, birds, and butterflies, as well as innumerable plants, are exploited for their commercial value. Even when species are protected by law, many are hunted, killed, and marketed illegally. According to the Global Biodiversity Outlook 4 (GBO 4) assessment, the majority of wild plant and animal species are declining in their range and/or population size.[6]

As a result of these human activities, Earth is rapidly losing many of its species, although no one knows exactly how many. About 2 million species have been described and classified, but scientists estimate that 5 to 30 million species may exist on Earth. Because so many species remain unidentified, the exact number of species becoming extinct can only be estimated. Recently the World Wildlife Fund reported that since 1970, more than 10,000 populations of vertebrates, representing more than 3,000 species, have been reduced on average by half.[7] The most dramatic declines occurred in freshwater species; regionally, more declines occurred in the tropics.

Why is the loss of biodiversity so critical? Biodiversity is the mainstay of agricultural crops and of many medicines. It is a key factor in maintaining the stability of natural systems and enabling them to recover after disturbances such as fires or volcanic eruptions. Many of the essential goods and services provided by natural systems are derived directly from various living organisms. These goods and services are especially important in sustaining the poor in developing countries. There are also aesthetic and moral arguments for maintaining biodiversity: Once a species is gone, it is gone forever. Finding ways to protect the planet's biodiversity is one of the major challenges of environmental science. (Chapter 6 covers loss of biodiversity.)

Environmental Science and the Environmental Movement

As you read this book, you will encounter descriptions of the natural world and how it works. You will also encounter a great diversity of issues and problems that have arisen because human societies live in this natural world. We use materials from it (goods taken from natural ecosystems); we convert parts of it into the built environment of our towns, cities, factories, and highways; and we transform many natural ecosystems into food-producing agricultural systems. We also use the environment as a place to dump our wastes—solids, liquids, gases—which affects the rest of the world. The **environment**, then, includes the natural world, human societies, and the human-built world; it is an extremely inclusive concept.

Environmental Science. Things go wrong in the environment, sometimes badly. We have already considered four trends—human population growth, ecosystem decline, global climate change, and loss of biodiversity—that signal to us that we are creating problems for ourselves that we ignore at our peril. Lest you think that all we do is create problems, however, consider some of the great successes human societies have achieved. We have learned how to domesticate landscapes and ecosystems, converting them into highly productive food-producing systems that provide sustenance for more than 7 billion people. We have learned how to convert natural materials into an endless number of manufactured goods and structures, all useful for the successful building of cities, roadways, vehicles, and all that makes up a 21st-century human society. All of these successes, however, carry with them hazards.

[6]Secretariat of the Convention on Biological Diversity, *Global Biodiversity Outlook 4* (Montreal, 2014), accessed September 5, 2014, www.cbd.int/gbo3.

[7]World Wildlife Fund, *Living Planet Report 2014*.

Human actions have negative effects on the environment in two broad categories: cumulative impacts and unintended consequences. Sometimes we simply do too much of any one activity—too much burning, too much tree cutting, too much mining on steep slopes. Activities that would not pose a problem if a few people engaged in them are big problems if millions of people do. Sometimes it isn't the accumulation of an activity; it is that we are not paying attention to how the world works. There are unintended consequences of using chemical pesticides, as we've seen, or of dumping trash in wetlands. These two concepts, cumulative impacts and unintended consequences, will come up in the chapters ahead. This is where environmental science comes in.

Simply put, **environmental science** is the study of how the world works. Scientists help figure out ways to lower the negative impacts of our actions, to find alternative ways to meet the same needs, and to better anticipate the likely effects of what we are doing. All sorts of disciplines contribute to environmental science: history, engineering, geology, physics, medicine, biology, and sociology, to name a few. It is perhaps the most multidisciplinary of all sciences. As you study environmental science, you have an opportunity to engage in something that can change your life and that will certainly equip you to better understand the world you live in now and will encounter in the future.

The Early Environmental Movement. To understand how the world works today, we need some sense of history. Figure 1–5 is a timeline of some of the events and scientific findings, people, and policies of the American environmental movement as well as several international environmental events that will come up throughout the book.

In the United States, the modern environmental movement began less than 60 years ago. The roots of this movement were in the late 19th century, when some people realized that the unique, wild areas of the United States were disappearing. Environmental degradation, resource misuse, and disastrous events sparked scientific study and sometimes grassroots action. Scientific study yielded information on how the world works. Individuals and groups worked as stewards to make changes. Policies were put into place to better protect resources and people from environmental degradation.

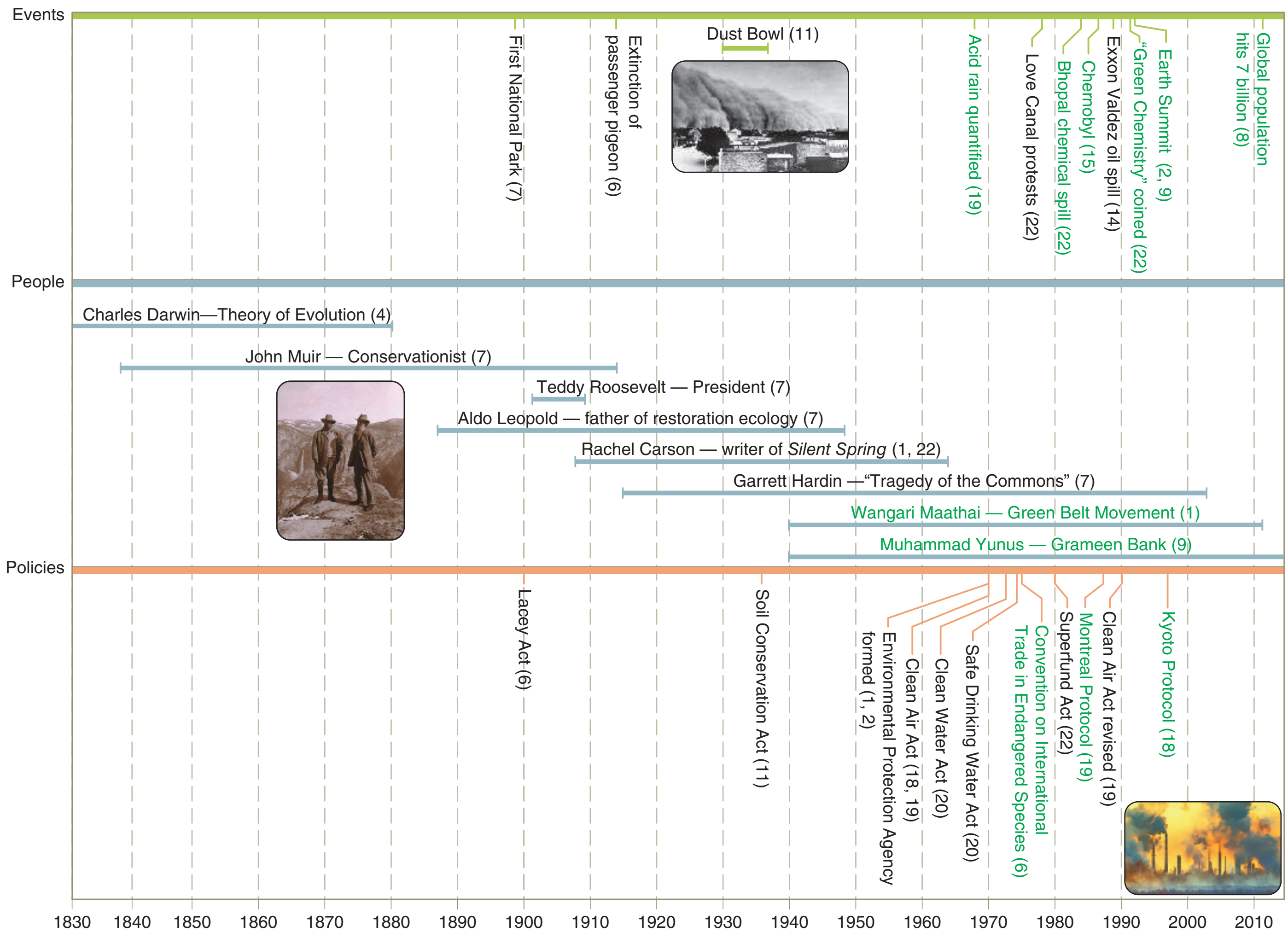

Figure 1–5 Timeline of selected American and international environmental events, people, and policies. These critical pieces of environmental history will be covered throughout the book. Numbers next to each of the events and scientific findings, people, and policies are the chapters in which they are discussed. International subjects are labeled in green.