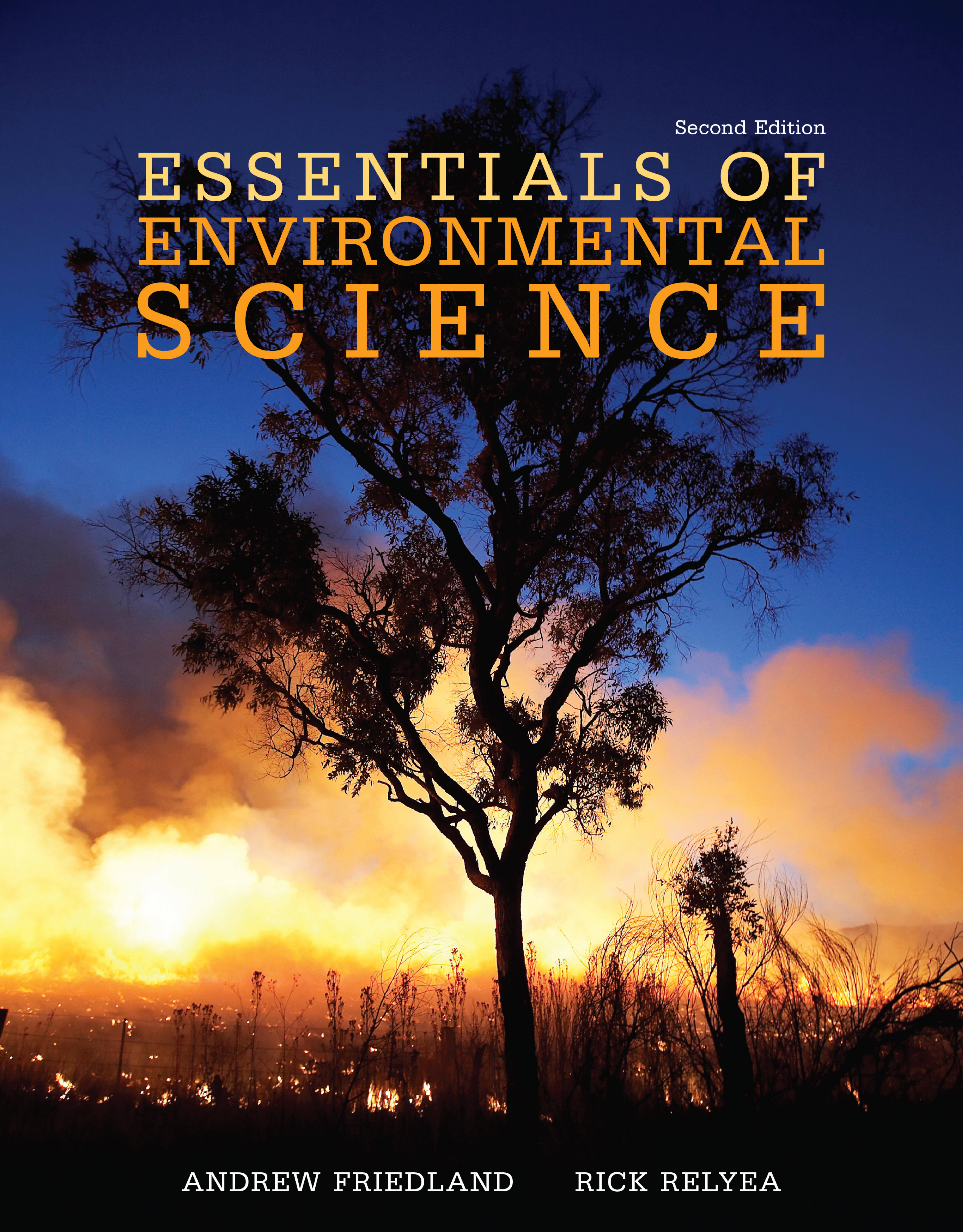
Second Edition

ESSENTIALS OF ENVIRONMENTAL SCIENCE



ANDREW FRIEDLAND RICK RELYEA

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SECOND EDITION

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Second Edition

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To Katie, Jared, and Ethan for their interest and enthusiasm

—AJF

To Christine, Isabelle, and Wyatt for their patience and inspiration

—RAR

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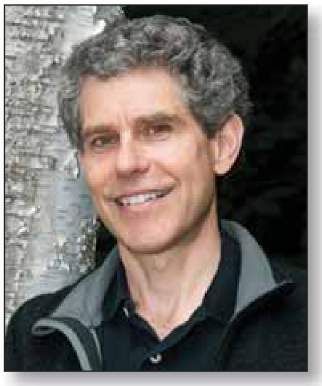

[Nancy Nutile-McMenemy]

Andrew Friedland is Richard and Jane Pearl Professor in Environmental Studies and chair of the Environmental Studies Program at Dartmouth College. Andy regularly teaches introductory environmental science and energy courses at Dartmouth and has taught courses in forest biogeochemistry, global change, and soil science, as well as foreign study courses in Kenya. In 2015, Andy brought his introductory environmental science course to the massive, open, online course format through the DartmouthX platform.

Andy received a BA degree in both biology and environmental studies, and a PhD in earth and environmental science from the University of Pennsylvania. For more than two decades, Andy has been investigating the effects of air pollution on the cycling of carbon, nitrogen, and lead in high-elevation forests of New England and the Northeast. Recently, he has been examining the impact of increased demand for wood as a fuel, and the subsequent effect on carbon stored deep in forest soils.

Andy has served on panels for the National Science Foundation, USDA Forest Service, and Science Advisory Board of the Environmental Protection Agency. He has authored or coauthored more than 65 peer-reviewed publications and one book, *Writing Successful Science Proposals* (Yale University Press).

Andy is passionate about saving energy and can be seen wandering the halls of the Environmental Studies Program at Dartmouth with a Kill A Watt meter, determining the electricity load of vending machines, data projectors, and computers. He pursues energy saving endeavors in his home as well and recently installed a 4kW photovoltaic tracker that follows the Sun during the day.

[Brian Mattes]

Rick Relyea is the David Darrin Senior '40 Endowed Chair in Biology and the Executive Director of the Darrin Freshwater Institute at the Rensselaer Institute of Technology. Rick teaches courses in ecology, evolution, and animal behavior at the undergraduate and graduate levels. He received a BS in environmental forest biology from the State University of New York College of Environmental Science and Forestry, an MS in wildlife management from Texas Tech University, and a PhD in ecology and evolution from the University of Michigan.

Rick is recognized throughout the world for his work in the fields of ecology, evolution, animal behavior, and ecotoxicology. He has served on multiple scientific panels for the National Science Foundation and the Environmental Protection Agency. For two decades, he has conducted research on a wide range of topics, including predator-prey interactions, phenotypic plasticity, eutrophication of aquatic habitats, sexual selection, disease ecology, long-term dynamics of populations and communities across the landscape, and pesticide impacts on aquatic ecosystems. He has authored more than 130 scientific articles and book chapters, presented research seminars throughout the world, and co-authored the leading ecology textbook, *Ecology: The Economy of Nature*. Rick recently moved to Rensselaer from University of Pittsburgh, where he was named the Chancellor's Distinguished Researcher in 2005 and received the Tina and David Bellet Teaching Excellence Award in 2014.

Rick's commitment to the environment extends to his personal life. He lives in a home constructed with a passive solar building design and equipped with active solar panels on the roof.

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Jeffery A. Schneider is an associate professor of environmental chemistry at the State University of New York in Oswego, New York. He teaches general chemistry, environmental science, and environmental chemistry.

Preface

We are delighted to introduce the second edition of *Essentials of Environmental Science*. Our mission has been to create a book that provides streamlined coverage of the core topics in the first environmental science course while also presenting a contemporary, holistic approach to learning about Earth and its inhabitants. The book not only engages the fundamentals of environmental science but also shows students how environmental science informs sustainability, environmental policies, economics, and personal choices.

This book took shape over the course of a decade. Subject to a rigorous development and review process to make sure that the material is as accurate, clear, and engaging as possible, we wrote and rewrote until we got it right. College instructors and specialists in specific topics have checked to make sure we are current and pedagogically sound. The art development team worked with us on every graphic and photo researchers sifted through thousands of possibilities until we found the best choice for each concept we wished to illustrate. The end-of-chapter problems and solutions were also subject to review by both instructors and students. Here's what we think is special.

A Balanced Approach with Emphasis on the Essentials

Daily life is filled with decisions large and small that affect our environment. From the food we eat, to the cars we drive or choose not to drive, to the chemicals we put into the water, soil, and air, the impact of human activity is wide-ranging and deep. And yet decisions about the environment are not often easy or straightforward. Is it better for the environment to purchase a new, energy-efficient hybrid car or to continue using the car you already own, or to ride a bicycle or take public transportation? Can we find ways to encourage development without creating urban sprawl? Should a dam that provides electricity for 70,000 homes be removed because it interferes with the migration of salmon?

As educators, scientists, and people concerned about sustainability, our goal is to help today's students prepare for the challenges they will face in the future. *Essentials of Environmental Science* does not preach or tell students how to conduct their lives. Rather, we focus on the science and show students how to make decisions based on their own assessments of the evidence.

Ideal for a One-Semester First Course in Environmental Science

Essentials of Environmental Science contains 15 chapters, which is ideal for an initial, one-semester course. At a rate of one chapter per week, both instructors and students are able to get through the entire book in a given semester, therefore maximizing its use.

Focus on Core Content

We understand that students drawn to this course may have a variety of backgrounds. Through its streamlined presentation of core content and issues, *Essentials of Environmental Science* seeks to stimulate and inspire students who may never take another science course. At the same time, our text includes coverage appropriate for students who will go on to further studies in science.

A Pedagogical Framework to Reinforce Classroom Learning

We have built each chapter on a framework of learning tools that will help students get the most out of their first course in environmental science. Pedagogical features include:

- **Chapter opening case studies:** Each chapter opens with a detailed case study that motivates the student by showing the subject of the chapter in a real-world context.
- **Understand the Key Ideas:** A list of key concepts follows the opening case. This tool helps students organize and focus their study.
- **Gauge Your Progress:** After each major chapter section, these review questions ask students to test their understanding of the material.
- **Photos and line art:** Developed in conjunction with the text by specialists in the field of science illustration, figures have been selected and rendered for maximum visual impact.
- **Revisit the Key Ideas:** Chapter summaries are built around the Key Ideas list to reinforce chapter concepts.
- **Working Toward Sustainability:** Chapters conclude with an inspiring story of people or organizations that are making a difference to the environment.
- **Check Your Understanding:** At the end of each chapter, Check Your Understanding questions, in multiple-choice format, test student comprehension.
- **Apply the Concepts:** A multilevel response question at the end of each chapter helps students solidify their understanding of key concepts by applying what they have learned in the chapter to relevant situations.
- **Measure Your Impact:** In the Measure Your Impact question at the end of each chapter, students are asked to calculate and answer everyday problem scenarios to assess their environmental impact and make informed decisions.
- **Graphing Appendix:** A graphing appendix at the end of the book helps students review graphing essentials.

We'd Love to Hear from You

Our goal—to create a balanced, holistic approach to the study of environmental science—has brought us in contact with hundreds of professionals and students. We hope this book inspires you as you have inspired us. Let us know how we're doing! Feel free to get in touch with Andy at andy.friedland@dartmouth.edu and Rick at Env.Science.Relyea@gmail.com.

Supplements

For the Instructor

Teaching Tips offer a chapter-by-chapter guide to help instructors plan lectures. Each chapter's Teaching Tips outline common student misconceptions, providing suggestions for in- and out-of-class activities and a list of suggested readings and websites.

Lecture PowerPoints have been pre-built for every chapter with your student in mind. Each lecture outline features text, figures, photos, and tables to help enhance your lecture.

JPEGs for every figure from the text–including their labels–are available in high resolution to incorporate in your lectures.

Labs give your students the opportunity to apply key concepts, collect data, and think critically about their findings.

Printed Test Bank includes approximately 100 multiple-choice, free-response, and footprint calculation questions per chapter. These questions are tagged to the "Key Ideas" for each chapter and organized by their level of difficulty.

Computerized Test Bank includes all of the printed test bank questions in an easy-to-use computerized format. The software allows instructors to add and edit questions and prepare quizzes and tests quickly and easily.

Course Management Coursepacks include the student and instructor materials in Blackboard, WebCT, and other selected platforms.

For the Student

The following resources are available for students online at www.macmillanhighered.com/friedlandessentials2e:

Flash Cards
Drag and Drop Exercises
Labs
Science Applied Essays

Acknowledgments

From Andy Friedland . . .

A large number of people have contributed to this book in a variety of ways. I would like to thank all of my teachers, students, and colleagues. Professors Robert Giegengack and Arthur Johnson introduced me to environmental science as an undergraduate and a graduate student. My colleagues in the Environmental Studies Program at Dartmouth have contributed in numerous ways. I thank Doug Bolger, Michael Dorsey, Karen Fisher-Vanden, Coleen Fox, Jim Hornig, Rich Howarth, Ross Jones, Anne Kapuscinski, Karol Kawiaka, Rosi Kerr, David Mbora, Jill Mikucki, Terry Osborne, Darren Ranco, Bill Roebuck, Jack Shepherd, Chris Sneddon, Scott Stokoe, Ross Virginia, and D.G. Webster for all sorts of contributions to my teaching in general and to this book.

In the final draft, four Dartmouth undergraduates who have taken courses from me, Matt Nichols, Travis Price, Chris Whitehead, and Elizabeth Wilkerson, provided excellent editorial, proofreading, and writing assistance. Many other colleagues have had discussions with me or evaluated sections of text including Bill Schlesinger, Ben Carton, Jon Kull, Jeff Schneider, Jimmy Wu, Colin Calloway, Joel Blum, Leslie Sonder, Carl Renshaw, Xiahong Feng, Bob Hawley, Meredith Kelly, Rosi Kerr, Jay Lawrence, Jim Labelle, Tim Smith, Charlie Sullivan, Jenna Pollock, Jim Kaste, Carol Folt, Celia Chen, Matt Ayres, Becky Ball, Kathy Cottingham, Mark McPeek, David Peart, Lisa Adams, and Richard Waddell. Graduate students and recent graduate students Andrew Schroth, Lynne Zummo, Rachel Neurath, and Chelsea Vario also contributed.

Four friends helped me develop the foundation for this textbook and shared their knowledge of environmental science and writing. I wish to acknowledge Dana Meadows and Ned Perrin, both of whom have since passed away, for all sorts of contributions during the early stages of this work. Terry Tempest Williams has been a tremendous source of advice and wisdom about topics environmental, scientific, and practical. Jack Shepherd contributed a great deal of wisdom about writing and publishing.

John Winn, Paul Matsudeiro, and Neil Campbell offered guidance with my introduction to the world of publishing. Beth Nichols and Tom Corley helped me learn about the wide variety of environmental science courses that are being taught in the United States.

A great many people worked with me at or through W. H. Freeman and provided all kinds of assistance. I particularly would like to acknowledge Jerry Correa, Ann Heath, Becky Kohn, Lee Wilcox, Karen Misler, Cathy Murphy, Hélène de Portu, Beth Howe, and Debbie Clare. I especially want to thank Lee Wilcox for art assistance, and much more, including numerous phone conversations. Thanks also to Bill Minick, Julio Espin, Christine Buese, and Tracey Kuehn. We were grateful to David Courard-Hauri for help with the first edition.

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I'd also like to acknowledge Dick and Janie Pearl for friendship, and support through the Richard and Jane Pearl Professorship in Environmental Studies.

Finally, I'd like to thank Katie, Jared, and Ethan Friedland, and my mother, Selma, for everything.

From Rick Relyea . . .

First and foremost I would like to thank my family—my wife Christine and my children Isabelle and Wyatt. Too many nights and weekends were taken from them and given to this textbook and they never complained. Their presence and patience continually inspired me to push forward and complete the project.

Much of the writing coincided with a sabbatical that I spent in Montpellier, France. I am indebted to Philippe Jarne and Patrice David for supporting and funding my time at the Centre d'Ecologie Fonctionnelle et Evolutive. I am also indebted to many individuals at my home institution for supporting my sabbatical, including Graham Hatfull and James Knapp.

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Reviewers

We would like to extend our deep appreciation to the following instructors who reviewed the book manuscript at various stages of development. The content experts who carefully reviewed chapters in their area of expertise are designated with an asterisk (*).

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Students Are Engaged When Material Is Made Relevant and Personal

Human Health Risk

Citizen Scientists

The neighborhood of Old Diamond in Norco, Louisiana, is composed of four city blocks located between a chemical plant and an oil refinery, both owned by the Shell Oil Company. There are approximately 1,500 residents in the neighborhood, largely lower-income African Americans. In 1973, a pipeline explosion blew a house off its foundation and killed two residents. In 1988, an accident at the refinery killed seven workers and sent more than 70 million kg (159 million pounds) of potentially toxic chemicals into the air. Nearly one-third of the children in Old Diamond suffered from asthma and there were many cases of cancer and birth defects. The unusually high rates of disease raised suspicions that the residents were being affected by the two nearby industrial facilities.

By 1989, local resident and middle school teacher Margie Richard had seen enough. Richard organized the Concerned Citizens of Norco. The primary goal of the group was to get Shell to buy the residents' properties at a fair price so they could move away from the industries that were putting their health at risk. Richard contacted environmental scientists and quickly learned that to make a solid case to the company and to the U.S. Environmental Protection Agency (EPA), she needed to be more than an organizer; she also needed to be a scientist.

The residents all knew that the local air had a foul smell, but they had no way of knowing which chemicals were present or their concentrations. To determine whether the air they were breathing exposed the residents to chemical concentrations that posed a health risk, the air had to be tested. Richard learned about specially built buckets that could collect air samples. She organized a "Bucket Brigade" of volunteers and slowly collected the data she and her collaborators needed. As a result of these efforts, scientists were able to document that the Shell refinery was releasing more than 0.9 million kg (2 million pounds) of toxic chemicals into the air each year.

> The unusually high rates of disease raised suspicions that the residents were being affected by two nearby industrial facilities.

The fight against Shell met strong resistance from company officials and went on for 13 years. But in the end, Margie Richard won her battle. In 2002, Shell agreed to purchase the homes of the Old Diamond neighborhood. The company also agreed to pay an additional $5 million for community development and it committed to reducing air emissions from the refinery by 30 percent to help improve the air quality for those residents who remained in the area. In 2007, Shell agreed that it had violated air pollution regulations in several of its Louisiana plants and paid the state of Louisiana $6.5 million in penalties.

For her tremendous efforts in winning the battle in Norco, Margie Richard was the North American recipient of the Goldman Environmental Prize, which honors grassroots environmentalists. Since then, Richard has brought her message to many other minority communities located near large polluting industries. She teaches people that success requires a combination of organizing people to take action to protect their environment and learning how to be a citizen scientist. ■

Sources: The Goldman Environmental Prize: Margie Richard. http://www.goldmanprize.org/node/100; M. Scallan, Shell, DEQ settle emission charges, *Times-Picayune* (New Orleans), March 15, 2007. http://www.nola.com/news/t-p/riverparishes/index.ssf?/base/news-3/1173941825153360.xml&coll=1.

Margie Richard became a citizen scientist to help document the health risk of nearby chemical plants. [Photo courtesy of Goldman Environmental Prize]

◀ The citizens of Norco, Louisiana, live in the shadows of chemical plants and oil refineries. [Mark Ludak/The Image Works]

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Chapter Opening Case Studies

An intriguing case study launches each chapter and prompts students to think about how environmental challenges relate to them.

Students Are Engaged When Material Is Made Relevant and Personal (continued)

MEASURE YOUR IMPACT

What is the Impact of Your Diet on Soil Dynamics? In the landmark 1997 report "Livestock Production: Energy Inputs and the Environment," Cornell University ecologist David Pimentel wrote that feeding grain to cattle consumes more resources than it yields, accelerates soil erosion, and reduces the supply of food for the world's people. Some highlights of the report include the following:

- Each year, an estimated 41 million tons of plant protein is fed to U.S. livestock to produce an estimated 7 million tons of animal protein for human consumption. About 26 million tons of the livestock feed comes from grains and 15 million tons from forage crops. For every kilogram of high-quality animal protein produced, livestock are fed nearly 6 kg of plant protein. The 7 billion animals consume five times as much grain as the entire U.S. human population.
- Every kilogram of beef produced takes 100,000 liters of water. Some 900 liters of water go into producing a kilogram of wheat. Potatoes are even less "thirsty," at 500 liters per kilogram.
- About 90 percent of U.S. cropland is losing soil to erosion at 13 times the rate of soil formation. Soil loss is most severe in some of the richest farming areas: Iowa, for example, loses topsoil at 30 times the rate of soil formation. Iowa has lost one-half of its topsoil in 150 years of farming. That soil took thousands of years to form.

Over the course of 1 week, make a daily record of what you eat and drink. At the end of the week, answer the following questions:

(a) Evaluate the components of your diet for the week. How many portions of animal protein did you eat each day?
(b) Most agricultural fields receive inputs of phosphorus, calcium, and magnesium, which are usually obtained by mining rocks containing those elements, grinding them up, and adding them to fertilizers. Assess the likely impact of this practice on the demand for certain rocks and on soil dynamics.
(c) Describe changes you could make to your diet to minimize the impacts you cited above.
(d) How do you think your diet would compare to that of a person in a developing country? How would their ecological footprint compare to yours? *Hint:* You may have to draw upon previous chapters you have read as well as this chapter to answer this question.

Measure Your Impact

In the end-of-chapter "Measure Your Impact" exercises, students calculate and answer problem scenarios to assess their environmental impact and make informed decisions.

Numerous U.S. Examples

Local and regional examples make the material relevant.

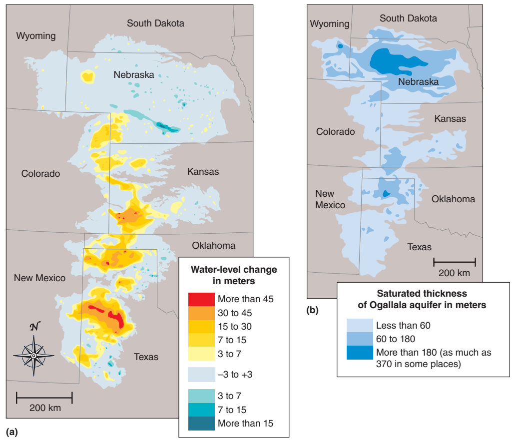

FIGURE 9.4 **The Ogallala aquifer.** The Ogallala aquifer, also called the High Plains aquifer, is the largest in the United States, with a surface area of about 450,000 km^2 (174,000 $miles^2$). (a) The change in water level from 1950 to 2005, mostly due to withdrawals for irrigation that have exceeded the aquifer's rate of recharge. (b) The current thickness of the aquifer.

WORKING TOWARD SUSTAINABILITY

Is the Water in Your Toilet Too Clean?

In certain parts of the world, such as the United States, sanitation regulations impose such high standards on household wastewater that we classify relatively clean water from bathtubs and washing machines as contaminated. This water must then be treated as sewage. We also use clean, drinkable water to flush our toilets and water our lawns. Can we combine these two observations to come up with a way to save water? One idea that is gaining popularity throughout the developed world is to reuse some of the water we normally discard as waste.

This idea has led creative homeowners and plumbers to identify two categories of wastewater in the home: *gray water* and *contaminated water.* **Gray water** is defined as the wastewater from baths, showers, bathroom sinks, and washing machines. Although no one would want to drink it, gray water is perfectly suitable for watering lawns and plants, washing cars, and flushing toilets. In contrast, water from toilets, kitchen sinks, and dishwashers contains a good deal of waste and contaminants and should therefore be disposed of in the usual fashion.

Around the world, there are a growing number of commercial and homemade systems in use for storing gray water to flush toilets and water lawns or gardens. For example, a Turkish inventor has designed a household system allowing the homeowner to pipe wastewater from the washing machine to a storage tank that dispenses this gray water into the toilet bowl with each flush (FIGURE 9.25).

Many cities in Australia have considered the use of gray water as a way to reduce withdrawals of fresh water and reduce the volume of contaminated water that requires treatment. The city of Sydney estimates that 70 percent of the water withdrawn in the greater metropolitan area is used in households, and that perhaps 60 percent of that water becomes gray water. The Sydney Water utility company estimates that the use of gray water for outdoor purposes could save up to 50,000 L (13,000 gallons) per household per year.

Unfortunately, many local and state regulations in the United States and around the world do not allow use of gray water. Some localities allow the use of gray water only if it is treated, filtered, or delivered to lawns and gardens through underground drip irrigation systems to avoid potential bacterial contamination. Arizona, a state in the arid Southwest, has some of the least restrictive regulations. As long as a number of guidelines are followed, homeowners are permitted to reuse gray water. In 2009, in the face of a severe water shortage, California reversed earlier restrictions on gray

FIGURE 9.25 **Reusing gray water.** A Turkish inventor has designed a washing machine that pipes the relatively clean water left over from a washing machine, termed gray water, to a toilet, where it can be reused for flushing. Such technologies can reduce the amount of drinkable water used and the volume of water going into sewage treatment plants. [Sevin Coskun]

Working Toward Sustainability

At the end of each chapter, students are inspired by a success story that focuses on how environmental problems are being addressed by individual action.

Apply the Concepts

Multilevel response questions at the end of each chapter encourage students to apply chapter concepts to everyday situations.

APPLY THE CONCEPTS

The Food and Drug Administration (FDA) has developed guidelines for the consumption of canned tuna fish. These guidelines were developed particularly for children, pregnant women, or women who were planning to become pregnant, because mercury poses the most serious threat to these segments of society. However, the guidelines can be useful for everyone.

(a) Identify *two* major sources of mercury pollution and *one* means of controlling mercury pollution.
(b) Explain how mercury is altered and finds its way into albacore tuna fish.
(c) Identify *two* health effects of methylmercury on humans.

Students Identify and Master Key Ideas Using In-Chapter Pedagogy

Understand the Key Ideas/ Revisit the Key Ideas

"Key Ideas," introduced at the beginning of each chapter and revisited at the end, provide a framework for learning and help students test their comprehension of the chapter material.

UNDERSTAND THE KEY IDEAS

Humans are dependent on Earth's air, water, and soil for our existence. However, we have altered the planet in many ways, large and small. The study of environmental science can help us understand how humans have changed the planet and identify ways of responding to those changes.

After reading this chapter you should be able to

- define the field of environmental science and discuss its importance.
- identify ways in which humans have altered and continue to alter our environment.
- describe key environmental indicators that help us evaluate the health of the planet.
- define sustainability and explain how it can be measured using the ecological footprint.
- explain the scientific method and its application to the study of environmental problems.
- describe some of the unique challenges and limitations of environmental science.

REVISIT THE KEY IDEAS

- **Define the field of environmental science and discuss its importance.**

Environmental science is the study of the interactions among human-dominated systems and natural systems and how those interactions affect environments. Studying environmental science helps us identify, understand, and respond to anthropogenic changes.

- **Identify ways in which humans have altered and continue to alter our environment.**

The impact of humans on natural systems has been significant since early humans hunted some large animal species to extinction. However, technology and population growth have dramatically increased both the rate and the scale of human-induced change.

- **Describe key environmental indicators that help us evaluate the health of the planet.**

Five important global-scale environmental indicators are biological diversity, food production, average global surface temperature and atmospheric CO_2 concentrations, human population, and resource depletion.

- **Define sustainability and explain how it can be measured using the ecological footprint.**

Sustainability is the use of Earth's resources to meet our current needs without jeopardizing the ability of future generations to meet their own needs. The ecological footprint is the land area required to support a person's (or a country's) lifestyle. We can use that information to say something about how sustainable that lifestyle would be if it were adopted globally.

- **Explain the scientific method and its application to the study of environmental problems.**

The scientific method is a process of observation, hypothesis generation, data collection, analysis of results, and dissemination of findings. Repetition of measurements or experiments is critical if one is to determine the validity of findings. Hypotheses are tested and often modified before being accepted.

- **Describe some of the unique challenges and limitations of environmental science.**

We lack an undisturbed "control planet" with which to compare conditions on Earth today. Assessments and choices are often subjective because there is no single measure of environmental quality. Environmental systems are so complex that they are poorly understood, and human preferences and policies may have as much of an effect on them as natural laws.

GAUGE YOUR PROGRESS

✓ What is the scientific method, and how do scientists use it to address environmental problems?

✓ What is a hypothesis? What is a null hypothesis?

✓ How are controlled and natural experiments different? Why do we need each type?

Gauge Your Progress

The questions in the "Gauge Your Progress" feature, found at the end of each major section in the chapter, help students master one set of concepts before moving on to the next.

Students Visualize the Concepts Using Art as a Learning Tool

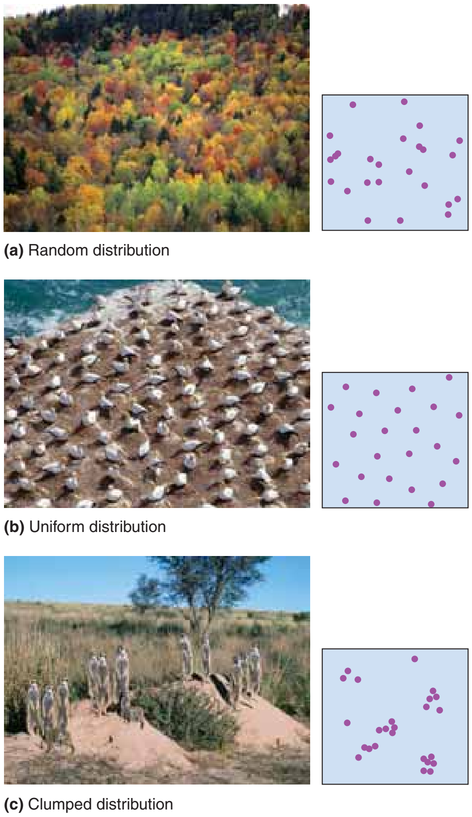

FIGURE 4.13 Population distributions. Populations in nature distribute themselves in three ways. (a) Many of the tree species in this New England forest are randomly distributed, with no apparent pattern in the locations of individuals. (b) Territorial nesting birds, such as these Australasian gannets (*Morus serrator*), exhibit a uniform distribution, in which all individuals maintain a similar distance from one another. (c) Many pairs of eyes are better than one at detecting approaching predators. The clumped distribution of these meerkats (*Suricata suricatta*) provides them with extra protection. [a: David R. Frazier Photolibrary, Inc./Science Source; b: Michael Thompson/Earth Scenes/Animals Animals; c: Clem Haagner/ARDEA]

Instructive Art and Photo Program

The text uses visuals to make complex ideas accessible. The illustration program includes fully integrated teaching captions to help students understand and remember important concepts.

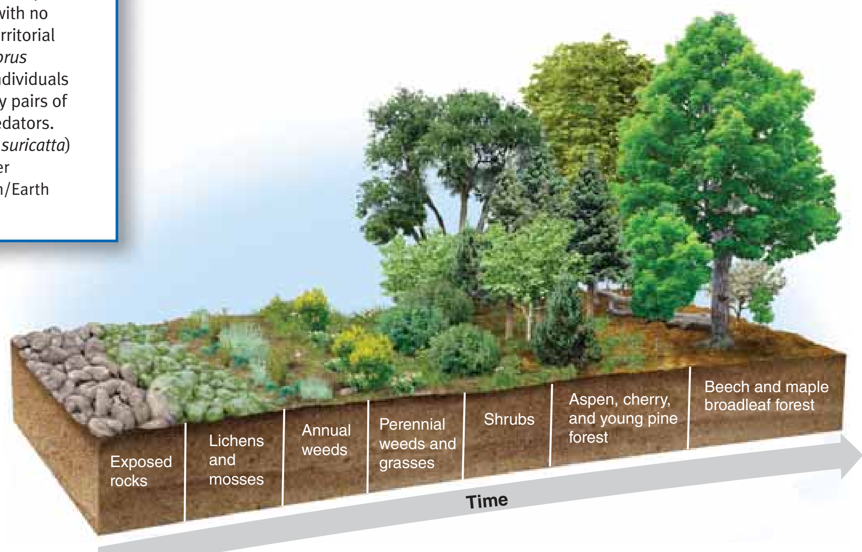

FIGURE 4.21 Primary succession. Primary succession occurs in areas devoid of soil. Early-arriving plants and algae can colonize bare rock and begin to form soil, making the site more hospitable for other species to colonize later. Over time, a series of distinct communities develops. In this illustration, representing an area in New England, bare rock is initially colonized by lichens and mosses and later by grasses, shrubs, and trees.

ESSENTIALS OF ENVIRONMENTAL SCIENCE

SECOND EDITION

CHAPTER 1

Introduction to Environmental Science

To Frack, Or Not to Frack

The United States—like other developed countries—is highly dependent on fuels such as coal and oil that come from the remains of ancient plants and animals. The use of these fossil fuels is responsible for many environmental problems, including land degradation and the release of air and water pollutants. Among the fossil fuels, natural gas, also known as methane, is the least harmful producer of air pollution; it burns more completely and cleanly than coal or oil, and it contains fewer impurities.

Due to technology advances, oil and mining companies have recently increased their reliance on an old method of oil and gas extraction called hydraulic fracturing, or *fracking*. Fracking uses high-pressure fluids to force open cracks in rocks deep underground. This technique allows extraction of natural gas from locations that were previously so difficult to reach that extraction was economically unfeasible. As a result, large quantities of natural gas are now available in the United States at a lower cost than before. A decade ago, 40 percent of energy in the United States was used to generate electricity and half of that energy came from coal. As a result of fracking, electricity generation now uses less coal and more natural gas. Since coal emits more air pollutants—including carbon dioxide—than does natural gas, increased fracking initially appeared to be beneficial to the environment.

However, reports soon began appearing in the popular press and scientific journals about the negative consequences of fracking. Large amounts of water are used in the fracking process. Millions of gallons of water are taken out of local streams and rivers and pumped down into each gas well. A portion of this contaminated water is later removed from the well and needs to be properly treated after use to avoid contaminating local water bodies.

A variety of chemicals are added to the fracking fluid to facilitate the release of natural gas. Mining companies are not required to publicly identify all of these chemicals. Environmental scientists and concerned citizens began to wonder if fracking was responsible for chemical contamination of underground water, and in one case, the poisoning of livestock. Some drinking-water wells near fracking sites became contaminated with natural gas, and homeowners and public health officials asked if fracking was the culprit. Water with high concentrations of natural gas can be flammable, and footage of flames shooting from kitchen faucets after someone ignited the water became popular on YouTube, in documentaries, and in feature films. However, it wasn't clear if fracking caused natural gas to contaminate well water, or if some water wells contained natural gas long before fracking began. Several reputable studies showed that drinking water wells near some fracking sites were contaminated, with natural gas concentrations in the nearby wells being much higher than in more distant wells. These issues need further study, which may take years.

> Footage of flames shooting from kitchen faucets became popular on YouTube.

Scientists have begun to assess how much natural gas escapes during the fracking and gas extraction process. As we will learn in Chapter 14, methane is a greenhouse gas, and is much more efficient at trapping heat from Earth than carbon dioxide, which is the greenhouse gas most commonly produced by human activity. As the number of potential environmental issues associated with fracking began to increase, environmental scientists and activists began to ask whether ▶

This woman asserts that methane from fracking has leached into her well water. Here, flames shoot out from her kitchen sink as she holds a match to it. [JIM LO SCALZO/EPA/Landov]

◀ A hydraulic fracturing site like this one near Canton, Pennsylvania can contain many features that are prominent on the landscape including a concrete pad, a drilling rig, and many storage containers. [Les Stone/Corbis] fracking was making the greenhouse problem and other environmental problems worse. By 2015, it appeared that opponents of fracking were as numerous as supporters.

Certainly, using natural gas is better for the environment than coal, though using less fossil fuel—or using no fossil fuel at all—would be even better. However, at present it is difficult to know whether the benefits of using natural gas outweigh the problems that extraction causes. Many years may pass before the extent and nature of harm from fracking is known.

The story of natural gas fracking provides a good introduction to the study of environmental science. It shows us that human activities that are initially perceived as causing little harm to the environment can have adverse effects, and that we may not recognize these effects until we better understand the science surrounding the issue. It also illustrates the difficulty in obtaining absolute answers to questions about the environment, and demonstrates that environmental science can be controversial. Finally, it shows us that making assessments and choosing appropriate actions in environmental science are not always as clear-cut as they first appear.

The process of scientific inquiry builds on previous work and careful, sometimes lengthy investigations. For example, we will eventually accumulate a body of knowledge on the effects of hydraulic fracturing of natural gas. Until we have this knowledge available to us, we will not be able to make a fully informed decision about energy-extraction policies. In the meantime, we may need to make interim decisions based on incomplete information. This uncertainty is one feature—and exciting aspect—of environmental science.

To investigate important topics such as the extraction and use of fossil fuels, environmental science relies on a number of indicators, methodologies, and tools. This chapter introduces you to the study of the environment and outlines some of the important foundations and assumptions you will use throughout your study.

Sources: S. G. Osborn et al., Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing, *Proceedings of the National Academy of Sciences* 108 (2011): 8172–8176; Drilling down. Multiple authors in 2011 and 2012. *New York Times,* viewed at: http://www.nytimes.com/interactive/us/DRILLING_DOWN_SERIES.html

Understand the Key Ideas

Humans are dependent on Earth's air, water, and soil for our existence. However, we have altered the planet in many ways, large and small. The study of environmental science can help us understand how humans have changed the planet and identify ways of responding to those changes.

After reading this chapter you should be able to

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Environmental science offers important insights into our world and how we influence it

Stop reading for a moment and look up to observe your surroundings. Consider the air you breathe, the heating or cooling system that keeps you at a comfortable temperature, and the natural or artificial light that helps you see. Our **environment** is the sum of all the conditions surrounding us that influence life. These conditions include living organisms as well as nonliving components such as soil, temperature, and the availability of water. The influence of humans is an important part of the environment as well. The environment we live in determines how healthy we are, how fast we grow, how easy it is to move around, and even how much food we can obtain. One environment may be strikingly different from another—a hot, dry desert versus a cool, humid tropical rainforest, or a coral reef teeming with marine life versus a crowded city street.

We are about to begin a study of **environmental science**, the field that looks at interactions among human systems and those found in nature. By **system** we mean any set of interacting components that influence one another by exchanging energy or materials. A change in one part of a system can cause changes throughout the entire system.

An environmental system may be completely human-made, like a subway system, or it may be natural, like weather. The scope of an environmental scientist's work can vary from looking at a small population of individuals, to multiple populations that make up a species, to a community of interacting species, or even larger systems, such as the global climate system. Some environmental

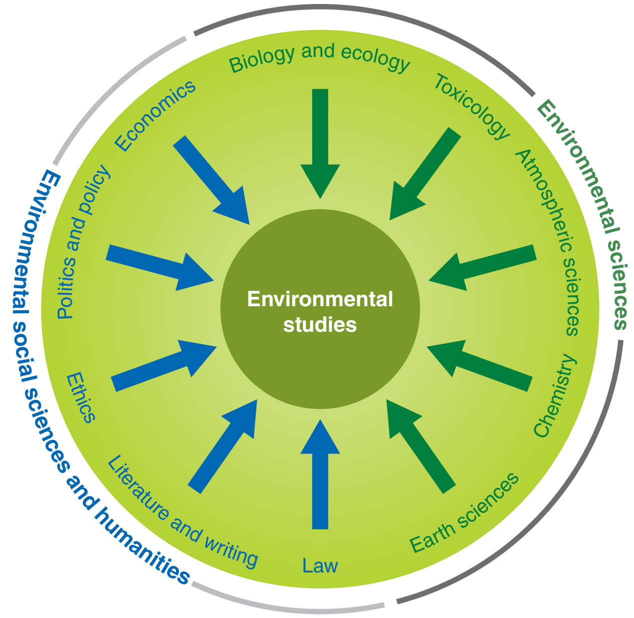

FIGURE 1.1 Environmental studies. The study of environmental science uses knowledge from many disciplines.

scientists are interested in regional problems. Other environmental scientists work on global issues, such as species extinction and climate change.

Many environmental scientists study a specific type of natural system known as an *ecosystem*. An **ecosystem** is a particular location on Earth whose interacting components include living, or **biotic,** components and nonliving, or **abiotic,** components.

It is important for students of environmental science to recognize that environmental science is different from *environmentalism,* which is a social movement that seeks to protect the environment through lobbying, activism, and education. An **environmentalist** is a person who participates in environmentalism. In contrast, an environmental scientist, like any scientist, follows the process of observation, hypothesis testing, and field and laboratory research. We'll learn more about the scientific method later in this chapter.

So what does the study of environmental science actually include? As FIGURE 1.1 shows, environmental science encompasses topics from many scientific disciplines, such as chemistry, biology, and Earth science. And environmental science is itself a subset of the broader field known as **environmental studies**, which includes additional subjects such as environmental policy, economics, literature, and ethics. Throughout the course of this book you will become familiar with these and many other disciplines.

We have seen that environmental science is a deeply interdisciplinary field. It is also a rapidly growing area of study. As human activities continue to affect the environment, environmental science can help us understand the consequences of our interactions with our planet and help us make better decisions about our actions.

GAUGE YOUR PROGRESS

- ✓ What factors make up an organism's environment?
- ✓ In what ways is the field of environmental studies interdisciplinary?
- ✓ Why is environmental science research important?

Humans alter natural systems

Think of the last time you walked in a wooded area. Did you notice any dead or fallen trees? Chances are that even if you did, you were not aware that living and nonliving components were interacting all around you. Perhaps an insect pest killed the tree you saw and many others of the same species. Over time, dead trees in a forest lose moisture. The increase in dry wood makes the forest more vulnerable to intense wildfires. But the process doesn't stop there. Wildfires trigger the germination of certain tree seeds, some of which lie dormant until after a fire. And so what began with the activity of insects leads to a transformation of the forest. In this way, *biotic,* or living, factors interact with *abiotic,* or nonliving, factors to influence the future of the forest.

The global environment is composed of small-scale and large-scale systems. Within a given system, biotic and abiotic components can interact in surprisingly complex ways. In the forest example, the species of trees that are present in the forest, the insect pests, and the wildfires interact with one another: they form a system. This small forest system is part of many larger systems and, ultimately, one global system that generates, circulates, and utilizes oxygen and carbon dioxide, among other things.

Humans manipulate their environment more than any other species. We convert land from its natural state into urban, suburban, and agricultural areas (FIGURE 1.2).

FIGURE 1.2 The impact of humans on Earth. Housing development is one example of the many ways in which humans convert land from its natural state. [Martin Wendler/Science Source]

(a) (b)

FIGURE 1.3 It is impossible for millions of people to inhabit an area without altering it. (a) In 1880, fewer than 6,000 people lived in Los Angeles. (b) In 2009, Los Angeles had a population of 3.8 million people, and the greater Los Angeles metropolitan area was home to nearly 13 million people. [a: The Granger Collection, New York; b: LA/AeroPhotos/Alamy]

We change the chemistry of our air, water, and soil, both intentionally—for example, by adding fertilizers—and unintentionally, as a consequence of activities that generate pollution. Even where we don't manipulate the environment directly, the simple fact that we are so abundant affects our surroundings.

Humans and their direct ancestors (other members of the genus *Homo*) have lived on Earth for about 2.5 million years. During this time, and especially during the last 10,000 to 20,000 years, we have shaped and influenced our environment. As tool-using, social animals, we have continued to develop a capacity to directly alter our environment in substantial ways. *Homo sapiens*—genetically modern humans—evolved to be successful hunters: when they entered a new environment, they often hunted large animal species to extinction. In fact, early humans are thought to be responsible for the extinction of mammoths, mastodons, giant ground sloths, and many types of birds. More recently, hunting in North America led to the extinction of the passenger pigeon (*Ectopistes migratorius*) and nearly caused the loss of the American bison (*Bison bison*).

But the picture isn't all bleak. Human activities have also created opportunities for certain species to thrive. For example, for thousands of years Native Americans on the Great Plains used fire to capture animals for food. The fires they set kept trees from encroaching on the plains, which in turn created a window for an entire ecosystem to develop. Because of human activity, this ecosystem—the tallgrass prairie—is now home to numerous unique species.

During the last two centuries, the rapid and widespread development of technology, coupled with dramatic human population growth, has increased both the rate and the scale of our global environmental impact substantially. Modern cities with electricity, running water, sewer systems, Internet connections, and public transportation systems have improved human well-being, but they have come at a cost. Cities cover land that was once natural habitat. Species relying on that habitat must adapt, relocate, or go extinct. Human-induced changes in climate—for example, in patterns of temperature and precipitation—affect the health of natural systems on a global scale. Current changes in land use and climate are rapidly outpacing the rate at which natural systems can evolve. Some species have not "kept up" and can no longer compete in the human-modified environment.

Moreover, as the number of people on the planet has grown, their effect has multiplied. Six thousand people can live in a relatively small area with only minimal environmental effects. But when 4 million people live in a modern city like Los Angeles, their combined activity will cause greater environmental damage that will inevitably pollute the water, air, and soil and introduce other consequences as well (**FIGURE 1.3**).

GAUGE YOUR PROGRESS

- ✓ In what ways do humans change the environment?
- ✓ What is the relationship between the development of technology and environmental impacts?
- ✓ How does human development have an impact on natural systems?

Environmental scientists monitor natural systems for signs of stress

One of the critical questions that environmental scientists investigate is whether the planet's natural life-support systems are being degraded by human-induced

TABLE 1.1 **Some common environmental indicators**

Environmental indicator	Unit of measure	Chapter where indicator is discussed
Human population	Individuals	5
Ecological footprint	Hectares of land	1
Total food production	Metric tons of grain	7
Food production per unit area	Kilograms of grain per hectare of land	7
Per capita food production	Kilograms of grain per person	7
Carbon dioxide	Concentration in air (parts per million)	14
Average global surface temperature	Degrees centigrade	14
Sea level change	Millimeters	14
Annual precipitation	Millimeters	3
Species diversity	Number of species	4, 13
Fish consumption advisories	Present or absent; number of fish allowed per week	12
Water quality (toxic chemicals)	Concentration	9
Water quality (conventional pollutants)	Concentration; presence or absence of bacteria	9
Deposition rates of atmospheric compounds	Milligrams per square meter per year	10
Fish catch or harvest	Kilograms of fish per year or weight of fish per effort expended	7
Extinction rate	Number of species per year	4
Habitat loss rate	Hectares of land cleared or "lost" per year	13
Infant mortality rate	Number of deaths of infants under age 1 per 1,000 live births	5
Life expectancy	Average number of years a newborn infant can be expected to live under current conditions	5

changes. Natural environments provide what we refer to as **ecosystem services**—the processes by which life-supporting resources such as clean water, timber, fisheries, and agricultural crops are produced. We often take a healthy ecosystem for granted, but we notice when an ecosystem is degraded or stressed because it is unable to provide the same services or produce the same goods. To understand the extent of our effect on the environment, we need to be able to measure the health of Earth's ecosystems.

To describe the health and quality of natural systems, environmental scientists use *environmental indicators.* Just as body temperature and heart rate can indicate whether a person is healthy or sick, **environmental indicators** describe the current state of an environmental system. These indicators do not always tell us what is causing a change, but they do tell us when we might need to look more deeply into a particular issue. Environmental indicators provide valuable information about natural systems on both small and large scales. Some of these indicators are listed in Table 1.1.

In this book we will focus on the five global-scale environmental indicators listed in Table 1.2: biological diversity, food production, average global surface temperature and carbon dioxide concentrations in the atmosphere, human population, and resource depletion. These key environmental indicators help us analyze the health of the planet. We can use this information to guide us toward **sustainability,** by which we mean living on Earth in a way that allows us to use its resources without depriving future generations of those resources. Many scientists maintain that achieving sustainability is the single most important goal for the human species. It is also one of the most challenging tasks we face.

Biological Diversity

Biological diversity, or **biodiversity,** is the diversity of life forms in an environment. It exists on three scales: *genetic, species,* and *ecosystem* diversity. Each of these is an important indicator of environmental health and quality.

GENETIC DIVERSITY Genetic diversity is a measure of the genetic variation among individuals in a population. Populations with high genetic diversity are better able to respond to environmental change than populations with lower genetic diversity. For example, if a population of fish possesses high genetic diversity for disease resistance, at least some individuals are likely to survive whatever diseases move through the population. If the population declines in number, however, the amount of genetic diversity it can possess is also reduced, and this reduction increases the likelihood that the population will decline further when exposed to a disease.

SPECIES DIVERSITY Species diversity indicates the number of *species* in a region or in a particular type of habitat. A **species** is defined as a group of organisms

TABLE 1.2 Five key global environmental indicators

Indicator	Recent trend	Outlook for future	Overall impact on environmental quality
Biological diversity	Large number of extinctions, extinction rate increasing	Extinctions will continue	Negative
Food production	Per capita production possibly leveling off	Unclear	May affect the number of people Earth can support
Average global surface temperature and CO_2 concentrations	CO_2 concentrations and temperatures increasing	Probably will continue to increase, at least in the short term	Effects are uncertain and varied, but probably detrimental
Human population	Still increasing, but growth rate slowing	Population leveling off Resource consumption rates are also a factor	Negative
Resource depletion	Many resources are being depleted at rapid rates. But human ingenuity frequently develops "new" resources, and efficiency of resource use is increasing in many cases	Unknown	Increased use of most resources has negative effects

that is distinct from other groups in its morphology (body form and structure), behavior, or biochemical properties. Individuals within a species can breed and produce fertile offspring. Scientists have identified and cataloged approximately 2 million species on Earth. Estimates of the total number of species on Earth range between 5 million and 100 million, with the most common estimate at 10 million. This number includes a large array of organisms with a multitude of sizes, shapes, colors, and roles (**FIGURE 1.4**). Scientists have observed that ecosystems with more species, that is, higher species diversity, are more resilient and productive. For example, a tropical forest with a large number of plant species growing in the understory is likely to

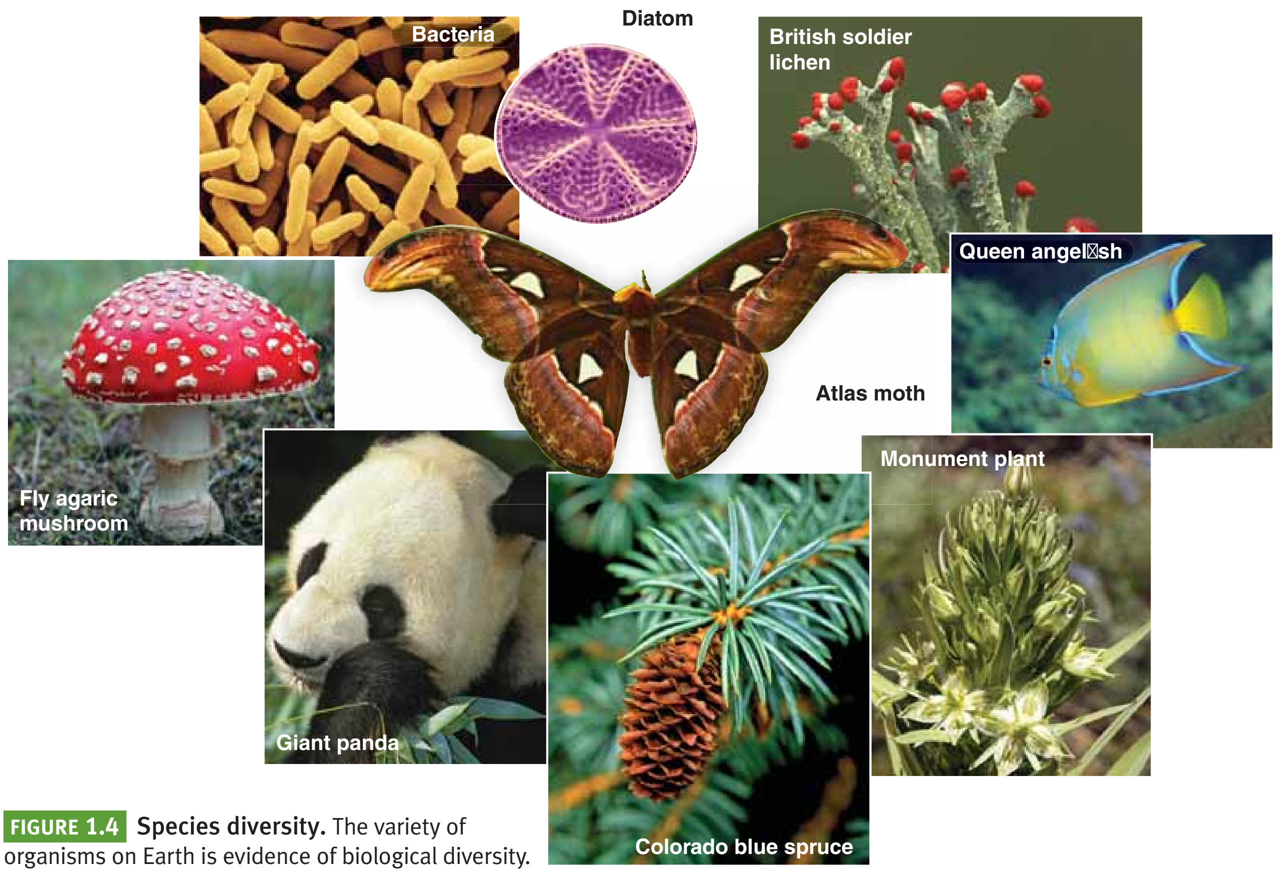

FIGURE 1.4 Species diversity. The variety of organisms on Earth is evidence of biological diversity.

[By row. Top: Medical-on-Line/Alamy; Biophoto Associates/Science Source; Ed Reschke/Peter Arnold Inc./Getty Images Middle: brytta/iStockphoto.com; TranceDrumer/Shutterstock; Peter Leahy/Shutterstock Bottom: Gerard Lacz/age fotostock; Michael P. Gadomski/Science Source; Science Photo Library/Alamy] be more productive, and more resilient to change, than a nearby tropical forest plantation with one crop species growing in the understory.

Environmental scientists often focus on species diversity as a critical environmental indicator. The number of frog species, for example, is used as an indicator of regional environmental health because frogs are exposed to both the water and the air in their ecosystem. A decrease in the number of frog species in a particular ecosystem may be an indicator of environmental problems there. Species losses in several ecosystems can indicate larger-scale environmental problems.

Not all species losses are indicators of environmental problems, however. Species arise and others go extinct as part of the natural evolutionary process. The evolution of new species, known as **speciation,** typically happens very slowly—perhaps on the order of one to three new species per year worldwide. The average rate at which species go extinct over the long term, referred to as the **background extinction rate,** is also very slow: about one species in a million every year. So with 2 million identified species on Earth, the background extinction rate should be about two species per year.

Under conditions of environmental change or biological stress, species may go extinct faster than new ones evolve. Some scientists estimate that more than 10,000 species are currently going extinct each year—5,000 times the background rate of extinction. Habitat destruction and habitat degradation are the major causes of species extinction today, although climate change, overharvesting, and pressure from introduced species also contribute to species loss. Human intervention has saved certain species, including the American bison, peregrine falcon (*Falco peregrinus*), bald eagle (*Haliaeetus leucocephalus*), and American alligator (*Alligator mississippiensis*). But other large animal species, such as the Bengal tiger (*Panthera tigris*), snow leopard (*Panthera uncia*), and West Indian manatee (*Trichechus manatus*), remain endangered and may go extinct if present trends are not reversed. Overall, the number of species has been declining (**FIGURE 1.5**).

(a) (b) (c) (d)

FIGURE 1.5 **Species on the brink.** Humans have saved some species from the brink of extinction, such as (a) the American bison and (b) the peregrine falcon. Other species, such as (c) the snow leopard and (d) the West Indian manatee, continue to decline toward extinction. [a: Richard A McMillin/Shutterstock; b: Jim Zipp/Science Source; c: Alan Carey/Science Source; d: Douglas Faulkner/Science Source]

ECOSYSTEM DIVERSITY Ecosystem diversity is a measure of the diversity of ecosystems or habitats that exist in a given region. A greater number of healthy and productive ecosystems means a healthier environment overall.

As an environmental indicator, the current loss of biodiversity tells us that natural systems are facing strains unlike any in the recent past. It is clearly an important topic in the study of environmental science, and we will look at it in greater detail in Chapters 4 and 13 of this book.

Food Production

The second of our five global indicators is food production: our ability to grow food to nourish the human population. Just as a healthy ecosystem supports a wide range of species, a healthy soil supports abundant and continuous food production. Food grains such as wheat, corn, and rice provide more than half the calories and protein humans consume. Still, the growth of the human population is straining our ability to grow and distribute adequate amounts of food.

In the past we have used science and technology to increase the amount of food we can produce on a given area of land. World grain production has increased fairly steadily since 1950 as a result of expanded irrigation, fertilization, new crop varieties, and other innovations. At the same time, worldwide production of grain *per person,* also called *per capita* world grain production, has leveled off. FIGURE 1.6 shows a downward trend in wheat production since about 1985.

In 2008, food shortages around the world led to higher food prices and even riots in some places. Why did this happen? The amount of grain produced worldwide is influenced by many factors. These factors include climatic conditions, the amount and quality of land under cultivation, irrigation, and the human labor and energy required to plant, harvest, and bring the grain to market. Why is grain production not keeping up with population growth? In some areas, the productivity of agricultural ecosystems has declined because of soil degradation, crop diseases, and unfavorable weather conditions such as drought or flooding. In addition, demand is outpacing supply. The rate of human population growth has outpaced increases in food production. Furthermore, humans currently use more grain to feed livestock than they consume themselves. Finally, some government policies discourage food production by making it more profitable to allow land to remain uncultivated, or by encouraging farmers to grow crops for fuels such as ethanol and biodiesel instead of food.

Will there be sufficient grain to feed the world's population in the future? In the past, whenever a shortage of food loomed, humans have discovered and employed technological or biological innovations to increase production. However, these innovations often put a strain on the productivity of the soil. Unfortunately, if we continue to overexploit the soil, its ability to sustain food production may decline dramatically. We will take a closer look at soil quality in Chapter 6 and food production in Chapter 7.

Average Global Surface Temperature and Carbon Dioxide Concentrations

We have seen that biodiversity and abundant food production are necessary for life. One of the things that makes them possible is a stable climate. Earth's temperature has been relatively constant since the earliest forms of life began, about 3.5 billion years ago. The temperature of

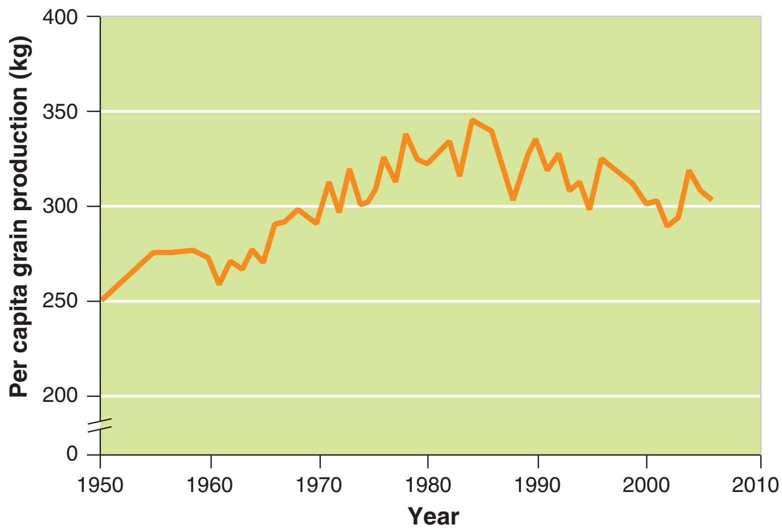

FIGURE 1.6 World grain production per person. Grain production has increased since the 1950s, but it has recently begun to level off. [After http://www.earth-policy.org/index.php?/indicators/C54.]

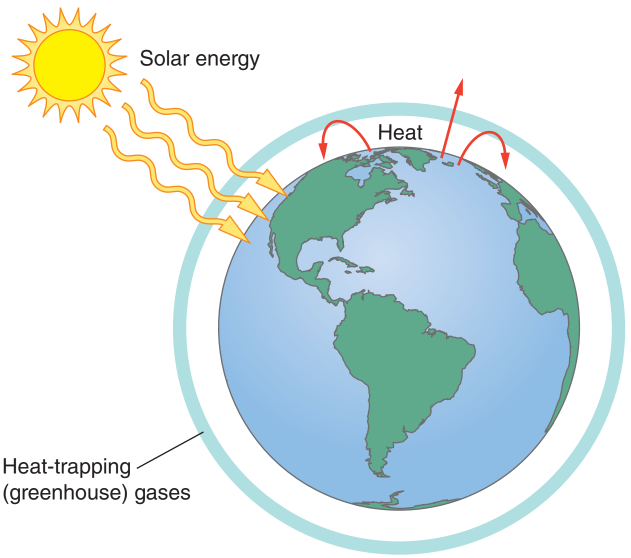

FIGURE 1.7 The greenhouse effect. As Earth's surface is warmed by the Sun, it radiates heat outward. Heat-trapping gases absorb the outgoing heat and reradiate some of it back to Earth. Without these greenhouse gases, Earth would be much cooler.

Earth allows the presence of liquid water, which is necessary for life.

What keeps Earth's temperature so constant? As FIGURE 1.7 shows, our thick planetary atmosphere contains many gases, some of which act like a blanket trapping heat near Earth's surface. The most important of these heat-trapping gases, called **greenhouse gases,** is carbon dioxide (CO_2). During most of the history of life on Earth, greenhouse gases have been present in the atmosphere at fairly constant concentrations for relatively long periods. They help keep Earth's surface within the range of temperatures at which life can flourish.

In the past two centuries, however, the concentrations of CO_2 and other greenhouse gases in the atmosphere have risen. During roughly the same period, as the graph in FIGURE 1.8 shows, global temperatures have fluctuated considerably, but have shown an overall increase. Many scientists believe that the increase in atmospheric CO_2 during the last two centuries is **anthropogenic**—derived from human activities. The two major sources of anthropogenic CO_2 are the combustion of fossil fuels and the net loss of forests and other habitat types that would otherwise take up and store CO_2 from the atmosphere. We will discuss climate in Chapter 3 and global climate change in Chapter 14.

Human Population

In addition to biodiversity, food production, and global surface temperature, the size of the human population can tell us a great deal about the health of our global environment. The human population is currently 7 billion and growing. The increasing world population places additional demands on natural systems, since each new person requires food, water, and other resources. In any given 24-hour period, 364,000 infants are born and 152,000 people die. The net result is 212,000 new inhabitants on Earth each day, or *over a million additional people every 5 days.* The rate of population growth has been slowing since the 1960s, but world population size will continue to increase for at least 50 to 100 years. Most population scientists project that the human population will be somewhere between 8.1 billion and 9.6 billion in 2050 and will stabilize between 7 billion and 10.5 billion by 2100.

Can the planet sustain so many people (FIGURE 1.9)? Even if the human population eventually stops growing, the billions of additional people will create a greater demand on Earth's finite resources, including food, energy, and land. Unless humans work to reduce these pressures, the human population will put a rapidly growing strain on natural systems for at least the first half of this century. We discuss human population issues in Chapter 5.

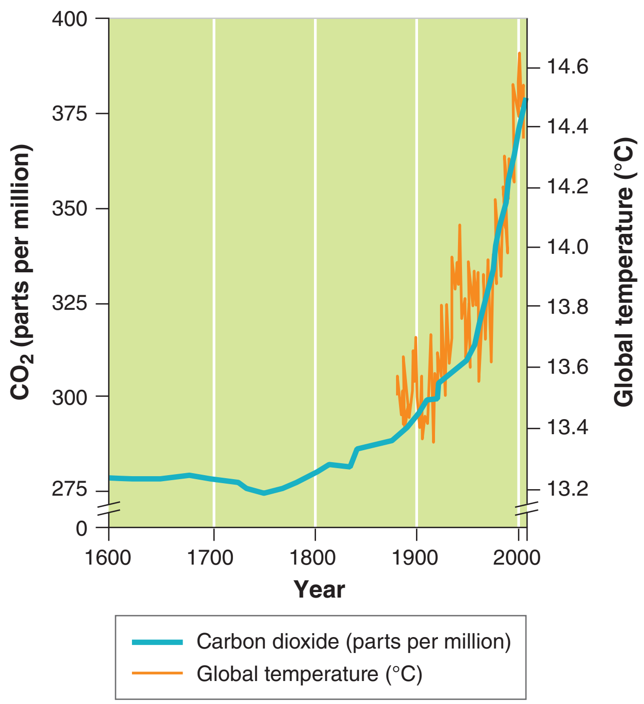

FIGURE 1.8 Changes in average global surface temperature and in atmospheric CO_2 concentrations. Earth's average global surface temperature has increased steadily for at least the past 100 years. Carbon dioxide concentrations in the atmosphere have varied over geologic time, but have risen steadily since 1960. [After http://data.giss.nasa.gov/gistemp/2008/. http://mb-soft.com/public3/co2hist.gif.]